Probestation Manual

1) Introduction

This document provides you with some basic information about the probe-station in our lab. Before working with the probestation, study the contents of this manual. This knowledge is important to avoid systematic errors in measurements or damage to your device our the measurement setup.

2) General concepts and components

In order to understand how cables are used in the setup it is important to understand “Guarding” and “Shielding” and the difference between co-axial and tri-axial cables. Finally also personal high voltage protection and interlock will be discussed.

Shielding: Co-axial cables have a centre conductor that contains the signal. The outer conductor is called the “Shield”. The shield is connected to the ground of the laboratory. In our case that is the ground of the power-line system. Any powerplug has the to high voltage pin but also a third pin that contains the ground. By definition the ground is at voltage 0. Any electronic circuit that is independent and has in no parts a direct connection to g round is called floating, meaning that within the circuit voltage differences are well defined, however, the absolute values of voltages with reference to ground are unknown, meaning that they could be 10V, 50V or whatever value. This value would have no impact on the functionality of the circuit, but could potentially be a hazard for the operator. Therefore the shield has two different important functions: (i) protect the operator from voltage hazards, (ii) work as a faradaic cage that “shield” electromagnetic AC fields which would introduce noise (50 Hz) into the signal.

Guarding: Tri-axial cables have an inner conductor (the signal), an outer conductor (the shield) and also the second conducting layer between the signal and the shield called the guard. The source measure unit takes care that the guard is always at the same voltage level as the signal (with a so-called buffer circuit). Therefore the guard can be at high voltages. The reason to employ guarding is the need to reduce capacitive currents and cable leakage when measuring small signals (< 1nA). As the signal core and the guard shell are always at the same potential, there is no leakage or capacitive current from the signal. Of course between guard and shield there will be a large potential difference, but the guard is powered by a buffer circuit and does not impact on the signal measurements. **Clearly if accidentally the guard gets connected to the shield, a hugh voltage current will arise, that is not measured by the instrument and that would damage the instrument.** In the probestation setup, triaxial cables are used to connect the HI-port from the Source Measure Unit (that is where potential is actually applied) to the device under test (the probes). The LO-Port (at 0 V) are connected to coaxial cables.

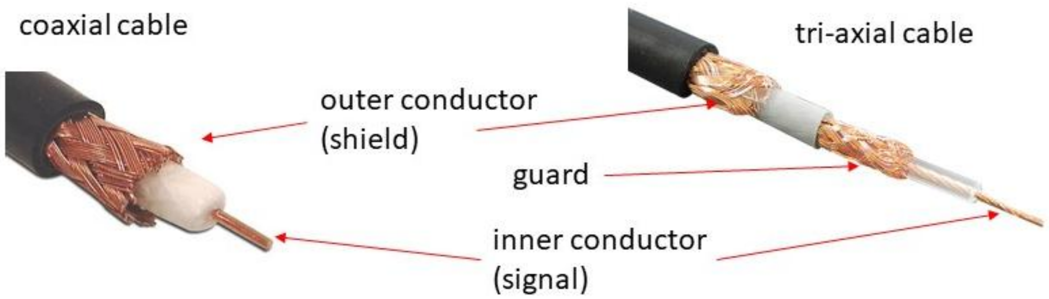

Fig.1: Coaxial and Triaxial cables

High voltage hazards: Direct contact with conductors at potentials higher 25 V or currents > 100 mA represents a serious health risk. In coaxial or triaxial cables the signal, that presents a potential health risk is on the inner conductor and thus shielded. Cables and metallic BNC connectors can be touched without risk. In places were the signal conductor is exposed (probe-station, connections to devices), a metallic encasement working as a Faradaic cage to shield noise and to mitigate voltage hazards has to be used. An Interlock circuit probes if the encasement / the faradaic cage is properly closed. The interlock circuit is connected via the Digout-Connector to the Source Measure Unit. In case of an open door, potentials > 25 V cannot be applied and a warning appears.

