Freiberg Instruments

Freiberg Instruments GmbH ☉Delfter Straße 6☉ 09599 Freiberg – Germany

Manual and documentation

MDPspot

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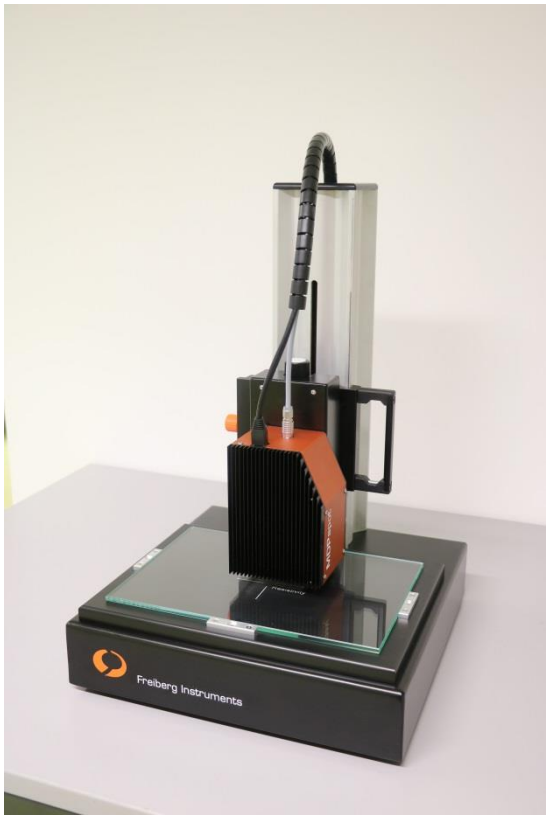

We work constantly at the advancement of all measuring systems.

Subject to alterations.

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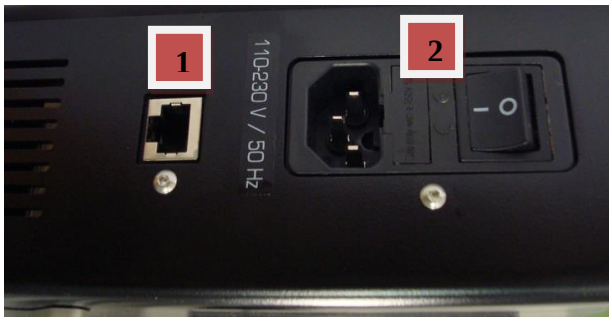
1. Introduction

Welcome as a MDPspot owner. The MDPspot is a tool for the contactless and destruction free electrical semiconductor characterization. It is intendet as a table top lifetime measurement system for characterisation of a variety of different silicon samples at different preparation stages.

In the next chapters a description of the theory of the measurement, an explanation how to install and operate the system and how to use the software can be found.

2. Quick Installation

1. Unpack and remove the MDPspot from the crates.
2. Check the crates contents and inspect if there is any damage observable. Report damage to shipper immediately.
3. Plug in the ethernet (1) to PC connection and the 110-230 V (2) cable in the rear of the tool as shown in the figure below



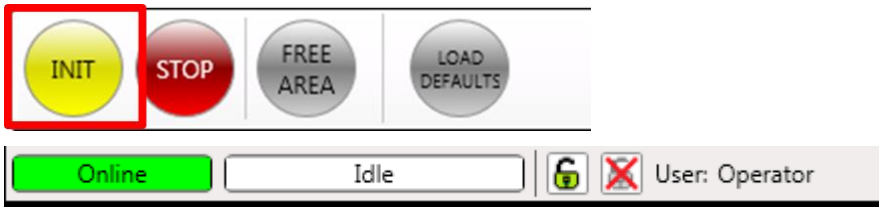
rear view

4. Connect the system via the ethernet cable with a computer (details on first software setup can be found in the software section)
5. Install the measurement software “MDPStudio”.
6. Start the measurement software “MDPStudio”
7. Turn the tool on (6)
8. Software connection status to the tool can be seen in the lower left corner

3. Quick Measurement

1) Turn the measurement system on and start the software (MDPStudio)

2) Press INIT and the status of the software should be green and display “online” after a few seconds



3) Place the sample underneath the measurement head and adjust the distance between measurement head and sample

The distance should be between 0.5 and 1.5 mm, otherwise the lasers are automatically switched off for safety reasons.

4) Adjust the measurement parameters or simply press “**Auto SteadyStateMDP**”, in this case the software chooses the best conditions.

5) Press either “**SHOT**” for a single measurement or “**CONT**” for continuous shooting

6) Press “**STOP**” and have a look at the resulting signal and readjust the parameters if n ecessary

4. Important Information

4.1 Declaration of Conformity

Machine Typ: **MDPspot**

Serial number: _____

The MDP laboratory equipment is conform to the European legal provision about the electromagnetic compatibility (2004/108/EG), the directive of the modification of CE marketing (93/68/EG), the EG machine directive (2006/42/EG) and the EG low tension directive (2006/95/EG).

For the evaluation of the manufacture about the compatibility the following European engineer standards were adducted:
DIN EN ISO 12100-1 and 2

The CE sign is arranged on the specification plate. Please attend on the obligatory national and local regulations!

Through a non-coordinated modification oft he equipment this declaration looses its validity.

_____

CEO Dr. Dornich

4.2 Target Audience

The manual is written for the operating personal of the MDP equipment.
The operators should have the essential professional competence for all work with the equipment.
The personal is obliged to read and completely understand the manual.
The documentation ought to be placed in reach of the equipment.

4.3 Intended Application

- The handler is in charge to only use the MDP equipment in the descript manner.
- The handling of the measuring equipment is only allowed subjected to the conditions named:
  - in this manual
  - on the specification plate
  - in the technical specification corresponding to the respective brief.
- The MDP equipment is used for contactless electrical characterization of semi-conductors. It is configurated for the measurement of certain materials.

