aixDBLI

6"/8" Double Beam Laser Interferometer

Technical Documentation
&
User Manual

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12/07

Safety Instructions / Sicherheitshinweise

	D US	Achtung, bewegte Teile! Verletzungsgefahr! Im eingeschalteten Zustand nicht hineingreifen! Attention, moving parts! Danger of injury! Do not touch the machine when swichted on!
	D US	Achtung, Laserstrahlen! Ohne Augenschutz Verletzungsgefahr! Attention, laser beams! Danger of getting hurt without eye protection
	D US	Achtung, spannungsführende Teile! Gefahr des elektrischen Schlages! Im eingeschalteten Zustand nicht berühren! Attention, high voltage! Danger of electrical shock! Do not touch during operation!
	D US	Achtung, allgemeiner Gefahrenhinweis! Informationen im Handbuch beachten! Attention, general hazard! Pay attention to the information given in the manuals!

Contents

Part I.

Technical Documentation

1. Introduction technical documentation

1.1. General information

The aixDBLI measurement system is used for the manual and semi automatic electrical and electromechanical characterization of piezoelectric films deposited on wafer substrates.

This manual contains the information required to ensure that the aixDBLI System is operated in a way it is developed for. As an integral part of the aixDBLI the manual must always be at hand near the system. The manual describes all stages of the serviceable life of the aixDBLI: Transport, installation, initial commissioning, operation, maintenance, service, storage, and disposal. Check the table of contents to locate the relevant chapter.

This system manual may show or describe components which are not part of the aix*ACCT* scope of delivery. Such information is intended for better understanding. However, aix*ACCT* excludes any liability for such components and the corresponding information. OEM manuals (OEM = original equipment manufacturer) will contain safety relevant information and are an integral part of the system documentation.

Subject to changes without notice.

NOTE: Read Section 2 *Safety concept* carefully prior to any work at the aixDBLI System! It contains important information for your own personal safety. This chapter must have been read and understood by all persons who work at the aixDBLI System during any stage of its serviceable life.

It is in the responsibility of the end user of the aixDBLI System to guarantee that the system is operated in accordance with the binding regulations. This means:

- Only qualified and trained personnel operates and works with the aixDBLI System.
- It is mandatory to read and observe the information contained in this manual.
- Maintenance is performed according to this manual.

1.2. User qualification and training

The aixDBLI System provides an authorization management with different user access rights. The following user access levels are provided:

- Operator
- Technician
- Engineer
- Calibrator
- Superuser

The end user is responsible that the access level of the personnel is restricted to their specific training, knowledge and experience. For more information refer to the User Manual which also describes the user management and system software.

This document is intended for technically qualified personnel who have successfully passed appropriate training for their access right on the aixDBLI System. This training must have been performed or authorized by aixACCT Systems. Only appropriately trained personnel can correctly implement the safety regulations contained in this document. Personnel without this training are considered as unauthorized. Unauthorized personnel are not permitted to work on the aixDBLI System. aixACCT Systems declines all liability for damages which occur when stipulations are disregarded.

1.3. Contact and system information

Address any kind of questions and inquiries about the aixDBLI System and its documentation to:

aixACCT Systems GmbH
Dennewartstr. 25-27
D-52068 Aachen
Germany

phone	**++49 241 963 1410**
fax	**++49 241 963 1411**
e-mail	**info@aixacct.com**
website	**http://www.aixacct.com**

Specify all information given on the type label of the aixDBLI System in addition to your inquiry when you contact aixACCT Systems. The type label to identify your system is shown in Fig. 1.1. It can be found at the rear of the electrical rack near the main switch.

Fig. 1.1: Type label at the bottom rear of the aixDBLI System rack.

1.4. Warranty

aixACCT Systems will repair or replace, at its location of business, within the period of one year from delivery at no expense to the purchaser faulty or damaged hardware or software where such faults or damages are the direct result of design or manufacture of the aixACCT measurement system and / or its measurement software. The liability of aixACCT Systems is limited to the repair or replacement, at our option, of any defective product and shall in no event include incidental or consequential commercial damages of any kind.

Limitations on warranty

The warranty set forth above does not extend to and shall not apply to:

1. aixACCT measurement systems which have been repaired or altered by others than the aixACCT Systems personnel, unless the user has properly altered or repaired the aixACCT measurement system in accordance with procedures previously approved in writing by aixACCT Systems.

2. aixACCT measurement systems which have been subject to misuse, neglect, accident, or improper installation.

This warranty is offered only to the original purchaser of the aixACCT measurement system and on the premises of the original shipping address. Movement of the equipment to another premises, especially over country borders, will lead to the invalidity of the guarantee claims.

1.5. Export limitations

The aixACCT measurement system contains subsystems whose export is governed by the Bundesausfuhramt of the Federal Republic of Germany concerning commodities of this type. Neither the aixACCT measurement system nor its subcomponents may be exported without first contacting aixACCT Systems and the Bundesausfuhramt.

1.6. Copyright and trademarks used in this manual

The legal end user of the aixACCT measurement systemmay reproduce this document for use with his measurement system only. For safety reasons complete copies must be made. Any other reproduction without written permission by aix*ACCT* is forbidden.

The system software may be used for the aixACCT measurement systemonly. It is strictly forbidden to make copies or give the software to third parties.

Products and company names listed in this manual are trademarks or trade names of their respective companies. The use of trademarks, brand names etc. in this document does not entitle third parties to consider these names to be unprotected.

1.7. Declaration of Conformity

aixACCT Systems GmbH hereby declares that the design of the system

Type: Double Beam Laser Interferometer

Model: aixDBLI

complies with the essential health and safety requirements of the following directives:

EC - Directive for Machines 98/37/EC

EC-EMC (Electro Magnetic Compatibility) Directive 2004/108/EC

EC - Low Voltage Directive 2006/95/EC

Applied harmonized and national standards as well as technical specifications where applicable:

EN 61010 -1

EN 60204 -1

EN 61000 -6-2

EN 61000 -6-3

The operation manual for the system is available in English.

NOTE: This declaration does not contain a gratification for properties. Please follow the safety guidelines of the delivered product documentation. In case of non-agreed modifications of the product without the consent of aixACCT this declaration loses its validity.

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2. Safety concept

2.1. General safety regulations

NOTE: This section contains information that the any user of the aixDBLI System must know and understand to minimize the risk of injuries!

Measurement systems from aix*ACCT* Systems are designed to protect the user against all possible hazards. After review by trained and qualified safety personnel, the user should generate specific safety procedures with regard to the particular application of the equipment and local regulations, and make certain that operators are familiar with these procedures. Additional safety requirements may arise from additional devices (e.g. UPS, Vibration controller).

WARNING: Do not open the components of the aixDBLI system under any circumstances!!! There is danger to life because of the supply voltage. No adjustments are possible by the user.

2.2. Liability

Information furnished by aixACCT Systems in this manual is believed to be accurate and reliable. aixACCT Systems assumes no liability for the user or misuse of the information provided herein.

aixACCT Systems is not liable for any damages or injuries incurred as the result of opening the aixDBLI system components by any person or the operation of this system in a manner inconsistent with the procedures and recommendations in the operation manual of the aixDBLI system. Any changes or modifications not expressly approved by written permission of aixACCT Systems will void the user's authority to operate the equipment.

1. **NOTE:** Carefully read and understand the manuals provided by aix*ACCT* before using the measurement system.

2. **WARNING:** During operation there is danger of crushing, tripping or being caught up in the machine when the chamber doors are open. These dangers cannot be avoided due to the function of the machine but any areas of danger are clearly labeled with the signs overleaf.

3. **WARNING:** Never use the machine with open doors or removed safety covers. There is danger through moving parts and laser beam exposure.

4. **WARNING:** The measurement systems runs with voltages up to 200 V. In case of equipment failure the voltage can be present until the operator switches the power off at the main switch. Do not touch the electrical connections or probe tips.
5. **WARNING:** Do not touch the probe tip needles with your fingers as this may destroy them and result in injury.
6. **CAUTION:**Do not lean or sit on any part of the chamber, probe station, or rack.

2.3. aixDBLI System safety concept

The aixDBLI system consists of an extensive set of safety features based on SEMI standard S2 to allow an easy but on the other hand save operation of the system. This safety circuit system ensures safe measurements with respect to the laser beam, the mechanically moving parts, and those parts of the electrical circuit that operate at voltages higher than 30 V. Please read this information carefully and acquaint yourself with the multi-level safety features before starting to operate the system! There are two different modes of operation which are selected by a key-operated-switch. This is the normal *Normal mode* and the *Service mode* which is intended to be used only for maintenance of the system by specifically trained persons.

It should be noted that the position of the aixDBLI System is important where safety is concerned. The injury risk can be kept minimal if ergonomic conditions according to the demands of SEMI are taken into consideration. It is the responsibility of the customer to ensure that these requirements are met.

No supervision of chemicals etc. is required for operating the aixDBLI System.

The following components are part of the safety concept:

Main Power Switch - located at the rear side of the rack. This switch disconnects the whole system from mains. When this switch is turned off the whole system is disconnected from power and the Uninterruptible Power Supply (UPS) will not provide any output power and cannot be activated. Additionally, the main switch is provided with an excess-current fuse.

Emergency Off Buttons - There are three Emergency Off (EMO) buttons distributed strategically at different system positions. So the user can easily reach at least one at any time during operation or maintenance of the system. One is located above the keyboard in the rack mount system. The second can be found on the front side between the two doors of the acoustic insulating chamber and the third at the service door at the left side of the acoustic chamber. All three EMO buttons are connected in series. So pressing of any one of the Stop buttons will turn the whole system into the emergency stop status. This means that the power supplies for the laser, the 200 V amplifier, and the DBLI controller are immediately turned off. Furthermore the wafer prober movement is stopped and blocked and the functions of the interlock switches in the chamber doors are disabled.

Interlock switches - Every door of the chamber is equipped with a normally open contact switch to detect if any door of the chamber is not properly closed. The possible mode of operation in this case depends on the position of the key-operated-switch and is described below.

Laser Beam Shutter - located in the chamber directly behind the laser output. The shutter opens only during measurements or for beam alignment in service mode.

Uninterruptible Power Supply - In case of a power failure the UPS supplies power to the TF Analyzer 2000 system and the aixDBLI Control Unit to enable an orderly shut down of the computer systems without data losses. Also the LCD monitors, the laser, and the chamber lighting are connected to the UPS.

CAUTION: All system parts which are connected to the UPS are still connected to power even if the EMO emergency stop button is activated.

To energize the system, the Main power switch must be turned ON and all three Emergency Stop switches must be released.

There are two different stages of operation of the aixDBLI, the *Normal mode* and the *Service mode*. Standard operation mode for measurements by the operator is the *Normal mode*. To access the *Service mode*, a key-operated-switch must be turned into the SERVICE position.

2.3.1. Safety functions *Normal mode*:

For measurements in the *Normal mode* the chamber of the aixDBLI has to be completely closed, both front doors and the service door at the side. In this operation condition, the ceiling light in the chamber will be shut off, the laser is on, the laser beam shutter opens during measurements, and the wafer stage is supplied with voltage.

If the front door is opened e.g. for changing the wafer, the laser beam will be immediately shut off by the laser beam shutter which is located directly in front of the laser beam output. The stage power will be switched off and the ceiling light in the chamber is switched on. Additionally, the 200 V amplifier is disabled by an control bit. The same will happen in case that the side door is opened, although this is not necessary in the *Normal mode*.

In case that the stage moves, although the chamber is opened and the *Normal mode* condition is selected, the user should press an Emergency Stop button, in case there might happen any damage to humans or material or setup.

2.3.2. Safety functions during *Service mode*:

The *Service mode* is allowed only for special trained and instructed operators! It is the responsibility of the aixDBLI System owner that the service key is only accessible to these people. aixACCT Systems is not liable for any injuries or damages as a result of improperly operation of the system.

WARNING: Do not select the *Service mode*, if you are not properly instructed and experienced for service on the aixDBLI System.

In *Service mode* you can operate the system the same as in *Normal mode*. But laser and wafer stage are **NOT** switched off when one of the chamber doors is opened. The wafer stage can be moved and also 200 V amplifier can be set into the enabled state during measurements. This operation is only necessary for the beam alignment procedure and service adjustments and measurements.

CAUTION: Never touch the probe tips during measurements in *Service mode* as high voltage can be applied.

WARNING: In case you plan to open the chamber establish a controlled access area around the aixDBLI chamber. Limit the access to those persons who are trained in laser safety principles.
WARNING: Put on blue laser goggles to protect your eyes from the laser beam. Do not attempt to view either a direct or reflected beam without proper eye protection. The use of laser protective eyewear is especially important during alignment procedures.
WARNING: Use non reflecting tools for operations at the laser or laser beam path.
WARNING: Always turn the key-operated-switch back into *Normal mode* after finishing the service operation. Remove the key and logout as user on the system.
CAUTION: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure.

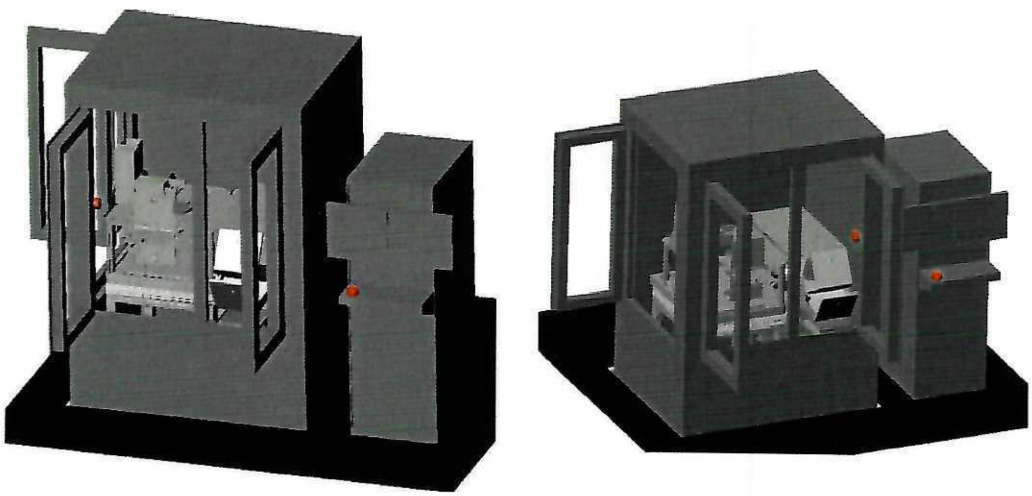
WARNING: All moving parts are enclosed in the measurement chamber and can be moved only in *Service mode* with open doors.

- Do **NOT** reach into the prober during operation! Take care to keep long hair or loose clothing from getting caught in the system.
- Do **NOT** open the load cover of the loader module during operation. The safety instructions in the OEM manual of the prober must be obeyed strictly because of the danger of moving parts.
- Do **NOT** use the probe system with an open or removed safety cover. The interlock stops the mechanical stage moving while the prober load cover is open.

2.4. Positions of safety fixtures and labels.

2.4.1. Emergency Off (EMO) buttons

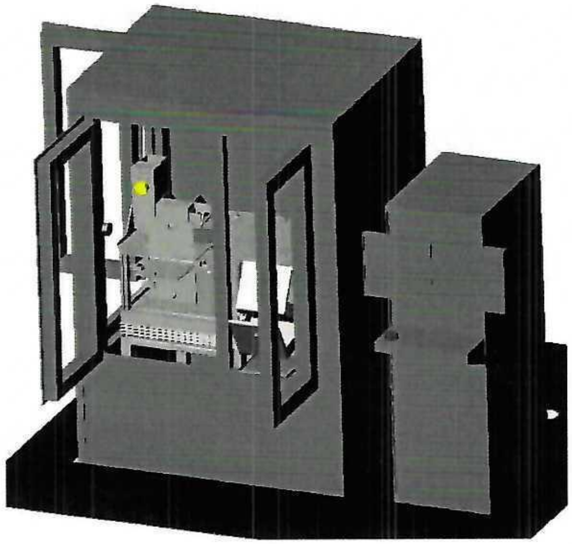
The positions of the three *Emergency Off* buttons can be found in the following pictures:

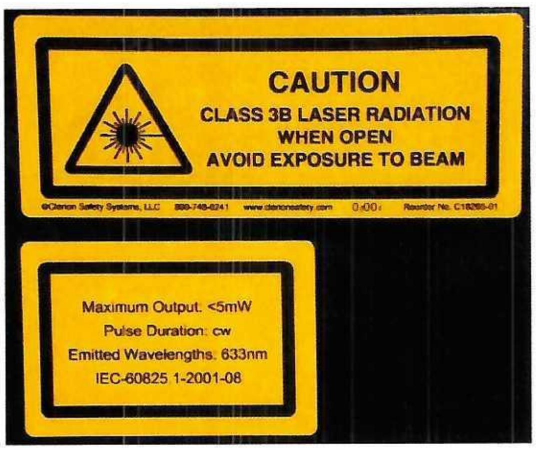


2.4.2. Laser warning labels

Laser warning labels are placed on each part of the system which is part of the laser system. Each door of the chamber shows the following label:

The cover of the laser and laser beam path inside the chamber is labeled additionally like it is shown below:





2.4.3. Electrical hazard warning labels

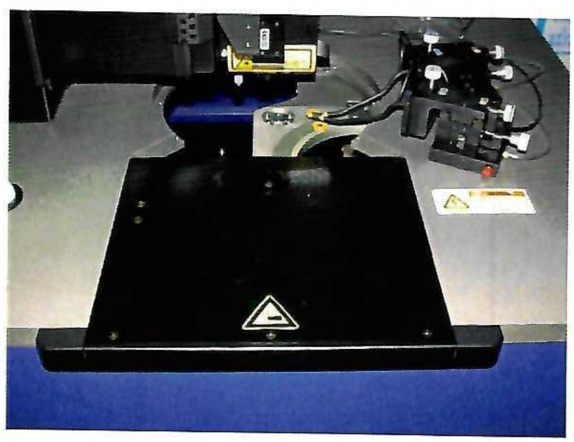
For *Normal mode* of operation it is not possible to touch any electrical hazardous parts of the aixDBLI System.

Only in *Service mode* an electrical hazard exists at the probe tips inside the chamber. Do not touch the probe tips while performing simultaneously a measurement. An electrical hazard warning label is placed at the position of the probe tips.

2.4.4. Moving parts warning labels

Moving the probe station is disabled in *Normal mode* of operation. So no pinch and crunch hazard exists in this mode when the chamber doors are opened e.g. to change the wafer.

Only in *Service mode* a pinch and crunch hazard exists at the prober stage inside the chamber. Do not touch the prober stage when a measurement is running or someone else wants to manually change the wafer position. A warning label is placed on the cover of the probe station.



2.5. Safety regulations

Review the following safety precautions to avoid injury and prevent damage to the instrument or equipment connected to it. The safety features of this instrument may be negated if the equipment is not operated in the manner stated in this manual. Refer all maintenance procedures to qualified personnel.

2.5.1. Lockout and tagout procedure

Maintenance and service work can be extremely dangerous if the serviced components are not shut down and secured properly. Contact with live parts, the release of stored energy, or the unexpected start-up of the serviced component can cause serious injury to personnel and also damage the equipment. These hazards can be avoided through the strict use of the lockout and tagout procedure. In short, this means that you have to shut down, de-energize, lock out, and tag out the component before servicing it. Before beginning any maintenance or service work, the following steps must be performed:

1. Shut down all electrical components like described in Chapter 5.4.
2. Switch the main power switch at the bottom rear of the rack into position OFF and lock it with a key-operated padlock like displayed in Fig. 2.1. This prevents a re-energizing of the system by mistake.

Fig. 2.1: Main power switch locked in safe position.

3. Switch off the air pressure valve at the bottom rear of the rack and lock it with a key-operated padlock like displayed in Fig. 2.2
4. Post a prominent tag onto each lockout device. This tag is a warning to others that the component must not be put back into operation until the lock and the tag have been removed by the authorized person. Tags must be written in a language that can be understood by all personnel. They must contain the following information:
   - A warning text or prohibitive sign
   - Name and phone number of the person in charge
   - Date and time when the component has been locked out
5. Release, restrain, or otherwise render safe all potential hazardous stored or residual energy. Stored energies can be electrical, mechanical or heat.

Fig. 2.2: Air pressure switch locked in safe position.

Proceed as follows to remove lockout and tagout devices:

1. Inspect the component to ensure that it is operationally intact and that nonessential items are removed from the area
2. Make sure that everyone is positioned safely and away from the component
3. Remove the lockout/tagout devices
4. Make sure that all employees who work with the system know that the lockout/tagout devices have been removed and that the component will be energized
5. Start the aixDBLI System like it is described in Chapter 5.1.

2.5.2. Injury Precautions

- **Use the Power Cord Provided**
  To avoid fire hazard, use only the power cord provided with this instrument.
- **Avoid Electric Overload**
  To avoid electric shock or fire hazard, do not apply a voltage to a terminal that is outside the range specified for that terminal.
- **Avoid Electric Shock**
  To avoid electric shock, do not touch the high-voltage output connector or the load circuit while the instrument is on.

- **Ground the Product**
  This product is grounded through the ground conductor of the power cord. To avoid electric shock, the ground conductor must be connected to earth ground. Before making connections to the input and output terminals of the product, ensure that the product is properly grounded.
- **Do Not Operate Without Covers**
  To avoid electric shock or fire hazard, do not operate this instrument with the covers removed.
- **Use Proper Fuses**
  To avoid fire hazard, use only the fuse type and rating specified for this instrument.
- **Indoor Use Only**
  This instrument is intended for indoor use only in a dry and clean environment.
- **Do Not Operate in Wet or Damp Conditions**
  To avoid electric shock, do not operate this instrument in wet or damp conditions.
- **Do Not Operate in an Explosive Environment**
  To avoid injury or fire hazard, do not operate this instrument in an explosive environment.

2.5.3. Product damage precautions

- **Use the Proper Power Source**
  Do not operate this instrument from a power source that is different than the voltage specified on the type label.
- **Provide Proper Ventilation**
  To prevent the instrument from overheating, provide proper ventilation and keep a minimum gap of 1 inch from the vents to the surroundings.
- **Do Not Operate with Suspected Failures**
  If you suspect there is damage to this instrument, have it inspected by qualified personnel.

2.6. Health hazard analysis

2.6.1. Radiation

Standard configuration There is no risk of radiation for the standard configuration of the aixDBLI System.

Laser Equipment The aixDBLI System is equipped with a continuous wave Class IIIa-Medium Power Laser (Class 3B Laser Product IEC 825-1-93). Laser and optical beam path are twofold encapsulated. During *Normal mode* operation the laser radiation is not accessible. The accessible radiation is limited by a protecting chamber with normally open interlock switches at each door. The laser beam path itself is additionally encapsulated. The covers can be opened only by a key operated latch.

2.6.2. Earthquake safety

The overall earthquake safety very much depends on the installation place, the close environment inside the facility and the geographical site. An interlocking coupling between the isolation table and wafer prober with optics is part of the earthquake protection.

2.6.3. Total risk evaluation

The chances of injury have been reduced as they are dependent on several events occurring at the same time:

- Irresponsible behavior of the operator
- Accidental motion in the danger area
- Inappropriate use of the system in service mode

2.7. Material safety data sheet (MSDS)

There are no chemical substances inherent in, or shipped with, the equipment.

The equipment user is solely responsible to obtain MSDSs which contain safety relevant information for all chemical substances which are used for processing, maintenance, or service of the aixDBLI System.

The data sheets can be obtained either from the suppliers who deliver the chemicals or they are available on the Internet. Please use a common search engine including the name of the chemical and the keyword msds.

Read the material safety data sheets thoroughly and follow all directions.

3. System overview

The aixACCT Double Beam Laser Interferometer (aixDBLI) is an optical measurement system to detect electrical and electromechanical properties of a material that is deposited on a wafer. The system can handle 6 inch as well as 8 inch wafers.

The major components of the system are a measurement chamber for thermal and acoustic isolation, a wafer prober for precise x-, y-, z-positioning, a Class IIIa-Medium Power Laser (Class 3B Laser Product IEC 825-1-93) and additional optics to create the optical path and a rack mount system for all control electronics of the whole system. Optionally, a wafer handler and a pattern recognition system can be added for a fully automatic performance of the aixDBLI System.

The measurement chamber and additional covers of the laser beam path prevent the laser beam and stray reflections from escaping the laser operation area. Furthermore it protects the highly sensitive set up from thermal streaming and reduces the influence of external parasitic noise. The chamber has three doors. Two on the front side, which are used either for loading manually single wafers or for loading a cassette into the wafer handler. A third door is on the left side panel, which is solely reserved for service and maintenance.

Fig. 3.1 and Fig. 3.2 show front and side view of the principal system set up with its main components. Dimensions in mm scale and the positions of the doors are given. They comply with the demands of SEMI standard S8.

3.1. Measurement chamber

All optical components from the laser source to the photo detector have to be insulated from exterior influences, e.g. light radiation, acoustic vibration, ground vibration, temperature changes, and air flow. Thus, this part of the setup is mounted on an optical table and housed inside an insulating chamber. The optical table eliminates ground vibration influences, while the chamber insulates the beam path against the other exterior influences. To reduce the footprint of the system, the table size is minimized fitting the optical setup and the wafer stage enclosed by the chamber (see Fig. 3.1).

Stabilized helium-neon laser: Key component of the system is a single intensity stabilized helium-neon laser.

Laser Class	IIIa - Medium power laser product (CDRH) 3B laser product (IEC 825-1-93)
Wavelength	632.8 nm
Output power @ 632.8 nm	< 5.0 mW (typ. 1.4 mW)

Laser beam path: The beam of a single intensity stabilized laser is split into two beams, a reference beam and the measurement beam. The measurement beam is reflected on each front and back side of the sample. Without applied voltage the interference pattern is adjusted in a way that the output voltage of the photo diode detector is in its working point. The optical path is additionally encapsulated with most of its components like beam splitters, mirrors and lenses. This has a safety aspect as it prevents in usual operator mode any parasitic beam reflections. Furthermore the encapsulation reduces disturbing acoustical and air flow effects and prevents accidental misadjustments. It is accessible

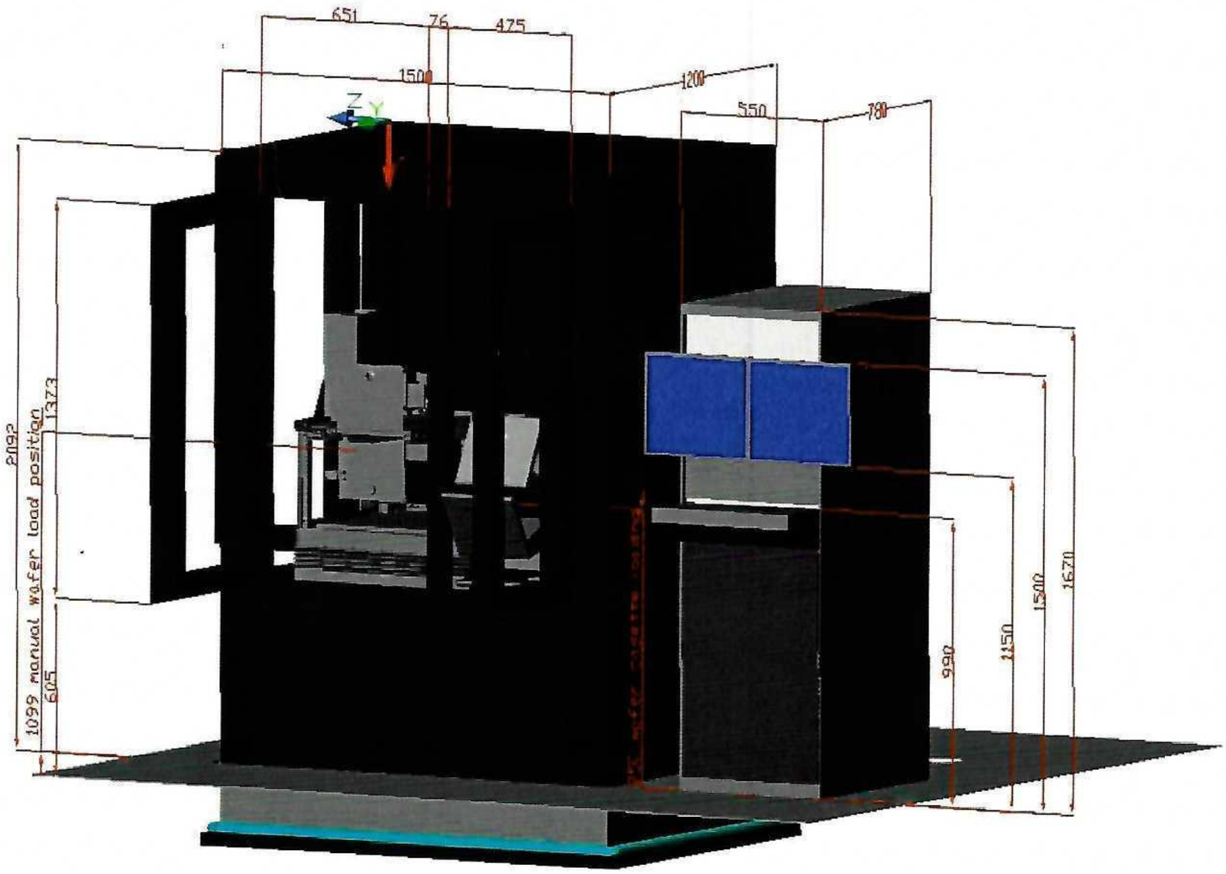


Fig. 3.1: Schematic of the aixDBLI system front view with chamber and rack with electronic components.

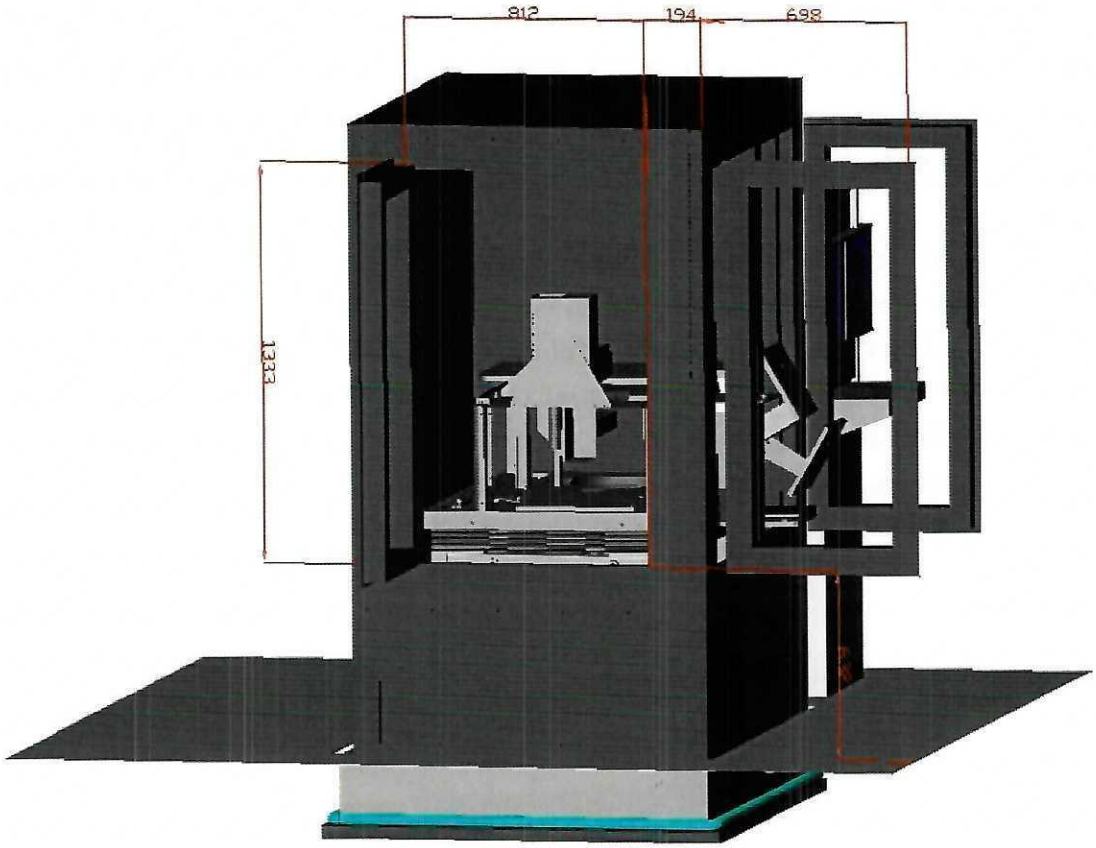


Fig. 3.2: Schematic of the side view of the aixDBLI System with open maintenance doors.

with a service key only. Class 3B laser radiation may be accessible when opened.

If a voltage is applied to the sample, the thickness of the sample will change. This causes a change in optical path length of the measurement beam relative to the reference beam. This change in path length results in a change of the interference pattern which is detected by the photo detector. Finally, the output voltage of the photo detector corresponds with the change in thickness of the sample.

Stage and stage control: The stage includes the wafer holder. Stepper motors move the wafer to the position of the test structure. In conjunction with the picture given by the wafer camera and the displayed coordinates the position of interest can be approached easily. To move the stage a joystick function is available. The control software for the wafer stage runs on the aixDBLI Control Unit and prober bench computer system.

Cameras: There are four different cameras build into the system. They can be selected and viewed by mouse in the view of the right control monitor. In normal operation mode only the Wafer and the Interference cameras are active. Two alignment cameras are additionally active in service operation mode.

The Wafer camera gives a picture of the position of the wafer relatively to the laser spot. The laser spot defines the position of the measurement. Using the camera picture displayed on the monitor and the coordinates of the wafer position the position of interest can be moved into the spot of the laser light. In addition to support the positioning of the wafer, the Wafer Camera view helps to contact the electrodes and place the wafer in focus height. The camera is supported with a detented zoom objective featuring zoom factors of 0.7x to 4.5x, and a focus adjust. The camera is mounted under a 30°angle viewing from the rear, because the perpendicular direction is blocked by the laser beam path. This requires a high depth of focus fetured by the objective to get an overall sharp image. Thus the image is also compressed by about 14% in the vertical axis. For alignment the camera is mounted onto a manual x/y stage, the crosshair in the camera picture is aligned to the laser spot center when the wafer is in alignment height. A LED light source with a diffuse screen plate is used to illuminate the wafer. The diffuse light is reflected by the wafer in the same angle opposite of the camera to get a well illuminated picture.

The Interference camera gives pictures of the interference pattern. This camera view is used to check the interference pattern and to assist in the alignment procedure.

The Alignment Cameras 1 and 2 are used only for the beam alignment procedure. They are active only in service mode and not necessary for measurements.

Positioner: Micro positioners are used to establish electrical contact between the test system and the electrodes. The needles can be individually positioned and allow an easy adjustment to the wafer teststructures.

Beam working point controller: The photo diode detects the interference pattern amplitude of the reference and the measurement beam. To guarantee high resolution of the measurement results, the working point is the point of maximum sensitivity and linearity within a wavelength period of the laser light, $\lambda/2$. The working point is kept constant by a control circuit from aixDBLI Control Unit, which measures the photo detector voltage, and adjusts the piezo driven mirror of the reference beam via an amplifier. Voltage generated by this unit is 0 - 150 V, current is limited to 10 mA.

Vibration damping Control: The wafer prober offers a vibration damping unit, but an additional vibration damping system is needed for high resolution. Therefore wafer prober and wafer handler are positioned on an additional active vibration damping system. Please refer to the vibration controller manual for further information and safety.

Wafer Handler: A wafer hadler robot is available as an upgrade to the system. After a wafer cassette is inserted into the wafer handler and the software is started, the wafer handler is responsible for the wafer load and unload.