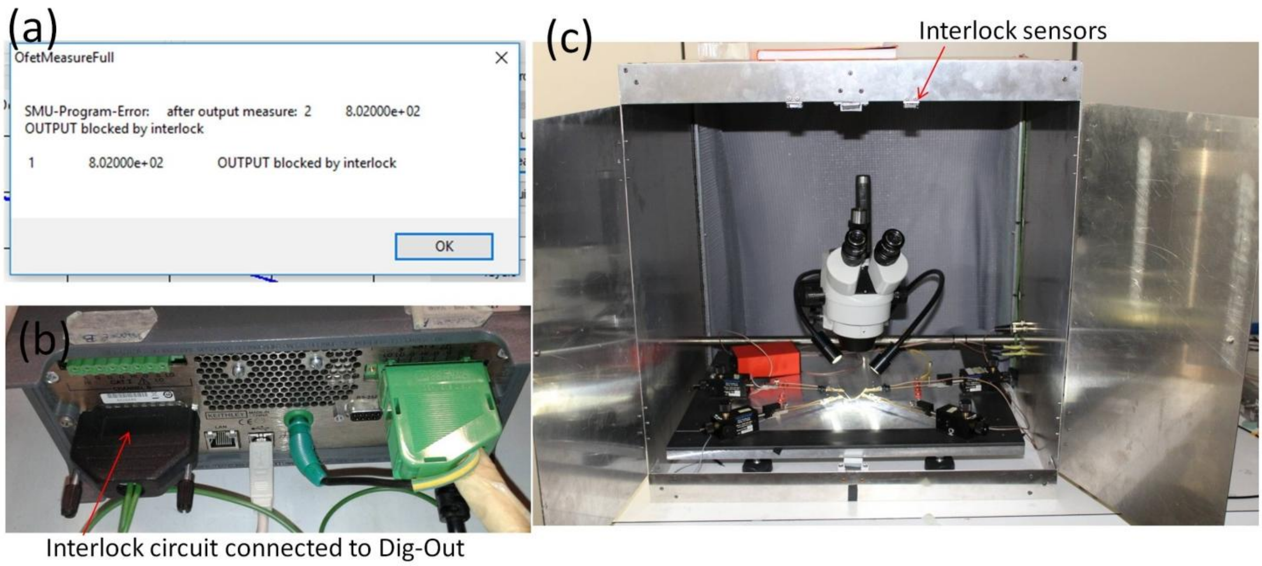

Fig.2: Interlock circuit: warning issued when doors of probestation are not properly closed. Back of Keithley Source Measure Unit showing the Interlock Circuit connected to the Digout Port. Encasement containing the probestation and microscope.

Micromanipulator probes: The micromanipulators containing the probes are fragile precision instruments and have to be handeled with care (Fig. 3a and b). They are attached to the table of the probestation with strong magnets. When placing the manipulators on the magnet one has to be careful as the magnetic force is strong! Tilt the micromanipulator before approaching the magnet as shown in Fig.1c. Positioning is achieved with three screws on the back of the manipulator. Do not apply strong forces. The movement range is limited. If one goes beyond this range one risks to damage the manipulation mechanism. After use restore the probe into the central position. Never touch the tip of the manipulator with bare hands. The tips are sharp fragile needles. If they hit a surface or an object in uncontrolled manner the tip will get deformed and it will become more difficult to contact with micrometer precision.

One has to distinguish two kinds of probes according to their electrical connections (Fig. 3b). The ones labelled S1 or S2 are connected with normal coaxial cables and they do not contain a guard shielding. They should be connected to the Lo when using triaxial cables. Manipulators labelled D or G are connected to triaxial connectors. In the probestation the cable is however co-axial, but it contains no shield! The inner connector is the signal, the outer connector the guard. When for some reason one would like to connect a coaxial cable one needs a coax-triax adapter that mates the guard with the shield (Fig.3d) . This kind of adapter is kept on top of the probestation. Never use this adapter for other purposes – high voltage hazard! After using the probestation position the micromanipulators in the central position, that all four tips are in the optical field of the microscope.

In case of problems with the micromanipulators, you can ask Alberto Costa from the mechanical workshop next door. For experienced users only: in case of a loose screw you can use the hex-keys in the AFM room to tighten it.