4.4 Not intended Application

All applications notwithstanding the technical data on the specification plate or the terms named in the contract of delivery and the usage with missing or damaged safety installations is prohibited.

4.5 Safety Installations

The following arrangements serve the security of the operating personal:

- electrical access with grounding conductor and safety plug
- laser protection routines

Without any of these installations a usage of the equipment is forbidden.

4.6 Impact of the Warning Notices

Observe the warning notices! They are distinguished:

Warning notice:

5. Fundamental Advices

5.1 Preface

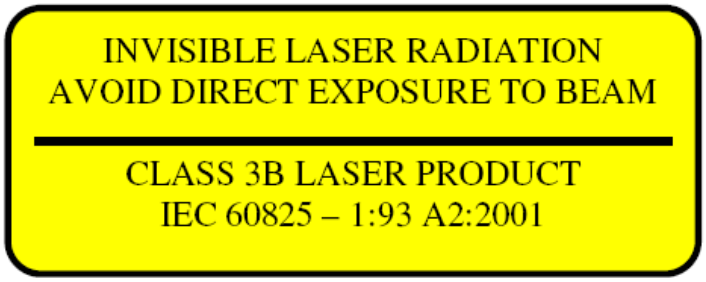
It's necessary to consider the warning notices. The defiance can lead to damage of healthy and property.

Service and repairing of the equipment is only allowed to skilled personal.

The removal of the whole equipment or single parts should be carried out by consideration of the local legal regulations.

5.2 Security Warnings

1. **Warning notice:** *Usage of (invisible) LASER radiation!* The radiation source is placed in the optical modules of the microwave cavities. Don't expose any body parts, e.g. eyes, arms, to the radiation! This will lead to irreversible damages. All works at this partition of the equipment should only be carried out by members of Freiberg Instruments.



2. **Warning notice:** *Usage of microwave radiation!* Don't open any SMA-connectors or microwave coaxial cable! Don't contact with or look into open ends of the microwave contributing system!

3. Specification of used LASER and microwave system are due to used equipment are arranged in following chapters.

5.3 Commissioning and Operating Method

The equipment is constructed for contactless and non-destructive electrical characterization of semiconducting materials.

Transport:
MDP systems are well prepared for transport. Open the cases carefully.

Commissioning occurs by:

1. Positioning the equipment on a horizontal area, in case of MDP ingot systems screw the support pillars down and secure the counternut
2. Connecting with the main supply
3. Switching-on the master controller
4. Starting the connected personal computer

Keep in mind to place the sample materials on the intended position.

Warning notice: Defiance can lead to mechanical damages of samples and equipment!

5.4 Control of the Operating Status

Keep an eye on the operating status! It is displayed on the monitor.

5.5 Decommissioning

Decommissioning occurs by:

1. Shutting down the computer
2. turn the tool off
3. Disconnecting from the main supply

5.6 Storage

Only store the equipment in closed dust-free rooms.
Temperature should lie between 5 and 40 °C, relative humidity not be higher than 80%.

Warning notice: Disconnect from the power supply when store the equipment for a longer period of time.

5.7 Electricity

The MDP equipment runs with 110-230 V DC. Internal low tension in the range of +/-5 to +/-48 V DC is used.

For the connection with the main supply a grounding conductor is necessary (DIN VDE 0100-410 (IEC 60364-4-41)).

Observe the local regulations! Electrical circuit points should be periodically checked (DIN EN 0105, DIN EN 0702, BGV A2).

5.8 Mechanics

Inappropriate operation can cause damage of property and injuries.

Use the equipment only for compulsory measuring!
External tensions and vibrations should not be applied to the equipment!
For a better cooling of the equipment don’t place any other hardware at intervals of 20 cm.

5.9 Hazardous Materials

An assignment of hazardous materials is not intended.

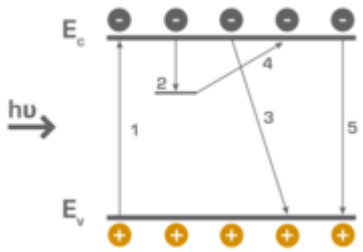
5.10 High Temperatures

The equipment can be warmed up by electrical lost heat. It's not allowed to excess a temperature of 40 °C!

6. Theory of the MDP measurement

The novel method MDP is well suited mapping of wafer or even ingots for inline metrology, because of its extraordinary sensitivity, resolution and speed.

The photoconductivity, which is closely related to the diffusion length is measured by microwave absorption during and after the excitation with a rectangular laser pulse. Figure 1 displays the measurement principle for MDP measurements and figure 2 course of the measured photoconductivity during the measurement.



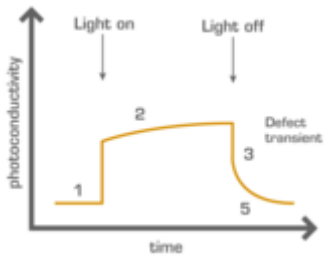


figure1: energy scheme of the measurement principle

figure2: exemplary signal

1. generation of free carriers
2. traps are filled with carriers
3. recombination of free carriers
4. thermal reemission of trapped carriers
5. temporally shifted recombination of reemitted carriers

The microwave spectrometers used work at about 10 GHz. They employ a resonant microwave cavity with the sample being electrically part of it. The sample is, however, geometrically outside of the measurement system to allow for scanning. The physical information is extracted from a time dependent measurement of the full complex dielectric constant of the sample.

The inline measurements take full advantage of the main features. This leads to inline maps of parameters at timescales which fit completely into the normal production processes.