Lighting Two 8W, 12 V fluorescent tubes are mounted at the side walls of the chamber. They are switched off, when the chamber is closed, and switched on when a front doors or the side door are opened. Each lamp has two tubes with one tube lit only, one tube can be used as spare.

3.2. Electronic components rack

The rack mount system comprises all electrical circuitry of the aixDBLI System and is shown in the schematic in Fig. 3.3. It contains the safety circuit, the drawer for keyboard and mouse, the TF Analyzer 2000, the aixDBLI Control Unit, additional power supplies and the Uninterruptable Power Supply (UPS). Detailed descriptions of the components are given below:

TF Analyzer 2000: An adapted TF Analyzer 2000 system with integrated PC generates all signals needed for a variety of large- and small-signal measurements. It incorporates the waveform generator, the analog sampling unit, the recording amplifiers and the computer for data acquisition and calculations. Also, advanced signal processing enables high resolution measurements without the need of additional hardware, e.g. a lock-in amplifier or an oscilloscope. The electric and electromechanical characteristics of a sample are measured simultaneously. A large variety of characterization tasks, automation, and database support is possible as specified for the TF Analyzer 2000 system FE module and software. The maximum output voltage generated by this unit is +/-25 V. Steady state current is limited to 1 A.

aixACCT +/- 200 V amplifier: This amplifier generates the voltage that is applied to the wafer. This unit is controlled by the TF Analyzer 2000. Maximum input voltage is +/- 5 V, maximum output voltage is +/- 200 V. The steady state current is limited to 35 mA.

Prober Bench Electronics and PC-Controller / DBLI Controller: responsible for control of the wafer prober system for high accuracy positioning. Also the this system performs the beam regulation and interfaces to the wafer stage control system and cameras. In addition, digital I/O bits are supplied by this unit (0 - 24 V).

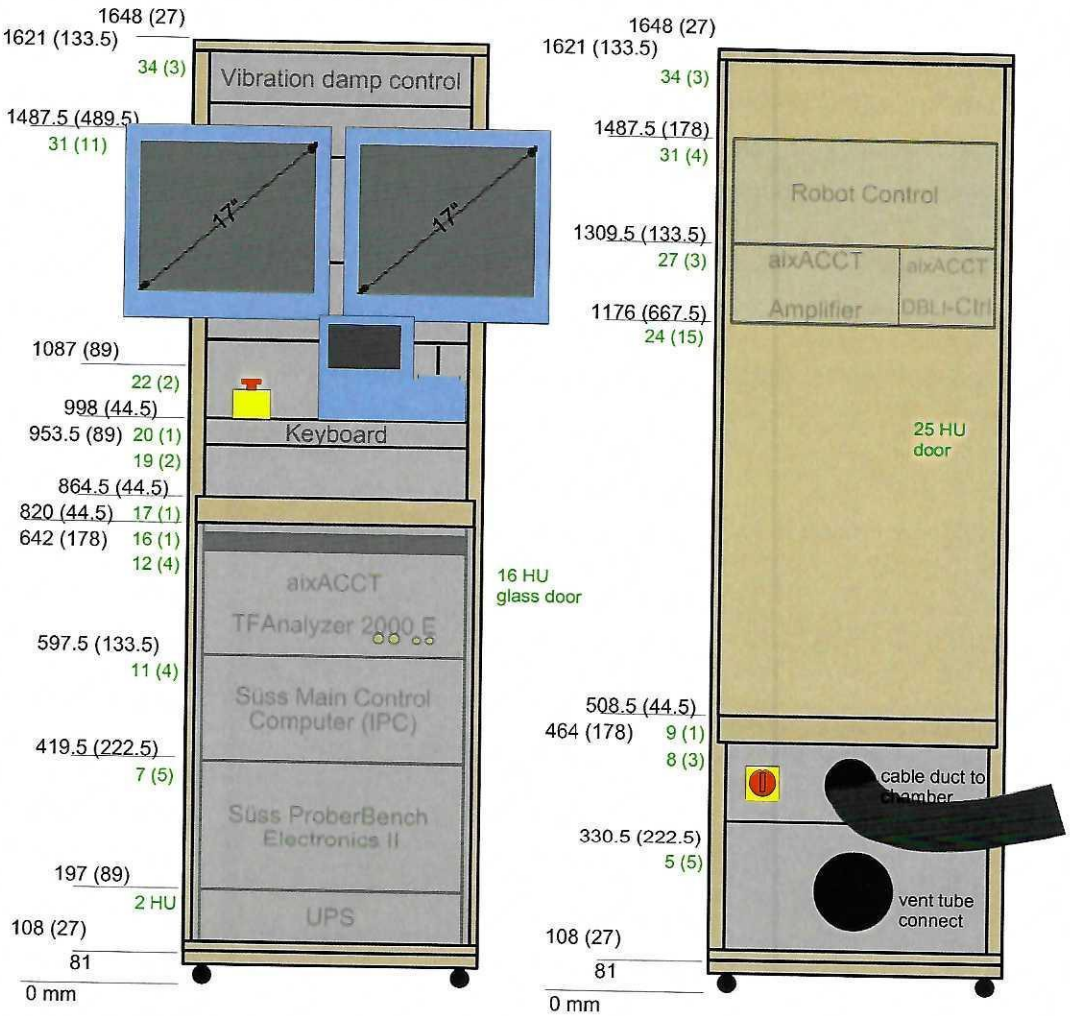


Fig. 3.3: Detailed schematic of the aixDBLI System rack with electronic components.

Beam working point controller This unit as described above is located in the rear of the rack next to the 200 V amplifier. It features diagnostic LEDs and a reset button for restart in case of an internal controller error.

Uninterruptable Power Supply (UPS): The UPS supplies the aixACCT Analyzer PC and the wafer prober control PC including their displays when power is interrupted. This enables the user to save all unsaved data and shut down the system in case of a main power failure. The UPS output voltage is 110 - 120 V, maximum power 1500 VA/1050 W. The output power cables of the UPS and connected devices are labeled *UPS powered*, because they may maintain power in an EMO condition. In case the master switch is turned off, the UPS does not supply power to any component of the system. Unsaved data will be lost. Please refer to the UPS manual for further information, especially for safety, operation and maintenance. Do not change any settings, because it may be harmful to the system.

Vibration damping Control: The controller of this unit as described above is mounted in the rack mount system.

4. Installation

Transport, assembly and acceptance of the aixDBLI System may only be carried out when technically qualified and authorized aixACCT personnel supervise the work. Support from the customer whilst setting up is possible and desirable.

4.1. Transport

The aixDBLI System will be delivered in 4 wooden crates. Preliminary and application dependent sizes and weights are:

	Width [mm]	Depth [mm]	Height [mm]	Gross weight [kg]
Wafer prober/DBLI	1340	1340	1730	500
Rack	600	800	1850	300
Isolation chamber	2200	820	1620	500
Loader	600	1400	1000	300

It is important that the crates are not tilted or exposed to significant shocks during transportation. A lifting truck will be necessary to transport the system to its final position.

If the courier or the end user should become aware of any damage to the transport crates or should notice that either the Shockwatch or Tiltwatch indicator is red they should inform aixACCT Systems or the insurance company.

4.2. Facility requirements

Supply connections: The end user provides the connections to supply the aixDBLI System with electric power, compressed air and vacuum in the required capacity and quality.

Supply lines must be installed in compliance with local safety regulations and with the information in the media diagrams. The lines must be protected against mechanical damage or stress. Lines on the floor must be covered properly to prevent the risk of tripping.

Fuses, Mainpower externals The user is responsible to provide a max. 20 A lead fuse for the main cable and ground-fault circuit interrupter if required.

Electrical power supply:	
Power Voltage Frequency Power consumption	 100 - 120 V nominal 50/60 Hz max 2000 VA typ. 500 W w/o vibration damping & loader
Protection Class	I
Transient Overvoltage	Overvoltage Categorie II
Plugs EU	socket strip with grounded mains plug 16A/250V CEE-7/VII / DIN49441
Plugs US	socket strip with grounded mains plug 20A/1150V UL, SCA, NEMA 5-20P

Compressed air and vacuum: Additional facility requirements for the aixDBLI System are compressed air to operate the Vibration Isolation Table (VIT) and a vacuum connection for the wafer chuck.

Air flow and vacuum:	
Compressed air (VIT)	Filtered, dry, and oil free $\geq$ 4 bar (max. 8 bar), flow rate insignificant
Compressed air input (VIT)	8 mm
Vacuum	Less than 200 mbar absolute, flow rate insignificant
Vacuum input	8 mm

Ventilations system: The rack with the electronic components needs a connection to a ventilation system for thermal cooling. It is equipped with an exhaust connection at the rear. The air flow is required for sufficient cooling of the system.

	Diameter [mm]	Air flow [l/s]	Air flow [cubic foot/min]
Rack vent tube connect	150	50 - 100	100 - 200

System dimensions: The aixDBLI System consists of two components, the isolation chamber with wafer prober, DBLI, and loader and the rack with the electronic components. They are connected with a 100 mm diameter cable conduit.

	Width [mm]	Depth [mm]	Height [mm]	Weight [kg]
Isolation chamber (incl. DBLI, prober, and loader)	1500	1250	2100	1000
Rack	810	1000 1250 (pulled out keyboard)	1670 1960 (including beacon)	200

Clearance distances for escape routes must be kept within the local safety regulations. Safety doors, covers, etc. must be installed in such a way that the aixDBLI System remains accessible from all sides for maintenance and service work. Clearance distances from the chamber respectively rack walls are given in the table below

Front [mm]	1300
Back [mm]	700
Left [mm]	1000
Right [mm] (from rack)	700
Top [mm]	510
Between Chamber and Rack [mm]	200

Floor plans of the front and bottom view of the aixDBLI System are given in Fig. 4.1 and Fig. 4.2.

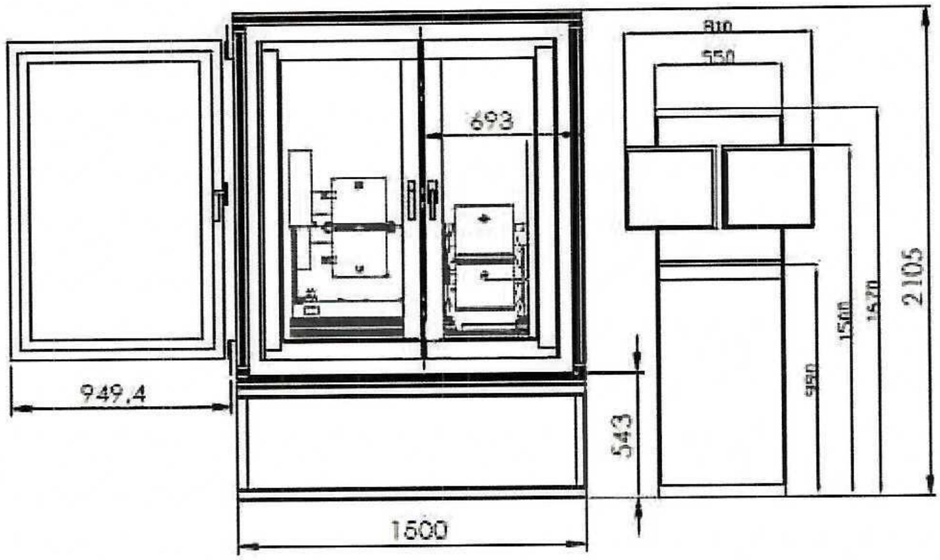


Fig. 4.1: Front view of chamber and rack with dimensions and open service door.

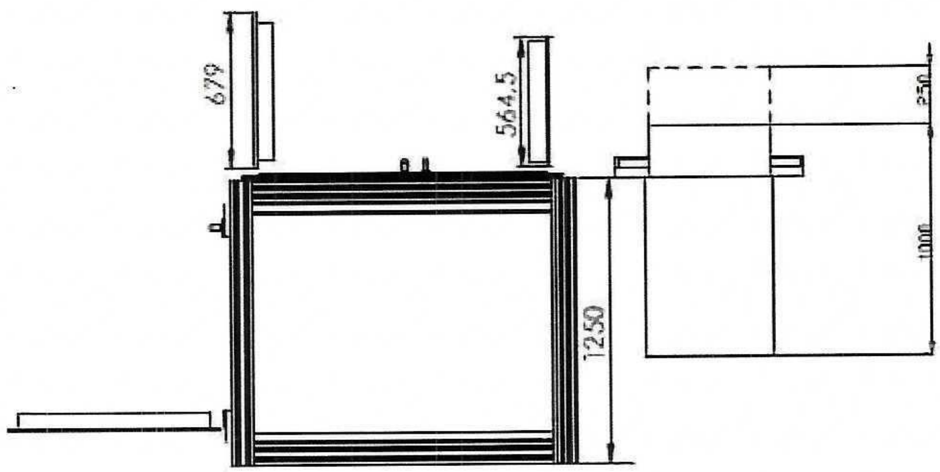


Fig. 4.2: Bottom view of chamber and rack with dimensions and open front and service doors.

4.3. Assembly

Only specially trained aixACCT service technicians are permitted to install and to commission the aixDBLI System. Other persons are not allowed to perform these tasks.

For this reason, the required steps are not described here.

4.4. Acceptance

The safety- and interlocking functions must be demonstrated when the aixDBLI System is handed over to the end user. The aixDBLI System must be ready for operation and must have been successfully subjected to previous operational and functional testing. Both end user and aixACCT service technician must provide written confirmation (acceptance report) that safety-related, precautionary devices are functioning correctly.

At the end of a successful system acceptance check, the acceptance report will be signed by an authorized representative from aixACCT and by a specialist delegated by the end user.

4.5. Environmental conditions and earthquake protection

The aixDBLI System is for use within a clean room environment, at an operating temperature of approx. 22 °Cand a relative humidity between 25 to 60 %.

Environment conditions		
Temperature		
	Operating range	19°C - 24°C
	Target temperature	22°C
	Base plate temperature	16°C - 21°C
Humidity		
	Tool area	25% - 60%
	Support equipment area	25% - 60%

The aixDBLI System does not produce vibrations. The wafer prober and all optical measurement components are set on a vibration isolation table in order that the equipment is not disturbed by movement or vibrations from outside. Nevertheless, the aixDBLI System must not be exposed to notable vibrations. For this reason, make sure that no equipment creating heavy vibrations is installed in the vicinity of the aixDBLI System. Also make sure that the ground on which the system is installed is capable of absorbing vibrations.

5. System operation

The aixDBLI System must only be used as described in Chapter 1. All work instructions and procedures which could impair personnel or equipment safety are strictly prohibited. The branch-specific and local regulations concerning prevention of accidents must be followed.

Work place: With appropriate instructions and checks, the end user guarantees for a work environment around the aixDBLI System that is orderly and clean. The work place lighting should provide a minimum level 500 lux or should conform with the local regulations.

Escape, rescue and alarm plan: The end user is responsible for creating an escape, rescue and alarm plan for the work place and the aixDBLI System surroundings.

5.1. System power up

This chapter describes the single steps to power up the aixDBLI System.

1. In case of a foregoing emergency shut off, release all pressed Emergency Stop buttons.

2. Turn, if necessary, the main power switch at the rear side of the rack into ON position.

3. Switch on the Uninterruptible Power Supply (UPS) at the bottom of the rack by pressing and holding the I button on the UPS front panel (refer to UPS manual for details).

4. The green *POWER UP* button should be lit now. If not, e.g. after a power failure it may be necessary to press the red *POWER DOWN* button first and wait approx. 1 minute.
5. Press the green *POWER UP* button at the front of the rack. All necessary components will be powered up automatically in the right boot sequence.
6. A vibration control unit (mounted at top front side of the rack) may require to be switched on manually.

7. When all components have finished the power up sequence after approx 1 minunte, the graphical user interface of the measurement software is loaded. The last thing which appears is the wafer camera picture on the left screen. Now the system can be used as it is described in the User Manual and the system status should be checked as described in 5.5. Before performing measurements the system should warm up about 20 minutes for laser stabilisation.

5.2. Operation mode selection

The key-operated-switch left beside the *POWER UP* and *POWER DOWN* buttons is used to switch between the two operation modes of the aixDBLI System. The typical mode of operation is the *Normal mode* which is used to do measurements with the system.

WARNING: Do not select the *Service mode*, if you are not properly instructed and experienced for service on the aixDBLI System.

In *Service mode* you can operate the system the same as in *Normal mode*. But laser and wafer stage are **NOT** switched off when one of the chamber doors is opened. The wafer stage can be moved and also 200 V amplifier can be set into the enabled state during measurements. This operation is only necessary for the beam alignment procedure and service adjustments and measurements.

WARNING: Always turn the key-operated-switch back into *Normal mode* after finishing the service operation. Remove the key and logout as user on the system.

CAUTION: Never touch the probe tips during measurements in *Service mode* as high voltage can be applied.

WARNING: In case you plan to open the chamber, put on the blue laser spectacles to protect your eyes from the laser beam.
WARNING: Do not attempt to view either a direct or reflected beam without eye protection.

5.3. Machine state beacon

A beacon is installed on top of the rack to indicate the operation state of the machine.

Beacon color	Meaning
Green	System in regular operation mode
Green & Orange	System in regular operation mode and waits for user input
Orange	An error has occurred and user interaction is required
Red	Service mode is active.
Red (blinking)	Danger! An Emergency Stop button has been pressed or system power failure.

5.4. System power down

To shut down the aixDBLI System please proceed with the following steps:

1. Press the red *POWER DOWN* switch.

2. Wait until all PC components in the rack are shut down and turn then the main power switch at the rear side of the rack into OFF position.

6. Appendix

6.1. Maintenance

The end user is obliged to make sure that the aixDBLI System is only operated when it is in a perfectly sound technical operating condition. All maintenance and service work must be performed in accordance with the information provided in the system documentation.

6.1.1. Personnel qualifications

All maintenance and service work is only for those users who have been appointed the Calibrator or Superuser qualification level. See the User Manual for the specification of qualifications.

6.1.2. Visual inspections

The aixDBLI concept keeps the amount of required maintenance work to a minimum. Most of the components do not require any kind of maintenance work if you observe the stipulations for normal operating conditions. It is sufficient to make regular visual inspections. In addition, you should always listen for unusual noise and pay immediate attention to any malfunctioning.

6.1.3. Maintenance contract

aixACCT Systems recommends to have the entire system overhauled by aixACCT service technicians on a regular basis. Various important wear-sensitive system parts such as laser, parts of the wafer prober and parts of the wafer robot etc. will then be replaced by new parts. Please contact aixACCT for information about a customer-specific maintenance contract.

6.1.4. OEM manuals

Instructions for maintenance work which make reference to any OEM manuals must be carried out in strict accordance with the stipulations in the relevant manuals.

6.1.5. Spare parts

Use only original spare parts for maintenance and service work. For information on spare parts, please send an e-mail to: support@aixacct.com

6.1.6. Safety

Before you perform any maintenance work at the aixDBLI System, you must have read and fully understood the Safety Chapter 2. Pay attention to all hazard alerts in this Safety Chapter.

6.1.7. Maintenance mode

You must switch the aixDBLI System into the service mode to carry out certain maintenance work. See Chapter 5.2 for the selection of the service mode.

6.1.8. Auxiliary devices and used materials

Auxiliary devices The following items should be at hand before starting with the service and operation work.

- Standard tool box
- Standard safety equipment
- Clean and lint-free clean room gloves

Operating materials The following list specifies parts that become solid waste as a result of operation, maintenance and servicing of the aixDBLI System. The disposal of these parts must be regulated by the end user according to the local safety regulations.

- Cleaning agents
- Lint-free cloth
- Isopropanol (isopropyl alcohol, 2-propanol)

NOTE: Unsuitable solvents.
Acetone, methanol and ethanol are unsuitable solvents. These chemicals attack seals made of nitrile and fluorocarbon rubber (e.g. Perbunan and Viton). In addition, methanol is toxic. Avoid these solvents. Use isopropanol instead.

6.1.9. Maintenance logbook

aixACCT Systems recommends that a record of all maintenance work performed at the aixDBLI be kept in a logbook. This is particularly important if various different personnel are responsible for maintenance work on one system. A logbook allows the end user to keep a reliable check on the type and date of performed maintenance work.

The following entries are recommended for the maintenance logbook

Action Specifies the specific type of required maintenance work

Interval Specifies the recommended maintenance intervals

Mode Specifies the necessary operation mode of the aixDBLI System selected by the key-operated-switch, Normal mode = (NM) or Service mode (SM)

User / Comments Here you can find which user group is allowed to perform this maintenance work and brief notes on the work itself or references to relevant chapters or documents which contain further explanations. Instructions for maintenance work which make reference to any OEM manuals must be carried out in strict accordance with the stipulations in the relevant manuals. Refer to the Safety Chapter 2 too!

Date and Signature Here you can keep a record of the performed maintenance work. Make copies of the maintenance schedule for this purpose.

Action	Interval	Mode	User / Comments	Date & Signature
Checking the probe tips & wedge	daily	OM	Technician, see Section 6.1.11	
Calibration measurement	daily	OM	Technician, see Section 6.1.12	
Checking the main switch	quarterly	SM	Super User, see Section 6.1.13	
Checking the Emergency STOP buttons	quarterly	SM	Super User, see Section 6.1.14	
Checking the interlock switches	quarterly	SM	Super User, see Section 6.1.15	

6.1.10. Maintenance schedule

The required maintenance work at aixDBLI system parts must be carried out at regular intervals. In addition, you should always listen for unusual noise and pay immediate attention to any malfunctioning which occurs in the system during the interim period between official system inspection procedures.

If the system does not operate like described in the Sections below bring the system in a safe operation state and immediately contact aixACCT Systems:

aixACCT Systems GmbH
Tel. +49 241 9631410
Fax. +49 241 9631411
e-mail support@aixacct.com

6.1.11. Check probe tips and wedge

Check the quality of the probe tips on a daily basis by visual inspection. Replace bent, twisted or broken probe tips with equivalent new ones. Probe tips can be cleaned automatically when a cleaning pad is installed on the chuck. Frequent contact failuers detected by the system may also indicate worn or contaminated probe tips, if wafer contamination or pad quality can be ruled out. The typical lifespan of probe tips and wedge is under regular operation conditions approximately 10000 to 100000 contacting cycles.

6.1.12. Perform quartz calibration measurement

The daily calibration measurement is used to check the aixDBLI System functionality after system start. A piezoelectric measurement is performed on a x-cut quartz single crystal with known piezoelectric response of 2.2 pm/V. The way how to do the measurement is described in the User Manual in the section for the Calibrator user.

Please contact aixACCT Systems in case of major deviations in the piezoelectric response or repeatability of the quartz sample.

6.1.13. Check main power supply

Maintenance and service personnel working on the electrical equipment must pay special attention to the following safety notes.

WARNING: Hazardous voltage!
The system contains parts which carry dangerous levels of voltage. Touching these parts will cause an electric shock. The shock may be lethal.
Prior to any work in the danger area:

- Switch out the system main power switch
- Ground the equipment
- Make sure no one switches the system on again during your work
- Check to make sure that no one is in the danger area before you switch the system on again

---

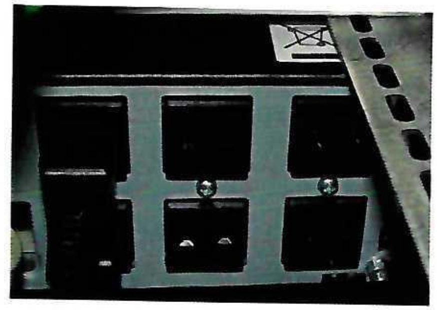
NOTE: Only personnel who have completed electronic professional training are permitted to perform work on the electrical equipment. Do not operate the aixDBLI System in *Service mode* if you are not properly instructed and experienced for service on this system.

Fig. 6.1: Main power switch at the bottom rear of the aixDBLI System rack.

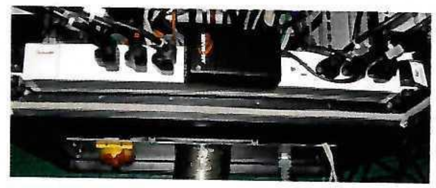
Check the switching function of the main power switch by means of a voltmeter:

1. Switch the main switch into the OFF position.
2. Open the rear panel of the rack mount system.

3. Check by means of a voltmeter in the outlet at the rear panel of the Uninterruptable Power Supply (UPS). One should detect 0 V.



4. Check by means of a voltmeter the voltage in the multi-outlet power-strip. One should detect 0 V.



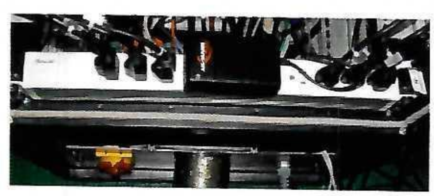
6.1.14. Check Emergency Off

To test this function you should boot up the aixDBLI system. Remove any wafer loaded into the system. Follow the steps below with every Emergency Off button. There are three buttons at different locations of the system.

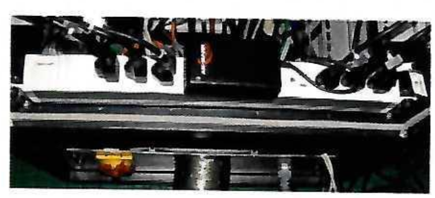
1. Press the selected Emergency Off button

2. Check by means of a voltmeter the supply voltage at the rear panel of the UPS. One should detect 110 - 120 V AC.

3. Check by means of a voltmeter the supply voltage in the multi-outlet power strip. One should measure 110 - 120 V AC.



4. Check that the power lights of the 200 V amplifier and DBLI working point controller are turned off. Check that the EMO lamp at the front panel of the ProberBench Electronic unit is turned off. Check that the laser power is turned off by viewing the laser power supply lamps in the rear of the prober unit to be off.



6.1.15. Check interlock switches

Follow the steps below to test the interlock switches in the chamber doors. They operate as normally open contact switches.

1. **WARNING:** Put on proper eye protection glasses before performing the maintenance task.
2. **WARNING:** During operation there is danger of crushing, tripping or being caught up in the machine when the chamber doors are open. These dangers cannot be avoided due to the function of the machine but any areas of danger are clearly labeled with the signs overleaf.
3. **WARNING:** The measurement systems runs with voltages up to 200 V. In case of equipment failure the voltage can be present until the operator switches the power off at the main switch. Do not touch the electrical connections or probe tips.

1. Set the aixDBLI System with the key-operation-switch into *Normal Mode*.
2. Open each door one after the other (3 doors).
3. Check that the automatic laser shutter has properly shielded the laser beam. No laser beam can be seen.
4. The chamber light is switched on.
5. The stage cannot be moved. To test, try to move the stage by the joy stick on the control panel.
6. The 200 V amplifier in the rack is disabled. The LED "OUTPUT ACTIVE" is switched OFF.

Testing of the interlock switched in *Service Mode*. In this mode the laser is **NOT** disabled, the wafer stage can move and voltage can be applied to the sample.

1. Set the aixDBLI System with the key-operated-switch into *Service Mode*.
2. Open one of the doors of acoustic chamber. Laser is not shielded by the shutter and the laser beam can be seen.

3. Chamber light is on.

4. The wafer stage can be moved. To check, move the wafer stage using the joy stick of the control panel.

5. Turn the key-operated-switch back into *Normal Mode* and remove the key.

6.2. Storage of the aixDBLI System

6.2.1. Deactivating the system

1. Remove any wafer from the aixDBLI if one is mounted in the chuck of the wafer stage.
2. Shut down the aixDBLI System by pressing the *Power Down* button.
3. Switch the Main Switch on the rear panel of the rack mount system into the OFF position.
4. Disconnect the main power plug of the aixDBLI from mains.
5. Disconnect the system from vacuum.
6. Disconnect the system from pressure air, which is connected to the wafer prober
7. Disconnect all network connections.
8. Cover the system to protect it from dust.

6.2.2. Storage conditions

The aixDBLI System may only be stored in its original packing units. The storage environment must fulfill the following conditions:

Temperature	10-50 °C
Relative humidity	30 - 80% (non-condensing)

6.3. Disposal of the aixDBLI System

6.3.1. Personnel qualifications

Knowledge of mechanical procedures and waste material is a prerequisite for correct system dismantling and the separation of system waste products.

6.3.2. Safety regulations

Read the Safety Chapter 2 of this document before you dispose of the system. Adhere to all the hazard alerts and read all safety data sheets.

6.3.3. User responsibility

The end user is responsible for proper disposal of the aixDBLI System in keeping with the relevant regulations. The end user must hand over the system to either a licensed private or public disposal company or he/she must recycle the unit himself or dispose of it in accordance with the pertinent regulations.

1. **WARNING: Window glass in doors of acoustic chamber**
   The doors of the acoustic chamber of the aixDBLI System contain glass. Careful handling is required in order to make sure the glass will not sliver and cause injury to the person working on the disposal.

1. **NOTE:** If the end user hands over the aixDBLI to a disposal company then he/she must also forward a copy of the System Manual to the company in question. The System Manual contains important information which is required for system disposal.

Companies that dispose of and recycle their own waste material must be officially licensed to do so and are subject to official supervision. They can, under certain circumstances, be exempted from the obligatory license, provided that they are in a position to meet the demands for protection of the environment. These companies are obliged to register. For further information contact the departmental office competent for environmental protection.

Environmental statutes Waste material must be recycled or disposed of in a manner which does not present a health hazard. Use only procedures and methods which do not cause damage to the environment. In particular, make sure that:

- Air, water and ground are not contaminated
- Flora and fauna are not endangered
- Irritation from noise and obnoxious odors does not occur
- Environment and landscape are not damaged

Sorting Subsequent to dismantling the system, you must sort the individual system parts into their respective waste categories. Do this in accordance with the classifications contained in the current European Waste Catalog (EWC) or other similar statutes. The EWC catalog is valid for all waste material. It makes no difference if the waste material is destined for disposal or recycling.

Administration of waste material Adhere to the official administration and handling plans which outline the procedure for dealing with waste material. These plans comprise the following:

- Type, amount and origin of waste material
- General technical regulations
- Special arrangements for specific waste products
- Suitable regions for dumping grounds and other disposal installations
- Natural persons and legal entities who have authorization to deal with waste material
- The estimated costs for recycling and disposal
- Measures which can be implemented to rationalize collection, sorting and handling of waste material
- Identification labels for hazardous waste

6.3.4. Disposal: Other assemblies and components

The components of the aixDBLI System comprise the following materials:

Material	Example
Metals and alloys	Aluminum (housing, cover plates, etc.) Copper (electric lines) Steel (profiles, fixation equipment such as screws, etc.) Stainless steel (process chamber)
Glass	Glass (sight glasses, panes used in display instruments)
Synthetic material and rubber	Synthetic materials (operating elements, tubing, casing, wheels, etc.) Rubber seals, silicon tubing
Composite materials	Electrical materials (cables, motors, components) Electronic materials (printed circuit boards, PC, monitor, printer)
Packaging	Wood (packing cases) Styrofoam (padding material) Plastic (foil) Iron (nails, wire)

Part II.

User Software Manual

1. Introduction user interface

This part of the manual describes the different ways of user interactions with the aixDBLI System to make semiautomatic and manual measurements. A user management system with five user groups allows different access to software menus and settings.

After power up of the system (see Technical Documentation Manual) the operating software will start up automatically and the monitor shows an initial screen. It is split into two halves to be displayed on the double monitor system of the aixDBLI rack. The left monitor as shown in Fig. 1.1 is used to display either camera views of the wafer or a wafer map. This view is mirrored onto the monitor inside the chamber if a door is opened. Both monitors in the rack are touchscreens for direct and easy control of the measurement software by hand.

The right part is shown in Fig. 1.2.

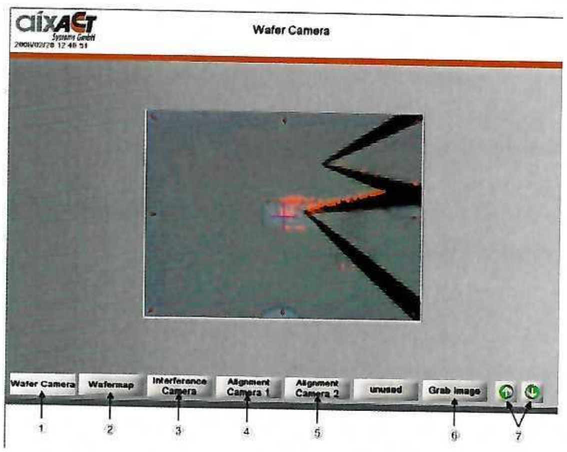


Fig. 1.1: Login screen after power up of the system.

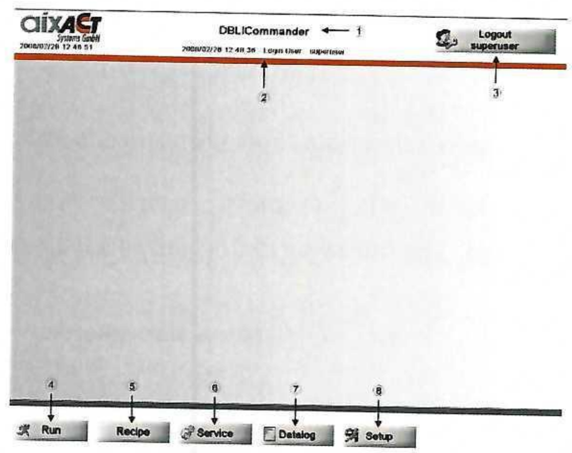


Fig. 1.2: Login screen after power up of the system.

The buttons at the bottom of the initial screen are shown while the aixDBLI is running. According to the actual task and the logged in user some of these buttons are temporarily inactive.

The buttons within the left screen allow to switch between different live camera views (1, 3, 4, 5), the actual status of the wafer map (2) or the lighting (7). The active camera image can be grabbed and saved by button (6).

The right screen is the action screen and summarizes the tasks of the aixDBLI. The *Run (4)* button starts semiautomatic or manual measuremnts, the *Recipe (5)* button allows to create or manipulate recipes as described in Chapter 4.4, the *Service (6)* button allows to run service tasks as e.g. setting the contact height (see Chapter 4.5), the *Datalog (7)* button shows diverse log files and the *Setup (8)* button is used to manage user accounts (see Chapter 6.4) and system preferences (see Chapter 6.6).

Within the header part a headline describing the active task (1) and a timestamp with the last system message (2) is shown. The logout button (3) can be used to switch between user accounts.

1.1. User groups

There are five different user groups with different permissions on the aixDBLI System:

- Operator
- Technician
- Engineer
- Calibrator
- Super User

Chapter 6.4 describes, how users are added to the different user groups.

In order to switch to another user the button *Logout <user>* in the top right edge must be pressed. The following dialog shows a list of all defined users to select.

Fig. 1.3: Login screen to switch to a different user account.

The following table summarizes the tasks which can be performed with the different user group access rights:

	Operator	Technician	Engineer	Calibrator	Super User
Run measurement (Chapter 2.2)	x	x	x	x	x
Manual meas. mode (Chapter 3.3)	-	x	x	x	x
Quartz calibration meas. (Chapter 3.6)	-	x	x	x	x
Align wafer (Chapter 3.5)	-	x	x	x	x
Exit software (Chapter 6.3)	-	x	x	x	x
Create/edit recipe (Chapter 4.4)	-	-	x	x	x
Set contact height (Chapter 4.5)	-	-	x	x	x
Check positions (Chapter 4.6)	-	-	x	x	x
System settings / maintenance (Chapter 5.3)	-	-	-	x	x
Change probe tips (Chapter 5.4)	-	-	-	x	x
System information (Chapter 5.5)	-	-	-	x	x
User management (Chapter 6.4)	-	-	-	-	x
Hardware calibration	-	-	-	-	x

2. Operator

SAFETY INSTRUCTIONS:

- Read and understand this Manual and the Safety Chapter 2 before operating this system.
- Only a trained person is to be permitted to operate this system. Training should include instruction in operating under normal conditions and emergency situations.
- Never change or defeat the function of electrical interlocks or other system "shutdown" switches.