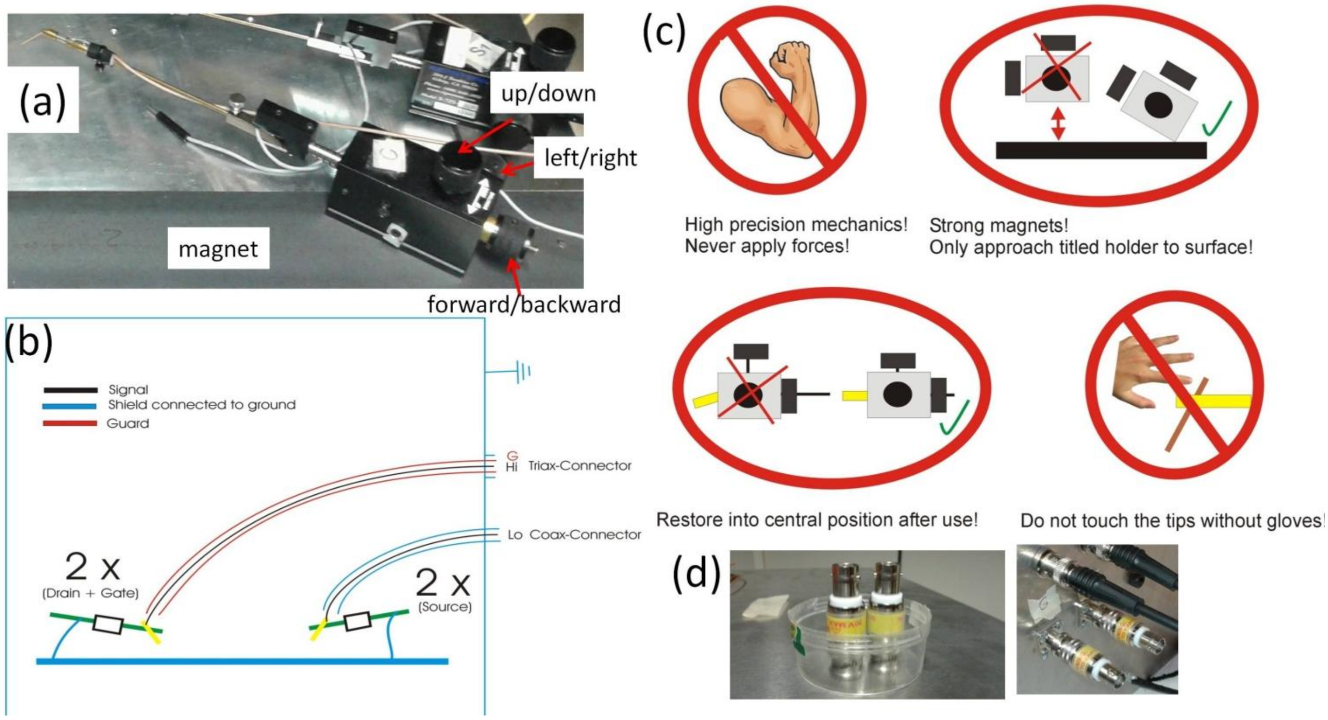

Fig.3: Micromanipulators: (a) Picture from inside the probestation (b) To kinds of electrical connections have to be distinguished. (c) how to handle micromanipulators. (d) adapter to connect triaxial connector from D or G manipulator to coaxial cable.

Source Measure Unit: The probestation is connected by default to a Keithley B2614B source measure unit. Other instruments that could be used are for example a Keysight B2912 source measure unit (has a 10 nA range, faster sampling options) or a electrometer Keithley 6517 (2 nA range, 500 V, only one channel). The Keithley B2614B SMU has two independent channels. Channel 1 on the left and channel 2 on the right. It employs green plastic adapters to connect cables to the back of the SMU that contain HI, LO, Guard, HISENSE, LOSENSE. Three different configurations are present for (i) triaxial cable connections (ii) coaxial cable connections and (iii) Four Point Probe measurements. When attaching the green plug to the instrument take care that the orientation is correct! On the back the instrument shows also the USB port and the interlock port (see above). Of relevance is further the green female banana plug for ground connections. This plug plug offers a ground that is low-pass filtered. On the normal powerline ground high frequency signals are typically present and increase noise in measurements, therefore it is suggested to use this as ground in electrical measurements. Use the male banaplug that exits from the channel connector cables to connect the LO to ground. In this way the measurement circuit is not floating but connected to ground.