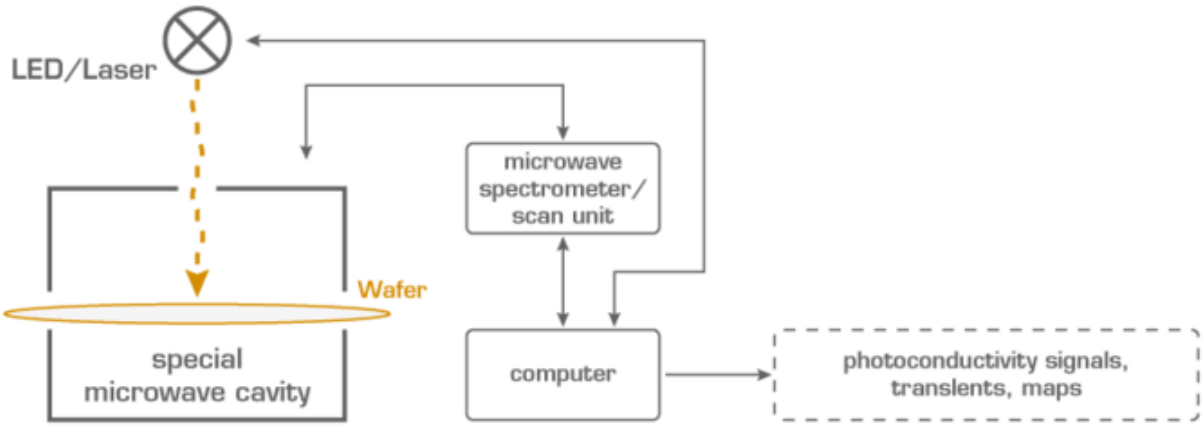


figure 3:setup for MDP measurements

When it comes to the measurement of raw wafers it has to be taken into account, that not the actual bulk lifetime, but the effective lifetime, which consists of the surface and the bulk recombination, is measured. The following simplified equation shows the relationship between bulk lifetime τ_{bulk}, diffusion coefficient D_n and wafer thickness W for as-grown silicon wafers.

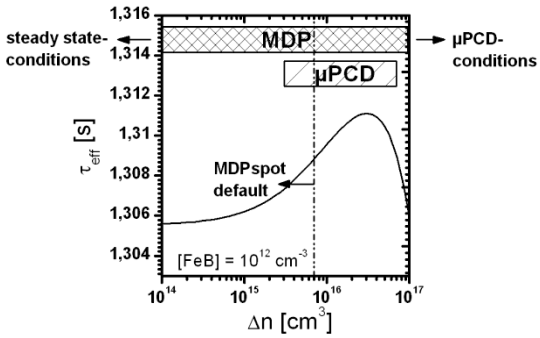
$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_{bulk}} + D_n \left(\frac{\pi}{W} \right)^2$$

Therefore the measured lifetime of an as-grown wafer with a thickness of 200 µm is limited to approximately 1.5 µs. However if the bulk lifetime is very small, it will dominate the effective lifetime, so that a low quality can be recognized.

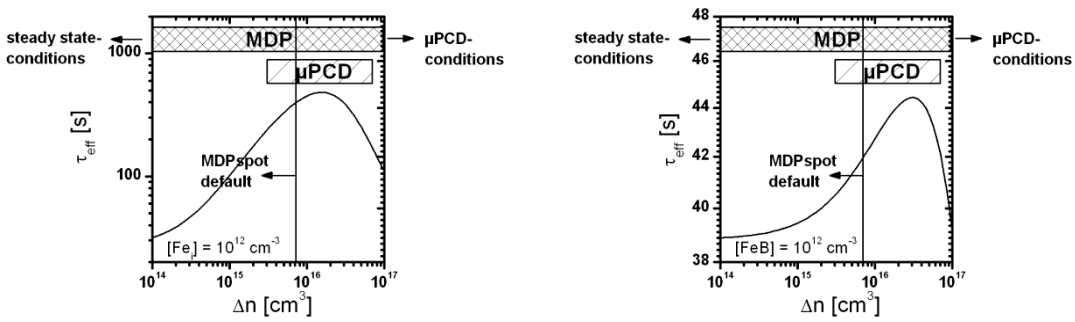
For further information have a look on our website:
www.FreibergInstruments.com
There you can find more detailed information about the measurement principle and case studies. Also a list of relevant literature is contained.

6.1 Injection level dependency

There is a strong physical dependency of minority carrier lifetime on injection which can be described by trapping, shockly read hall recombination or auger recombination depending on material and injection. Due to the high sensitivity the injection level of MDP can be choosen over a very wide injection range. Systems with one laser can cover a range of about 1,5 orders of magnitude in injection, due to technical limits. For a higher dynamic range laser arrays have to be used. It is desireable to measure at injection rates close to the operation conditions of the final device which is around 10^{14} cm^{-3} for final solar cells. Since there are different recombination centers and defects active as at much higher injection rates. To find a compromise there, the injection of MDP SPOT is choosen to have a upper limit right in the middle of established injection range of µ PCD measurement tools. Going down towards technological desireable low injection range.



(a) dependency lifetime on injection not passivated sample



(b) dependency lifetime on injection passivated samples

figure4: measurable injection range with MDPSpot for not passivated (a) and passivated samples (b)

7. MDPspot

7.1 Features and applications

The MDPspot tool is used for quality assurance of semiconducting material, especially silicon.