2.1. User login

After power up of the system the right monitor shows the login screen for the different users as described in Chapter 1. Log in as user *Operator* unless *Operator* is already logged in.

2.2. Run semiautomatic measurement

It is compulsory that the wafer thickness is set once before a measurement sequence on similar wafers can be started. All other menu entries are disabled until the wafer thickness and contact height are properly set. This has to be done by the Engineer (see Chapter 4.5). The procedure needs to be repeated e.g when wafers with a different thickness are to be measured. The thickness tolerance is dependent on the probe tip overtravel and laser focus, for an estimate thickness variation should be less than 100µm and less than the overtravel amount minus 10 µm. A wrong wafer thickness may cause contact failures or even damage the probe tips !

The flow chart of the semiautomatic measurement sequence for the operator is given in Fig. 2.1.

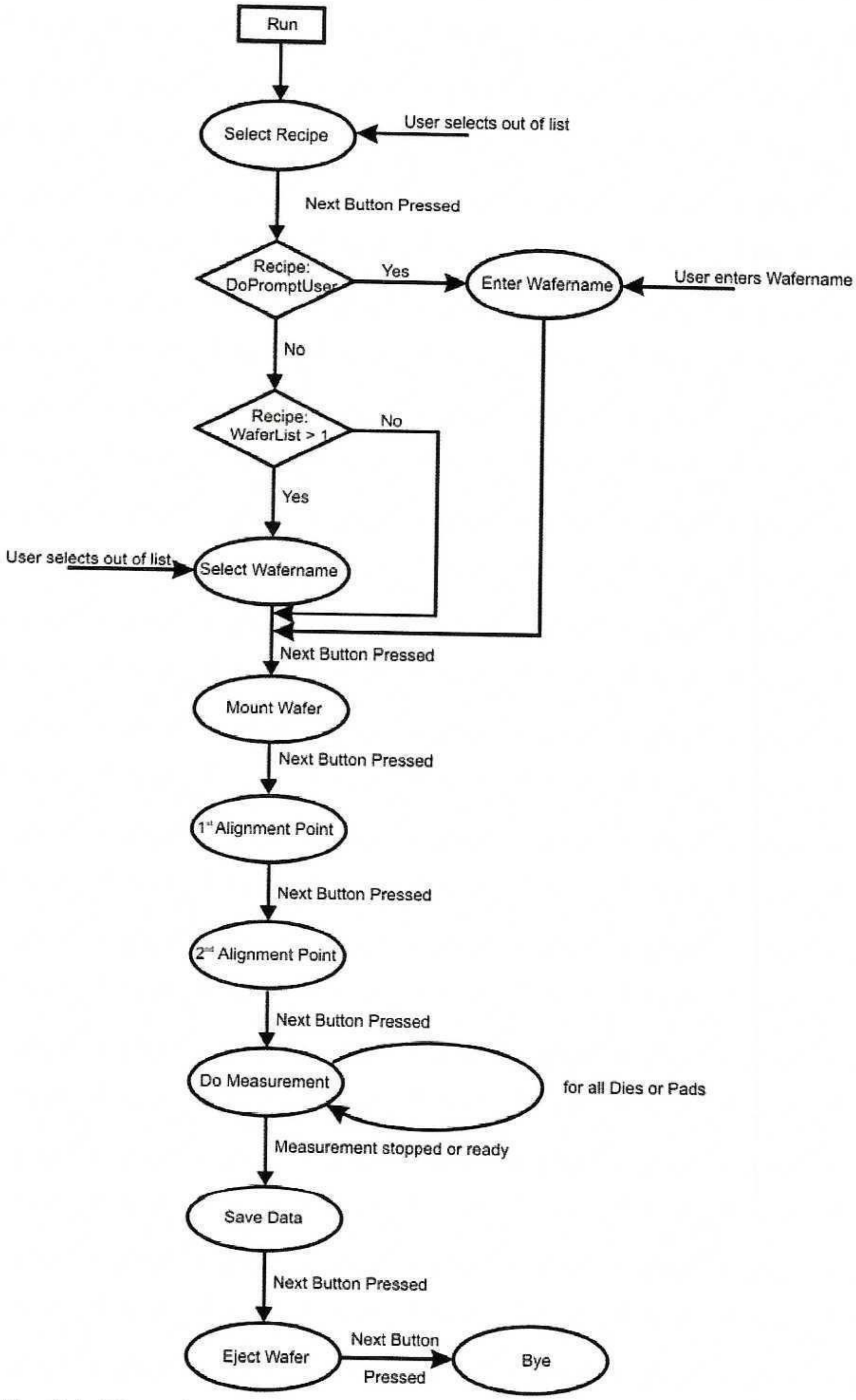


Fig. 2.1: Flow chart of the semiautomatic measurement sequence.

1. Start the measurement sequence by pressing the *Run* button. While running the actual task is selected in the status list at the left of the right screen.

2. Select an existing measurement recipe.

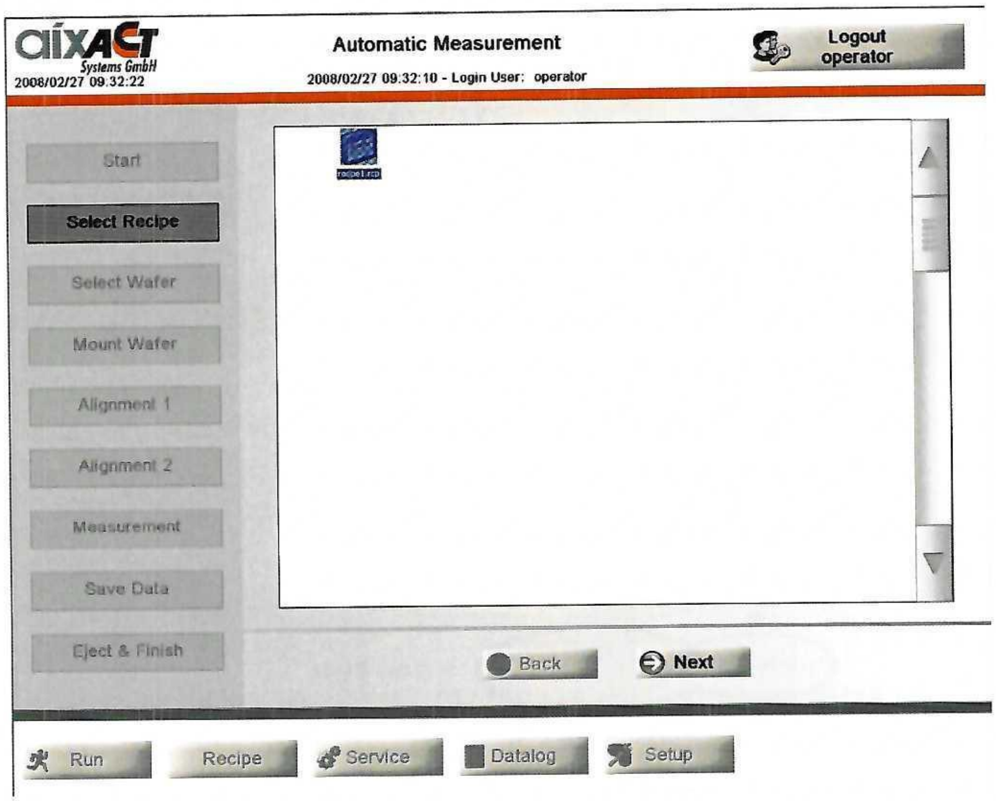


Fig. 2.2: Operator measurement sequence - select measurement recipe.

3. Depending on the recipe enter a wafer name in the dialog or select a wafer name from the list shown (this step is skipped for a recipe with one wafer name entry only) and press the *Next* button.

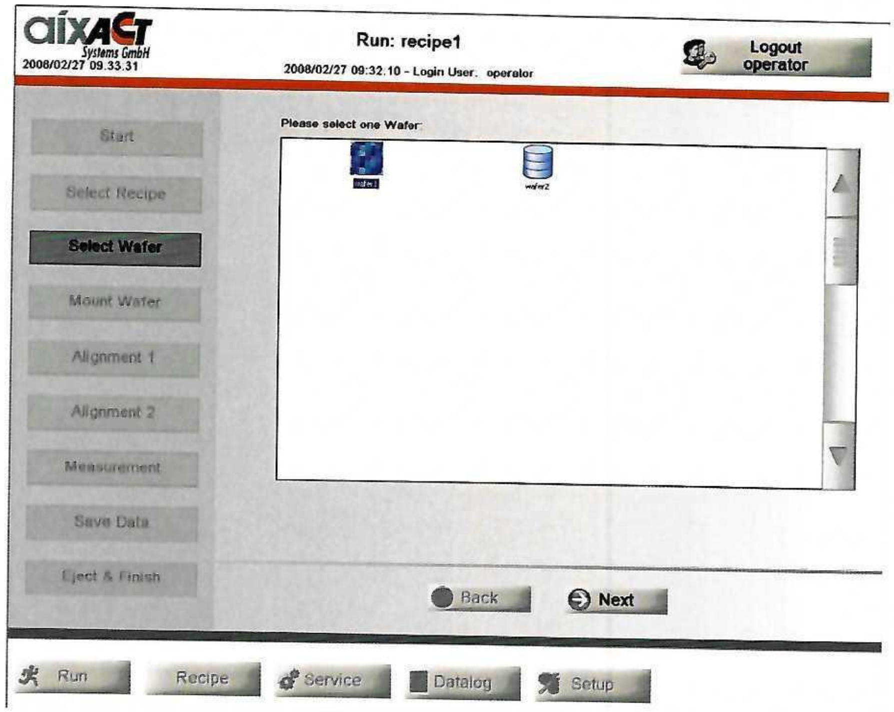


Fig. 2.3: Operator measurement sequence - select wafer name.

4. Open front left chamber door and lid, then load the specified wafer onto the wafer chuck. The wafer should be carefully placed against the bumpers in the rear, and pre aligned by matching the wafer notch with the hole in the chuck at the 6 o'clock position. Close the lid and door and press *Next*.

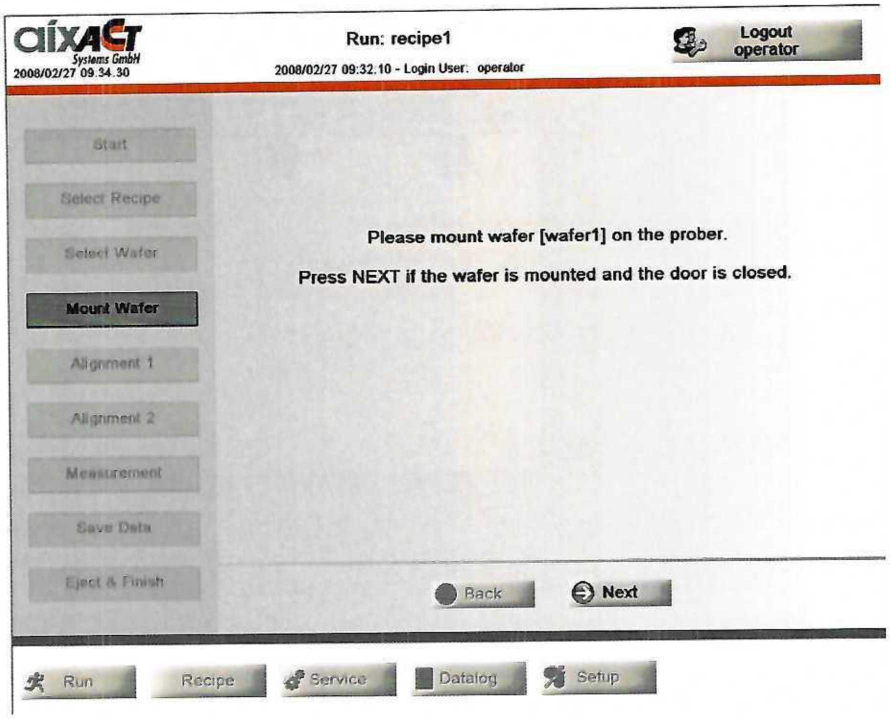


Fig. 2.4: Operator measurement sequence - mount wafer.

5. Use joystick to position the crosshair or laser spot onto the first alignment mark (The actual mark is defined by the wafer mask and the alignment position has to be clearly defined or trained by the Engineer in accordance with the recipe settings). If the Operator 'gets lost' searching the mark he can press *Go back to align position* to go back to the start position. When aligned, press *Next* button.

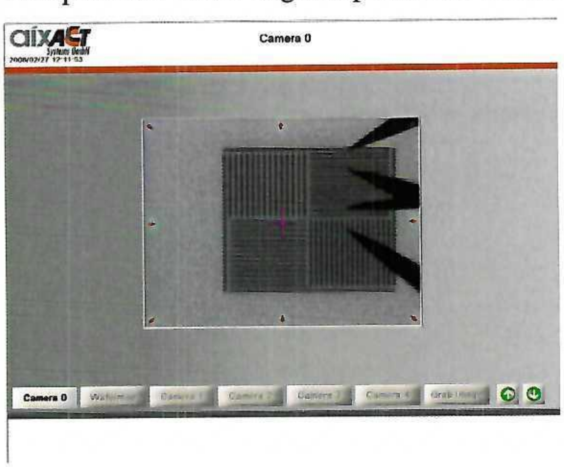


Fig. 2.5: Operator measurement sequence - align wafer camera image.

Fig. 2.6: Operator measurement sequence - align wafer.

6. Repeat last step to align the wafer with the second alignment mark. Then press *Next* button.

7. Automatic measurement of all dies and pads described in the recipe is performed.

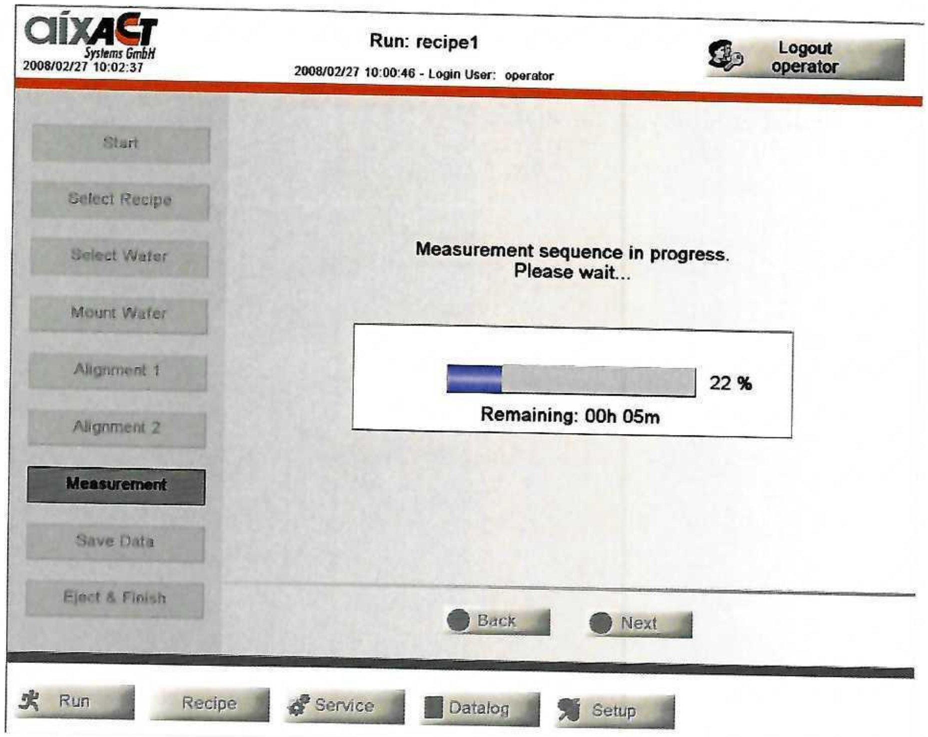


Fig. 2.7: Operator measurement sequence - measurement running.

8. Data will be automatically saved in the end.

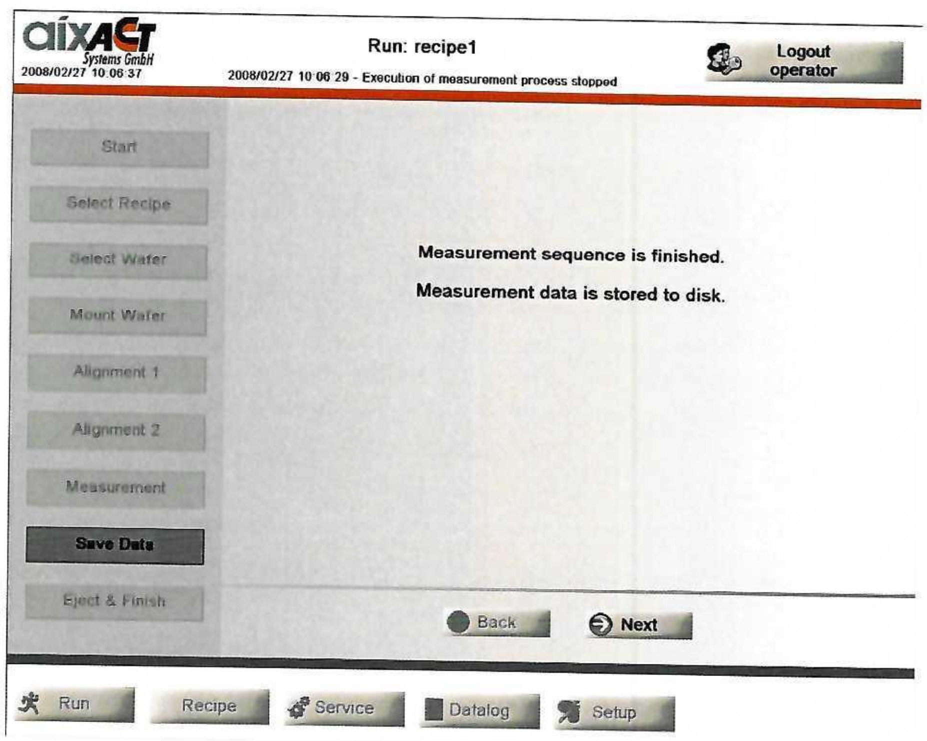


Fig. 2.8: Operator measurement sequence - save measurement data.

9. Wafer will be positioned into load position to be removed from the prober.

10. Press *Next* after removing the wafer.

3. Technician

SAFETY INSTRUCTIONS:

- Read and understand this Manual and all safety labels before operating this system.
- Only a trained person is to be permitted to operate this system. Training should include instruction in operating under normal conditions and emergency situations.
- This system is to be serviced only by trained and authorized personnel.
- Never change or defeat the function of electrical interlocks or other system "shutdown" switches.

3.1. User login

After power up of the system (see Technical Documentation Manual) the monitor shows the login screen for the different users as described in Chapter 1.

3.2. Run semiautomatic measurement

The procedure for the semiautomatic measurement is described in Chapter 2.2. Select the *Start Normal* which appears on the top right after pressing the *Run* button.

The menu for the technician to select a recipe for measurement differs from the one for the operator. To select a recipe the following dialog is shown.

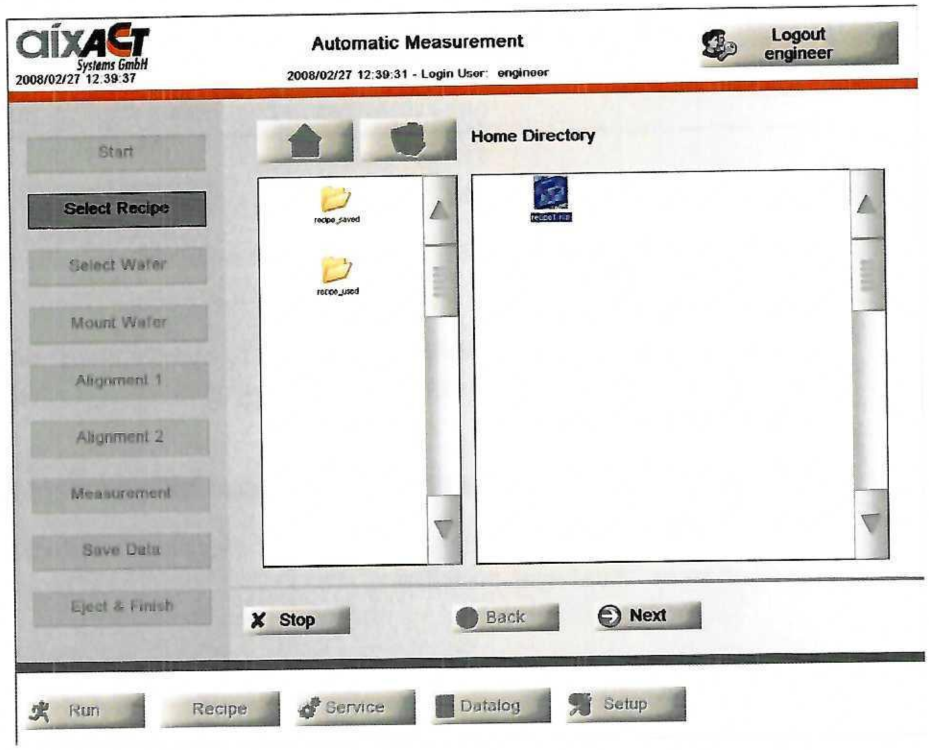


Fig. 3.1: Select recipe window for semiautomatic measurement for the engineer.

During the measurement a wafer map is displayed on the left screen. Different colours are used to specify the measurement status. The different colours represents the following results:

gray the die is measured but cannot be qualified due to missing qualification parameters

white the die is not measured yet

yellow there are multiple pads within the die

green die is ready and result is within expected range set in the recipe

red the result is out of the expected range

blue the pad failed due to poor reflection, short contact or poor electrical contact

Dependent on the selected recipe the coloured wafermap is stored with the measurement data.

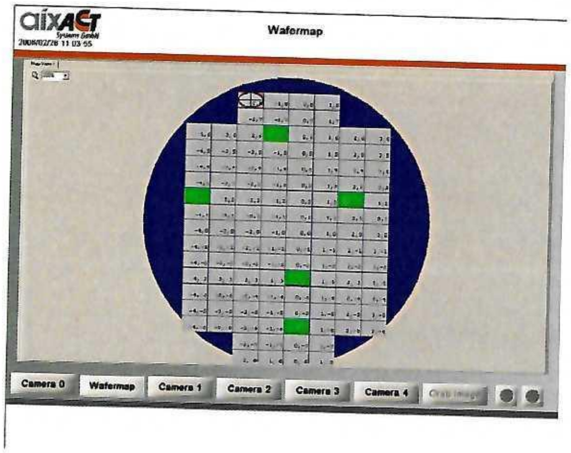


Fig. 3.2: Results of measurement sequence - coloured wafermap.

Fig. 3.3: Results of measurement sequence - right part.

3.3. Manual measurement

It is compulsory to set the wafer thickness once before a measurement can be started. All other menu entries are disabled until the wafer thickness and contact height are properly set. This has to be done by the Engineer (see Chapter 4.5). The procedure needs to be repeated e.g when wafers with a different thickness are to be measured.

There are two measurements which are supported by the aixDBLI System. This is the large signal piezoelectric measurement (PZM) for dielectric hysteresis and displacement characterization and the small signal capacitance and piezoelectric coefficient $d_{33,f}$ measurement (CVM). For test or research reasons these measurements can be manually performed on single test devices on the wafer without using a measurement recipe. Follow the steps below for a manual measurement:

1. If not done already, press the *Load wafer* button and load a wafer into the system.
2. Align the wafer as described in chapter 3.2.
3. Press the *Manual mode* button.
4. Move the laser spot to the desired measurement position on the wafer. It can be done in three ways or any combination of it:
   - Manually, using the joystick of the control panel.
   - By selection of the coordinates of a position.
   - By a predefined, selected wafermap and input of a specific die.

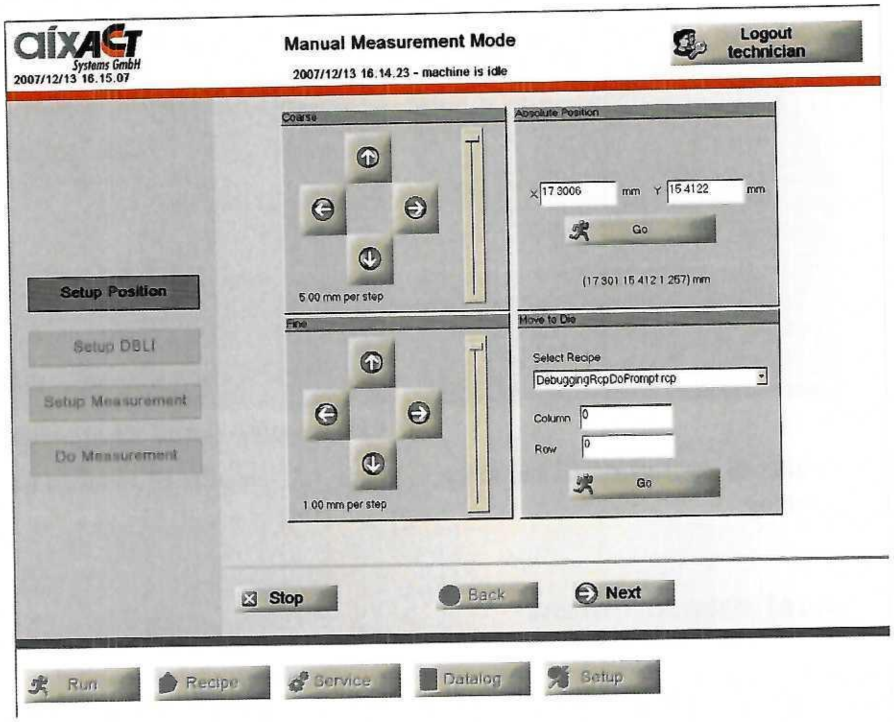


Fig. 3.4: Dialog window to move to the desired position on the wafer. Press *Next*.

5. In the next window the aixDBLI measure conditions are set by pressing the *Start Calibration (Hyster)* button. Continue afterwards by pressing *Next*.

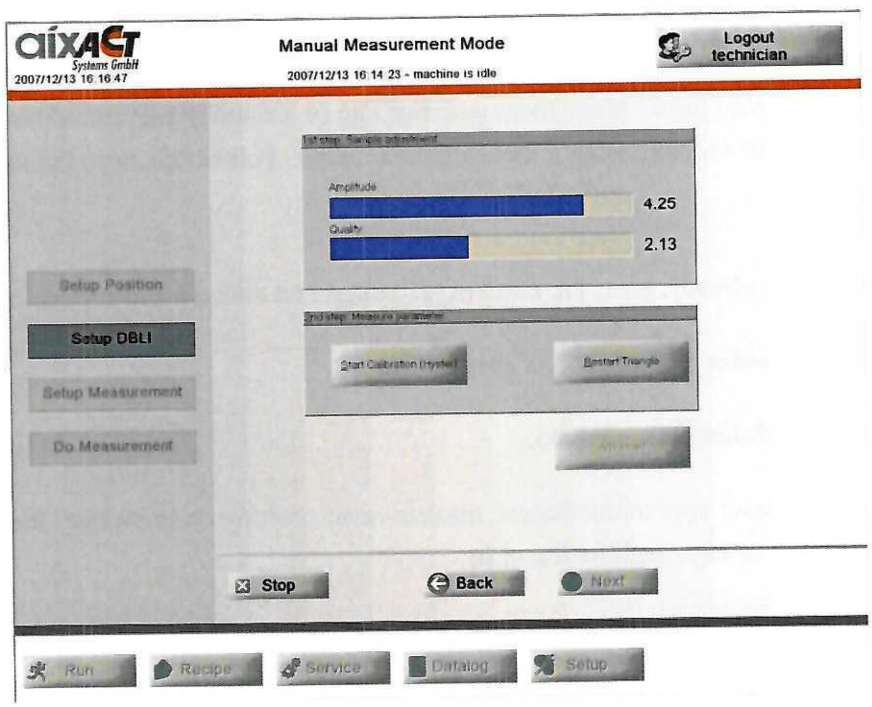


Fig. 3.5: Dialog window to estimate the aixDBLIcalibration settings.

6. Setup the measurement parameters. Details on the measurements and the parameters to be set can be found in Chapter 3.3.1 and Chapter 3.3.2.

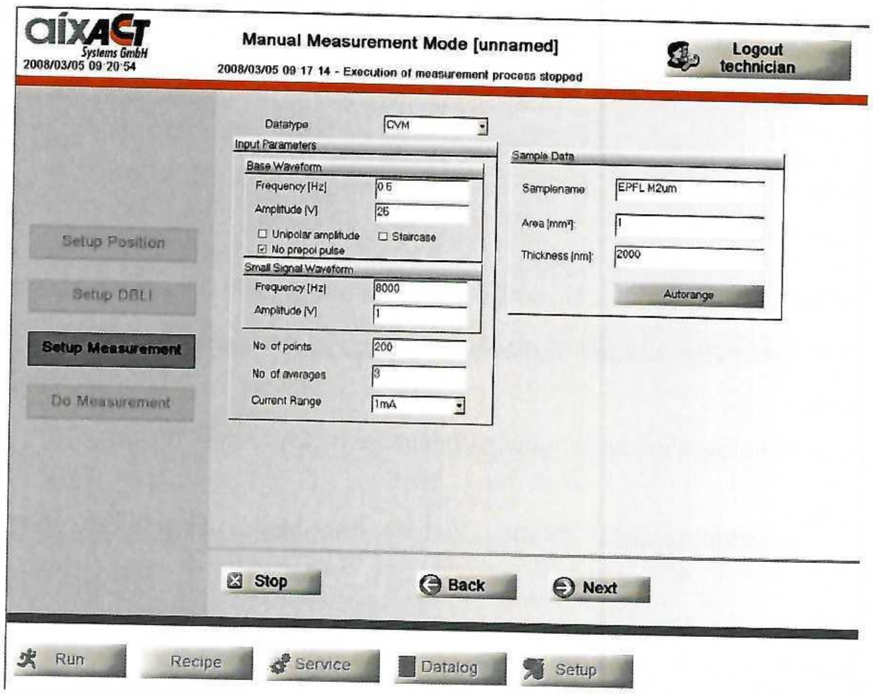


Fig. 3.6: Dialog window to configure the measurement settings.

7. Start a measurement by pressing the *Start* button. The results are shown in a graph as described in Chapter 3.3.1 and Chapter 3.3.2. The *Save as* button opens a dialog to select a place to save the shown measurement's data.

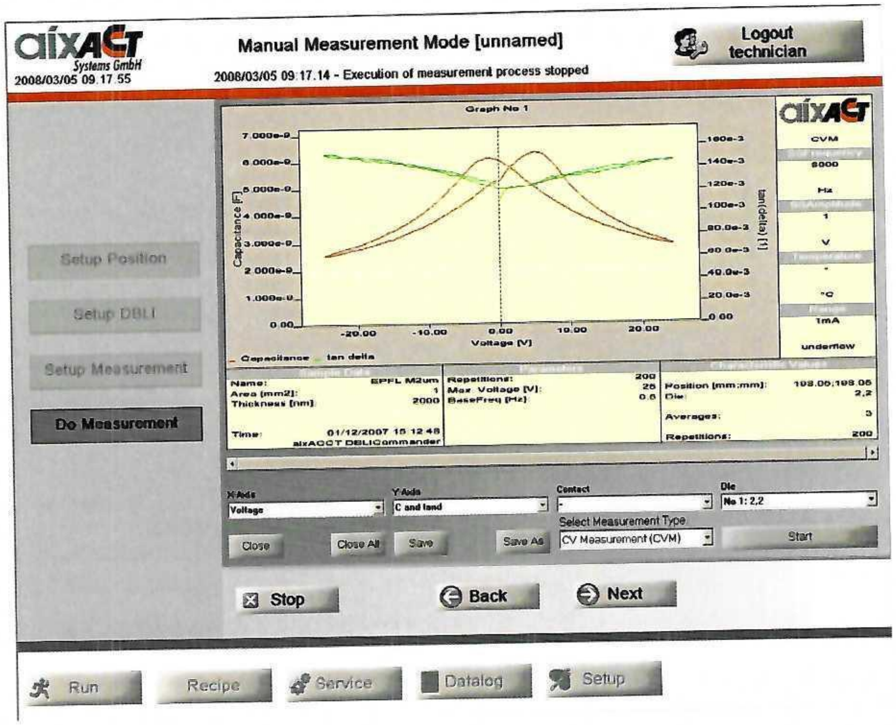


Fig. 3.7: Dialog window to view and manage measurement results.

The two measurement modes PZM and CVM are described in detail in the following two chapters.

3.3.1. Piezo Measurement - PZM

With the aixDBLI System and the piezo software you can perform large signal hysteresis measurements recorded simultaneously with sample displacement data. The displacement is captured by the double beam laser interferometer. This combination allows a comfortable and comprehensive investigation of the frequency dependence of the hysteresis loop and the piezoelectric or electrostrictive displacement.

The correlation of several process parameters can be examined on the shape of the butterfly curve in conjunction with the hysteresis loop. In addition to that, measurement parameters such as excitation signal, frequency and amplitude of the excitation signal can be varied.

Measurement procedure and typical measurement

A typical triangular voltage excitation signal for ferroelectric materials is shown in Fig. 3.8.

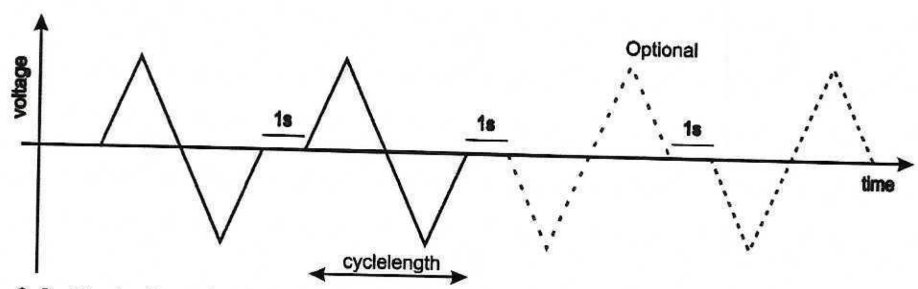


Fig. 3.8: Typical excitation waveform of a piezo measurement on a ferroelectric sample.

If selected the prepolarization pulse establishes a defined polarization state, that is the negative state of relaxed remanent polarization. The prepolarization pulse is followed alternatively by one or three consecutive bipolar excitation signals, each signal separated by 1 second of relaxation time. The butterfly curve and the hysteresis loop corresponding to the bipolar excitation signal are shown in Fig. 3.9.

The hysteresis loop corresponding to pulse no.1 starts in the negative relaxed remanent polarization state (P_{rrel-}) and turns into the positive saturation (P_{max+}). When the voltage equals zero the polarization reaches the positive remanent polarization state (P_{r+}). Following the curve it turns into the negative saturation (P_{max-}) and then back to the remanent polarization state (P_{r-}). P_{r-} is usually not equal to the starting point (P_{rrel-}) because of the polarization loss over time.

The butterfly loop is centered automatically to start at zero displacement.