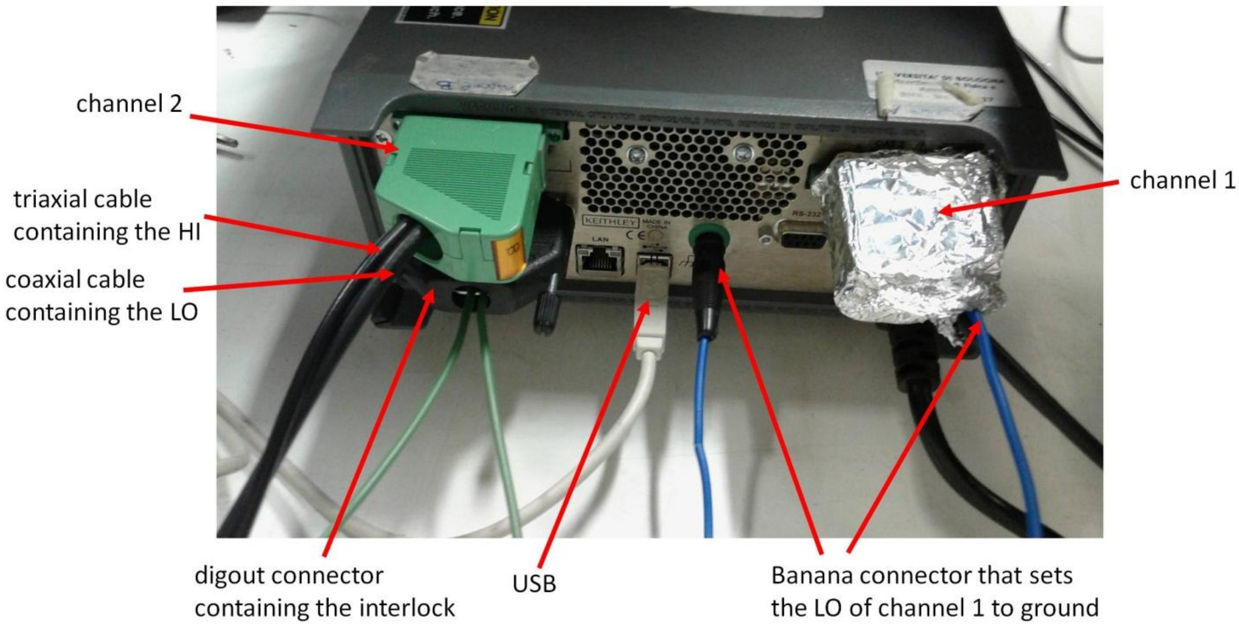

Fig. 4: Source Measure Unit connections

Optical Microscope/Illumination: Switch on the illumination using the switch close to the powerplug below the table (Fig.5 a). In this way the powerline connection into the probestation is interrupted and the noise is reduced when measuring.