The main features of this tool are:

- bench top based single spot measurement
- allows for single wafer control
- single spot measurement of minority carrier lifetime
- resistivity (option)
- advanced sensitivity for visualization of defects and impurities

The major applications of this state-of the art tool are:

- incoming and outgoing wafer inspection
- monitoring wafers after each step of production line
- material classification
- monitoring and recognition of crystal defects
- monitoring passivation homogeneity

7.2 Specifications

Laser:

Wavelength [nm]	Power [mW]	Class	DIN
978 nm	200 (cw)	3B	DIN EN 60 825-1:2001-11
660 nm	100 (cw)	3B	DIN EN 60 825-1:2001-11
405 nm	200 (cw)	3B	DIN EN 60 825-1:2001-11

Microwave:

Frequency [GHz]	Power [mW]
x-band, 9-10	max. 500

Materials: Si, compound semiconductors, epi layers

Resistivity range: 0.1…10^3Ωcm

Conduction type: p,n

Sample thickness: 100 µm … 156 mm

Meas. spot diam.: 1 mm (default)

7.3 Repeatability

Note that the repeatability of lifetime measurements is restricted due to the dissociation of FeB and the forming of BO_2-complexes during the irradiation with the laser light. If the mode "continuous shooting" is chosen, these effects can lead to an increased or decreased lifetime.

Figure 5 demonstrates this effect at an as-grown mc-Si sample. After several single shots the lifetime increases due to the FeB dissociation. Figure 6 shows a similar effect at a passivated mc-Si sample. The measurements were conducted at two consecutive days.

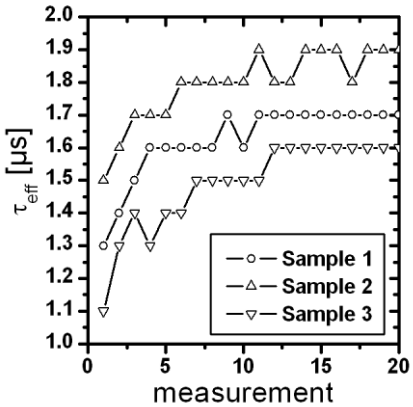


figure5: repeatabilility test at three as-grown Si samples

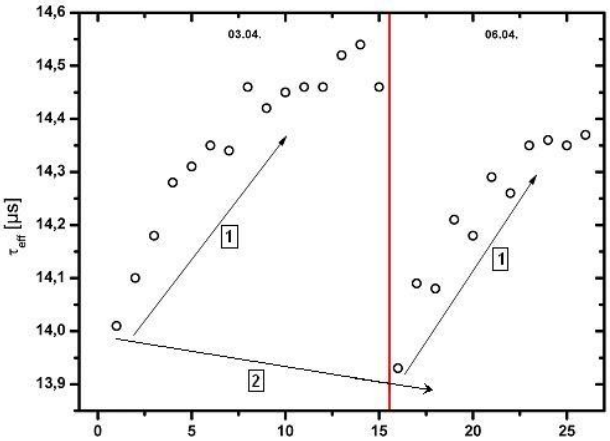


figure6: exemplary repeatability test of the minority carrier lifetime of a passivated mc-Si sample doped with B, the measurements were repeated 26 times at two different days (indicated by the red line);
1 - FeB pair dissociation; 2 – BO_n-complex association

8. Software

8.1 Installation and Connecting the Measurement System

Case 1: Installation within a network
Ethernet interface supports 100 MBit full duplex
UDP Port 7216 and 7217, has to be opened in firewalls/routers

Case 2: Installation with separate direct ethernet connection (gateway)

A standard patch cable can be used. The tool has an automated routine to identifiy if case 1 or 2 is valid. An unique IP-Adresse is needed for the tool.

Static IP adress is required and has to be assigned to the MDP SPOT.

Example:	IP tool:	192.168.75.2
	IP PC:	192.168.75.1
	netmask:	255.255.255.0.

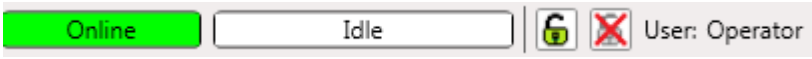
1. install the Software MDPStudio by starting the setup and following the instructions as given in the section 5 of this manual
2. start the MDPmap equipment
3. for the first installation open the folder: “C:\Program Files\Freiberg Instruments\MDPStudio” and open the settings.xml file
4. type in the IP address of your tool and set coordinates to polar
5. copy the colorscales and geometries in the respective folders in the MDPStudio folder
6. further installations of newer versions won’t change these files

8.2 Operator menu

To ensure an easy handling of the equipment by differently skilled users, we use a command structure.

Operators have only access to a simplified menu where they can load recipes, start and monitore measurements and examine the results. For the measurements the **operator** has to use a recipe defined by the engineers. Engineers have full access to every menu and influence on the measurement conditions. Read more about in the next chapters.