To gather additional information about the hysteresis loop, two additional cycles can optionally be applied. The second loop is applied to change the sample into the positive remanent polar-

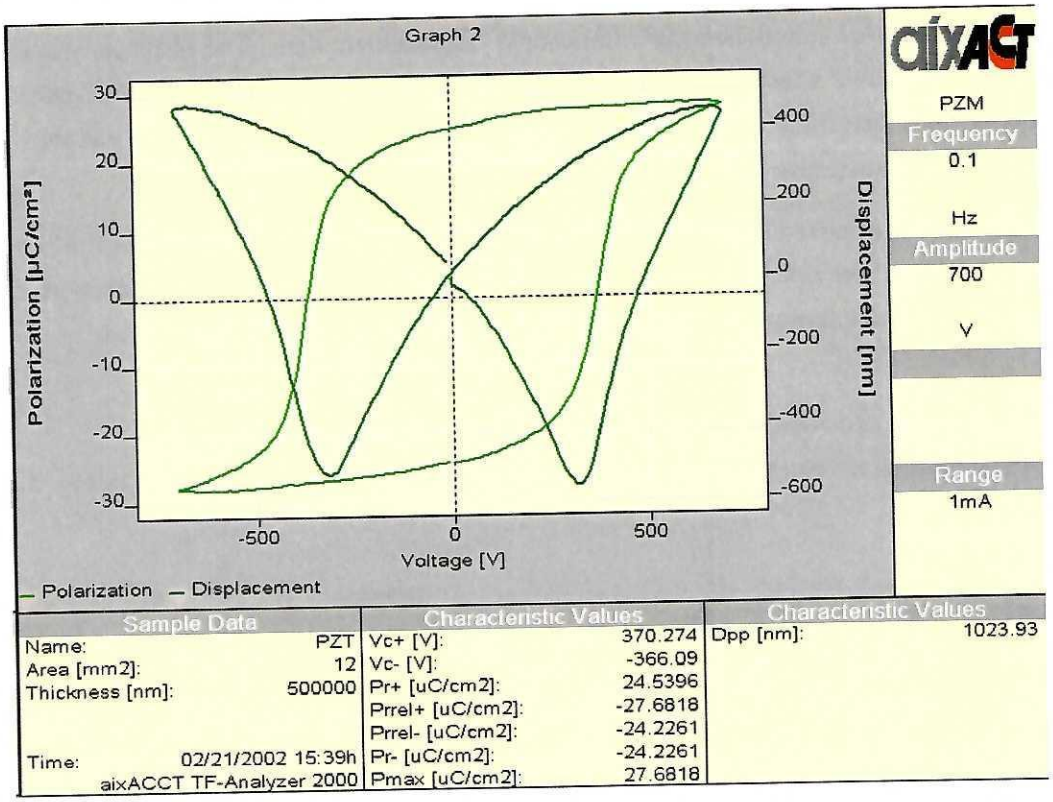


Fig. 3.9: Typical result of a piezo measurement.

ization state. No data are sampled during this loop. The third loop starts in the positive relaxed remanent polarization state (P_{rrel+}), turns into the negative saturation (P_{max-}) and crosses the polarization axis at zero volt excitation signal in the negative remanent polarization state (P_{r-}). Then the sample is driven into the positive saturation (P_{max+}) and ends in the positive remanent polarization state (P_{r+}) when the voltage is zero. The polarization loops are centered to the values $P(+V_{max})$ and $P(-V_{max})$. The parameters V_{c-}, P_{r-}, P_{rrel-} are extracted from the data of the first loop and respectively the parameters V_{c+}, P_{r+}, P_{rrel+} from the third loop. The closed hysteresis loop is plotted with the second half of the first and the second half of the third loop. The data of the first and third cycle are displayed for the displacement.

Result values of a Piezo measurement From the polarization and displacement measurement data additional characteristic values are calculated. Fig. 3.10 and Fig. 3.11 show typical displacement measurement results, where additional lines are drawn for the explanation of calculated parameters. In the following table Table 3.1 the calculated result values are listed with a description of the calculation method. The linear regression for the positive side is calculated from point $N/4$ to below $N/4$, for the negative side it is calculated from point $3N/4$ to below N where N is the total number of measurement points, for unipolar measurements the line is calculated from point $N/2$ to below N, in other words it is calculated for the non-switching branches of the butterfly loop. The first point of the displacement loop is set to 0 by definition.

The corresponding data points for polarization values are described also in the DHM (dynamic hysteresis) measurement.

Table 3.1: PZM Result value description:

Parameter	Unit	Description	Formula
Doffset	$[nm]$	displacement offset	displacement offset value from measured input voltage for first point (0)
Dpp	$[nm]$	peak to peak displacement	difference of maximum measured displacement point and minimum measured displacement point
Wloss	$[\mu J/cm^2]$	hysteresis loss energy	calculated area of P vs V loop
Cav	$[F]$	total average capacitance	average capacitance value of total measurement, linear regression of all P vs V points
EpsAv	[1]	average ϵ (dielectric number)	$\frac{Cav}{\epsilon_0} \frac{thickness}{area}$
d33av	$[nm/V]$	average d_{33}	average d_{33} value of total measurement, linear regression of all D vs V points
Me31av	$[C/m]$	average slope of e_31	linear regression of all D vs P points
d33av+	$[nm/V]$	average d_{33} positive side	linear regression slope D vs V values from V_{max} to $0V$ (non-switching)
d33av-	$[nm/V]$	average d_{33} negative side	linear regression slope D vs V values from $-V_{max}$ to $0V$ (non-switching)

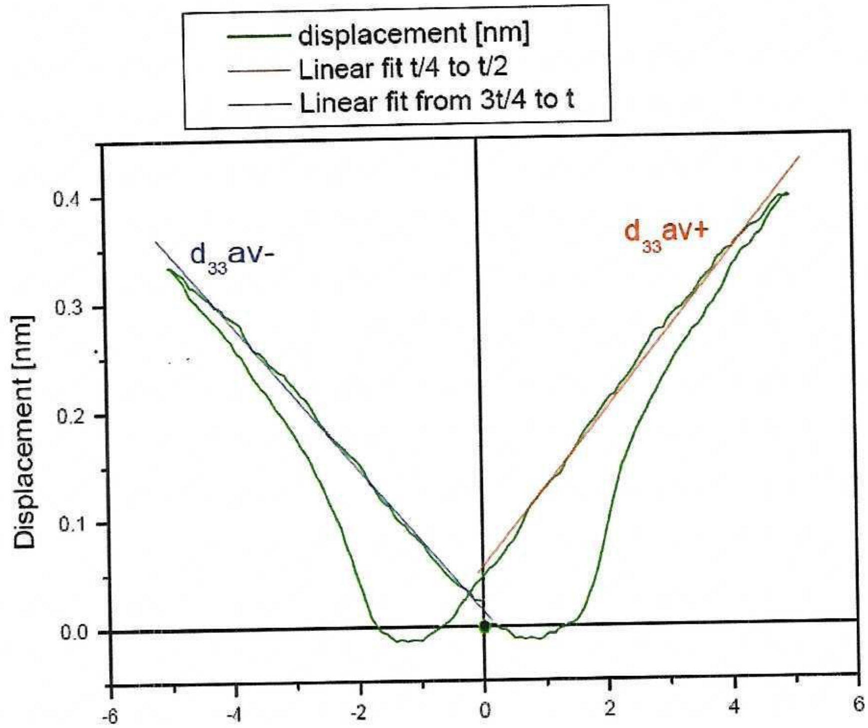


Fig. 3.10: Evaluation of typical parameters of Piezo measurements.

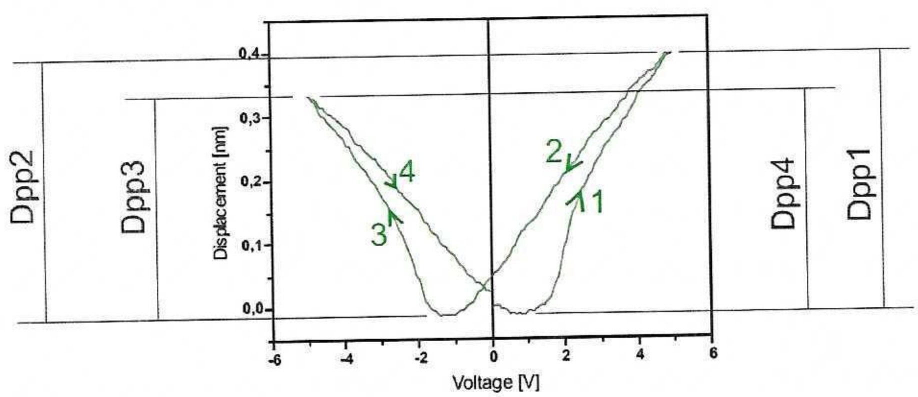


Fig. 3.11: Evaluation of typical parameters of Piezo measurements.

Execution of a Piezo measurement

To start a manual piezo measurement procedure please refer to section 3.3. Fig. 3.12 displays a screenshot of the piezo measurement dialog window. In the following table the input parameters of a piezo measurement are listed together with a short description and their possible ranges and values:

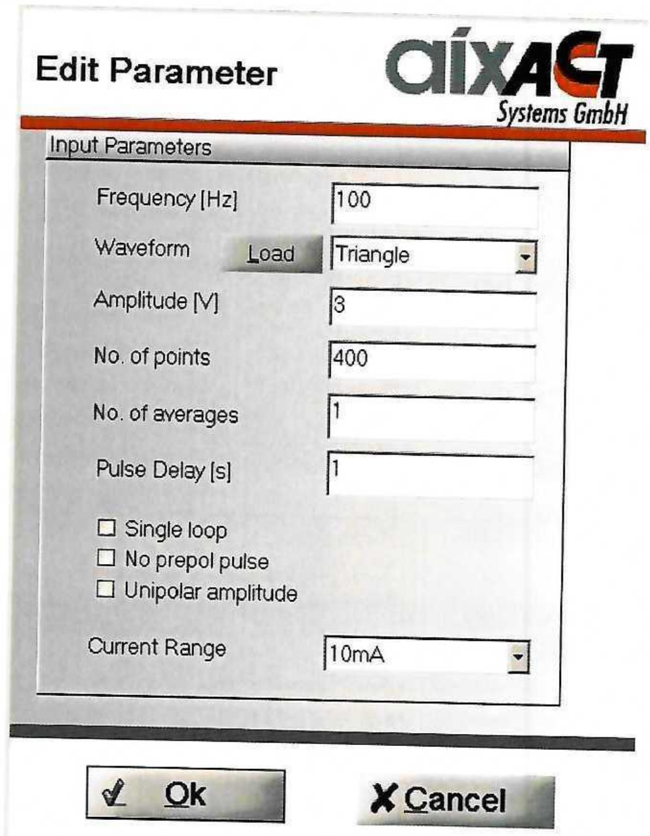


Fig. 3.12: Parameter dialog for piezo measurement.

Manual waveform It is possible to replace the typical triangular or sine waveforms for specific measurement types by user specific waveforms. To define a manual waveform the following dialog is used. This dialog is part of the Hysteresis software which may be used on a separate PC to create, load, edit, or save manual waveforms (*.tfw files). Waveform files have to be stored in the appropriate path to be selectable and usable for measurements.

Input Parameters

(1) Frequency	edit line	0.1 Hz to 2 kHz	frequency of the excitation signal
(2) Waveform	selection box	triangle, sine or manual	waveform of the excitation signal
(3) Amplitude	edit line	± 0.1 V to ± 25 V	amplitude of the excitation signal
(4) No. of points	edit line	20 to 1000	number of data points measured for one hysteresis loop
(5) No. of averages	edit line	1 to 100	number of measurement cycles to build the averaged loop
(6) Single loop	check box		Performs a measurement with only one pulse (instead of three). Setting of No. of averages > 1 results in one prepol pulse only.
(7) No prepol pulse	check box		Performs a measurement without prepolarisation pulse. This option cannot be set when leakage compensation is activated and no averaging is possible.
(8) Unipolar amplitude	check box		measurement with an unipolar voltage amplitude

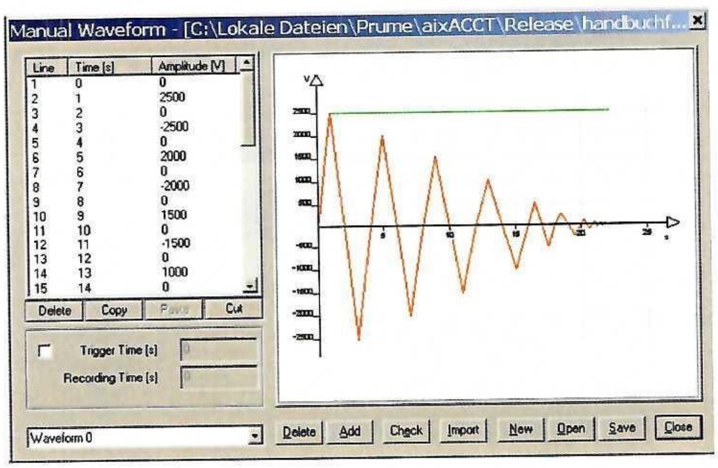


Fig. 3.13: Dialog window to create, edit and save user defined waveforms which are applied to the sample for measurement.

This dialog provides all necessary functions to define, edit, and save new waveforms. *Add* allows the easy creation of standard waveforms like sine, triangle or rectangle with user defined amplitude, frequency, and number of repetitions. Besides the manually edited waveform it is possible to import an ASCII data file with the *Import* button. The selected file should contain the name of the waveform in the first line and in the subsequently lines two numeric values for time and voltage separated by spaces or Tab characters should be given. The edited waveform is displayed as a red curve in the graph of the manual waveform dialog window. Start and duration of data recording can be set with the Trigger and Recording Time when the check box is enabled. The Start and duration time is visualized as a green curve in the graph. If both values are set to zero data will be recorded during the whole duration of the excitation signal. A check function is implemented to control if the edited waveform matches the hardware specifications of the Basic Unit and FE-Module. A user defined waveform file (file extension 'tfw') can be loaded in the Hysteresis and Piezo measurement procedure. Press *Load* next to the Waveform selection menu and select a saved waveform file. The defined waveforms will appear as additional entries in the selection menu. Please note that the recorded data depend on the polarization state of the sample which maybe changes if a waveform is applied for a second time or if the *Autorange* function has been carried out.

The user can load a manual defined waveform instead of using the default PZM signal. This is done by the *Load* button beside the waveform field. The following dialog appears:

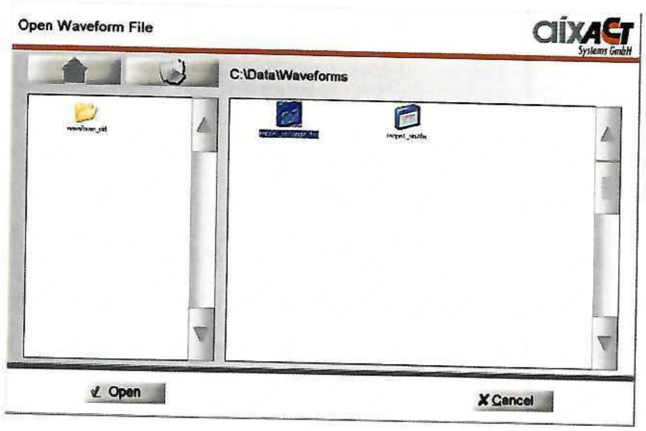


Fig. 3.14: Dialog for select a manual waveform file.

ASCII-format of the Piezo program

A Piezo measurement can be saved as an ASCII data file by using the *File - Export* function. The exported file contains a global header and separate data tables for each measurement. Each data table is preceded by its own specific header text lines. Four more text lines follow after the first line (*Piezo*) which describe the program version, the type of data (result or data), the TF Analyzer 2000 system file version, and a TimeStamp at which time the file has been created.

A blank line follows after this header section and then the table data. In front of the numerical data there are a variable number of text lines describing the measurement conditions under which the data have been recorded. The first text line always contains the tag *Table* and the number of the table separated with a tabulator stop. The last text line in front of the numerical data describes the contents of the data columns and their units. Denotation and meaning are listed in Table 3.2. Some of the columns are not filled, because they depend on the number of applied cycles.

Table 3.2: Denotation of the columns of the PZM program

Column	Denotation	Description
1	t	Time
2	V+	Applied Voltage signal (starting positive)
3	V-	Voltage signal (starting negative)
4	I1	Current from closed loop
5	P1	Polarization from closed loop
6	I2	Current from pulse No. 1
7	P2	Polarization from pulse No. 1
8	I3	Current from pulse No. 3
9	P3	Polarization from pulse No. 3
10	D1	Displacement (from closed loop)
11	D2	Displacement (from pulse No. 1)
12	D3	Displacement (from pulse No. 3)
13	Ch3	Additional voltage from external channel

The Piezo software module of the TF Analyzer 2000 system offers a $P(V)$, $D(V)$, a $I(t)$, and a $V(t)$, $I(t)$ representation of the data. The $I(t)$ curve display the measured current response of the sample versus time. To display the curve of the current response vs. time column 1 is assigned to the x-axis and col. 4, 6, or 8 is assigned to the y-axis. To display the polarization of the measurement you have to assign V_+ to the x-axis and column 5 or 7 to the y-axis. To display the $P(V)$ of the curve starting in the positive relaxed remanent polarization state assign V_- to the x-axis and col. 9 to the y-axis.

A clipping of the ASCII-file of the PZM is shown below.

Piezo
Program: Hyster 2.2
BasicUnit: BU 313
TfaFileType: data
TfaVersion: 3.0
TimeStamp: 02/21/2002 15:34h

Table 1
Timestamp: 02/21/2002 15:35h

Averages: 1 SampleName: PZT
Thickness [nm]: 1e+006
Area [mm2]: 63.6
Current Range: 4
Hysteresis Frequency [Hz]: 10
Hysteresis Amplitude [V]: 2000
Vc+ [V]: 1198.07
Vc- [V]: -1220.35
Pr+ [uC/cm2]: 35.1656
Prrel+ [uC/cm2]: 34.0763
Prrel- [uC/cm2]: -34.6488
Pr- [uC/cm2]: -35.4346
Pmax [uC/cm2]: 41.1607
DOffset [nm]: -34619.1
Dpp [nm]: 880.784
Ch3 [V]: -6.92548
Psw [uC/cm2]: 75.8095
Pnsw [uC/cm2]: 7.0844
dPsw [uC/cm2]: 65.7251
Settings: FC
Time[s] V+[V] V-[V] I1[A] P1[uC/cm2] I2[A] P2[uC/cm2] I3[A] P3[uC/cm2] D1[nm] D2[nm] D3[nm] Ch3[V]
[DATA, 13 columns]

3.3.2. CV and Piezo Coefficient Measurement - CVM

With the aixDBLI System and the CV software you can perform small signal capacitance vs voltage ($C(V)$) and loss tangent ($tan(\delta)(V)$) measurements on your samples. With the piezo option you can simultaneously measure the effective longitudinal piezoelectric coefficient $d_{33,f}(V)$ of a thin film and the phase of $d_{33,f}$ (here referred to as ϕ_{33}). The displacement is captured by double beam laser interferometer technique.

Measurement procedure and typical measurement

There are two possible ways to measure the small signal coefficients $C(V)$ and $d_{33,f}(V)$ versus the electrical bias voltage in this program. The first one uses a staircase like excitation voltage signal as shown in Fig. 3.15.

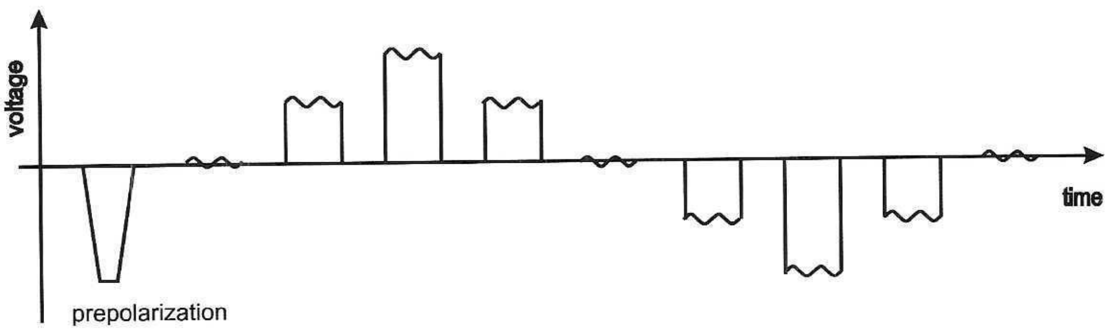


Fig. 3.15: Staircase like excitation waveform to measure a small signal coefficient vs. bias field.

The prepolarization pulse establishes a defined polarization state, usually the negative state of relaxed remanent polarization, after reaching $-V_{max}$. This pulse is followed by a number of consecutive unipolar excitation signal pulses, depending on the entered input parameters. The unipolar pulses are DC biased voltage pulses with an added sine wave AC small signal. The DC bias starts at zero volt, increases with each pulse up to the desired maximum excitation voltage V_{max}, decreases to $-V_{max}$ and back to zero. The capacitance and loss tangent are derived from the AC small signal current response of the sample measured by the virtual ground. The resulting $C(V)$ and $tan(\delta)(V)$ curves corresponding to the small signal excitation are shown in Fig. 3.18.

When using the second method, the excitation signal is a continuously changing triangular shaped base waveform of low frequency with a superimposed high frequency small signal voltage (see Fig. 3.16). This method allows fast measurements with less stress exposed to the sample.

Execution of a CV measurement

To start a manual CV measurement procedure please refer to section 3.3.

Fig. 3.17 displays a screenshot of this CVM dialog. In the following table Table 3.3 the input parameters of a $C(V)$ measurement are listed together with a short description and their possible ranges and values:

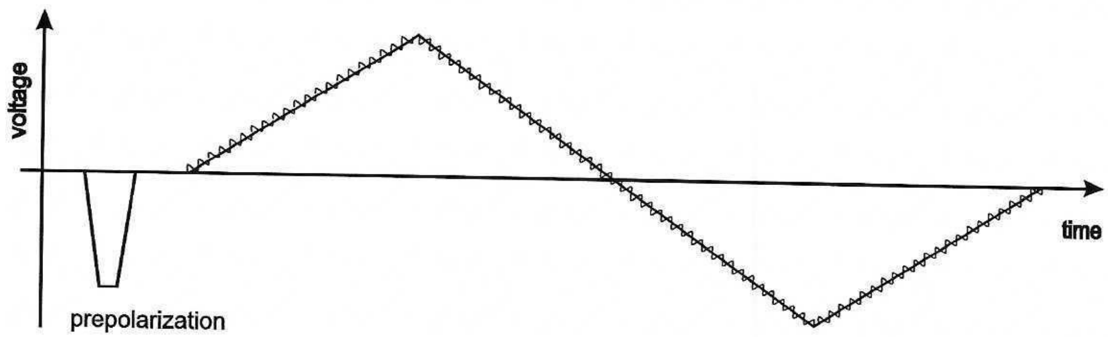


Fig. 3.16: Continuous excitation waveform for a small signal coefficient measurement vs. bias field.

Table 3.3: CVM Input Parameter description:

(1) Base Waveform			
Base Frequency	edit line	0.01 Hz to 100 Hz	used in continuous mode only
Amplitude	edit line	0 V to 25 V	maximum DC amplitude of the excitation signal
Unipolar Amplitude	check box		unipolar pulses only, if checked
No prepol pulse	check box		no prepolarisation pulse, if checked
Staircase	check box		staircase excitation signal instead of continuous, if checked
(2) Small Signal Waveform			
Frequency	edit line	1 Hz to 2000 Hz	frequency of the AC small signal
Amplitude	edit line	0.005 V to 25 V	amplitude of the AC small signal
No. of points	edit line	1 to 1000	number of total DC points measured
No. of averages	edit line	2 to 1000	number of AC wave repetitions per point

A typical CV measurement result is shown in Fig. 3.18.

Result values of a CV measurement

From the $C(V)$ and $d_{33,f}$ measurement data various charactaristic values are calculated. Fig. 3.19 shows a typical $C(V)$ and $d_{33,f}$ measurement result, where additional lines are drawn for the explanation of calculated parameters. In the following table Table 3.4 the calculated result values are listed with a description of the calculation method. The linear regression for the positive

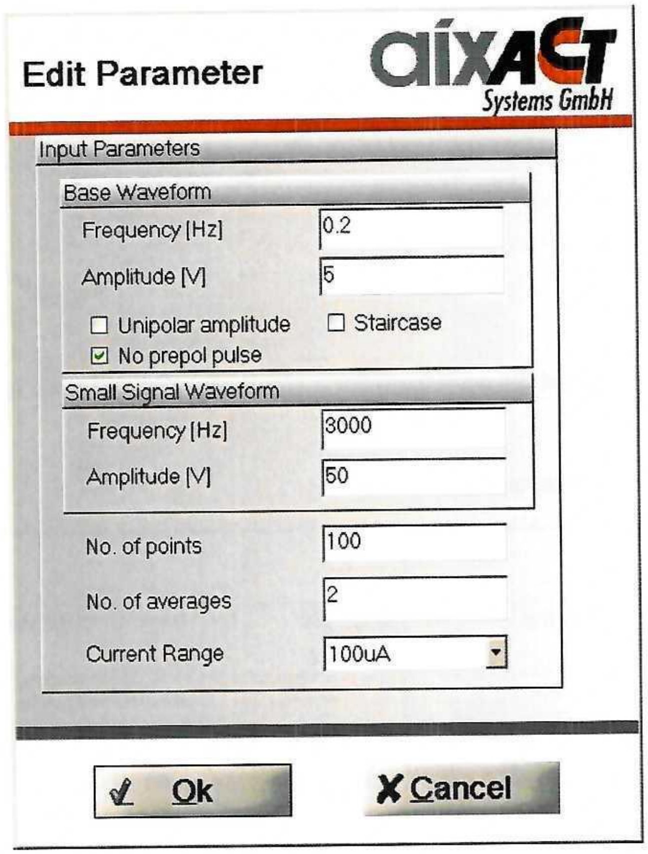


Fig. 3.17: Parameter dialog for CV measurement.

side is calculated from point $N/8$ to below $3N/8$, for the negative side it is calculated from point $5N/8$ to below $7N/8$ where N is the total number of measurement points, for unipolar measurements line is calculated from point $N/4$ to below $3N/4$.

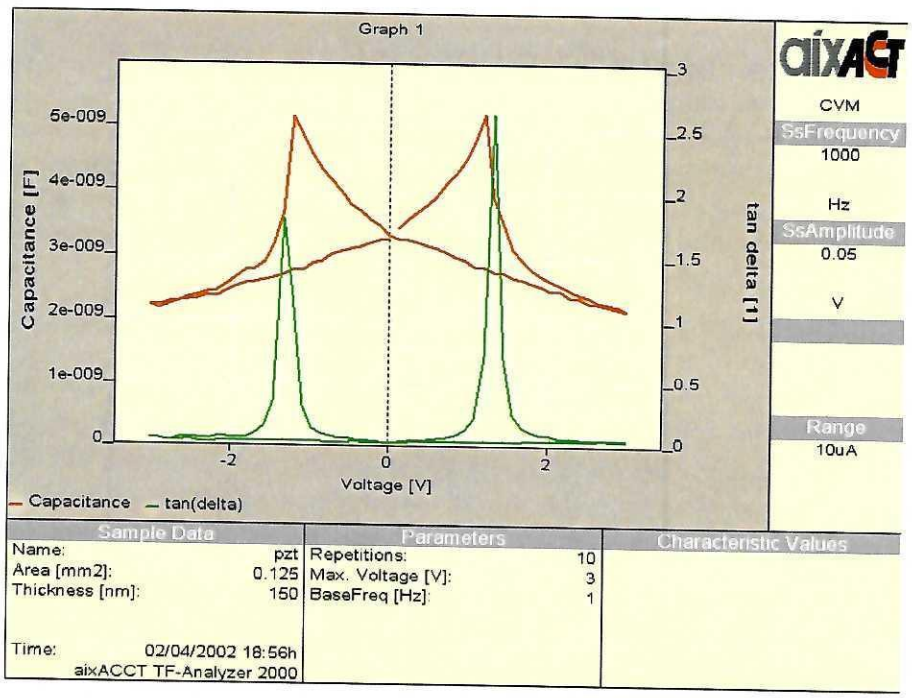


Fig. 3.18: Typical result of a CV measurement.

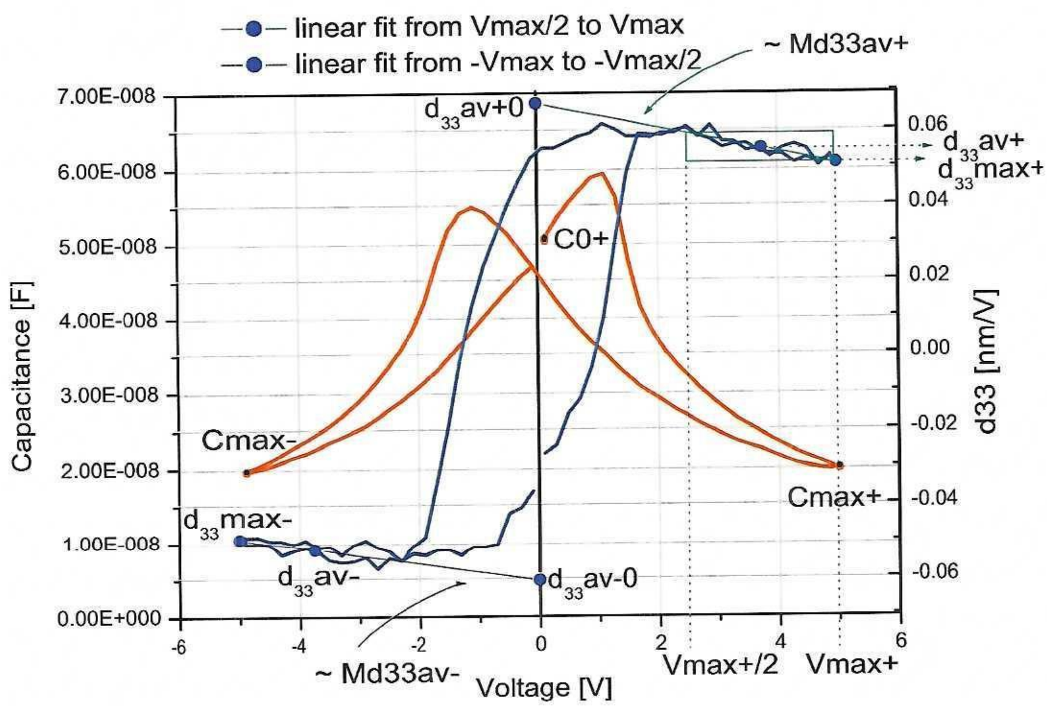


Fig. 3.19: Evaluation of typical parameters of CV and d33 measurements.

Table 3.4: CVM Result Value description:

Parameter	Unit	Description	Formula
C0+	$[F]$	capacitance at $0V$(Y axis)	first measured capacitance point
Cmax+	$[F]$	capacitance at V_{max}	capacitance point measured at max. voltage
Cmax-	$[F]$	capacitance at $-V_{max}$	capacitance point measured at negative max. voltage
Cav	$[F]$	average capacitance	average capacitance value of total measurement
EpsAv	[1]	average ϵ (dielectric number)	$\frac{Cav}{\epsilon_0} \frac{thickness}{area}$
d33av	$[nm/V]$	average $d_{33,f}$	average $d_{33,f}$ value of total measurement
Me31av	$[C/m]$	average slope of e_{31}	$\frac{Cav}{d33av}$
d33max+	$[nm/V]$	$d_{33,f}$ at V_{max} interpolated	linear regression line from $V_{max}/2$ to V_{max} at V_{max}
d33max-	$[nm/V]$	$d_{33,f}$ at $-V_{max}$ interpolated	linear regression line from $-V_{max}$ to $-V_{max}/2$ at $-V_{max}$
d33av+0	$[nm/V]$	$d_{33,f}$ at $0V$ interpolated from positive	linear regression line from $V_{max}/2$ to V_{max} at $0V$
d33av-0	$[nm/V]$	$d_{33,f}$ at $0V$ interpolated from negative	linear regression line from $-V_{max}$ to $-V_{max}/2$ at $0V$
d33av+	$[nm/V]$	average $d_{33,f}$ positive side	average value from $V_{max}/2$ to V_{max}
d33av-	$[nm/V]$	average $d_{33,f}$ negative side	average value from $-V_{max}$ to $-V_{max}/2$
Md33av+	$[nm/V^2]$	slope of positive $d_{33,f}$	slope of regression line from $V_{max}/2$ to V_{max}
Md33av-	$[nm/V^2]$	slope of negative $d_{33,f}$	slope of regression line from $-V_{max}$ to $-V_{max}/2$

ASCII-format of the CVM program

A clipping of the ASCII-file of the CVM is shown below.

CV
Program: Hyster 2.2
BasicUnit: BU 313
TfaFileType: data
TfaVersion: 3.0
TimeStamp: 10/24/2002 08:33:51

Table 1
SampleName: unnamed
Thickness [nm]: 200
Area [mm2]: 1
Current Range: 4
BaseFreq [Hz]: 1
SsFrequency [Hz]: 1000
SsAmplitude [V]: 0.05
Max. Voltage [V]: 3
Repetitions: 100
Timestamp: 10/24/2002 08:33:51
Bias[V] C[F] tan(delta)[1] d33[nm/V] phi33[deg] Ibias[A] Dbias[nm] reserved reserved
[DATA, 9 columns]

3.4. Service menu

The *Service* menu gives access to various service tasks dependent on the user logged in.

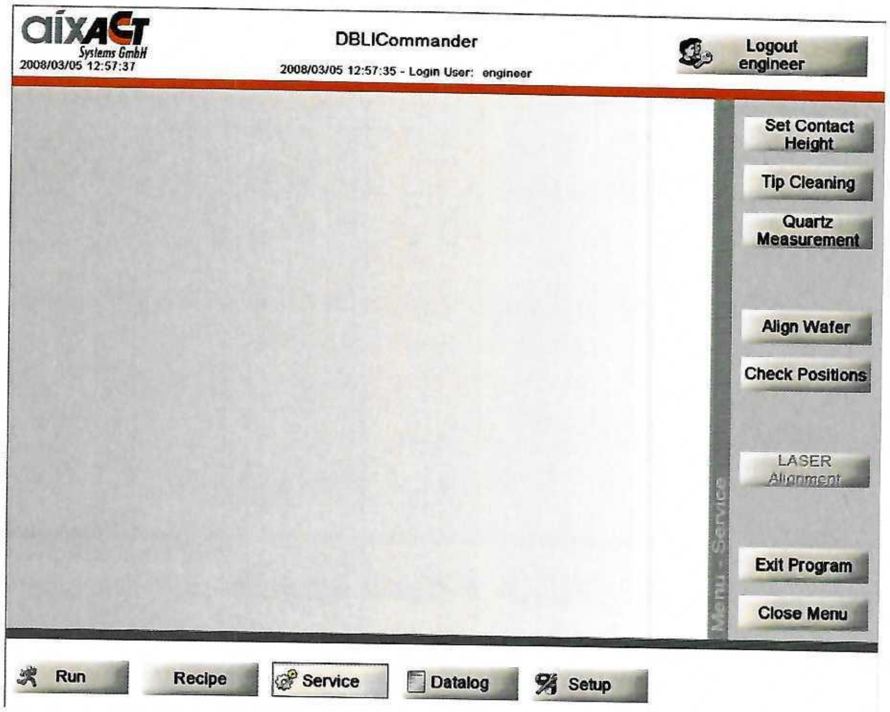


Fig. 3.20: Service menu funtions.

3.5. Align wafer

The aixDBLI The wafer may be aligned according to definitions within a recipe while performing several tasks. The menu item *Align wafer* can be reached via the *Service* menu. The alignment procedure is described in detail within the Chapter 2.2.

3.6. Quartz calibration measurement

This measurement is used for the daily inspection of the system functionality. An x-cut quartz calibration sample is part of the wafer chuck. Select the *Service* button and then *Calibration* from the right menu buttons (see Fig. 3.21).

After start of the measurement the sample is automatically contacted and the averaged piezoelectric coefficient $d_{33,av}$ of the quartz sample is measured typically 30 times to get a mean $d_{33,av}$ value and repeatability in percentage sigma over mean for static and dynamic repeatability. The result is displayed at the end of the measurement sequence and written to a log file. It is shown in Fig. 3.22. When the system is in an idle state this measurement is typically taken every full hour automatically.