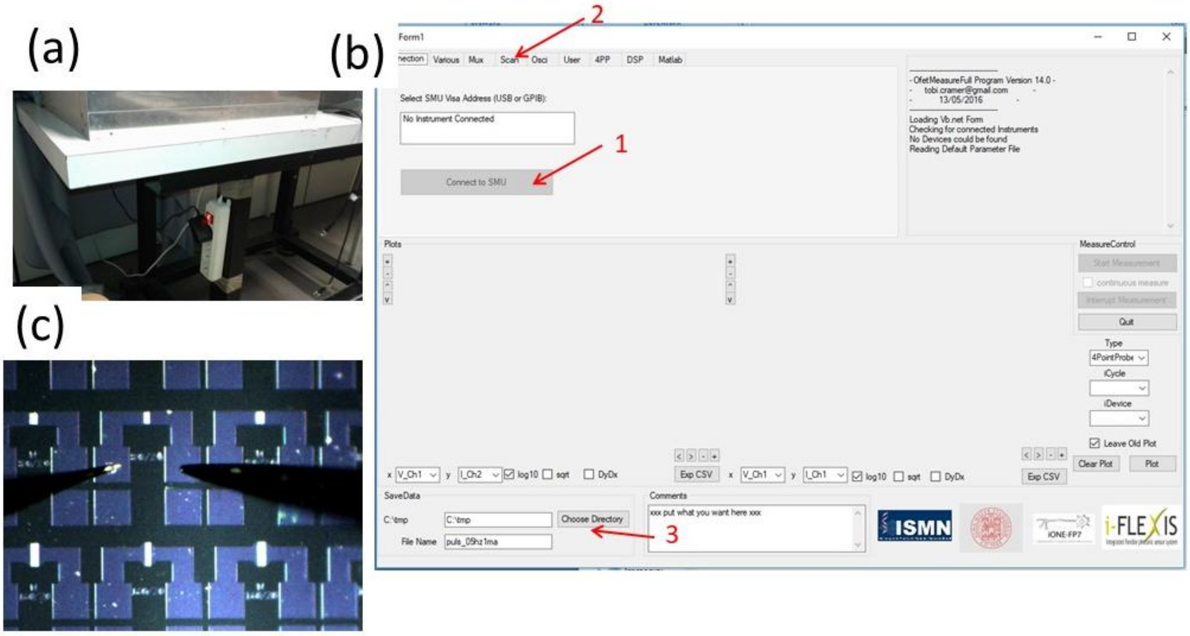

Fig.5: (a) Switch to control light. (b) SMUCS measurement software. (c) Needles of micromanipulator in contact with TFT

Software: The source measure units can be controlled manually or by software. A labview program that can do this for the Keithley 2614B unit as well as the Keysight 2912B unit is the SMUCS program written in Visual Basic. You can find the executable on the network drive: FisicaSemiconduttoriOrganici/Software/Smucs. The executable should run on all windows computers, but needs the agilent io 16.3 library and English decimal separator setup. For instructions see files stored in the Smucs folder. At time of writing the most updated version is Smucs15h. When using Smucs on the table top computer next to the probestation all should work fine. After opening the program click Connect (field 1) to connect to the source measure unit. After that one can set the directory where data is saved (field 3). In the tab one can set the kind of measurement to perform.

Micromanipulator needles/tips: Different needles are in use. Typically we have tungsten needles (grey) or brass needles (golden). You can find the needles in the cupboard on the right, next to the entrance door. In order to make contacts to fragile structures gold wires are attached to the tips. A pair of tips with gold wires is in the cupboard, too. Don’t remove the wires and handel them carefully. After use of special probe needles please mount the default ones (brass). Use gloves when touching /working with the needles!

3) Measurements

Normal characterizations: This is the standard configuration of the probe station. Manipulators are used to connect to a device. One or two channel measurements (transistors) can be performed. Triaxial cables are used to connect D and G manipulators. G is connected to channel 1 and D is connected to channel2. The S1 manipulator is connected to the LO of both channels. (Fig. 6a)