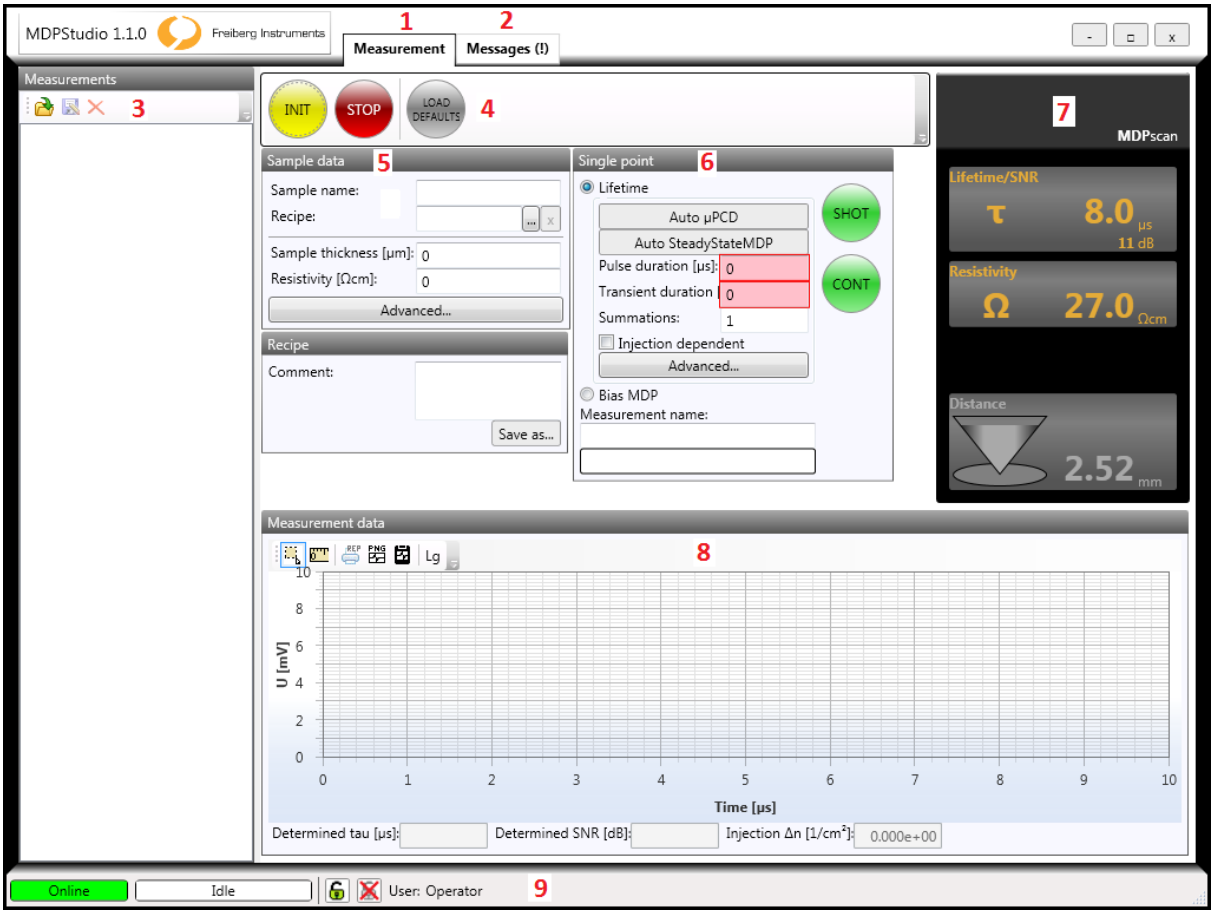
The user can be changed by clicking on the lock symbol in the status bar.



"**Engineer**" generates access to the whole user interface. The password is "engineer". After the first login, the passwort should be changed.

Engineers should set the measurement parameters and define them as default and than restrict the full access by a logging in as "**operator**".Measurement settings

8.3 Menu Structure – Overview



1 tab “Measurement” with all important software functions

2 tab “Messages”, where error messages are displayed

3 Measurement window with overview over all performed measurements

4 control bar

5 “sample data” window, where all important properties can be put in by the user

6 “single point” window, for single point measurements

7 display of the measured lifetime, resistivity and measurement distance

8 display of measured signal and lifetime result

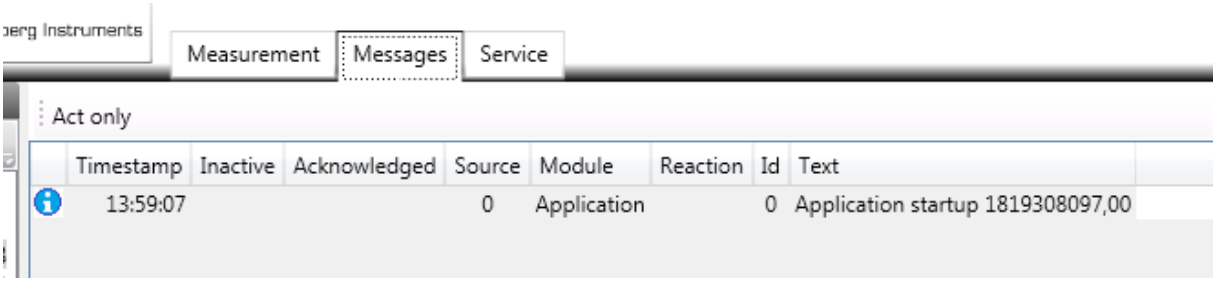
9 status bar

8.4 Description of Software functions

. Measurement tab

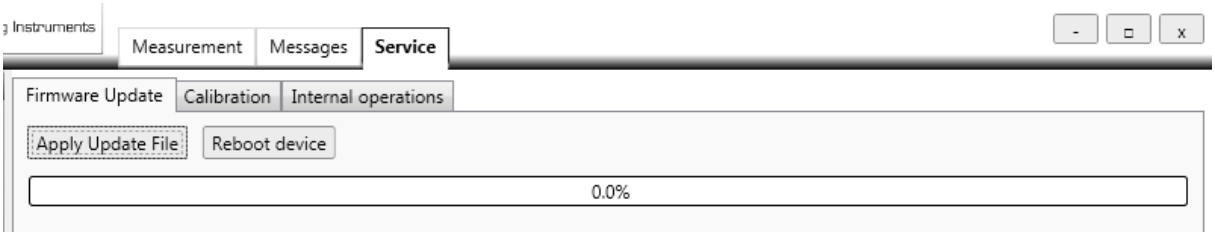
All important functions for the user are located in the measurement tab. They are described in the following sections.