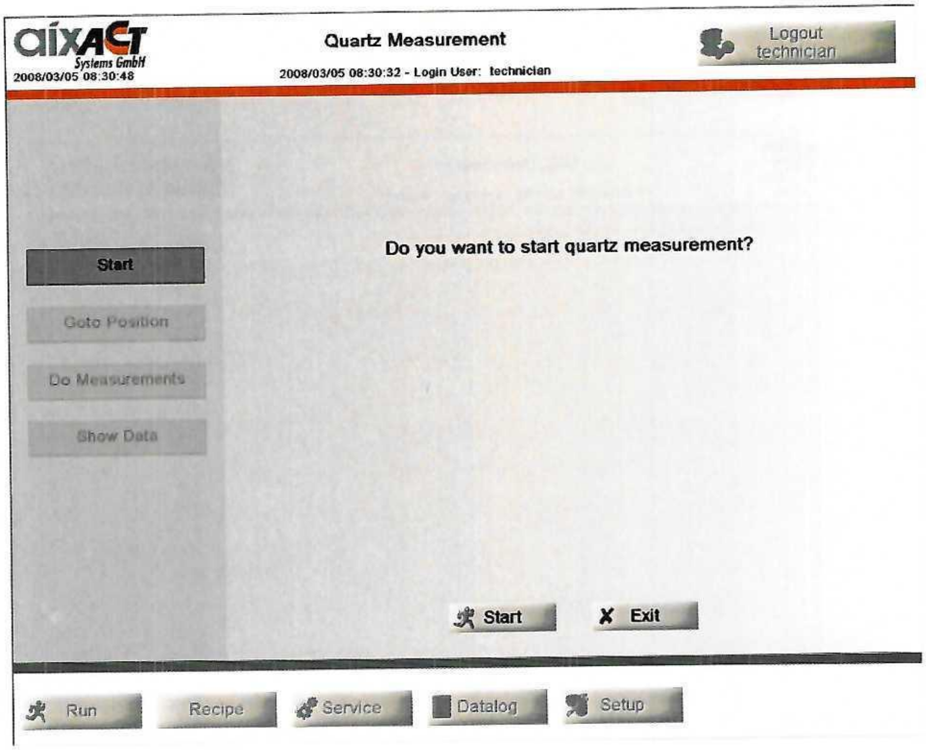


Fig. 3.21: Start window for an automatic quartz calibration measurement.

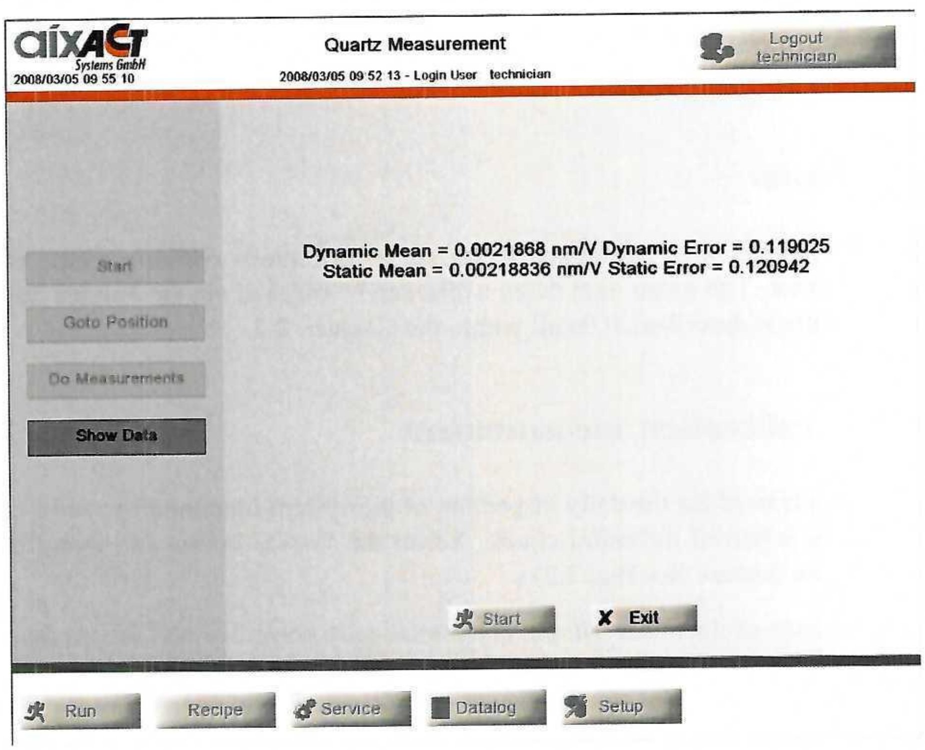


Fig. 3.22: Automatic quartz calibration measurement has finished and result value is displayed.

4. Engineer

SAFETY INSTRUCTIONS:

- Read and understand this Manual and all safety labels before operating this system.
- Only a trained person is to be permitted to operate this system. Training should include instruction in operating under normal conditions and emergency situations.
- This system is to be serviced only by trained and authorized personnel.
- Never change or defeat the function of electrical interlocks or other system "shutdown" switches.

4.1. User login

After power up of the system the monitor shows the login screen for the different users as described in Chapter 1.

4.2. Run semiautomatic measurement

The procedure for the semiautomatic measurement is described in Chapter 2.2. The menu for the engineer to select a recipe for measurement differs from the one for the operator and is described in chapter 3.2.

4.3. Manual measurement

The procedure for the manual measurement mode is described in Chapter 3.3.

4.4. Create and edit measurement recipes

This Section describes the task to create and edit new measurement recipes which are used in the semiautomatic measurement mode (see Chapter 2.2).

The creation of the recipe is the preparatory work that needs to be done before being able to preform semiautomatic measurements on the aixDBLI System.

Fig. 4.1 shows the recipe Graphical User Interface. In the upper line icons can be seen which are related to general functions for the recipe. This includes *New, Open, Save* and *Save as* recipes.

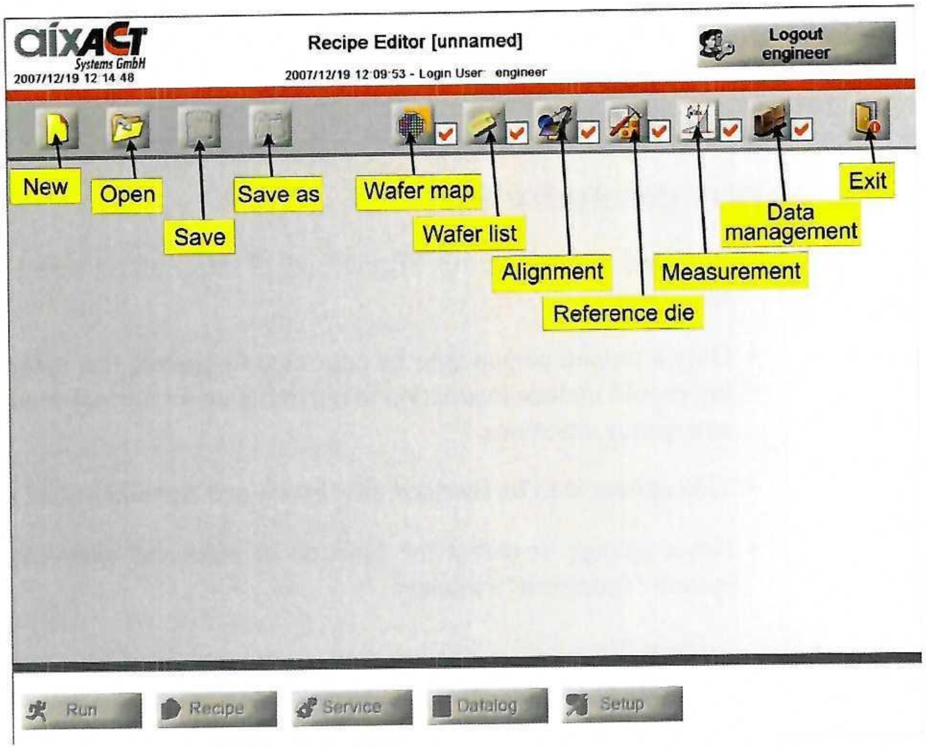


Fig. 4.1: Graphical User Interface after selection of the recipe menu.

NEW recipe will open up the wafer map editor, which allows to configure the x-y- positions of the test patterns etc.

OPEN recipe will open a saved recipe for modifications.

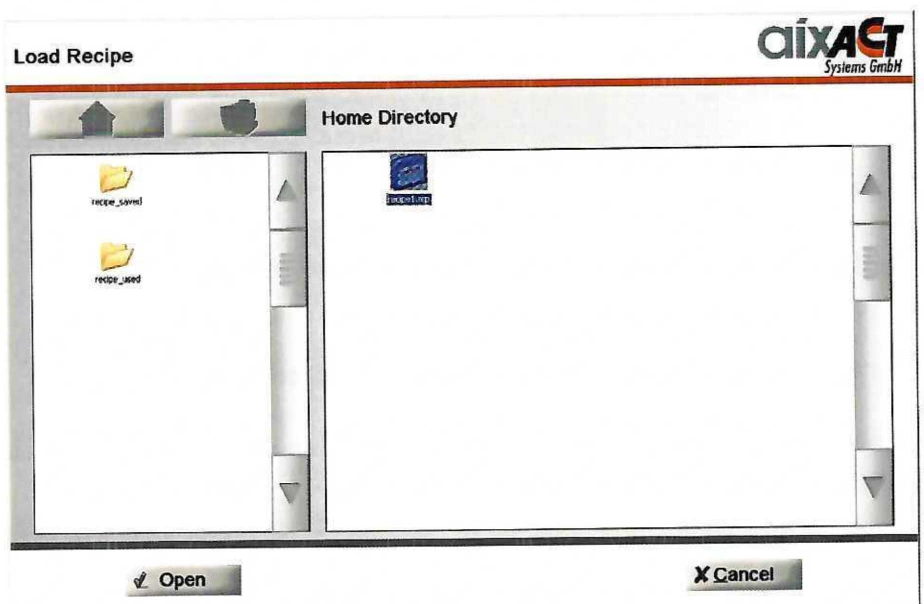


Fig. 4.2: Dialog to select recipe for open.

SAVE after modification the recipe can be saved or

SAVE AS new recipe filename.

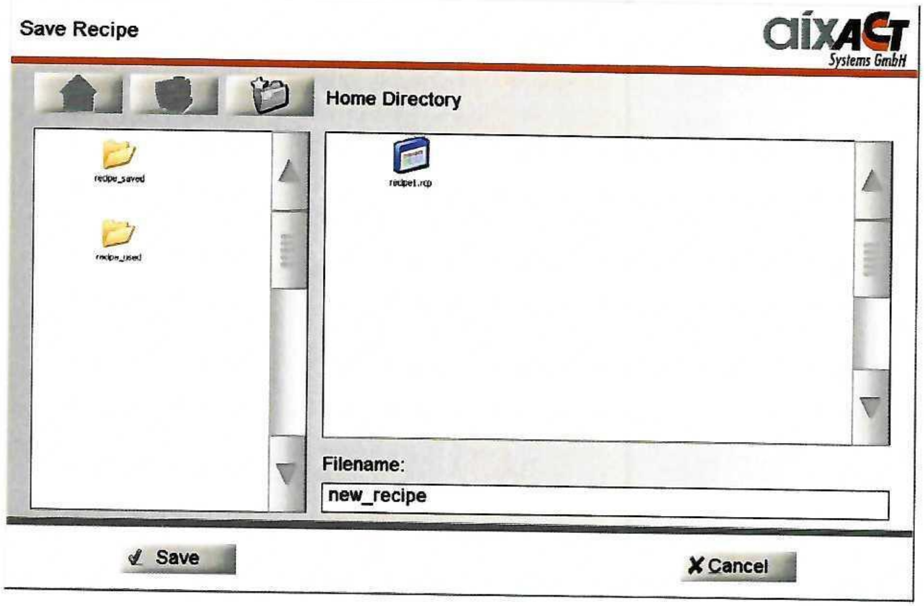


Fig. 4.3: Dialog to select name for save recipe.

EXIT exit the recipe editor in order to start any other task

Within creating a new or opening and modifying an existing recipe, six different settings need to be adjusted in order to create a perfect testing recipe. Therefore the icons on the right hand side are used. They e.g. define specific settings of the recipe like wafer map, alignment marks, reference points, measurement parameters and data handling settings. Details can be found in the following sections.

A color code is used to indicate to the user if the required action on each if the six sub menu items has been made. A check mark in green, yellow and red is used for the indication.

Red check mark - input has not yet been made

Yellow check mark - input has been typed in or changed, but has not yet been saved

Green check mark - input has been typed in and has been saved

4.4.1. Wafer map

By selecting the *Wafer map* button a map of number, position and size of dies can be created and edited to represent the structures on the wafers to be measured. Details can be found in the manuals of the OEM wafer prober.

4.4.2. Wafer list

The *Wafer list* button allows to specify a list of wafers with name and wafer thickness. At least information for one wafer needs to be inserted.

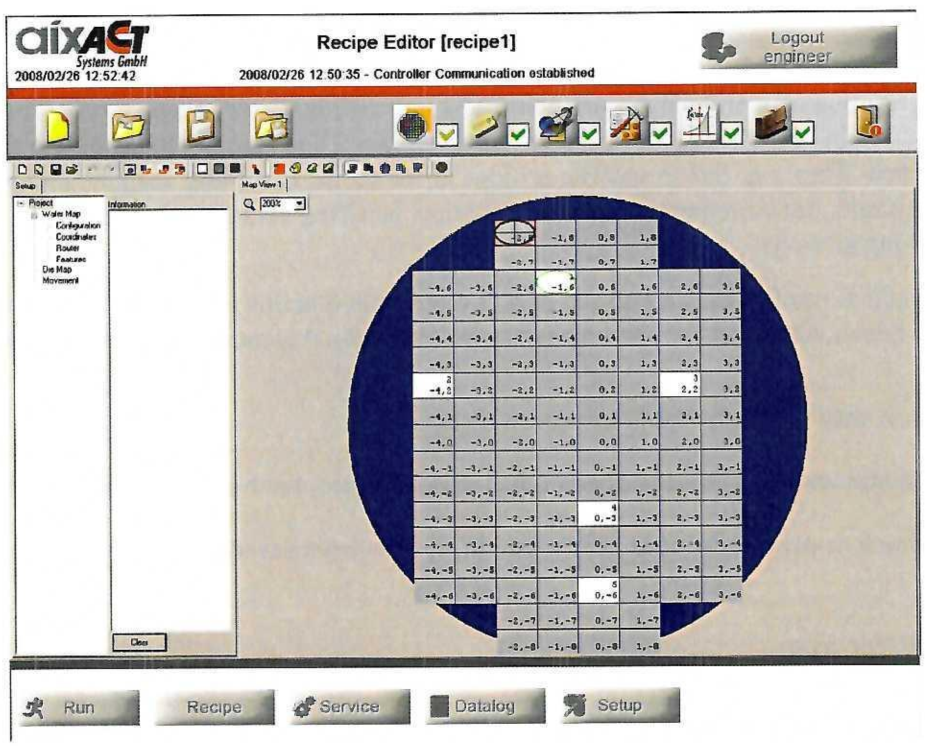


Fig. 4.4: Wafermap window dialog with tools to create and edit die structures on a wafer.

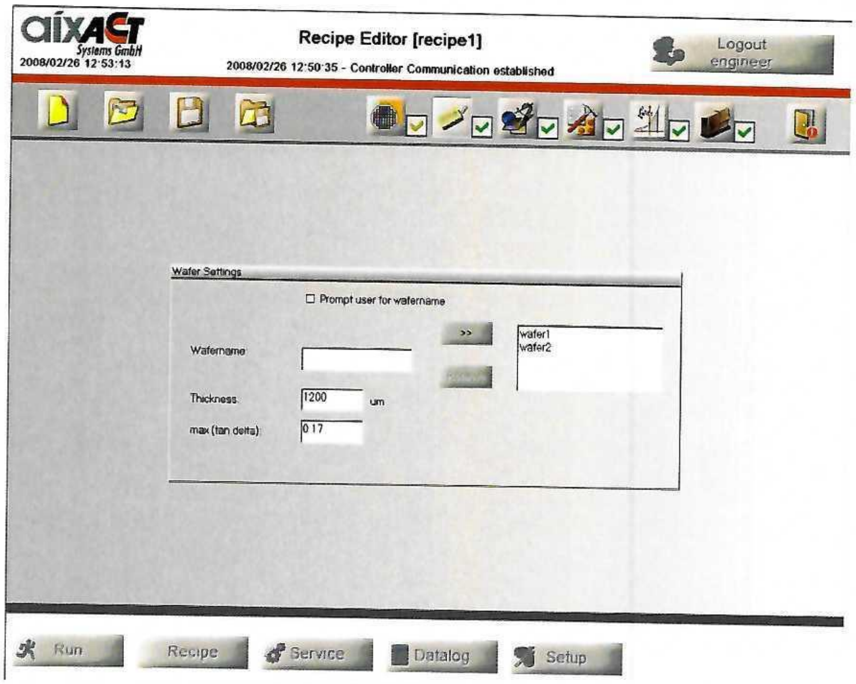


Fig. 4.5: Window to edit a list of wafers to be measured.

4.4.3. Wafer Alignment

The absolute x- and y-position and rotation of the wafer is calculated from two alignment marks, which need to be centered manually for semi-automatic systems. Type in the location of the two alignment marks on the wafer with their x- and y-coordinates. These coordinates will be used to drive the stage in the vicinity of the alignment marks to ease the manual alignment.

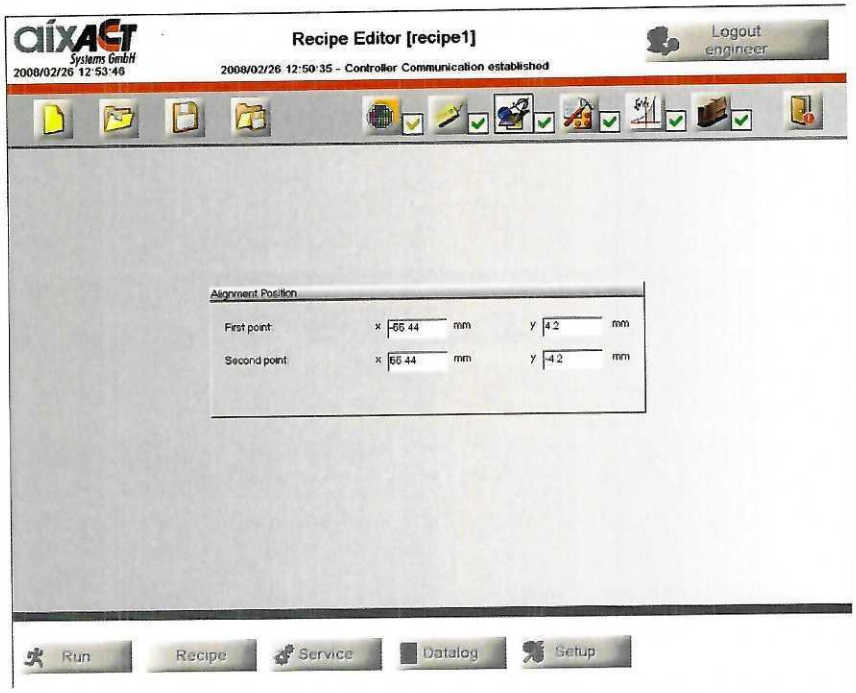


Fig. 4.6: Window to set the alignment marks of the wafer.

4.4.4. Reference die

Enter column and row value for the reference die selection, which will be used first. Additionally, type in the location of the measurement center position in x- and y-coordinates from wafer center as well as the area of the pads to be tested. You can assign a sample name. One can add this pad information to the list of pads that will be tested within one die. You can edit additional pads if more than a single sub die should be measured.

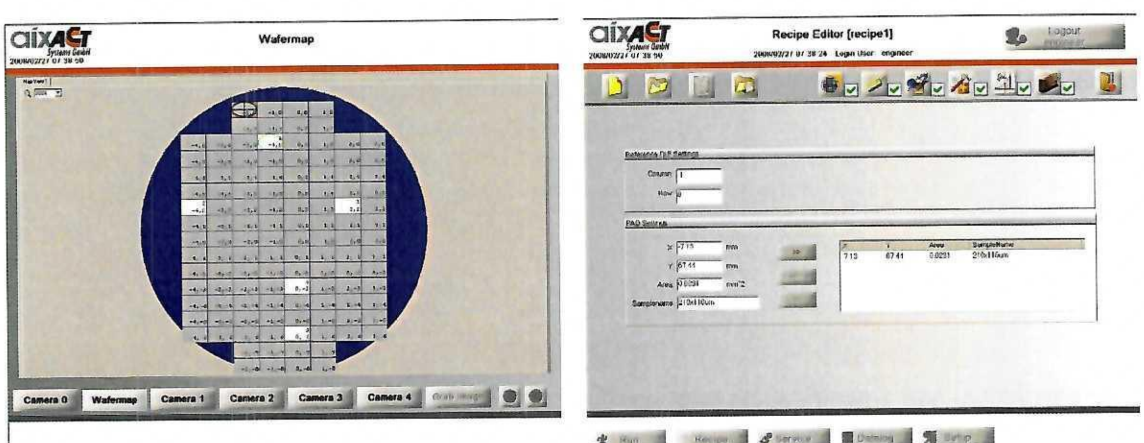


Fig. 4.7: Window to set the reference die with the position of one or more pads to be measured per die.

4.4.5. Measurement

This page allows to define the measurement or measurement sequence which will be performed on each position that should be tested on the wafer. One can select between CVM, which is the measurement of the small signal coefficient of the material. This is in particular the effective dielectric constant $\varepsilon_{33,f}$ and the effective piezoelectric coefficient $d_{33,f}$. Or one can select the PZM measurement which represents the large signal measurement of strain and polarization of the material. By selecting one of the two measurements the menu Input Parameters will change accordingly. Please type in the parameters for each measurement of the specific recipe according to 3.3.1 or 3.3.2.

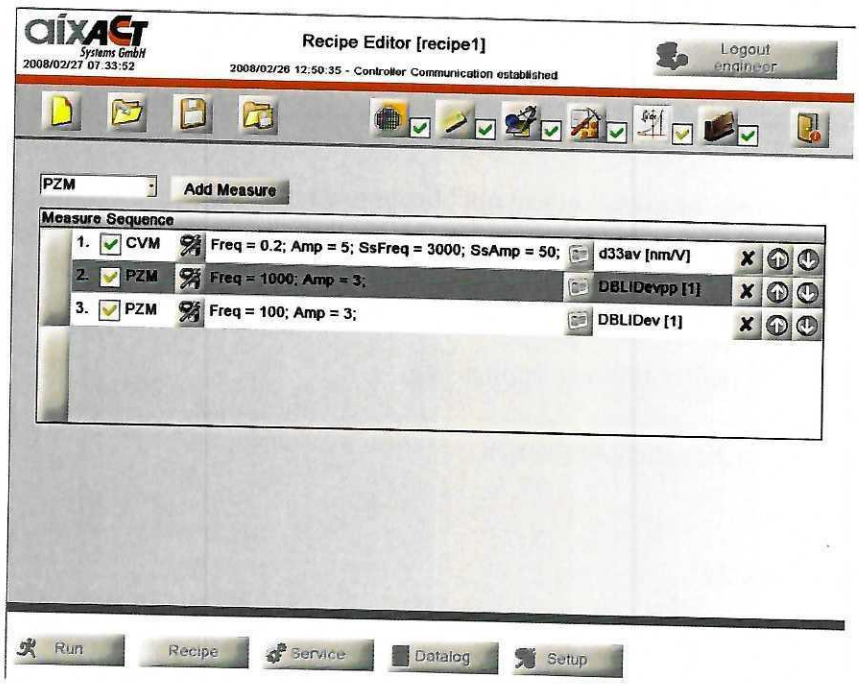


Fig. 4.8: Window showing the sequence of defined measurements .

The table summarizes the measurement setup sequence which has to be done on any pad to probe on the wafer. Each line includes a check icon to indicate the definition status of this specific measurement, the type of measurement, a button to change the measurement parameters (see chapter 3.3.1 and 3.3.2 for description of the parameter dialogs), the essential parameter values, a button to change the qualification parameters, a button to delete one measurement and arrows to change the order.

The dialog to change qualification parameter is shown in Fig. 4.9. These parameters are evaluated after each measurement in order to colour the wafermap die or pad. The possible colours and their meanings are described in 3.2.

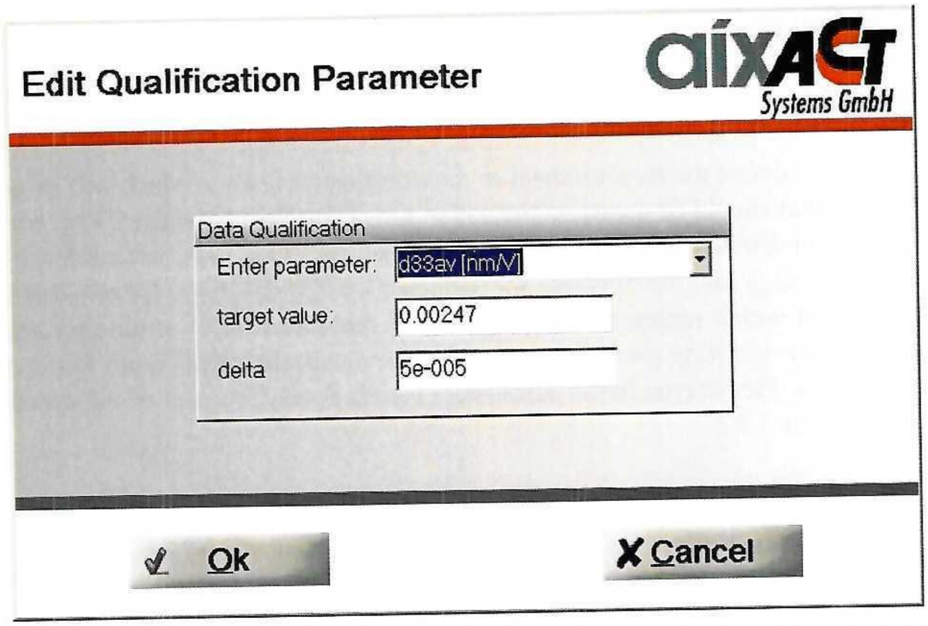


Fig. 4.9: Window to set the measurement qualification parameters.

4.4.6. Data management

This dialog allows to define different settings like

- path, where the data should be stored
- error handling
- action upon finish
- data evaluation

Set path allows to select the path, where the recorded data should be saved. A browse directory button can be pushed to select the destination more comfortably. Type in the name of the directory and file name prefix where the data should be saved.

The Error handling dialog determines how an occurring error should be treated. E.g. if there is dust on the top electrode and the light reflection is reduced, the measurement will not result in useful data. One can select between

- halt on error
- prompt user
- ignore error

The action upon finish of the measurement sequence can be selected

- beep
- nothing
- email to superuser

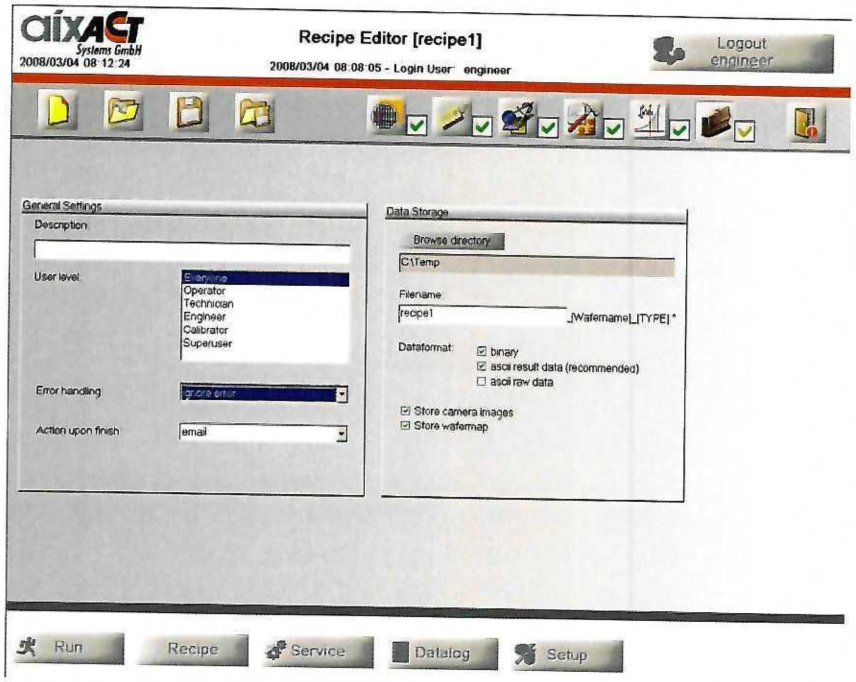


Fig. 4.10: Window to specify settings for data management and evaluation.

Finally, the data evaluation task can be decided. The user can define a target value and a deviation from the target value of a certain parameter. The software will automatically indicate in the wafer map if the recorded parameter value has been inside or outside the acceptable deviation from the target value.

4.5. Setting of the contact height

It is compulsory that the wafer thickness is set once before a measurement sequence on similar wafers can be started. All other menu entries are disabled until the wafer thickness and contact height are properly set. This has to be done by the Engineer (see Chapter 4.5). The procedure needs to be repeated e.g when wafers with a different thickness are to be measured. The thickness tolerance is dependent on the probe tip overtravel and laser focus, for an estimate thickness variation should be less than 100µm and less than the overtravel amount minus 10 µm. A wrong wafer thickness may cause contact failures or even damage the probe tips !

CAUTION: If wafer thickness and / or contact height are not properly set probe tips or wafer can be damaged!

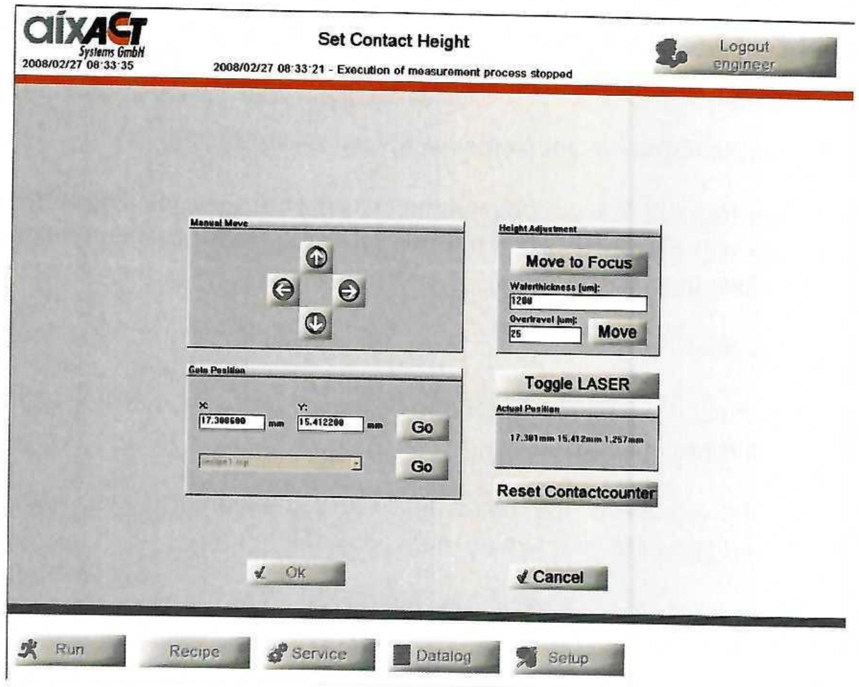


Fig. 4.11: Window to set the contact height of a wafer.

1. Log on as engineer, calibrator, or superuser
2. Load a wafer with the test feature and thickness to be measured (refer to wafer loading procedure dexscribed in 3.3)
3. Open chamber door
4. Manually lift the probe tips into their upmost position by turning Z knob clockwise
5. Close chamber door
6. Make sure correct wafer thickness in µm (defaults from current recipe) and desired overtravel (recommended 20-50µm) is entered.
7. If the tip was exchanged, press *Reset Contact Counter*
8. Use the *Manual Move* or *Goto Position* dialogs to move to a standard contact pad.
9. Press the *Move* button to automatically lift the chuck into the desired contact height less overtravel.
10. Move exactly to the desired pad position by joystick, you may turn on laser *Toggle LASER button* to hit the desired spot.
11. When laser is toggled on, center it on the pad or to the desired measurement spot.
12. Open chamber door (laser should turn off)

13. Carefully move the probe tips into camera view, make sure wafer isn't touched while moving because it may damage the tips.
14. Move tips to desired touch point (center of tip and mirror image).
15. Lower the tips (turning Z knob counterclockwise) until they just barely touch the surface. The gap will disappear when the tips hit the surface and they will start moving horizontally when in contact.
16. Close chamber door
17. Click *Move to Focus* button. The wafer will be moved into contact height and the tips will overtravel by the amount entered.
18. Check the final position (the tips should not be placed within the beam spot), for readjust start from 9. and press *OK* to finish this procedure.

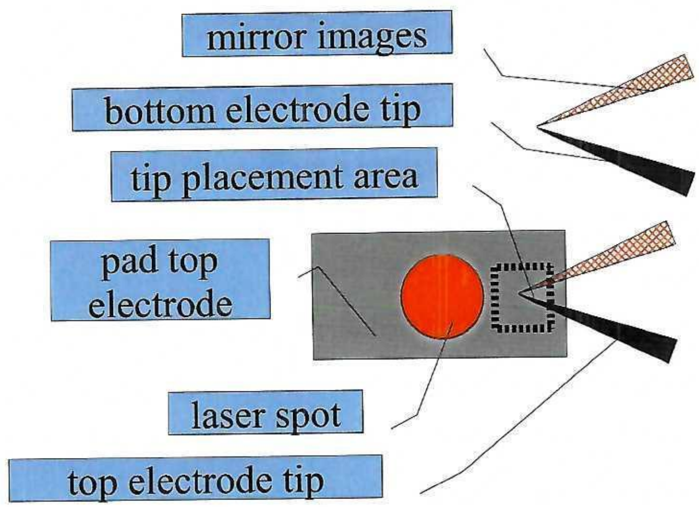


Fig. 4.12: Placement of the tips (shown on a 100 x 200 µm pad , dependent on the structure to be contacted).

4.6. Check positions

As an item of control die positions within a wafermap of a defined recipe can be compared to the real wafer position. Therefore the aixDBLI System must be aligned according to the definitions within this recipe. The alignment procedure is described in detail within the Chapter 2.2.

The menu item *Check positions* can be reached via the *Service* menu. The right screen shows the wafermap belonging to the recipe. Each position to check must be marked within the wafermap. The *Go to* button moves the chuck to that position. The adjustment of the reached position to the desired pad can be visually controlled with the help of the actual wafer camera image on the left screen.

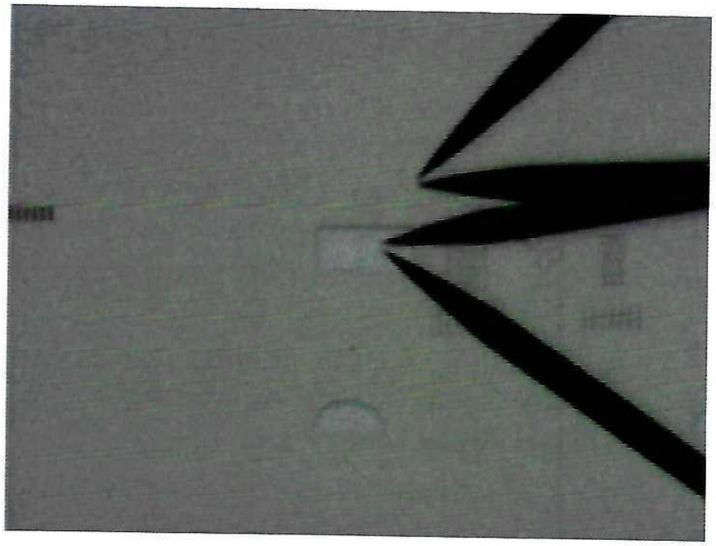


Fig. 4.13: Tips closely to the surface.