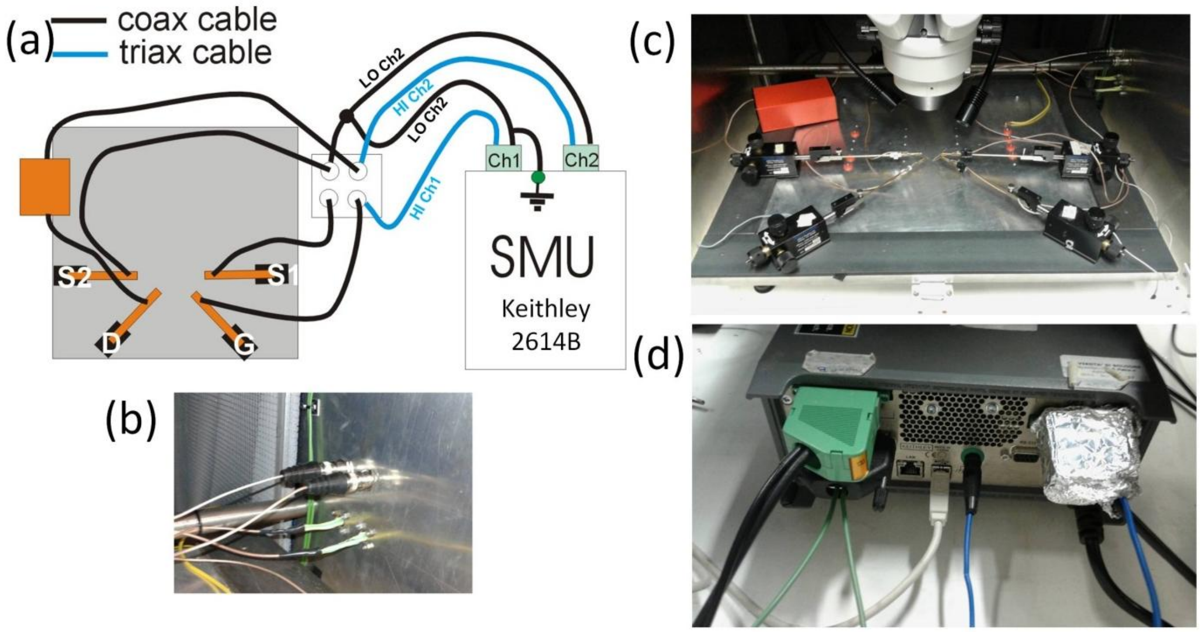

Figure 6: Connections for normal measurements (default): (a) connections involving triaxial cables (b) the connectors in the Faradaic cage (c) the probes in default position (d) connectors to the SMU

Four Point Probe Measurements: All four manipulators are connected to coaxial cab les. The green connector that contains HI, LO, HI SENSE and LO SENSE BNC connectors is used to connect the SMU to the four micromanipulators. (Fig. 7a). Triaxial to Coaxial adapter that connect the guard to shield are used on the outside of the probestation (Fig. 7b). Fig.7c shows a typical Van-Der-Pauw configuration for sheet resistance measurements. See Wikipedia for details. The SMUCS software has the Four-Point-Probe measurement implemented (4PP – see Fig. 7d). The picture shows an example in which a copper sheet is measured. HI and LO and HI Sense and Lo Sense are connected to corners of the rectangle. Care has to be taken to put them in the correct configuration. From the IV characteristics shown in Fig. 7d a resistance R=114μV/1A=114e-6 Ω is obtained. The sheet resistance then follows according to van der Pauw as $R_s=\pi*R/\ln 2=516\ \mu\Omega=0.5\mathrm{m}\Omega$. Knowing the specific resistance of copper a layer thickness of $d = \rho/R_s=1.68\mathrm{e}{-8}\ \Omega\mathrm{m} / 0.5\mathrm{e}{-3}\Omega=34\ \mu\mathrm{m}$. The measured copper piece has a nominal thickness of 35 μm, confirming the validity of the measurement.