2. Messages tab



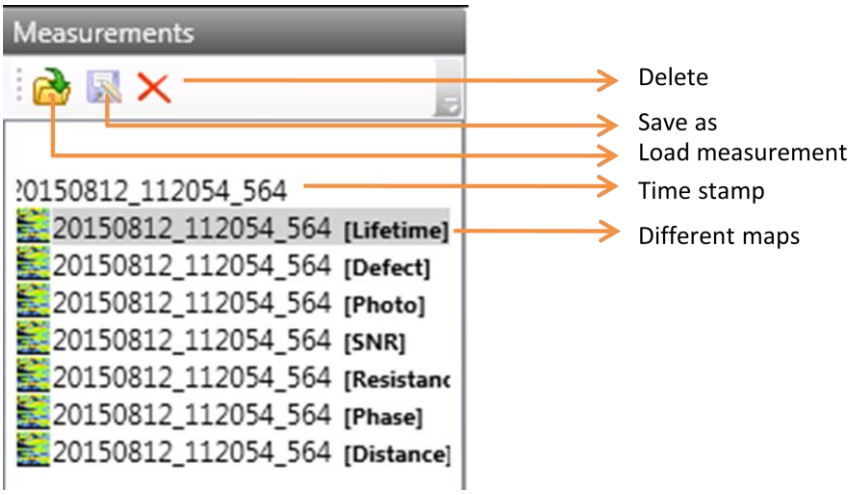
In this tab the error messages and information are displayed.

3. Service tab



In the service tab it is possible to calibrate the laser power, resistivity and distance. All these calibrations should only be performed by skilled personal. Please ask an employer of Freiberg Instrumets for support.

4. Measurement window

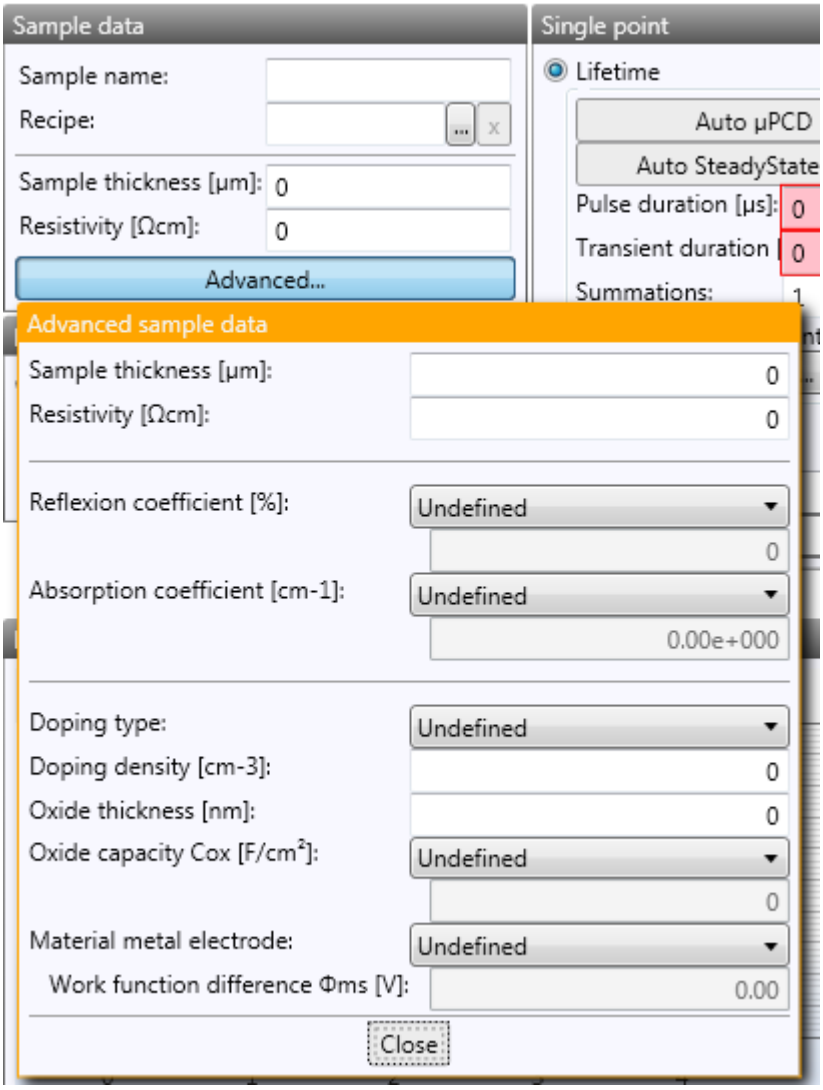


In the measurement window all measurements that were performed during the session are displayed and sorted by the timestamp. For each sample all maps and single point measurements are listed and can be displayed by clicking on them. It is possible to load old measurements, also in the offline modus, delete measurements and save them as xml files. By rightclicking on a measurement a menu appears with different evaluation options as the evaluation of the surface recombination velocity at passivated wafers. These options will be explained in next sections. Furthermore it is possible to save the measurements as csv files by rightclicking on a measurement and choosing “export”.

5. control bar

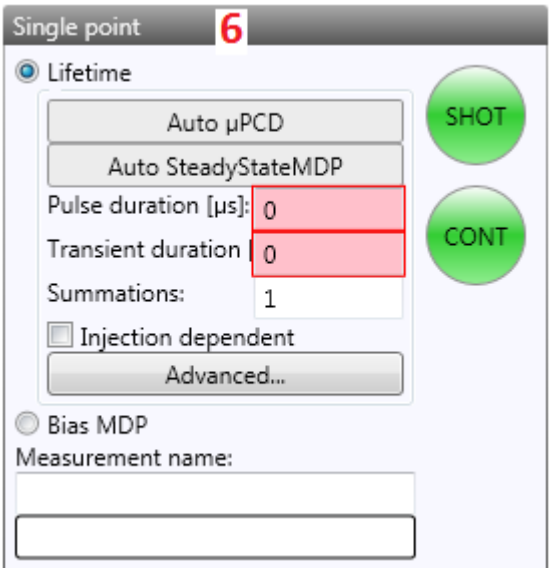
In the control bar 3 different buttons are available. With the **INIT**-Button the system will be initialized. This is usually done directly after the system is switched on. By clicking the **STOP**-Button the system immediately stops all activities followed by an initialization of the motion axes. This will take a few moments. With the **LOAD DEFAULTS** button the default recipe is loaded and all parameters are set back to their default value.