Fig. 4.14: Check positions - camera image.

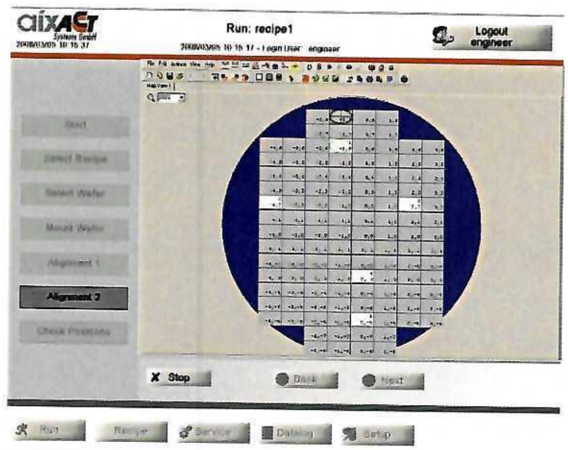


Fig. 4.15: Check positions - wafermap.

5. Calibrator

SAFETY INSTRUCTIONS:

- Read and understand this manual and all safety labels before operating this system.
- Only a trained person is to be permitted to operate this system. Training should include instruction in operating under normal conditions and emergency situations.
- This system is to be serviced only by trained and authorized personnel.
- Never leave the system stopped in such a manner that another worker can start the system while you are working on or within the system.
- Never change or defeat the function of electrical interlocks or other system "shutdown" switches.
- Routine inspections and corrective/preventative maintenance measures are to be conducted to make sure that all guards and safety features are retained and function properly.

5.1. User login

After power up of the system (see Part I) the monitor shows the login screen for the different users as described in Chapter 1.

5.2. System operation

Ways to operate and manage the aixDBLI System are described in Chapter 2.2, Chapter 3.3 and Chapter 4.4.

5.3. System settings and maintenance tasks

For system settings and maintenance tasks please refer to Chapter 6.1 in Part I. It is obligatory to have read and understood the safety regulations in Chapter 2 of Part I beforehand.

5.4. Change of probe tips

As stated in the maintenance section of the Technical Documentation the probe tips need to be replaced approximately every 10000 contacting cycles. The following procedure describes how to change the probe tips:

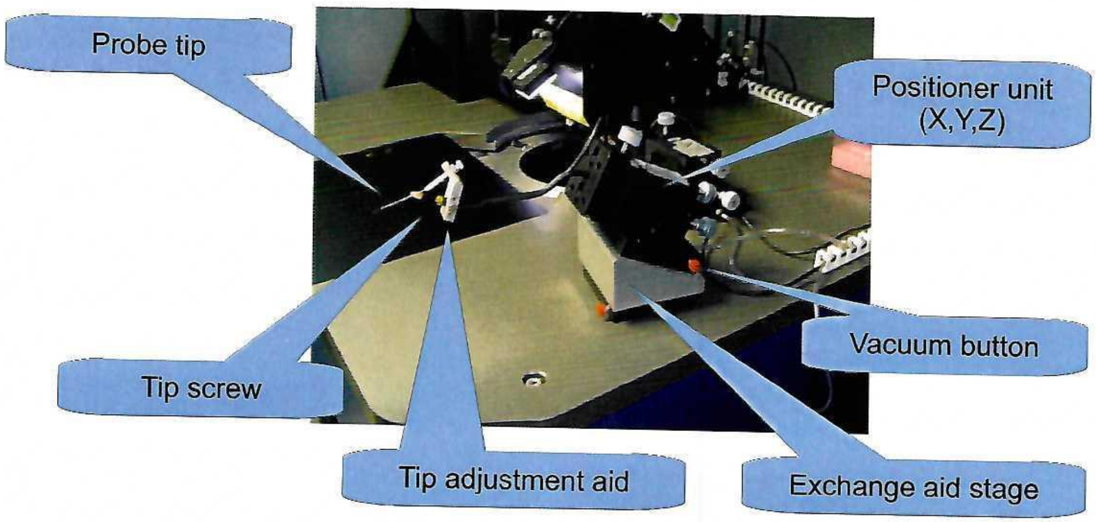


Fig. 5.1: Tip exchange overview.

1. Login as user Calibrator, if not done already.
2. Move wafer into eject position
3. Make sure the system is not in service mode to prevent high voltages being present at the probe tips !
4. Open left chamber door
5. Move probe tip up by turning Z knob clockwise
6. Carefully press vacuum button and slowly move positioner unit outwards, be cautious not to tip the unit or hit wafer or chuck with the probe

7. Place positioner onto exchange aid stage tip facing upwards and release vacuum button (see 1)

8. Hold tip with tweezer and release by turning screw ring clockwise (seen from tip side), then remove tip by pulling out downwards

9. Hold new tip with tweezer and carefully move tip into tip holder from below, make sure tip is inserted into correct low angle hole until placed against tip adjustment aid screw

10. Tighten (lock) tip holding screw

11. Press vacuum button and carefully place positioner back to the original position marked on the plate (tip under lens center close to laser spot ideally within camera view)

12. Close the chamber door

13. Fine adjust tip according to 'set contact height' procedure **??**

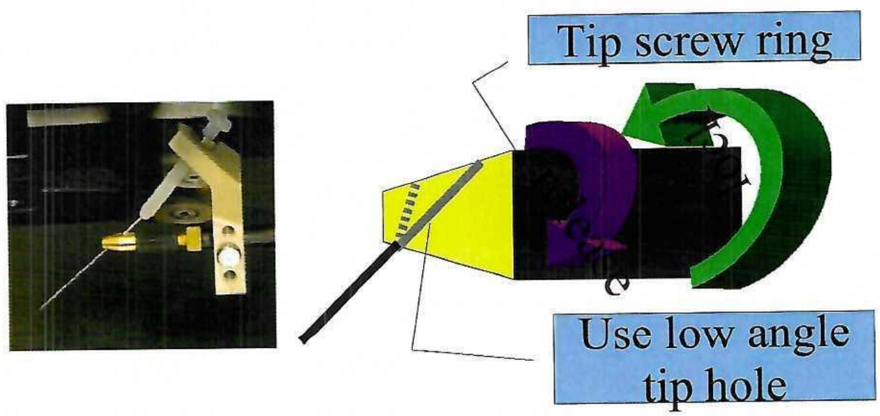


Fig. 5.2: Tip exchange detail.

5.5. System Information

Some useful system information like the communication status, failure conditions, the number of cleanings or license information can be found in the System Information window shown in Fig. 5.3 and Table 5.1. Typically red buttons indicate a failure or error. It can be opened via the *Setup* menu.

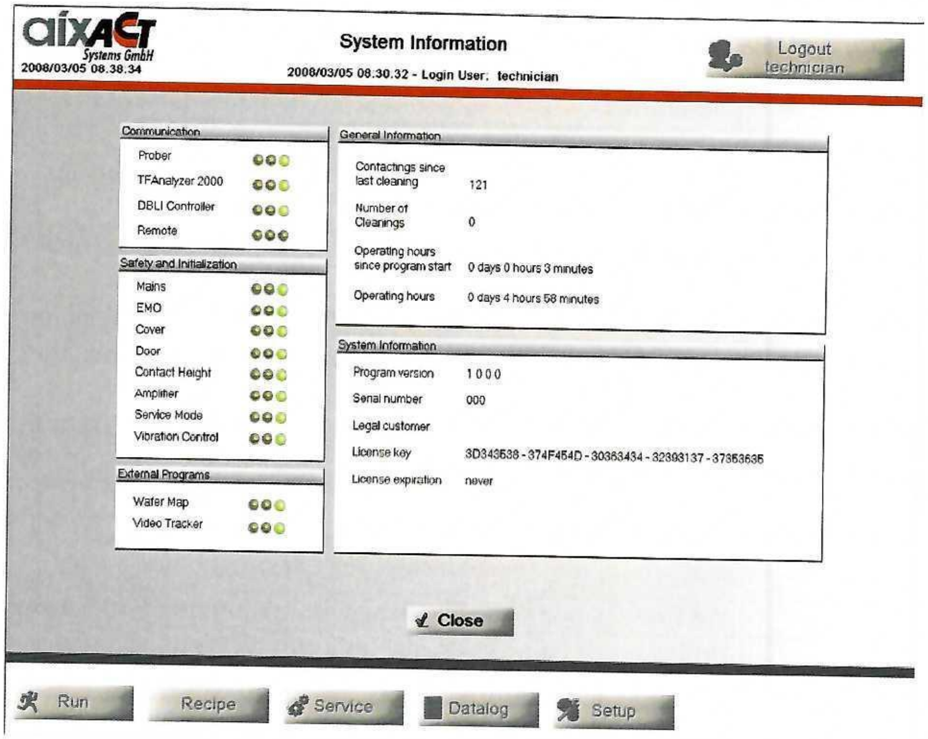


Fig. 5.3: Calibrator setup system information.

Table 5.1: System Status Information:

ID	Description
Prober	Internal network communication to the Suss prober controller is established
TFAnalyzer 2000	Internal network communication to the TFAnalyzer measurement system is established
DBLI Controller	Internal network communication to the beam working point controller is established, if failed (red) press the reset button on the controller (mounted in the rack rear)
Remote	External communication is established to remotely control the system (optional)
Mains	Mains power is present, red indicates running on UPS power
EMO	An EMO button was pressed and the system is in EMO state
Cover	Prober cover lid position, red indicates it is open and movements are blocked
Door	Chamber door interlock status, red indicates when a door is open in Normal operation mode
Contact Height	Contact Height setting, red indicates contact height has to be set (e.g. after power up) according to the procedure 4.5
Amplifier	Status of the 200 V amplifier, red indicates a failure or missing power
Service Mode	Status of the Service Mode key switch, red indicates Service Mode
Vibration Control	Status of the Vibration Controller, red indicates a failure or missing power
Wafer Map	Suss Wafer Map software is started when green, when red exit and restart software
Video Tracker	Suss Wafer Map software is started when green, when red exit and restart software

5.6. Change of the wafer chuck

The aixDBLI System can be used either for measurements on 6" or 8" wafers. An additional adapter needs to be mounted into the wafer chuck to hold 6" wafers. Please follow the given steps below to mount this adapter:

1. Login as user Calibrator, if not done already.
2. Bring wafer chuck into the wafer load position by pressing *Eject wafer*.
3. Open the front chamber door and remove any wafer from the chuck.

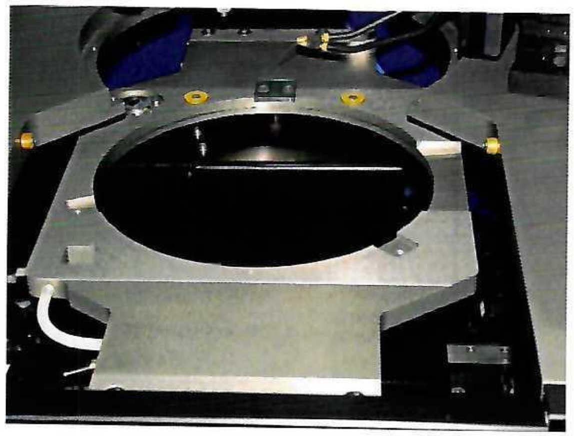


Fig. 5.4: 8 inch chuck in eject position.

4. Change the aixDBLI System into *Service mode* of operation (selected by the key-operated switch in the rack). Laser beam, wafer stage and high voltage are not automatically disabled in this operation mode.

WARNING: In *Service mode* laser beam, wafer stage and high voltage are not automatically disabled when a chamber door is opened. Don't use this mode if you are not properly instructed and experienced for service on the aixDBLI System. Use proper eye protection goggles!

5. Using the joystick move the wafer stage manually to gain easy access to the vacuum bridge screws.
6. If necessary you may remove the positioner units with tips (e.g. place them on the right hand edge of the top plate or onto the tip exchange aid wedge.
7. Remove the 8" chuck vacuum bridge by loosening the two hex wrench screws with an allen wrench and removing it with the two gaskets below. **WARNING:** make sure not to drop any screw or the bridge or the gaskets into the machine. If such happens, any part has to be get out to prevent damage to the stage.

Fig. 5.5: 8 inch chuck vacuum bridge mount.

8. Clean the contact surfaces of the grooves for the vacuum bridge and holders of the chuck inlay.

9. Carefully insert the 6" wafer chuck adaptor ring together with one vacuum gasket. The ring fits tightly into the 8" hole, so it must be inserted very straightly. Be careful not to touch the probe tips or any optics. Secure it with the provided four hex wrench screws.

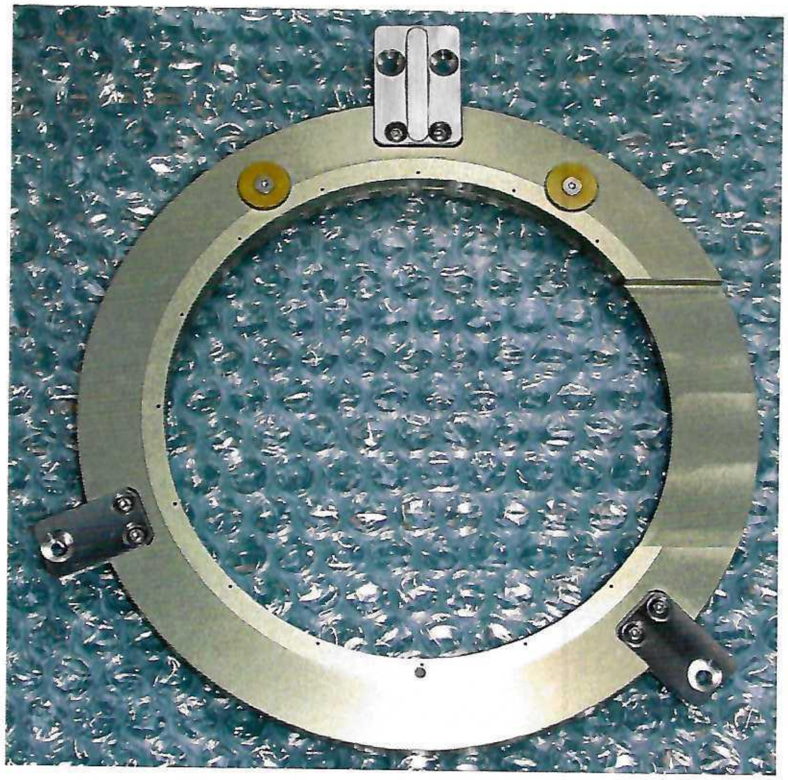


Fig. 5.6: 6 inch chuck adaptor ring.

10. If necessary place back the probe tips (refer to **??**)

11. Set the system back into *Normal mode* and remove the key of the key-operated switch.

12. The system is ready to measure 6" wafers now.

13. Check chuck planarity with flat 6" wafer (less than 10 μm bow) by visual inspection after setting the contact height (refer to **??**)

The steps to remove the 6" adapter are performed analogously in reversed order.

5.7. Optical alignment check

The alignment of the optical path can be checked if necessary as follows.

1. Login as user Calibrator, if not done already.

2. Go to the service menu and press *Laser Alignment*. The system will move to the quartz reference sample.

3. Select *Interference Camera* on the left screen, press the *Grab Image* button on, and save the image for reference to be sent to aix*ACCT* .

4. Select *Wafer Camera* on the left screen.

5. On the quartz sample, move the laser spot to the center of the round 100 μm pad as indicated in the picure Fig. 5.8 on the right hand side of the quartz sample.

6. Press the *Grab Image* button on the left screen and save the image for reference which could be sent to aix*ACCT* for reference.

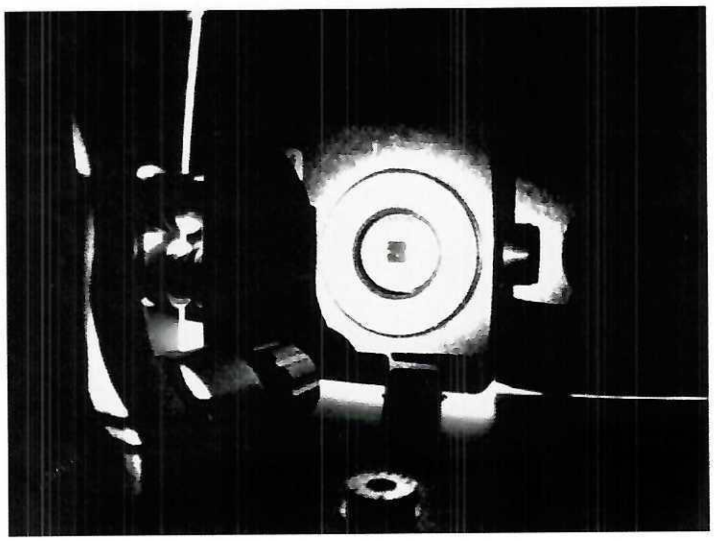


Fig. 5.7: Check interference pattern on the quartz sample.

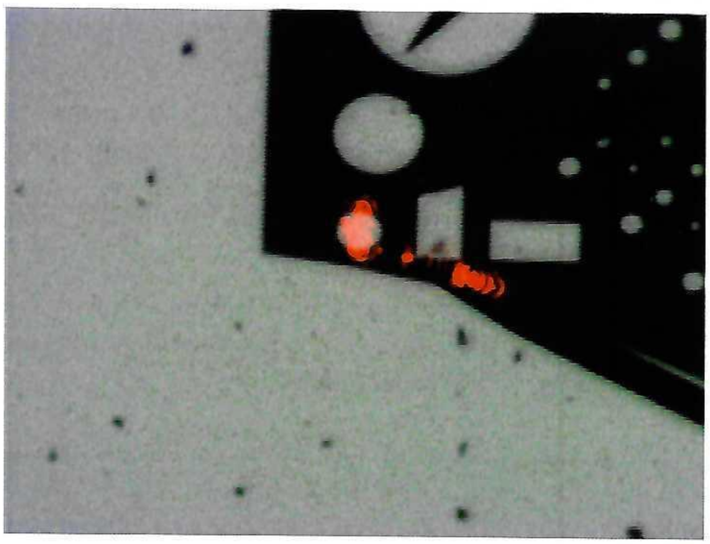


Fig. 5.8: Check optical alignment on the quartz sample.

6. Super User

SAFETY INSTRUCTIONS:

- Read and understand this manual and all safety labels before operating this system.
- Only a trained person is to be permitted to operate this system. Training should include instruction in operating under normal conditions and emergency situations.
- This system is to be serviced only by trained and authorized personnel.
- Consult Material Safety Data Sheets (MSDS) for hazards and required personal protective equipment listings.
- Never leave the system stopped in such a manner that another worker can start the system while you are working on or within the system.
- Never change or defeat the function of electrical interlocks or other system "shutdown" switches.
- Routine inspections and corrective/preventative maintenance measures are to be conducted to make sure that all guards and safety features are retained and function properly.

6.1. User login

After power up of the system (see Technical Documentation Manual) the monitor shows the login screen for the different users as described in Chapter 1.

6.2. System operation

Ways to operate and manage the aixDBLI System are described in Chapter 2.2, Chapter 3.3 and Chapter 4.4.

6.3. Exiting and starting the software

The software may be exited (e.g. in case of a serious failure, to get acces to Windows XP functions usually hidden behind the operating software, or software updates). Within the *Service* menu press the button *Exit*. To restart the software or if the software isn't started, double-click the icon *DBLICommander.exe* on the desktop. Exiting the software is not available to the standard Operator.

6.4. User management

As described in Chapter 1 the aixDBLI System offers five user levels for different tasks. Several user accounts may be defined for any user level. Within the *Service* menu the button *User Management* leads to the following dialog:

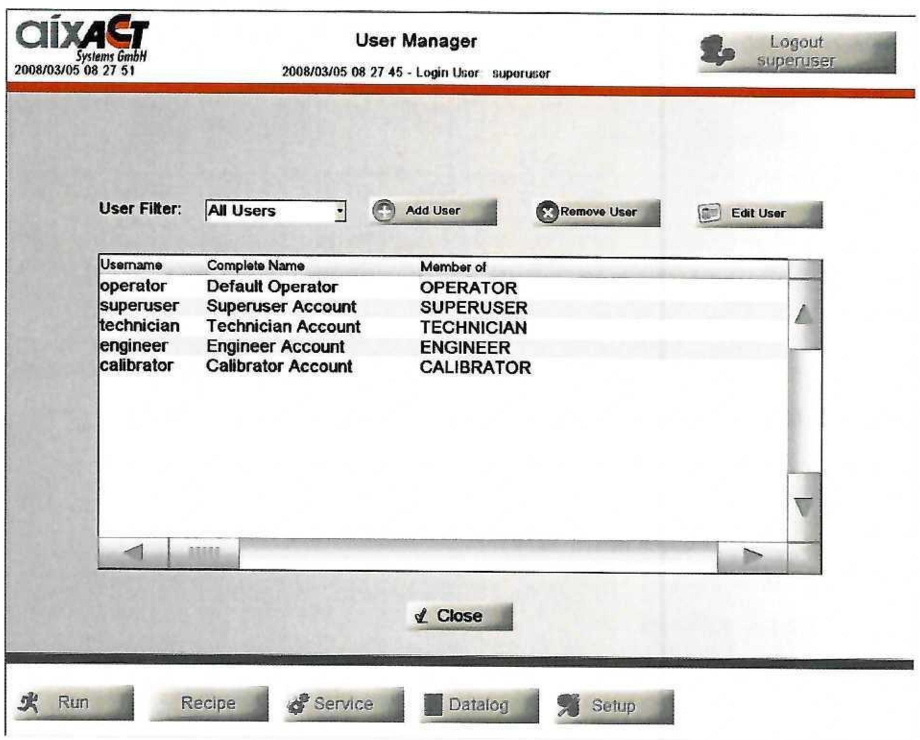


Fig. 6.1: Start window user management.

The button *Add User* allows to add a new user account to one or more user levels while the *Edit User* button allows to change an existing user account by the help of the following dialog:

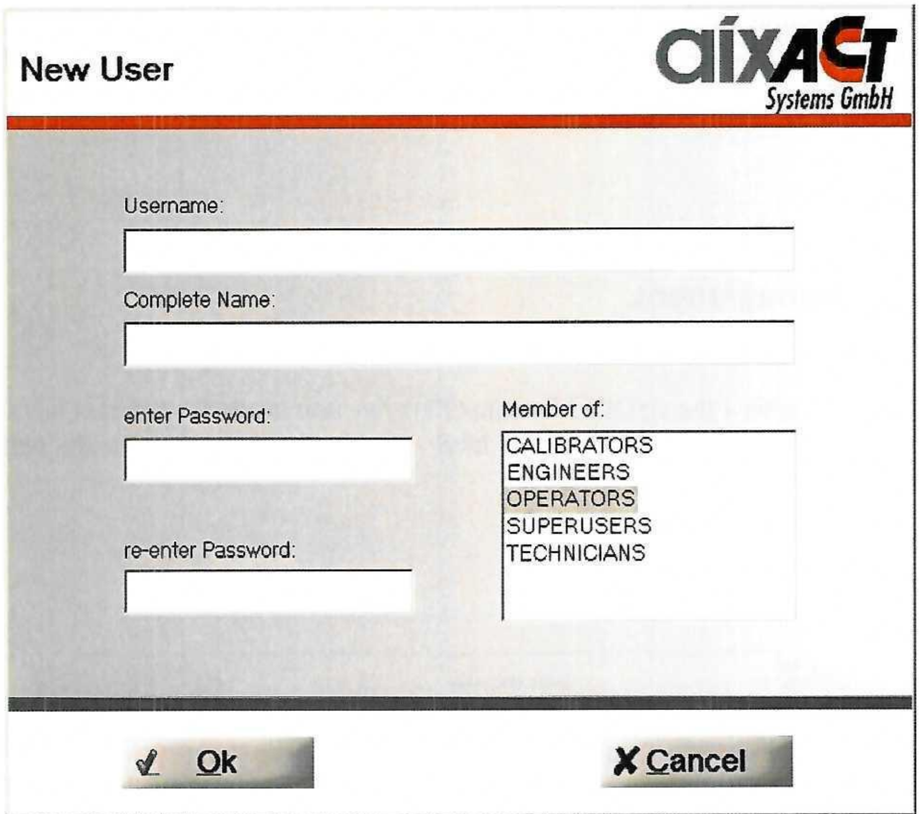


Fig. 6.2: Add new user account or edit existing user account.

6.5. System calibration and maintenance

The system calibration procedure is described in Chapter 5.3.

6.6. Preferences setup

The *Setup* menu includes a *Preferences Setup* button to change several system settings for the aixDBLI System. The main window is shown in Fig. 6.3.

Directories The TF Analyzer 2000 path is the fully qualified directory path to the directory on the TF Analyzer 2000 where measurement data is stored. The TF Analyzer 2000is connected via an internal network connection. This directory must be located on a shared filesystem which is accessible from the aixDBLI System. The stored measurement data is read by the aixDBLI System using the DBLICommander path. Recipes are stored in the Recipe path or its subdirectories.

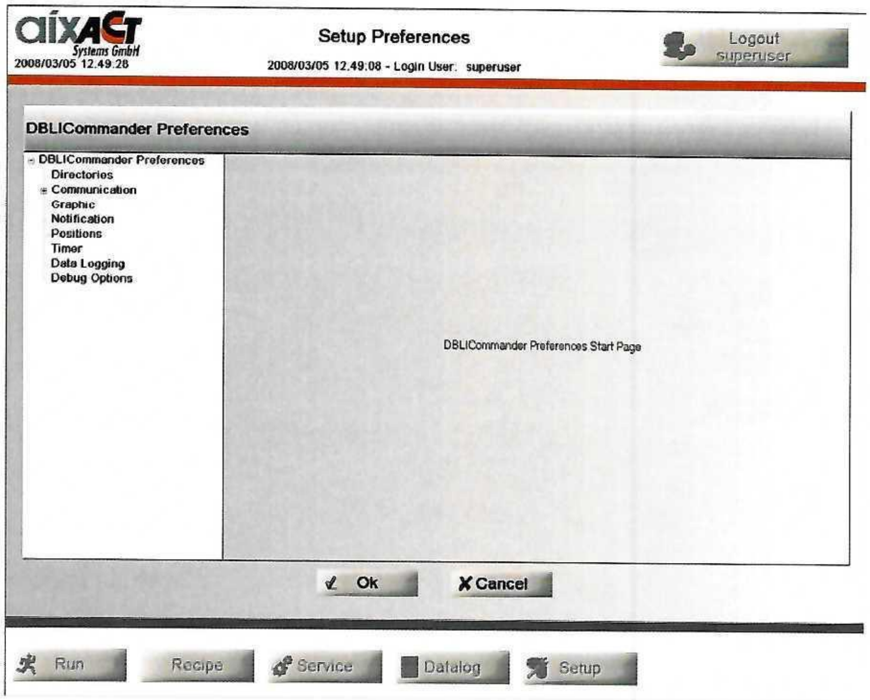


Fig. 6.3: Superuser setup preferences - Main window.

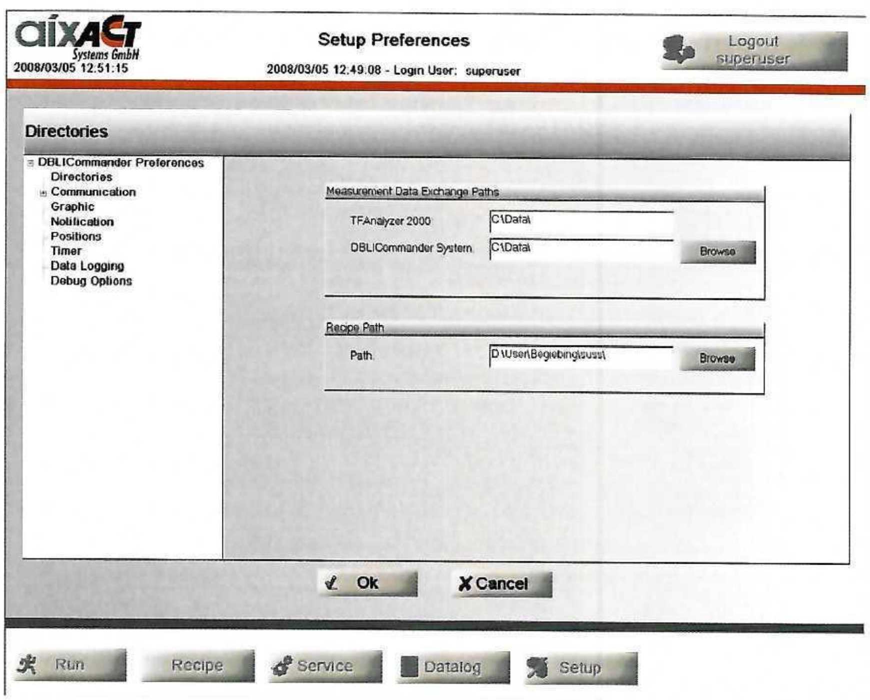


Fig. 6.4: Superuser setup preferences - Directories.

Communication with Prober The aixDBLI System communicates with the wafer prober using the selected driver. As recommended the necessary prober software is started automatically by the DBLICommander software.

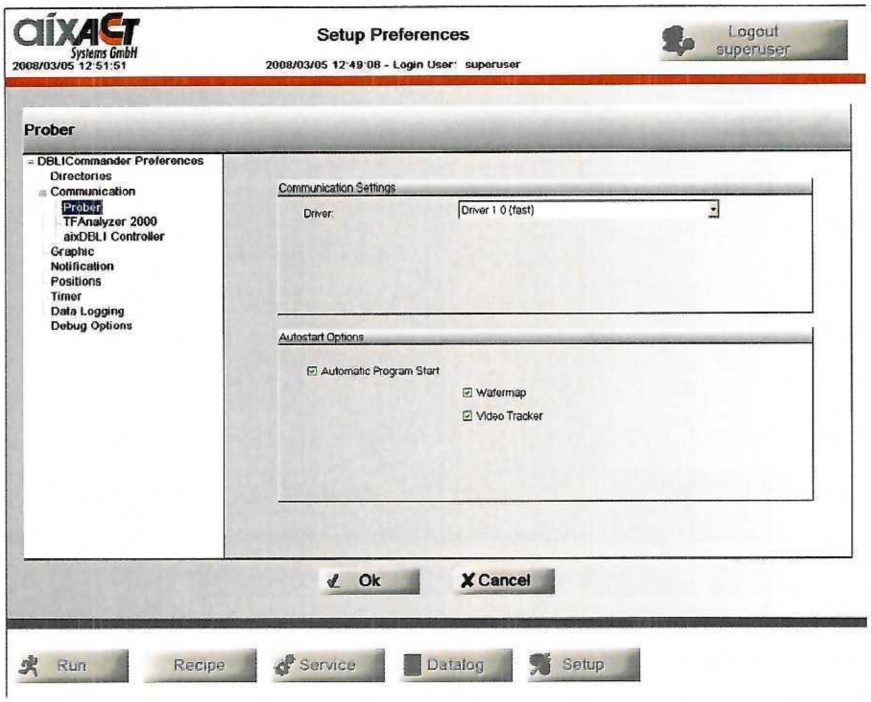


Fig. 6.5: Superuser setup preferences - Communication with wafer prober.

Communication with TF Analyzer 2000

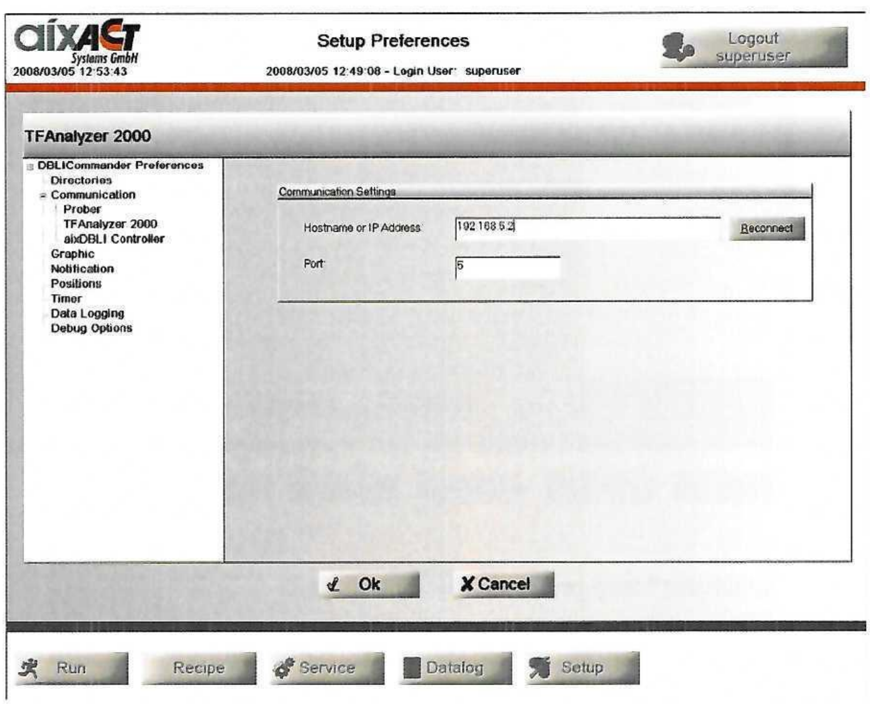


Fig. 6.6: Superuser setup preferences - Communication with TF Analyzer 2000.

Communication with aixDBLI Controller

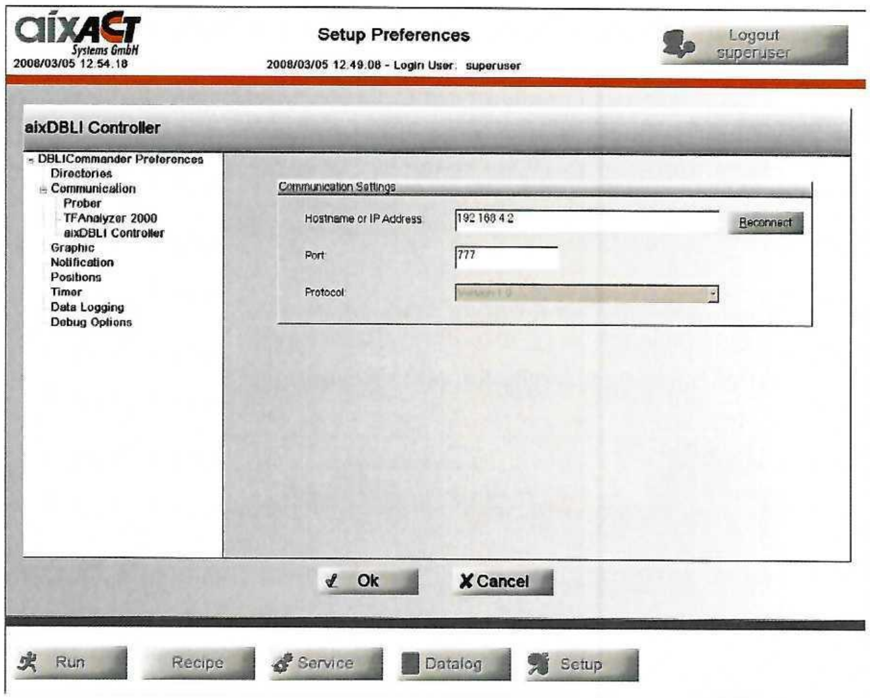


Fig. 6.7: Superuser setup preferences - Communication with aixDBLI Controller.