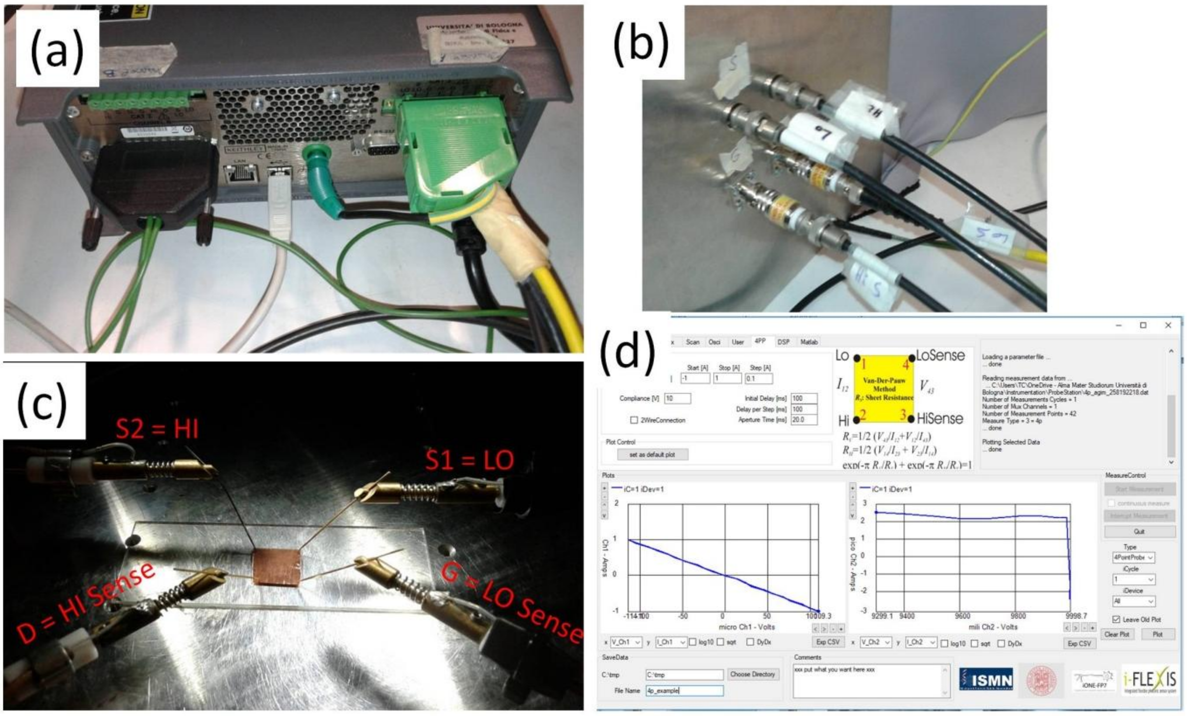

Figure 7: Four Point Probe Measurements: (a) Connectors on the back of the Source Measure Unit (b) 4 coaxial cables connected to the probe station (c) van der Pauw configuration (d) software

Measurements without micromanipulators: It is not suggested to use the probestation for measurements that do not employ micromanipulators but clamps to connect the device under test. For such a situation it is preferred to use the smaller Faradaic cage that is used for the electrochemical measurements. However, Figure 8a shows how to connect cables with clamps inside the probe station. To do so, one must remove first the three micromanipulators that are attached to BNC connectors (and not by soldering as the G manipulator). Position the manipulators on top of the Faradaic cage and take care that the tips are not touching anything (Fig.8b). Move the remaining micromanipulator D towards the back of the Faradaic cage to avoid damage. Connections can then be made to the S1, S2 and D ports with coaxial cables that end with clamps (Fig. 8c). Please note that the BNC connector of the D micromanipulator is protected inside an orange plastic box. This box is necessary as under normal measurement conditions, the outer conductor of the BNC cable is the guard, hence voltage protection in the form of a plastic box is necessary. (Fig. 8d)

Four point probe measurements without micromanipulator are not possible in the Faradaic cage.