6. sample data window

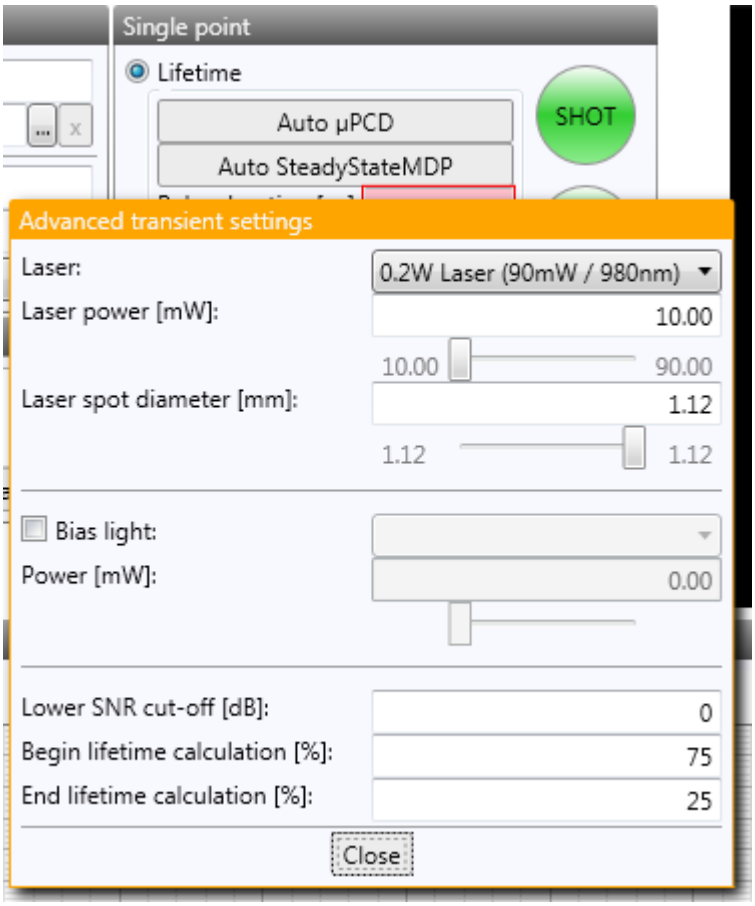


In the “sample data” window the user can put in a **sample name** Furthermore the **sample thickness** and **resistivity** can be given by the user. By clicking on “**Advanced**” an additional window with “**advanced sample data**” opens. Here the user can put in the surface treatment of the sample to estimate a **reflection coefficient** and choose an **absorption coefficient** for the injection determination. For BiasMDP measurements it is also necessary to put in the **doping type** of the sample, **oxide thickness**, **oxide capacity**, the **material of the metal electrode**, the **doping density** and the **work function difference** of the electrode metal.

7. single point window



If a single measurement at a certain location of the sample should be measured, the parameters have to be set in the single point window. It is always useful to do a single point measurement before measuring a complete map to adjust all parameters. First of all, the measurement method has to be choosen (**Lifetime**, **LBIC** or **BiasMDP**). For Lifetime measurements the software can generate appropriate pulse and transient length and summation automatically, if the buttons "**Auto µPCD**" or "**Auto steadystate MDP**" are clicked. Otherwise the user can put in the **pulse** and **transient duration** in µs along with the **summations**. By clicking on "**Advanced**" an additional window opens.



Here the **laser** and the **laser power in mW** have to be set by the user. It is also possible to activate a bias light. The measurement distance should be set to 0.5 to 1 mm, but if the sample is very cragged and bumpy, it maybe necessary to increase the measurement distance. Note that for LBIC and BiasMDP measurements the distance has to be set to 2 to 2.5 mm, because of the golden springs, that are used for the contacting.

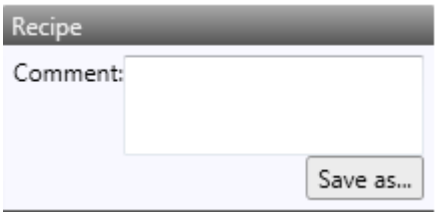
The **lower SNR cut off** can be used to filter very low signals, where no useful lifetime determination is possible. It is recommended to set the lower SNR cut off to 20.

The parameters "**Begin lifetime calculation**" and "**End lifetime calculation**" set the part of the transient that is used to evaluate the lifetime with linear regression. The default values are 75 % and 25 % respectively.

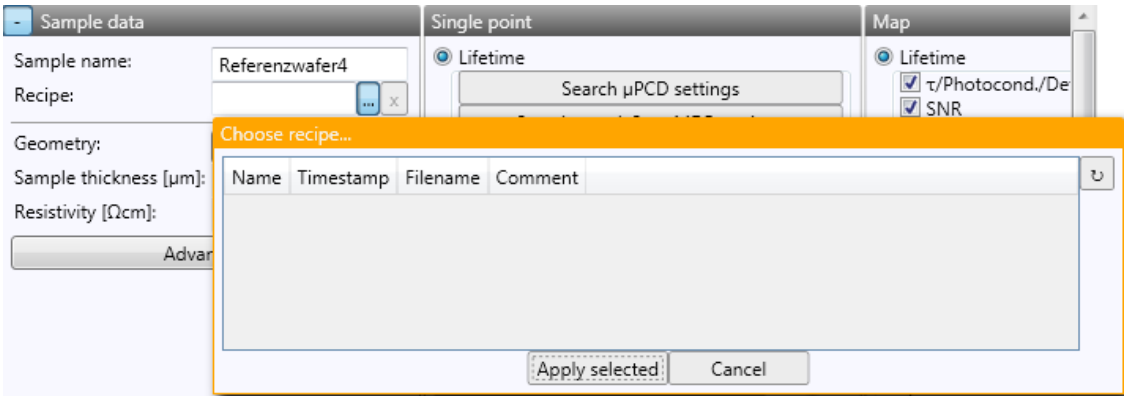
All these parameters have to be set for all three methods (Lifetime, LBIC and BiasMDP).