Graphic The aixDBLI software is designed to be used on a dual monitor system with the given resolution. The data graph mode items format the appearance of measurement data.

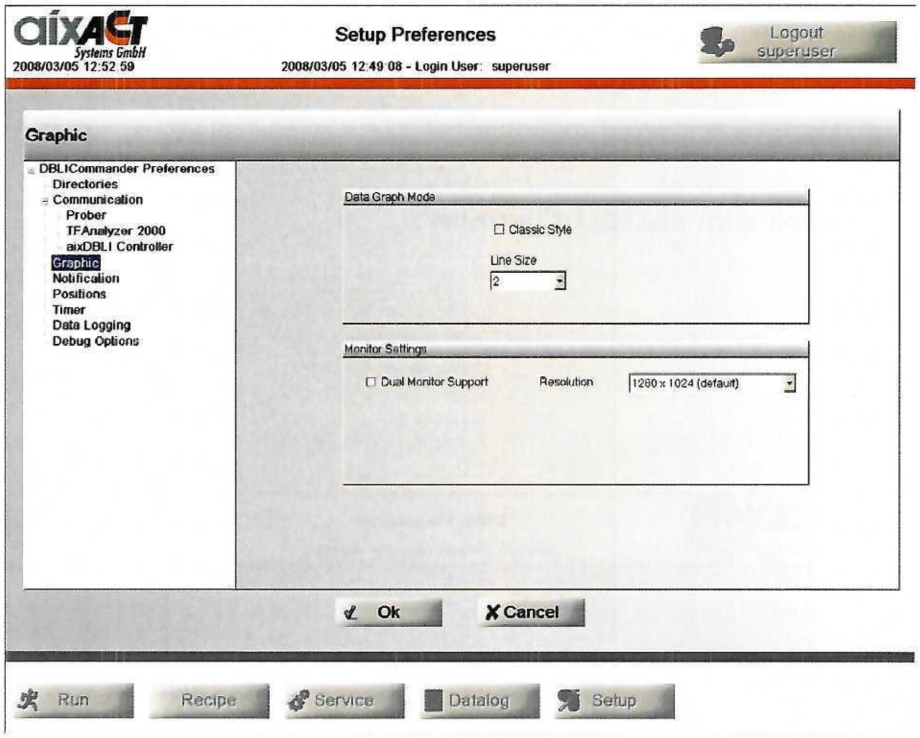


Fig. 6.8: Superuser setup preferences - Graphic.

Notification After finishing a semiautomatic measurement a notification may be sent.

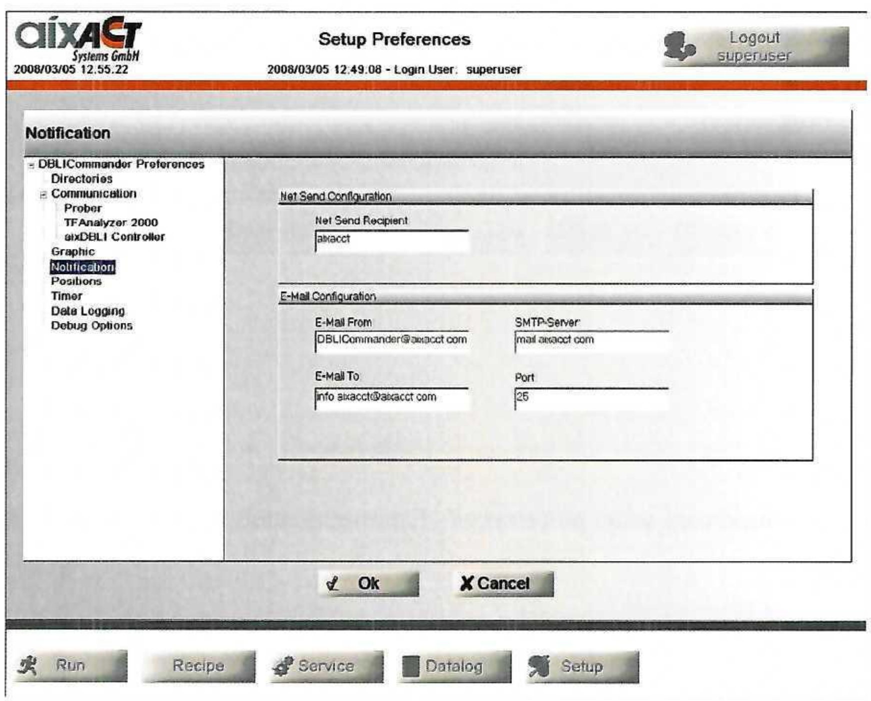


Fig. 6.9: Superuser setup preferences - Notification.

Positions The actual load and eject position of the chuck are defined. The quartz sample and the cleaning pad are fixed in order to position them automatically.

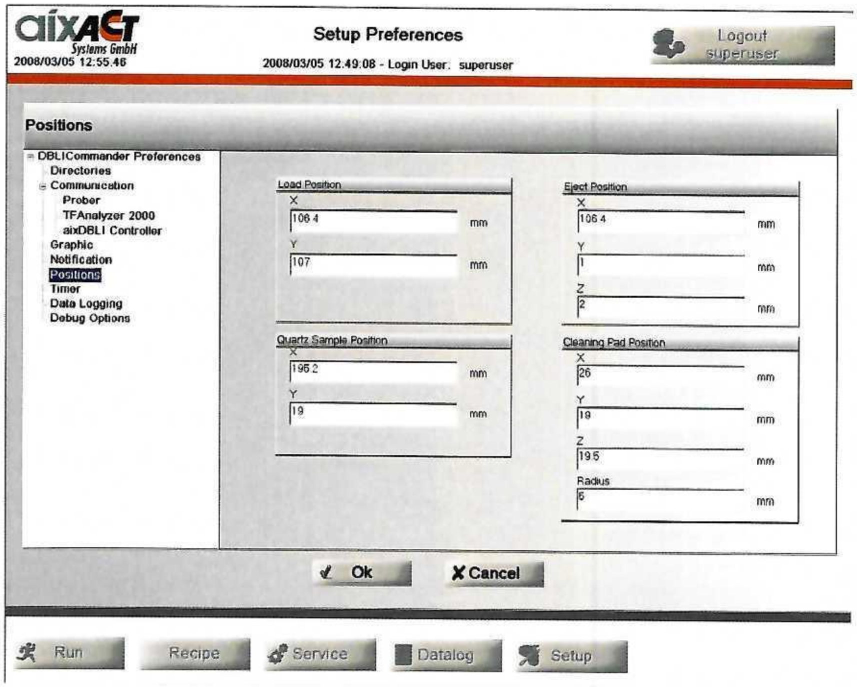


Fig. 6.10: Superuser setup preferences - Positions.

Timer The aixDBLI System tries to start a quartz measurement once per hour if no other process is pending which is checked at the given time.

Fig. 6.11: Superuser setup preferences - Timer.

Data Logging The kind and amount of information stored in the data log is configurable.

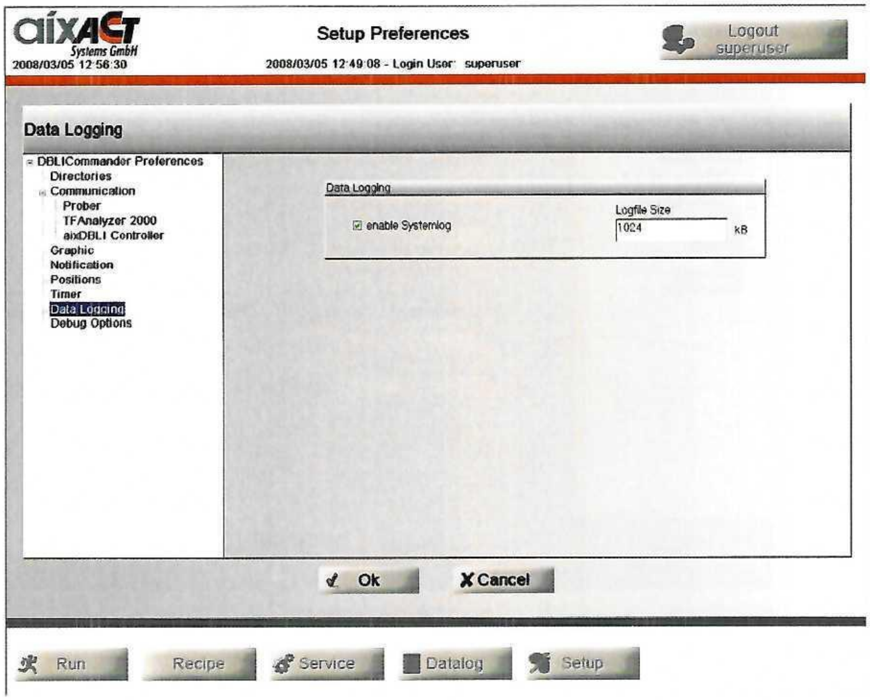


Fig. 6.12: Superuser setup preferences - Data log.

Debug Options For debugging purposes it may sometimes be useful to snap camera images.

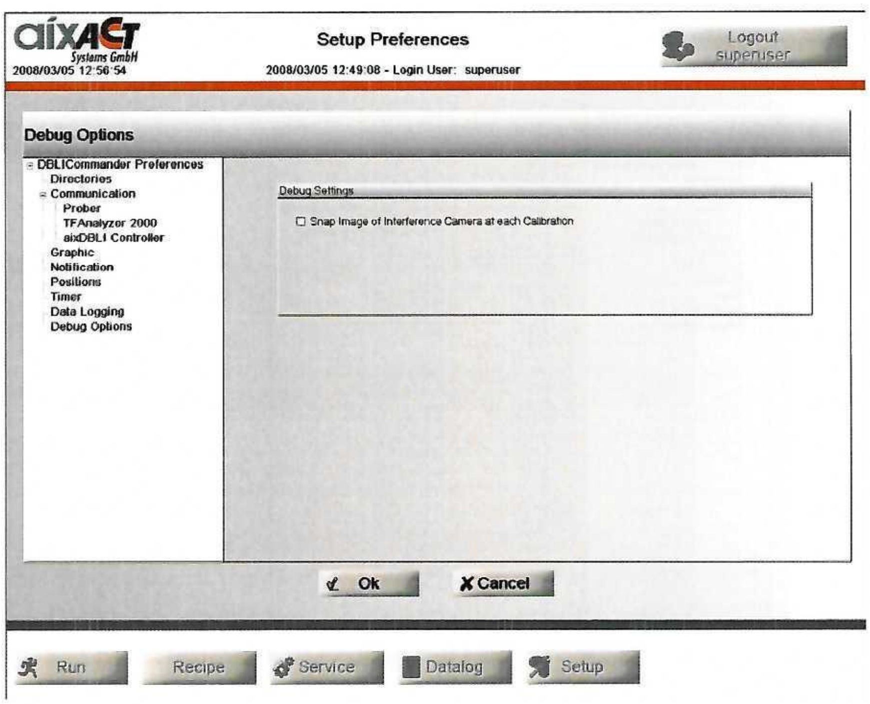


Fig. 6.13: Superuser setup preferences - Debug.

Part III.
Miscellaneous

7. Concept of aixACCT measurement systems

aixACCT Systems started with the first modular designed electrical characterization system for electro ceramic thin films and bulk ceramic samples: The TF Analyzer 2000. The intention of this measurement system is the comprehensive characterization of a wide range of materials and devices. Based on this, aixACCT Systems offers customized system solutions with both excellent electrical performance and unique test methods.

7.1. Specialized measurement systems

A variety of measurement systems are designed with the TF Analyzer 2000 system as core component to fulfill measurement tasks e.g. for thin films and MEMS devices, bulk ceramics, and multilayer actuators. For this purpose the TF Analyzer is e.g. connected to Atomic Force Microscopes (AFM) or wafer stages, controls external hardware components like temperature controller or high voltage amplifier, and reads additional data from displacement, temperature, or force sensors.

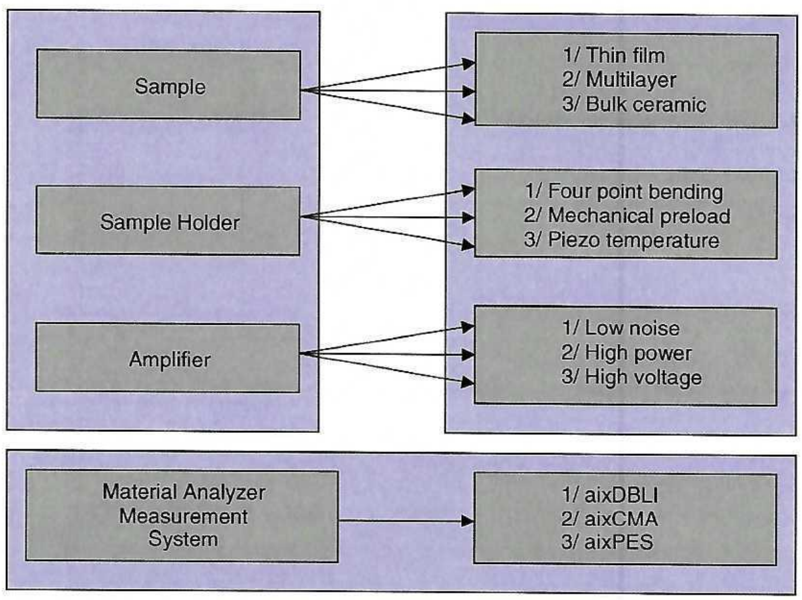


Fig. 7.1: System solutions for piezoelectric material and device testing based on modular product concept.

Additional software tools (e.g. aixPlorer and Resonance Analyzer) exist for management and advanced analysis of measurement data. For power users with large amounts of measurement data the measurement systems and software tools can be combined with database programs such as MySQL™ or MS Access™.

An overview over the different software programs and tasks is given in Fig. 7.2 for a ferroelectric material characterization system. The data acquisition program (e.g. Hyster) is the general measurement software used for the acquiring data running e.g. on a TF Analyzer 2000. After systematic excitation the response of the device under test is recorded in order to derive accurately material properties and to describe material behavior. It has advanced functions to easily view and export measurement data too.

For large amounts of measurement data the aixPlorer software has been developed. It allows to get a good overview over loads of measurement data and to copy, cut and paste single measurements respectively export them to ASCII data format. The contents of each measurement in a file is displayed in a small graph, which gives an impression of the measured data. Besides the data browsing capability the aixPlorer software contains additional functionalities to perform advanced data analysis on measurements recorded by aixACCT Systems equipment. All the measured and additionally evaluated data can be written into a professional database system like MySQL for further statistical analysis. The results can be read back into the aixPlorer software again to be displayed e. g. in a datasheet. This datasheet allows a comprehensive overview of up to nine measurement graphs on one page with additional characteristic data. The datasheet is an excellent way to get a fingerprint of the properties of a single sample or material batch e.g. for quality control or production process analysis. Please read the chapters about the aixPlorer or Hyster software in this manual for further details.

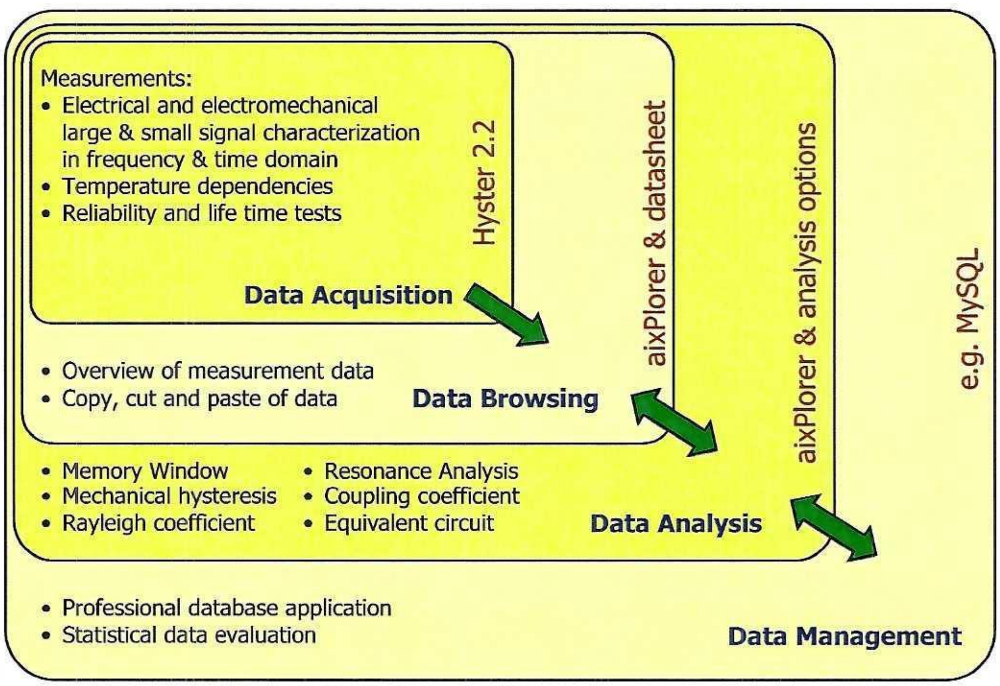


Fig. 7.2: Structure of aixACCT Systems software components.

7.2. Basic system TF Analyzer 2000

Each TF Analyzer 2000 consists of a Basic Unit and at least one measurement Module. The computer and the high precision power supplies are located in the Basic Unit. The specific amplifiers for high precision measurements are located in the Probe Heads in a separated housing.

As it can be placed very close to the sample, the loop between drive and return is hereby reduced and the signal to noise ratio is increased significantly. Changing the measurement Module means changing the characterization method. Doing so it is just needed to untie and reconnect four cables.

The following modules are offered for a variety of measurement tasks:

FE	dielectric and ferroelectric material characterization e.g. hysteresis loop and CV available with in-situ compensation and high speed integrator for advanced measurement demands
PS	investigation of the switching kinetics of ferroelectric materials
RX	investigation of the relaxation behavior of electro ceramic materials
DR	investigation of the self discharge behavior
IS	investigation of low impedance resonance spectra of multilayer actuators
MR	investigation of magneto-resistive tunnel junctions

The different measurement Modules are optimized for special measurement requirements and complement each other. The pulse switching module completes for example the investigation of the frequency dependence of the hysteresis loop very well. Thus, the investigation of this effect can be observed from the mHz range, using the static hysteresis and the dynamic hysteresis measurement of the FE module to the MHz range, using the PS module. Newest characterization methods are implemented e.g. static hysteresis measurement. This method helps to separate reversible and irreversible parts of the polarization. In correlation with the data from the imprint measurement, the user is able to perform a lifelong time extrapolation for the device under test e.g. for memory applications.

7.2.1. Basic Unit

The TF Analyzer 2000 system offers an efficient personal computer system, containing at least a Pentium III class processor, minimum 256 Mbyte memory, and a hard disk with more than 40 GByte capacity. Several interface cards which control the interaction with the Probe Head will complete the PC unit. A digital I/O-card provides 48 bit to control the amplification of the current to voltage converter and the electrometer. The analog input card is a high speed, high resolution data acquisition board. The maximum sample rate amounts to 1 MHz and the resolution is 16 bit at a voltage range of ± 10 V, equivalent to a 0.305 mV resolution. The arbitrary waveform generator applies the selected pulse train to the device under test. The vertical resolution amounts to 16 bit at ± 10 V, equivalent to 0.305 mV resolution as well.

The second part of the Basic Unit contains the power supplies for the measurement Module and additional circuit parts to handle the different measurement Modules. Electromagnetic shielding is realized and separates the two parts of the Basic Unit. This guarantees the performance of the high precision analog power supplies and fits in the overall concept of the TF Analyzer 2000 system to fulfill the requirements of the EMC.

7.2.2. Measurement Module

The concept of the TF Analyzer 2000 system includes the minimization of the incoupling loop between drive and return, because the measurement Module of the system contains the necessary amplifiers to drive a capacitive load and to record the data of the measuring cycle. Therefore, this setup can be used with any professional probe station without the need of long cables, because the Probe Head can be placed close to the device under test. This concept guarantees an optimum signal to noise ratio. Three amplifiers are located in the FE-module. Depending on the selected program, e. g. Dynamic Hysteresis or Fatigue two different amplifiers are used to drive the capacitive load. The hysteresis program allows cycle times between 1 s and 1 ms, respectively 1 μs depending on the configuration. In this case the TF Analyzer 2000 system offers an amplifier which provides voltage amplitudes up to 58 V_{pp}. In the case of a fatigue measurement the amplifier is changed to offer the user frequencies up to 20 MHz driving a 100 pF linear Styroflex-capacitor by an amplitude of 10 V_{pp}. The third amplifier detects the current response of the device under test. The method used to collect the data is the feedback method, which is realized by a current to voltage converter. This method reduces the influence of parasitic capacitance and back voltage known from the Sawyer Tower measurement drastically and enables direct hysteresis measurements on nanosized samples with sub micron square area for the first time. Fig. 7.3 shows the circuit design in principle.

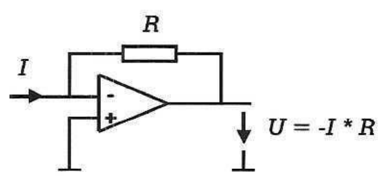


Fig. 7.3: Principle of the feedback method.

8. Introduction on piezoelectric materials

This chapter gives a short introduction to piezoelectric materials and their characteristic behavior. For further details please refer to standard text books like "Polar Oxides" edited by R. Waser, U. Böttger, and S. Tiedke.

8.1. Electrical classification of crystalline materials

All crystalline materials can be classified into 32 crystal classes and show electrostrictive material behavior. Electrostriction means that a material will change its length proportional to the applied squared electric field. A subgroup of 21 crystal classes are not centrosymmetric of which 20 reveal piezoelectric properties. Piezoelectricity is defined as linear correlation between mechanical stress or strain and electrical charge or voltage. The direct piezoelectric effect correlates with the induced charge when a mechanical force is applied to the ceramic. Whereas the converse piezoelectric effect describes the expansion of the sample applying an electrical field (see Fig. 8.1).

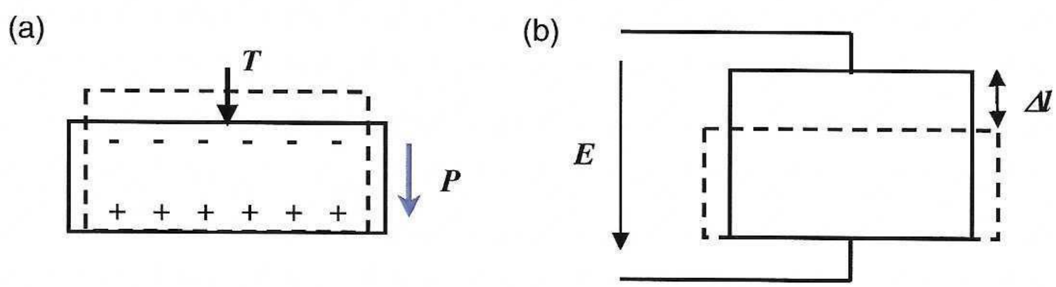


Fig. 8.1: (a) Direct piezoelectric effect: Mechanical stress T induces polarization charges. (b) Converse piezoelectric effect: An applied electric field results in a sample deformation Δl.

Structured according to their electrical behavior a subgroup of the piezoelectric materials are polar respectively pyroelectric materials. These materials show spontaneous polarization without externally applied by electric field or stress. A temperature change of the sample results in a change of the polarization charge in these materials. And finally if this spontaneous polarization can be switched due to an applied electrical field or mechanical force the sample belongs to a subgroup of pyroelectric materials called ferroelectric materials (see Fig. 8.2).

8.2. Basic material equations

The physical description of material characteristics can be done by a set of dependent and independent electrical, mechanical, and thermal variables. The correlation between these variables is given by the material characteristics like the dielectric coefficient ε for electric field E and dielectric polarization D or the coefficient of thermal expansion to correlate the temperature T with the mechanical strain S (see Fig. 8.3).

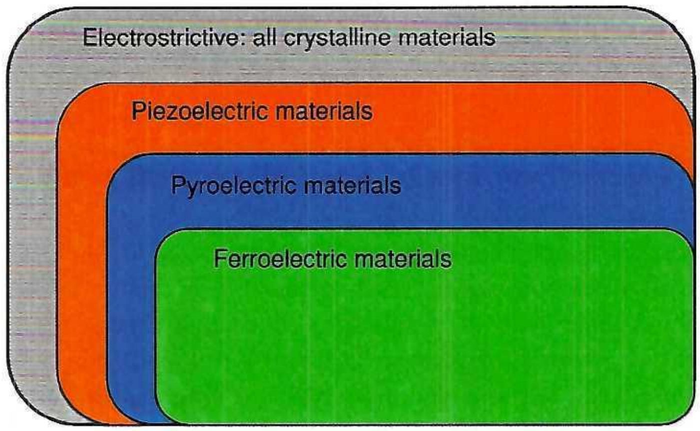


Fig. 8.2: Classification of crystalline materials due to their electrical response.

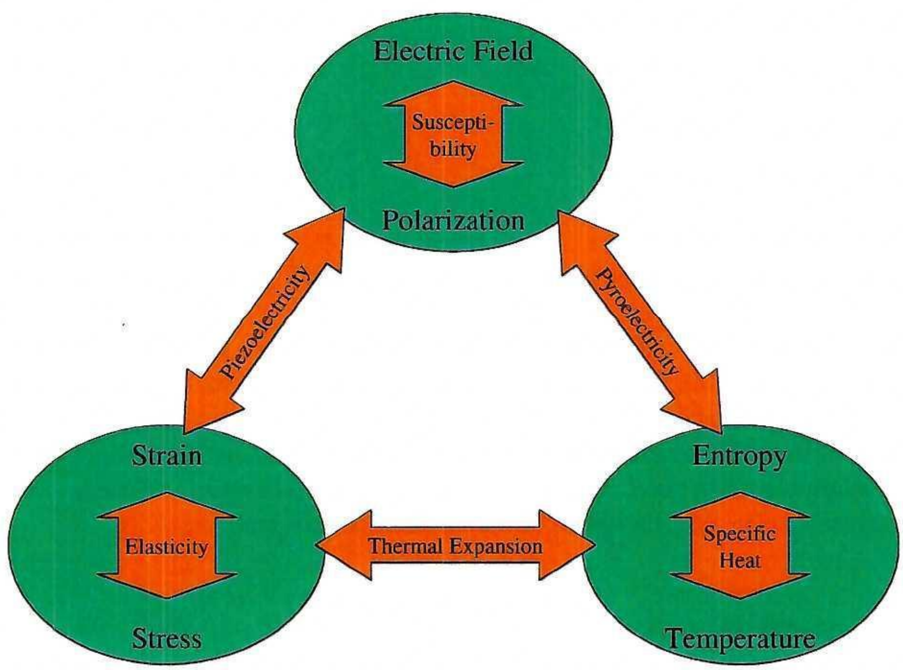


Fig. 8.3: Correlation of electrical, mechanical and thermal properties and their related material characteristics.

One representation of the piezoelectric material equations with linear small signal characteristics which includes electrical, mechanical and thermal material behavior can be written as:

$$S_{ij} = \alpha_{ij}^{T,E} \Delta T + s_{ijkl}^{\Delta T,E} T_{kl} + d_{ijk}^{\Delta T,T} E_k \tag{8.1}$$

$$D_i = p_i^{T,E} \Delta T + d_{ikl}^{\Delta T,E} T_{kl} + \varepsilon_{ij}^{\Delta T,T} E_i \tag{8.2}$$

The following tensor notation is used:

S_{ij} = mechanical strain

T_{kl} = mechanical stress

ΔT = temperature change

E_k = electric field

D_i = electric displacement

$\alpha_{ij}^{T,E}$ = thermal expansion coefficient at constant mechanical stress and electric field

$s_{ijkl}^{\Delta T,E}$ = elastic compliance at constant temperature and electric field

$d_{ijk}^{\Delta T}$ = piezoelectric coefficient at constant temperature

$p_i^{T,E}$ = pyroelectric coefficient at constant mechanical stress and electric field

$\varepsilon_{ij}^{\Delta T,T}$ = relative dielectric permittivity at constant temperature and mechanical stress

The basic equations can be simplified for isothermal systems in reduced matrix notation to

$$S_i = s_{ij}^E \, T_j + d_{ik}^t \, E_k \tag{8.3}$$

$$D_m = d_{mj} \, T_j + \varepsilon_{mk}^T \, E_k \tag{8.4}$$

For piezoelectric materials made of e.g. PZT the material matrices are only partly filled and these equations can be written as:

$$S_1 = s_{11}^E \, T_1 + s_{12}^E \, T_2 + s_{13}^E \, T_3 + d_{31} \, E_3 \tag{8.5}$$

$$S_2 = s_{12}^E \, T_1 + s_{11}^E \, T_2 + s_{13}^E \, T_3 + d_{31} \, E_3 \tag{8.6}$$

$$S_3 = s_{13}^E \, T_1 + s_{13}^E \, T_2 + s_{33}^E \, T_3 + d_{33} \, E_3 \tag{8.7}$$

$$D_3 = d_{31} \, T_1 + d_{31} \, T_2 + d_{33} \, T_3 + \varepsilon_{33}^T \, E_3 \tag{8.8}$$

These equations (8.5 - 8.8) are only valid for small changes of the independent variables T and E where the relations to the dependent variables S and D are linear.

In principle piezoelectric thin films, thick films and bulk ceramics, can all be described by these basic equations. But for thin films it is important to consider that it is not possible to measure the properties of the film itself only. Instead of this, the measured properties are always the result of a layered structure made of the substrate, the electrode layers, and the piezoelectric film. The measured parameters are effective material characteristics which are - due to the substrate clamping effect - smaller than values measured on bulk ceramics of the same material.

For piezoelectric thin films on a substrate the effective longitudinal and transverse piezoelectric coefficients $d_{33,f}$ and $e_{31,f}$ are defined as:

$$d_{33,f} = d_{33} - 2d_{31}\frac{s_{11}^E}{s_{11}^E + s_{12}^E} \tag{8.9}$$

$$e_{31,f} = \frac{d_{31}}{s_{11}^E + s_{12}^E} = e_{31} + e_{33}\frac{s_{13}^E}{s_{11}^E + s_{12}^E} \tag{8.10}$$

8.3. Characteristic material data

For micro-electromechanical systems (MEMS) based on piezoelectric thin films the electrical and electromechanical properties are essential for the device functionality. For this the focus of measurements is exclusively set to an electrical voltage excitation and measuring the current or charge responses and additionally the displacement response of the sample. Therein two cases can be distinguished: large signal and small signal measurements.

Large signal means that a triangular or sine wave voltage signal is applied with a maximum amplitude usually higher than the materials coercive field. Characteristic sample response is the hysteresis loop of the dielectric polarization (measured in μC/cm^2) and the butterfly loop of the displacement. An example measurement of a 130 nm thick PZT film is shown in Fig. 8.4. Typical parameters which are derived from the hysteresis loop are the coercive field values $Vc+$ and $Vc-$ (where the polarization is zero), and the remanent polarization values $Pr+$ and $Pr-$ (polarization values with no applied electric field $E = 0$ V/m). Especially for unipolar measurements where the total displacement is of interest an average d_{33} can be defined as the slope of the displacement hysteresis loop.

A small signal measurement is defined as a measurement with an alternating excitation signal which has only such a small amplitude that the sample response (e.g. capacitance respectively dielectric coefficient ε) is linear. This measurement can be repeated at different dc-bias voltage levels to find the material dependency in the operation point. This $C(V)$ dependency for ferroelectric materials is nonlinear again. With small signal capacitance vs. voltage $C(V)$ and loss tangent $tan(\delta)(V)$ measurements, further important parameters of ferroelectric capacitors can be determined. Especially it gives information about the reversible parts of polarization, and furthermore the switching process. A typical result of a 130 nm thick PZT film is displayed in Fig. 8.5. The small signal displacement response can be measured with a double beam laser interferometer Simultaneously to the dielectric measurement. This gives the dc-bias voltage dependent longitudinal piezoelectric coefficient $d_{33,f}(V)$ which is essential for the qualification of MEMS devices.

Several characteristic values for the dynamic dielectric and piezoelectric coefficient can be calculated from the loops, e.g. values at zero or maximum dc-bias voltage or averaged values using the whole loop.

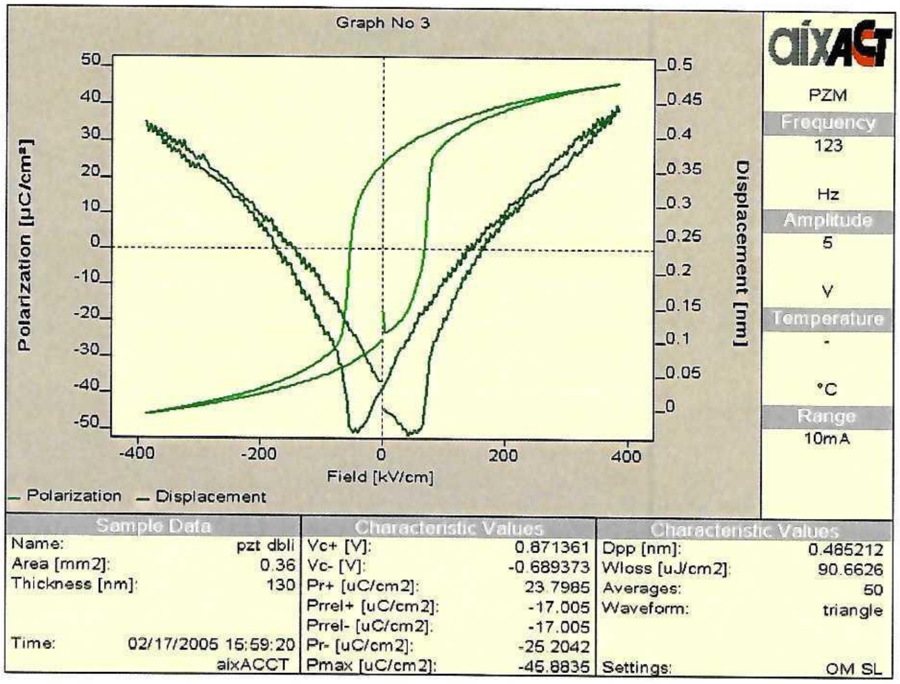


Fig. 8.4: PZT thin film sample response to large signal excitation voltage at room temperature.

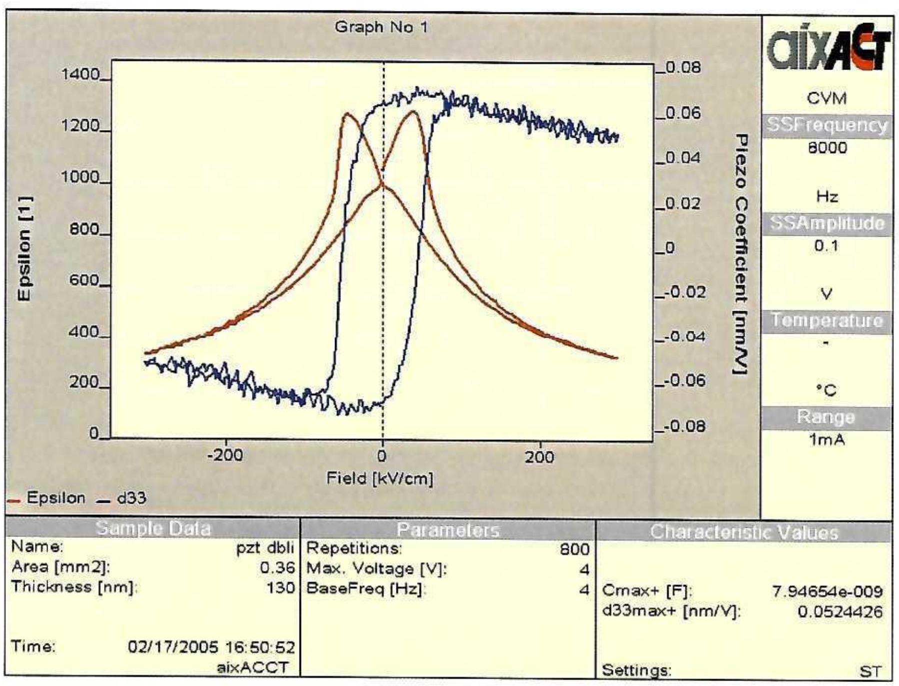


Fig. 8.5: PZT thin film sample response to a DC bias voltage signal superposed by a small signal excitation voltage at room temperature.