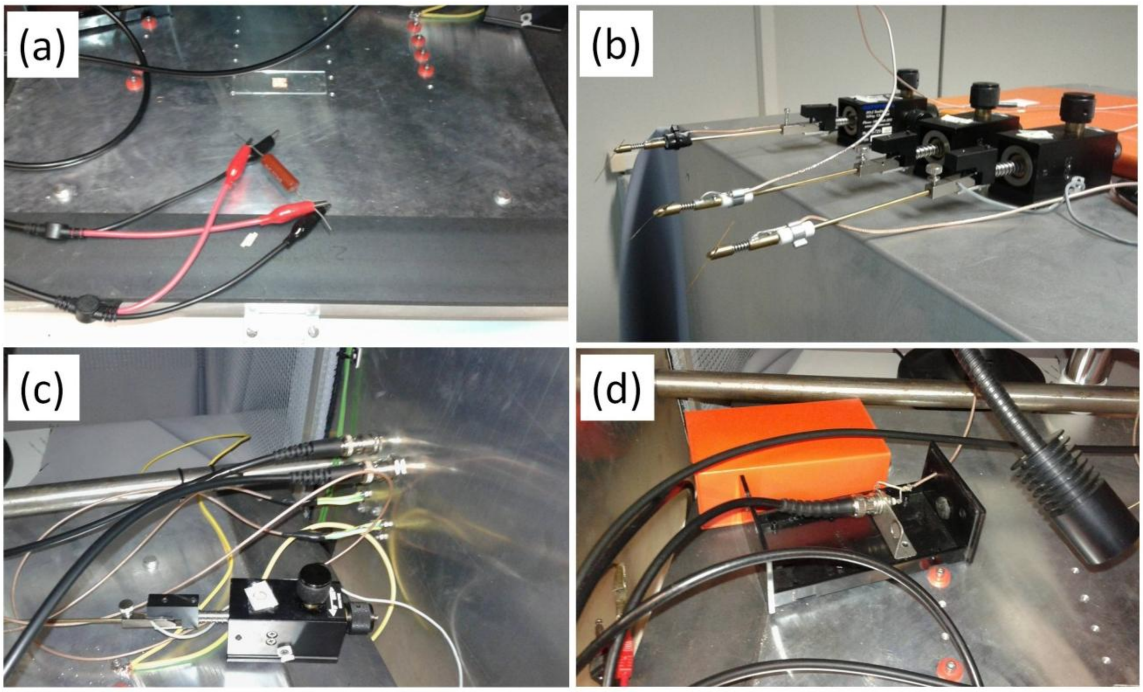

Figure 8: Using the probestation with clamps to connect a device under test. Micromanipulators are removed (b). For details see text.

4) Some specifications

To characterize the noise of the probe station the tips of the micromanipulators were not connected to a device but left on a typical central position. Figure 9 shows the obtained measurement results. Using triaxial cables and an aperture time of 20 ms to integrate over a powerline cicle, one obtains stable current measurements (Fig. 9a) that show noise of 120 fA rms (Fig.9b). The impact of power line noise (50 Hz) is visible when measuring with an aperture time of 1 ms (Fig 9c). The use of triaxial cables results in an improved shielding and a peak to peak oscillation amplitude of 20 pA is observed. Note that results were obtained in channel 2. Channel 1 typically shows larger fluctuations as it is closer to the powerline connection.

Fig. 9d shows the leakage that characterizes the system for channel 1 and channel 2. Note that this measurement has been obtained with large delays per step (10 sec !!) and large aperture time (200 ms –see Fig. 9e) to reduce capacitive current contributions and noise. In this way resistances of < 200V/6e-12A can be characterized.

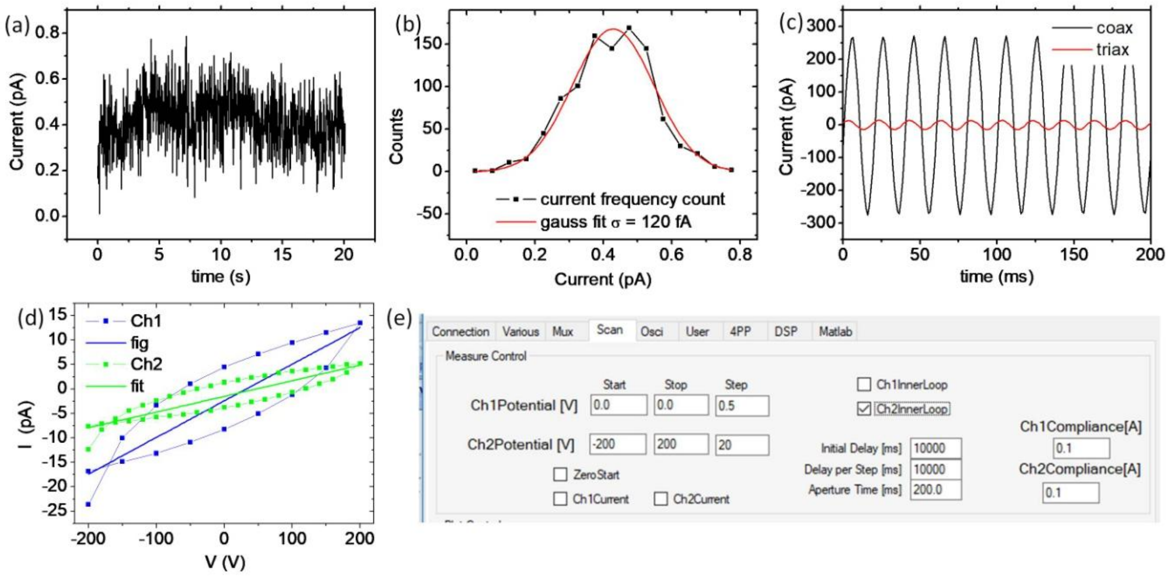

Figure 9: Some measurements showing the performance of the probestation setup.

4 Further reading

- Keithley User Manual
- parametric measurement handbook

Both books are in FisicaSemiconduttoriOrganici/Instrumentetion/Probestation