For Lifetime measurements, there is also the option "**injection dependent**". This option can be activated via the check box next to it. The user has to set the sample points and click the "**Start**"-button. The laser power of the laser, which is choosen in the "**Advanced transient settings**" menu, is now varied from its minimum to maximum with the set sample points number and a graph and chart is generated. It is recommended to use a large spot and bias light for a more accurate injection result.

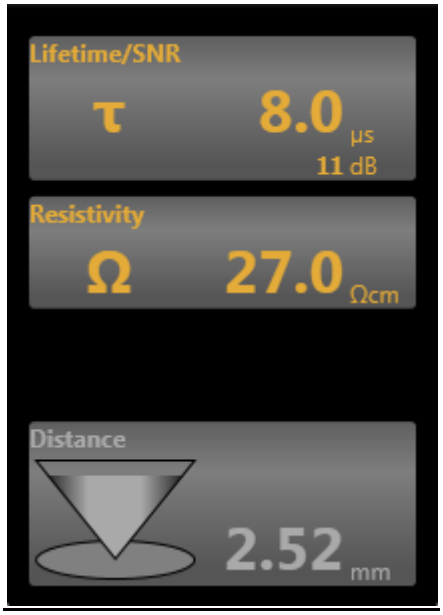
8. Recipe window



It is possible to save all measurement parameters in a recipe that can be loaded again in the sample data window.

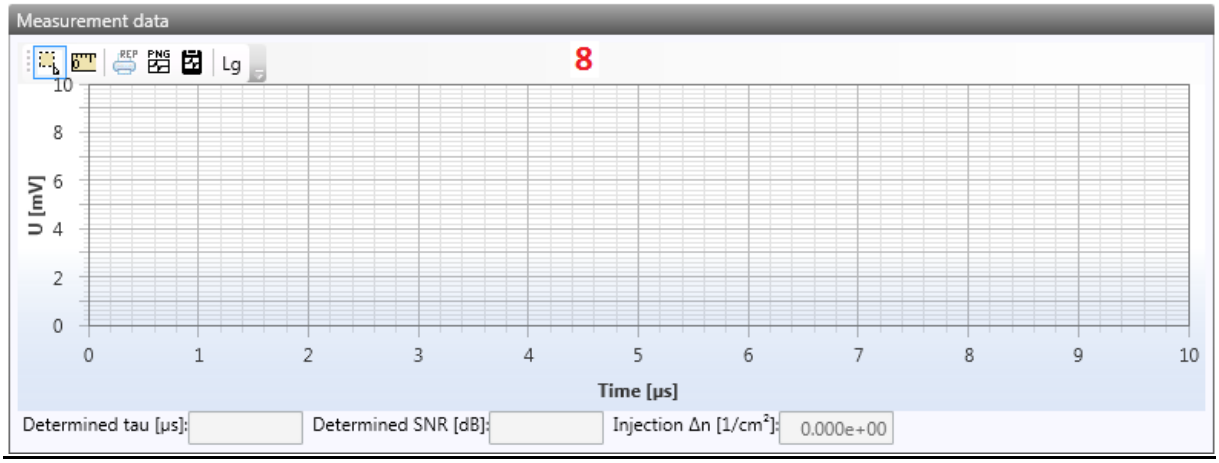


9. result and distance display



In this window an overview over the lifetime and resistivity measurement results are given. Furthermore the distance between measurement head and sample is depicted. It turns green, if the distance is between 0.5 and 1.5 mm and only then the laser can be turned on.

10. Measurement results



With this symbol it is possible to zoom into a certain area of the map.

If the user wants to determine the distance between two points in the map, he has to choose .

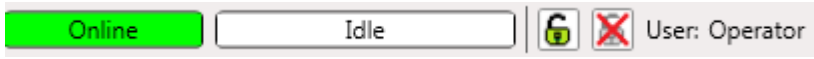
With a complete measurement repot with map and statistical values together with the measurement parameters can be printed as pdf.

To save a map or single point measurement as png-file the user has to press .

To save a map or single point measurement in the clipboard in order to e.g. simply paste it in a word document the user has to press .

The user can choose between Auto or standard color bar.Of course it is also possible to change the color bar setting by double clicking on the color bar.

11. status bar



In the status bar the status of the system can be monitored. When operating the system the status should be "**online**". If the system is "**Idle**" it is ready for the next measurement, otherwise this status displayes, what the system is doing at the moment e.g. scanarea. As describe above the user has to log in as **operator** or **engineer** via clicking on the lock in the status bar.

9. Service and Repair

9.1 Service

Regular maintenances of the equipment are not essential, but we suggest an annual service by the manufacturer to check all system settings and the operating ability of the construction. A vision control of the whole system is recommended every six month.
Electrical wiring should be controlled by accreted firms in the local mandatory intervals.
Try to avoid the equipment from heat, dirt and other environmental influences. This will elongate the lifetime of the equipment.

9.2 Troubleshooting

1. Control power plug!
2. Control Ethernet-connection between equipment and computer!
3. Check the operating switch!
4. Keep an eye on the SNR!
5. Restart the personal computer!
6. Contact the manufacturer!

9.3 Repair

We recommend all repairs to be done by members of Freiberg Instruments. Otherwise the operational reliability is not secured!

9.4 Spare Parts

Spare parts:
A list of spare parts can be achieved under:
service@FreibergInstruments.com