9. Electrical measurement methods

Electrical and electromechanical characterization of piezoelectric materials are the decisive factors to investigate their suitability for piezoelectric or pyroelectric sensor and actuator devices. Substantial for electrical characterization of a sample is the measurement of its current or charge response due to an applied electrical excitation voltage. The electromechanical response can be measured either by applying an electrical excitation signal and measuring the samples mechanical displacement or by applying a mechanical strain and recording the resulting charge displacement. The first method is commonly used as it allows the simultaneous electrical and electromechanical characterization.

First of all, the range of signal magnitude of relevant parameters needs to be estimated to determine the requirements for an electrical amplifier to guarantee accurate measurements. Relevant parameters are charge, current, applied voltage, frequency, and signal to noise ratio. The total polarization charge is determined by the geometry of the capacitor, the material and the applied voltage. The magnitude of the current I is given by the charge Q and the change in voltage per time, which is called the slew rate. Where A is the area of the capacitor, P the polarization of the material, V the applied voltage and dV/dt describes the slew rate of the signal form that is applied. E.g. a voltage pulse or a triangular voltage signal at different frequencies, which is a typical signal to record the hysteresis loop. The magnitude of the current flow during a polarization reversal in a ferroelectric capacitor can be calculated as

$$Q = D \cdot A \approx P \cdot A \Rightarrow I = \frac{dQ}{dt} = A \cdot \frac{dP}{dV} \cdot \frac{dV}{dt}. \tag{9.1}$$

Based on a typical thin film sample capacitor geometry with an area $A = 0.25\ \mathrm{mm}^2$, an operating voltage of 3 V and a remanent polarization value $P_r = 30\ \mu\mathrm{C/cm}^2$ of the material, the switching charge is $Q = P_{sw} * A = 2 * P_r * A = 150\ \mathrm{nC}$. Choosing a triangular excitation signal with 100 Hz frequency the average current magnitude will be roughly calculated to

$$I = \frac{60\ \mu\mathrm{Ccm}^{-2} \cdot 0.25\ \mathrm{mm}^2}{3\ \mathrm{V}} \cdot \frac{3\ \mathrm{V}}{2.5\ \mathrm{ms}} \approx 60\ \mu\mathrm{A}. \tag{9.2}$$

Due to the switching process around the coercive voltage V_c, dP/dV is not constant and the peak switching current will increase in one or two orders of magnitude. Besides the current magnitude it is necessary to know the bandwidth of the current in order to decide how the current can be recorded. The frequency spectrum of the current will define the bandwidth requirements for the recording amplifier which is important for the selection of an amplifier. Furthermore, the noise and ground bouncing is an important aspect, which will finally result in the estimation of the signal to noise ratio (SNR). These parameters all together decide how well the electrical properties of a piezo- or ferroelectric capacitor can be determined.

There exist three established methods to record the charge and current response of the sample. They are described in the following sections.

9.1. Sawyer Tower method

The Sawyer Tower measurement circuit is based on a charge measurement method which relies on a reference capacitor in series with the ferroelectric capacitor. The voltage drop at the reference capacitor is proportional to the polarization charge as defined by $V = Q/C$. But if the voltage on the reference capacitor increases, the voltage at the sample decreases (back voltage effect). So the reference capacitor has to be much larger than the measured capacitor. E.g. if the reference capacitor is 100 times larger, the voltage drop is about 1 %. This means the reference capacitor has to be adjusted to each sample. The Sawyer Tower method can be used up to high speeds which is primarily limited by cable reflections. As parasitic effects, cabling capacitances of the wiring between sample, reference capacitor and the recording amplifier are in parallel to the reference capacitor. Typical cable capacitance values are between 33 pF and 100 pF per meter. For small capacitors the capacitance of the ferroelectric material is blinded in the total measured capacitance. Furthermore, it is difficult to get precise reference capacitors which typically have several percent tolerance. In addition the cable capacitance has to be added to this capacitance. Moreover the input resistance of the voltage measurement device is in parallel to the reference capacitor. This loads to a discharge with a corresponding time constant, therefore the Sawyer Tower is less suitable for slow measurements.

9.2. Shunt method

The Shunt measurement substitutes the reference capacitor of the Sawyer Tower circuit by a reference resistance (shunt resistor). This measurement method is a current based method, i.e. the switching current is measured as a voltage drop at the shunt resistor ($V = R * I$), and integrated (e.g. numerically) to get the polarization charge $Q = \int Idt$. Similar difficulties as in case of the Sawyer Tower set-up appear. Though it is easier to get precision resistors, the resistance value of choice depends not only on the sample capacitance but also on the excitation frequency. Thus, the voltage drop increases with increasing frequency and the time constant of ferroelectric capacitor and shunt resistor influences the result at higher speed. Additionally, the cable capacitance as well as the input capacitance for the voltage measuring device are in parallel to the reference resistor. Therefore accurate measurements for large pads are possible but become increasingly difficult in case of small pads, where the parasitic capacitances come into effect.

9.3. Virtual Ground method

The Virtual Ground method uses a current to voltage converter which is based on current measurement using a an operational amplifier with feedback resistor. The output of the current to voltage converter is connected to the inverting input of the operational amplifier via the feedback resistance, the non inverting input is connected to ground. The voltage difference between both inputs is ideally zero but in reality just a few microvolts. So, the inverting input is virtually on ground level. This is helpful for the measurement - especially of small capacitors - as the cable capacitance is physically in place but electrically ineffective, because both electrodes of the capacitor are kept on the same potential. Also the sample is always applied to the full excitation voltage, since there is no back voltage. For high speed measurements, or voltage pulses, the inductance of the set-up and the impedance mismatch caused by the sample and sample holder will lead to reflection on the cable and thus to a measurable change of the results related to the set-up. Also the stability, bandwidth, and phase shift of the operational amplifier must be taken into account.

But as a whole the Virtual Ground method enables the highest precision for ferroelectric measurements. Therefore it is used as integral part of aixACCT measurement system.

10. Introduction on interferometric measurements

10.1. Measurement of piezoelectric properties

Considering piezoelectric material characterization, the resonance technique, which is widely used for bulk samples, is not applicable for thin films. The technique measures the natural frequency of a sample, which is determined by its fundamental vibration modes. Therefore, the characterization of thin films would require frequencies in the GHz range due to the small sample geometries. The difficulties arising from these high frequencies have yet to be solved.

Another approach is to measure the piezoelectric properties at sub resonance frequencies far below the characteristic frequency. Both the direct piezoelectric and the converse piezoelectric effect are used to evaluate the piezoelectric properties. Direct piezoelectric techniques require the measurement of the piezoelectric charge generated by the sample when mechanical stress is induced. With ferroelectric thin films, direct measurements are prone to mechanical difficulties due to the mechanical forces needed to generate a measurable charge buildup. Also, additional electric charge buildup is generated by the sample bending under mechanical stress. This produces errors during the measurement.

Using the converse piezoelectric effect, the electric field induced displacement of the sample are measured. Since the small thickness of thin films limits the voltage applicable to the samples, the displacements are in the angstrom range. The non-linear piezoelectric response of ferroelectric materials for different applied electric field requires an even higher resolution of about $1 - 10pm$. Interferometric techniques are one approach to achieve such high resolutions.

Of the different interferometric methods, homodyne interferometers are most commonly used. Using an active stabilization of the operating point, two optical path schemes have been developed over time: The single-beam Michelson interferometer measures the displacement of only one surface of a sample, whilst the double-beam Mach-Zehnder measures the displacement difference between the two major surfaces of the sample. Since the single-beam technique does not take sample motion into account, it is prone to errors resulting from sample bending. Therefore, the double-beam technique is the superior method for measuring ferroelectric thin films. Measuring only the displacement difference, any motion of the sample along the optical path is successfully suppressed. Hence, bending of the sample cannot contribute to the measured displacement. The disadvantage of this technique is a reduced resolution ($10^{-3} - 10^{-2}$ angstrom), resulting from the increased optical path length and loss of light intensity in the system.

10.2. Interferometry

10.2.1. Interference

Interference is achieved by superposition of two waves. If the waves have the same frequency, amplitude and direction of travel, a new wave with a changed amplitude, but the same frequency is produced. Depending on the phase difference between the two single waves, the amplitude of the combined wave is changed from zero (Fig. 10.1 C) to the doubled (Fig. 10.1 A) amplitude. The phase of the generated wave ist exactly at half the phase difference between the origin waves.

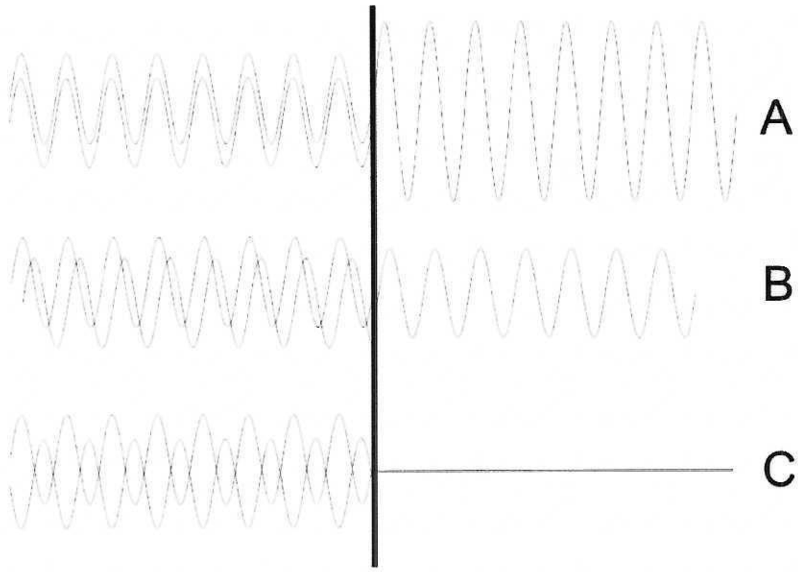


Fig. 10.1: Interference for A:$\Delta = 0$, B:$\Delta = \lambda/4$ and C:$\Delta = \lambda/2$

If the amplitudes of the origin waves are different, the total elimination or doubling is somewhat reduced. Hence it is advantageous to adjust both waves to a equal amplitudes. In order to use interference for high resolution measurements, the utilized waves have to have constant amplitude, frequency, phase, direction of oscillation and direction of travel over a long path. Waves with these properties are called coherent. If light waves in the visible spectrum are used, interference patterns are generated, helping the alignment of the measurement setup. This only happens, if both waves have at least one oscillation component in the same direction. Therefore, linear polarized light is used, which is typically generated by a LASER (*Light Amplification by Stimulated Emission of Radiation*).

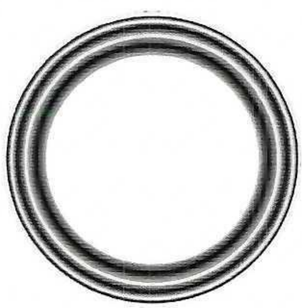


Fig. 10.2: Interference pattern of two beams

If two coherent light rays are superimposed, a pattern of concentric rings is generated, which travel in radial direction if the phase difference of both rays is changed (Fig. 10.2). Near the center of this pattern the rings are generated or eliminated. The intensity in the center of the pattern changes from the minimum I_{min} to the maximum I_{max} value, when the phase difference between the beams is changed from $\lambda/2$ to λ. The intensity can be calculated by:

$$I = \frac{1}{2}(I_{max} + I_{min}) + \frac{1}{2}(I_{max} - I_{min})\cos(2\pi \cdot \frac{x}{\lambda}) \tag{10.1}$$

, where x is the phase difference between the beams. Since the wave length is known, even tiny path length changes in one of the beams can be calculated, if the path length of the other beam is constant.

10.2.2. Interferometer

For measuring thickness changes of thin samples, one beam (measurement beam) is reflected on the top electrode of the the sample and the path length of the other beam (reference beam) is kept constant. A change of the sample thickness, e.g. by application of an electric field, is changing the path length of the measurement beam and therefore the intensity of the center in the interference pattern. The intensity can be calculated by:

$$I = \frac{1}{2}(I_{max} + I_{min}) + \frac{1}{2}(I_{max} - I_{min})\cos(2\pi\frac{2\Delta d}{\lambda} + \frac{\pi}{2}) \qquad (10.2)$$

, where the thickness change Δd of the sample is incorporated twice, since the path length of the beam is changed before and after the reflection.

Adjusting the path length of the reference beam, the operating point of the interferometer can be adjusted. The highest sensitivity $\Delta I/\Delta d$ is achieved at the steepest point, at $I = \frac{1}{2}(I_{max}+I_{min})$. Hence, this point ($\frac{\pi}{2}$) is chosen as operating point. Now, the cosine is replaced by a sine shifted by $\frac{\pi}{2}$ ($\cos(x + \frac{\pi}{2}) = \sin x$). Using small variations near the operating point, the sine function can be replaced by its argument ($\sin(x) \approx x$ for $x \ll 1$), the deviation is less than 0.1% for $x < 0.08$:

$$\begin{aligned} I &= \frac{1}{2}(I_{max} + I_{min}) + \frac{1}{2}(I_{max} - I_{min}) \cdot 4\pi\frac{\Delta d}{\lambda} && (10.3) \\ &= \frac{1}{2}(I_{max} + I_{min}) + (I_{max} - I_{min}) \cdot 2\pi\frac{\Delta d}{\lambda} && (10.4) \\ \Rightarrow \Delta I &= (I_{max} - I_{min}) \cdot 2\pi\frac{\Delta d}{\lambda} && (10.5) \end{aligned}$$

Measuring the center intensity with a photodetector, the thickness change of the sample can be calculated by:

$$\Delta d = \frac{\Delta I \cdot \lambda}{2\pi(I_{max} - I_{min})} \qquad (10.6)$$

If the voltage generated by the photo detector is proportional to the measured intensity I can be replaced by U:

$$\Delta d = \frac{\Delta U \cdot \lambda}{2\pi(U_{max} - U_{min})} \qquad (10.7)$$

10.2.3. Double-beam principle

Though measuring with one measurement beam yields a high resolution(10^{-5} up to 10^{-4} angstrom), Motion of sample along the beam path, e.g. due to sample bending, influences the measurement. With a double-beam setup, the measurement beam is also reflected on the sample backside, eliminating this influence. On the other hand, the resolution is decreased to due to the longer beam path and additional optical components. The typically achieved resolution of approx. 10^{-2} Angstrom is still sufficient for thin film measurements. Any remaining influences of sample bending are negligible.

10.3. Optical setup

10.3.1. Components

Before going into details of the measurement principle, it is helpful to understand the optical components utilized. Hence, a brief description of main components will be given first. In the Figures and corresponding descriptions, a cartesian coordinate system will be used, as indicated in the figures. The Y-direction is perpendicular to the mounting plane of the components and the negative Z-direction is the direction of travel of the laser beam. Positive X-direction is parallel to the mounting plane and perpendicular to the direction of travel.

10.3.2. Isolator

An optical faraday isolator (diaphragm) is used to keep reflected light from reentering the laser source. This enables the laser feedback loop to keep the intensity of the generated beam constant (Fig. 10.3).

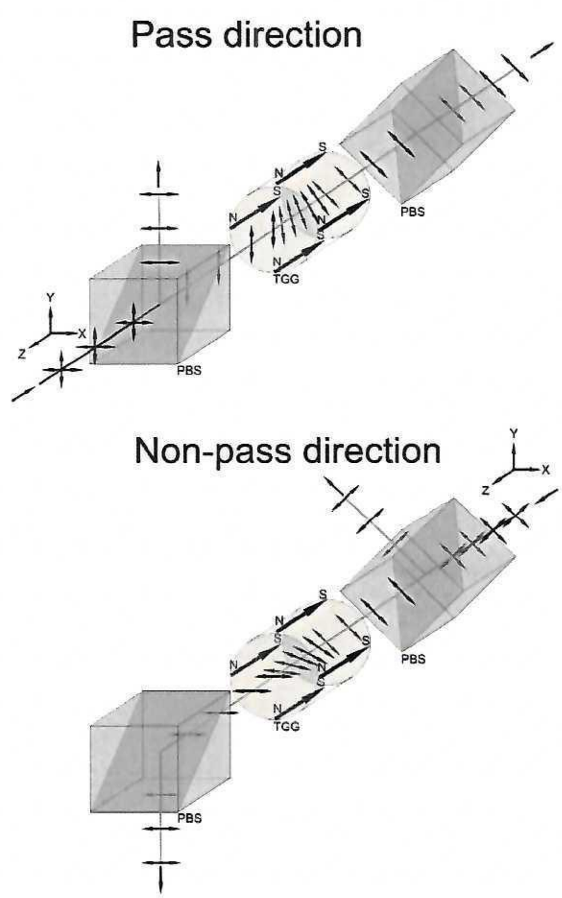


Fig. 10.3: Faraday isolator

The diaphragm consist of 2 polarizing beam splitter cubes (PBS, see below) mounted in front and behind a TGG-crystal. The crystal itself sits in a homogeneous magnetic field and changes the polarization of passing laser beam exactly 45°, independent of the direction of travel. This property is resulting of the Faraday effect and is also called Magneto-rotation. Both beam splitter cubes are mounted with an orientation difference of 45°. A beam traveling in the passing direction (Fig. 10.3 top) is filtered in the first beam splitter and rotated in the crystal. Since polarization change and mounting difference of the beam splitter cubes are the same, the beam passes the second beam splitter without loss.

A beam traveling in non-pass direction (Fig. 10.3 bottom) will be filtered in one beam splitter and rotated in the crystal. In this direction of travel, the beam polarization is rotated in the same direction as before, but the direction of travel is changed. Hence, the beam will reach the second beam splitter with a polarization which is perpendicular to the pass polarization direction of the cube. Therefore, the beam will be filtered out completely.

Special antireflectory coatings dampen the reflection on the entry surface of the isolator. In order to maximize the amount of laser radiation passing the isolator, the polarization of the laser source has to be aligned to the pass polarization direction of the first beam splitter.

10.3.3. Polarizing beam splitter PBS

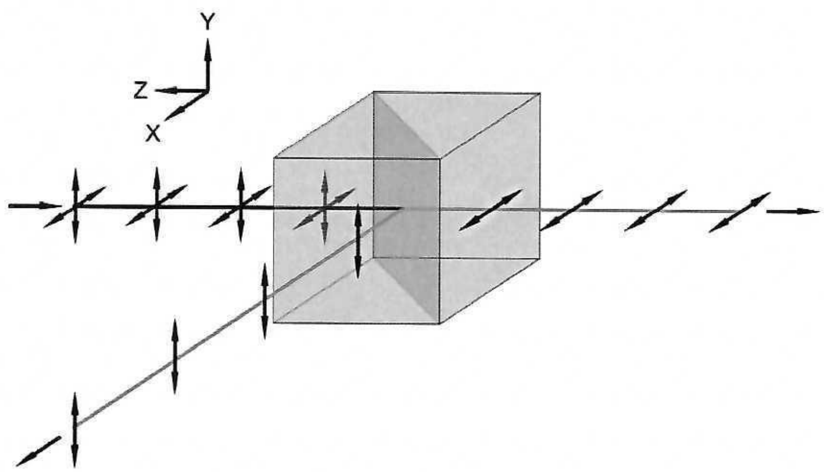


Fig. 10.4: Polarizing beam splitter

Polarizing beam splitter cubes (Fig. 10.4) are used to divide the beam or change its direction of travel. They consist of to 90° prisms glued together. Between the prisms, there is an active thin film, which is transmitting light which is polarized in X-direction and reflects light polarized in Y-direction. A beam polarized 45° to the X- and Y-direction will be splitted in two beams of the equal intensity. The transmitted and reflected beam is polarized in the X- and Y-direction, respectively. To change the direction of travel of a beam beam coming back to the beam splitter, its polarization has to be rotated 90°.

10.3.4. $\lambda/2$ plate

A $\lambda/2$ plate is used to rotate the polarization of the beam (Fig. 10.5). This plate is a crystal with different speeds of beam propagation (light speed) for light polarized in X- and Y- direction.

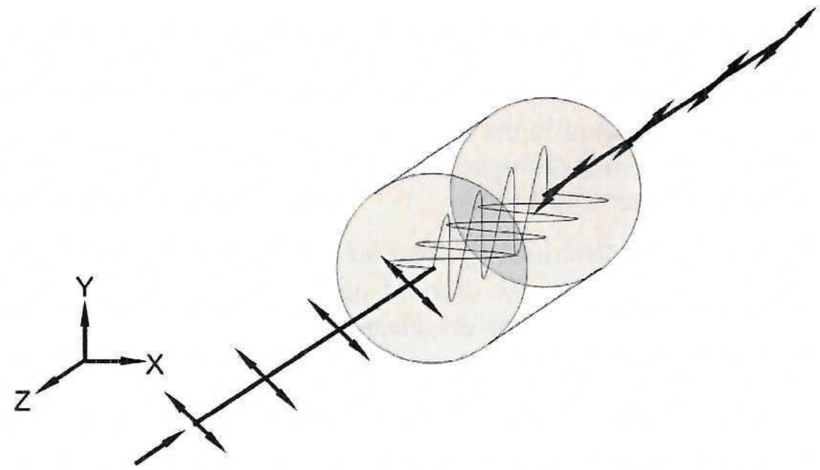


Fig. 10.5: $\lambda/2$ plate

The part of the beam polarized in Y-direction is delayed exactly one half of the wave length. Depending on the polarization of the entering beam, the polarization of the exiting beam will be rotated up to 180°. A 45° polarization will be changed to −45° and rotated 90°. For fine tuning, the $\lambda/2$ plate is seated in a holder with an adjustment range of 20°.

10.3.5. $\lambda/4$ plate

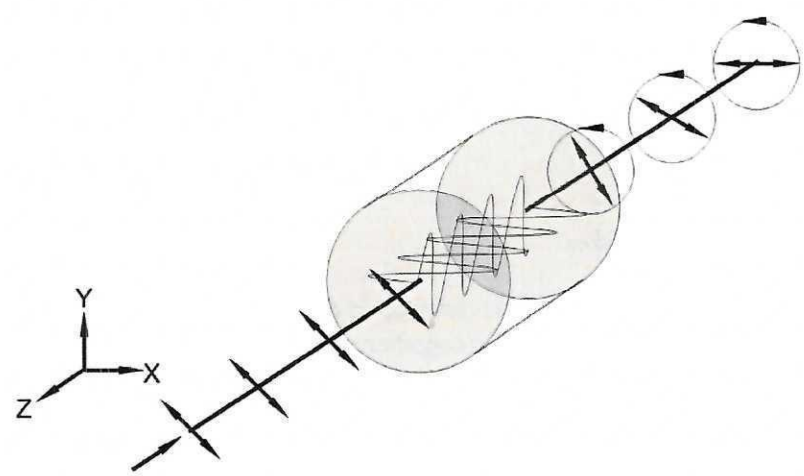


Fig. 10.6: $\lambda/4$ plate

The principle of a $\lambda/4$ plate (Fig. 10.6) is the same as the one of the $\lambda/2$ plate, but the delay is only a quarter of the wavelength. Linear polarized light is changed to circular polarized light and the other way around. If a beam passes a $\lambda/4$ plate twice, its effect on the beam is the same a $\lambda/2$ plate passed once.

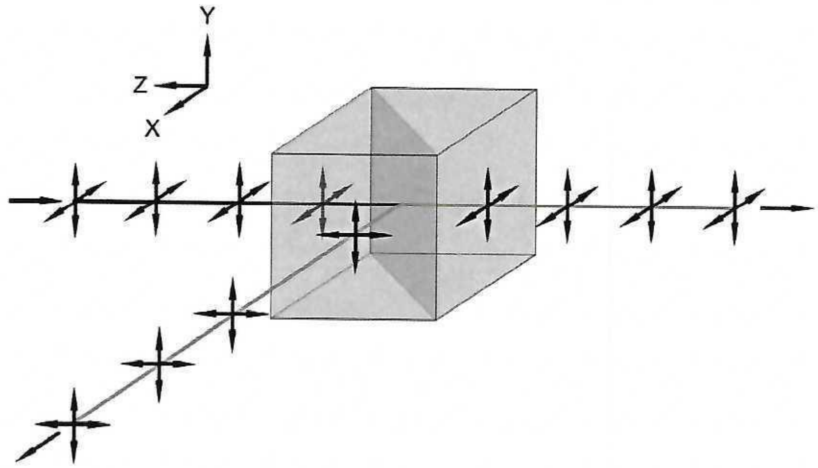


Fig. 10.7: Beam splitter

10.3.6. Beam splitter BS

The polarization of beams has to be the same for the interference to happen. If both beams come from different directions, a non-polarizing beam splitter has to be used (Fig. 10.7), if both beams should leave the optical component in the same direction. A normal beam splitter is build similar to a polarizing beam splitter with one difference: 50% of the beam is reflected and 50% is transmitted, independend from the polarization of the entering beam. Also, the the polarization of the beam stays unchanged.

10.3.7. Beam path

The optical path of the double-beam laser interferometer used in this work is shown Fig. 10.8. The laser beam, generated by an intensity stabilized He-Ne laser, passes the diaphragm and a shutter before it is reflected by the two mirrors M1 and M2 to the front side of the setup. The beam passes than the $\lambda/2$ plate P1 before entering the polarizing beam splitter (PBS1) on the upper rail. The diaphragm keeps reflected light out of the laser and the $\lambda/2$ plate is used to rotate the laser beam polarization. Rotation of the polarization determines the amount of intensity transmitted and reflected in the beam splitter (PBS1). The transmitted beam is used as measurement beam and has a the longer beam path. Hence, the losses in this beam are higher than in the reflected beam, which is used as reference beam. Higher losses can also result from less than optimal reflection of the sample surface and counterbalanced by increasing the intensity of the measurement beam.

The Measurement beam travels along the upper rail, passes the $\lambda/4$ plate P2 and is reflected downwards in the mirror M3. After being focused by the lens L1, the beam is reflected on the upper surface of the sample. Afterwards, the beam travels back to the beam splitter PBS1. By passing the $\lambda/4$ plate P2 twice, the polarization is rotated 90° resulting in a downward reflecting in PBS1. In PBS2, the measurement beam is reflected again and travels along the lower rail. It is reflected (M4) and focused (L2) again, this time on the lower sample surface. Another $\lambda/4$ plate P3 is used for polarization rotation. When the beam reaches PBS2 it is transmitted to the

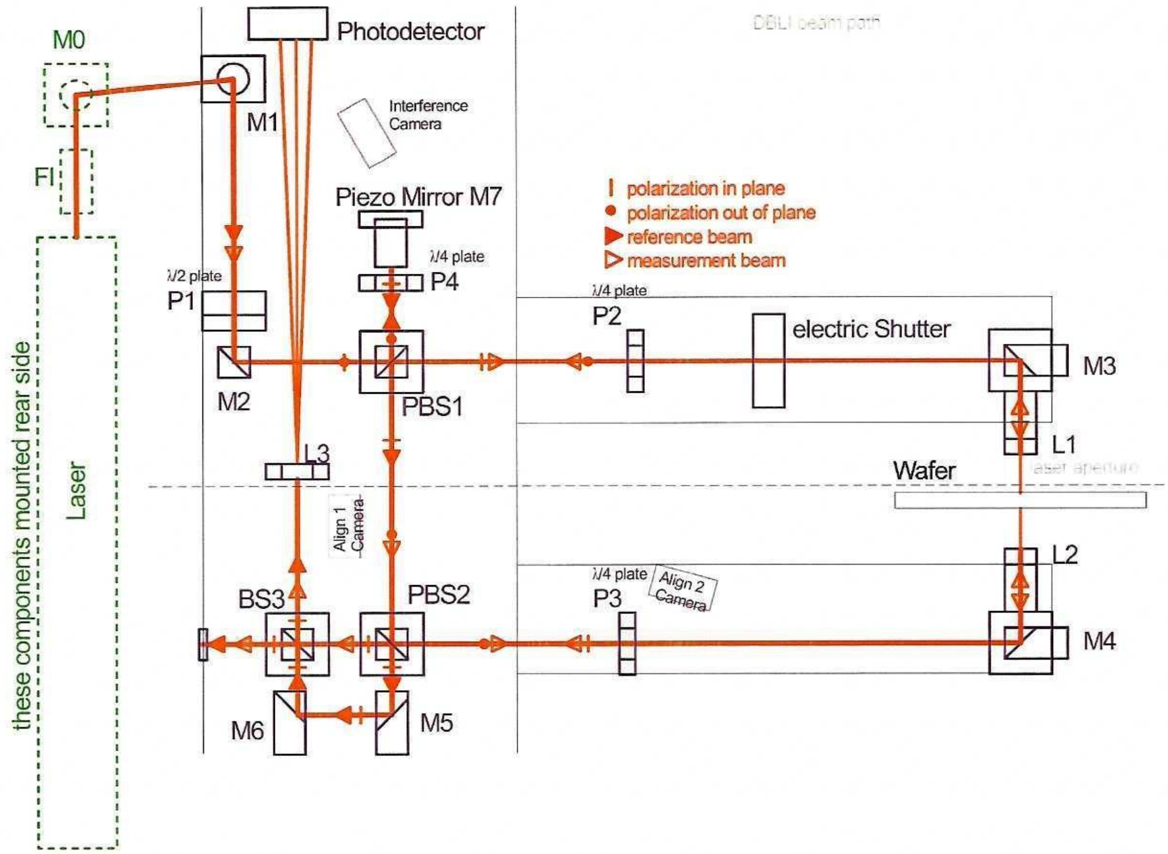


Fig. 10.8: Beam Path

non-polarizing beam splitter BS3. Inside BS3, half the beam is transmitted and half is reflected upwards to the photo detector.

The Reference beam, which is reflected upwards in PBS1, passes the $\lambda/4$ plate P4 and is reflected on the mirror M7 seated on a piezoelectric actor. This so called reference mirror can be shifted along the beam path to change the path length of the reference beam and to control the operating point of the interferometer. Since the $\lambda/4$ plate P4 turns the polarization, the reference beam is transmitted through PBS1 on its way back and passes PBS2. After being transmitted again, the beam is reflected in the Mirrors M5 and M6 until it reaches the beam splitter BS3. It reaches BS3 in the same polarization state as the measurement beam. Therefore, the superposition of both beams in BS3 results in the desired interference. The combined beam is broadened by lens L3 to enlarge the center of the interference pattern. The center intensity of the pattern is finally measured by the photo detector.

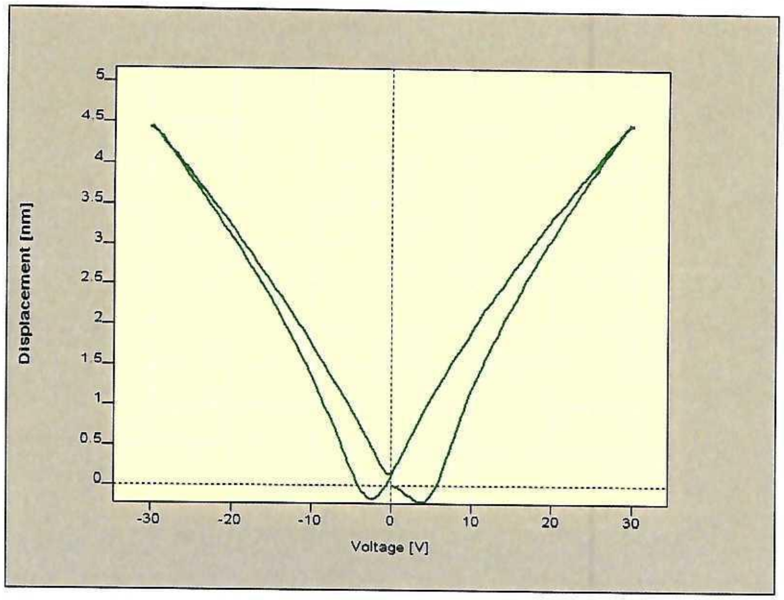


Fig. 10.9: Large signal displacement (butterfly loop) of a PZT thin film.

10.4. Measurements

The most common measurements done with laser interferometers are the characterization of the electrically induced large signal strain S and the calculation of the piezoelectric small-signal coefficient d_{33}.

10.4.1. Large signal strain S

The large signal displacement D or strain S is calculated directly from the intensity variations in the center of the interference pattern. A varying electric field with an amplitude higher than the coercive voltage is applied to the sample and the thickness change is measured. Since no noise reduction hardware is used during this measurements, the strain signal has to be improved by averaging over many cycles of the electric field.

10.4.2. Small signal piezoelectric coefficient d_{33}

Utilizing Lock-In amplification in hard- or software, it is possible to boost the Signal-To-Noise ratio (SNR) significantly. In order to use these techniques it is necessary to have a nearly linear relation between applied electric field and thickness change of the sample. Therefore, these methods are limited to small-signal measurements, where only intrinsic effects contribute to the electromechanical sample strain.

To characterize the sample behavior for different defined sample states, two electric fields have to be used. The sample characterization itself is done by a high frequency field with a small amplitude (small-signal field). The state of the sample is changed by a bias field which is either varied stepwise or with a very low frequency. Both fields are superimposed and applied to

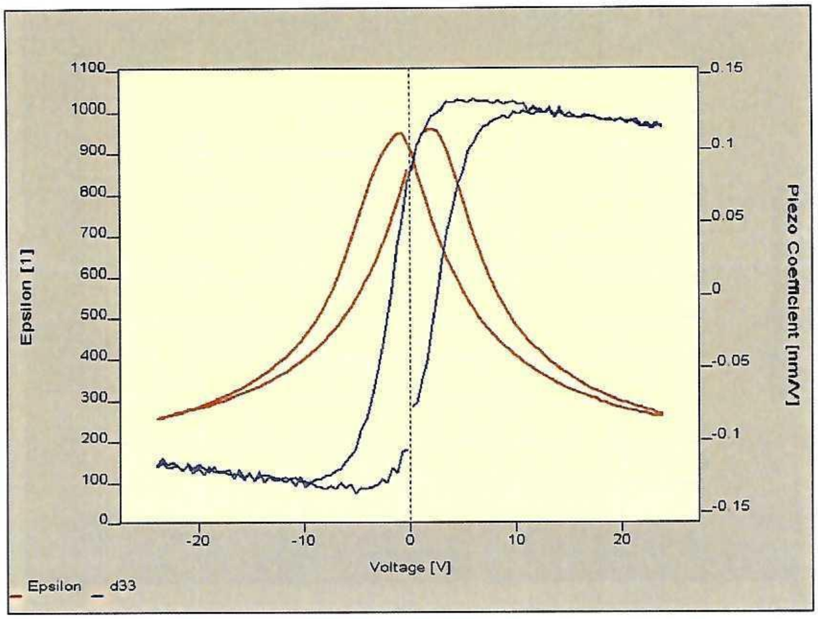


Fig. 10.10: Small signal dielectric and piezoelectric response of a PZT thin film.

the sample. The Lock-In amplification cancels out any effects arising from the bias field and only measures the small-signal response. By dividing the response by the amplitude of the small-signal field, the small-signal coefficient d_{33} is calculated.

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