Tutorial for Test and Characterization using Cascade 11000B and Agilent B1500A

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Chapter 1: Introduction to different Instruments in the Test Lab

1.1 Air Compressor

Air compressor is one of the very first things to be installed in the Test Lab and one of the most important. Air Compressor usually requires some kind of fuel such as electricity to power on. It is used to increase the pressure of a gas. It reduces the volume of the gas and increases its density without turning the gas into a liquid.. Increase in pressure of the gas also increases the temperature of the gas. The maximum pressure (psi) needed to run the instrument is between 90-110psi. Compressor should be used with an air receiver, or storage tank. The receiver stores compressed air and minimizes the run time of compressor.

Air compressor is highly useful when testing is performed at very low temperature. A small quantity of compressed air is regularly required in the movement of microscope.

Figure 1-1 Air Compressor

1.2 Air Drying Unit

The Air Drying Unit uses a heatless hygroscopic substance that induces or maintains the dryness in the sealed area. This device is installed where the user's air or nitrogen supply contains too much moisture for frost-free operation of a thermal test enclosure at low-test temperatures.

Typically, an Air Drying Unit supplies dry air inside a prober to prevent the condensation of liquids on the cooled surface of a Thermo Chuck Platform (chuck). This application allows the chuck to operate at below the freezing temperature.

Figure 1-2 Air Dryer (Front View)

Note: This figure was taken from http://www.1spectrum.com/PhotoGallery.asp?ProductCode=10107

1.3 Probe Station

Cascade MicroTech 11000-series probe station allows the full measurement of test device. It can be used for Noise, leakage, stray capacitance and measuring many different characteristics of the test device. Time to measure has been greatly reduced by using the Probe Station.

Whatever the application: DC or RF device characterization, wafer-level reliability, modeling, or yield enhancement, the 11000-series probe stations assure reliable and best measurements.

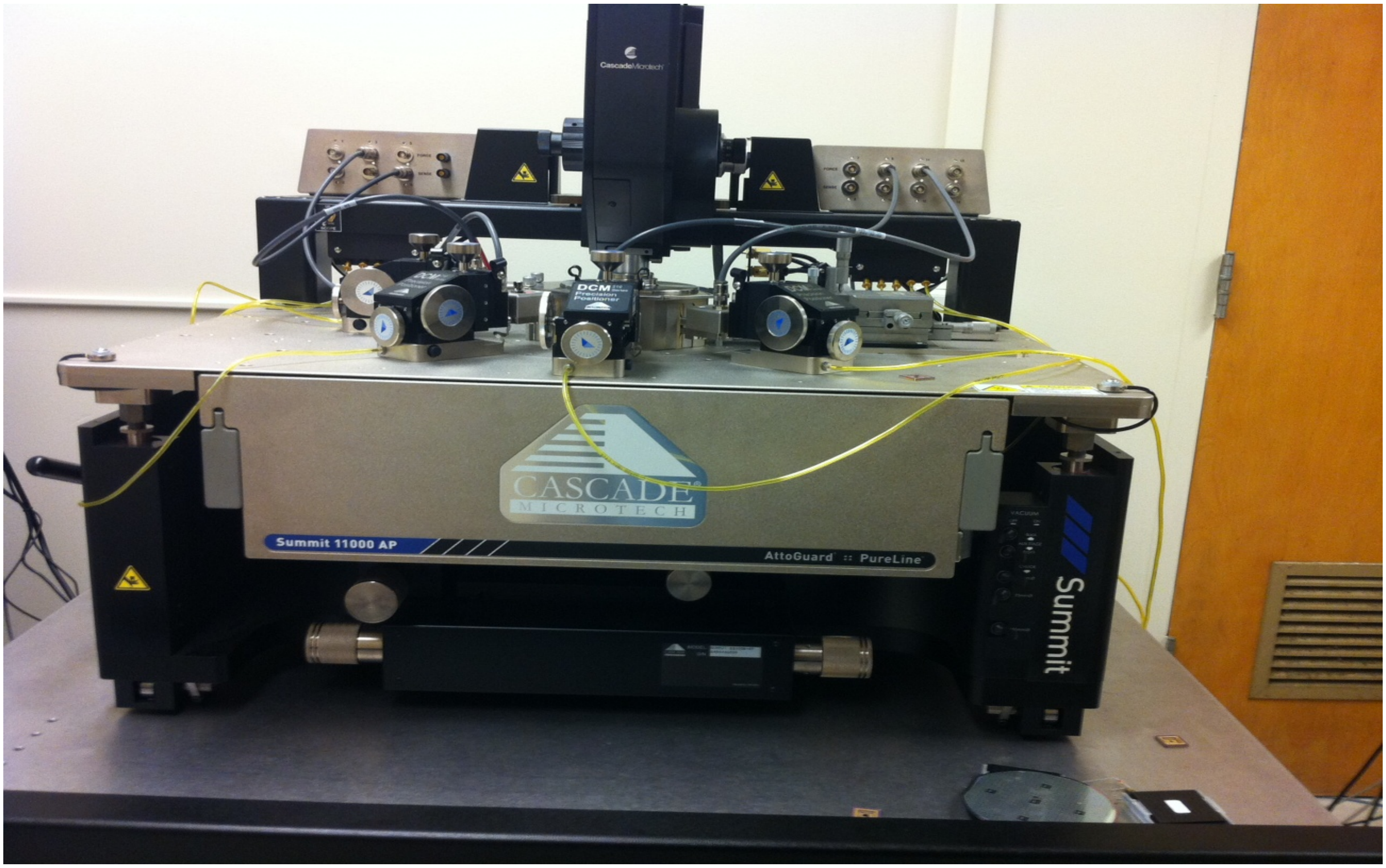


Figure 1-3 Probe Station (Front View)

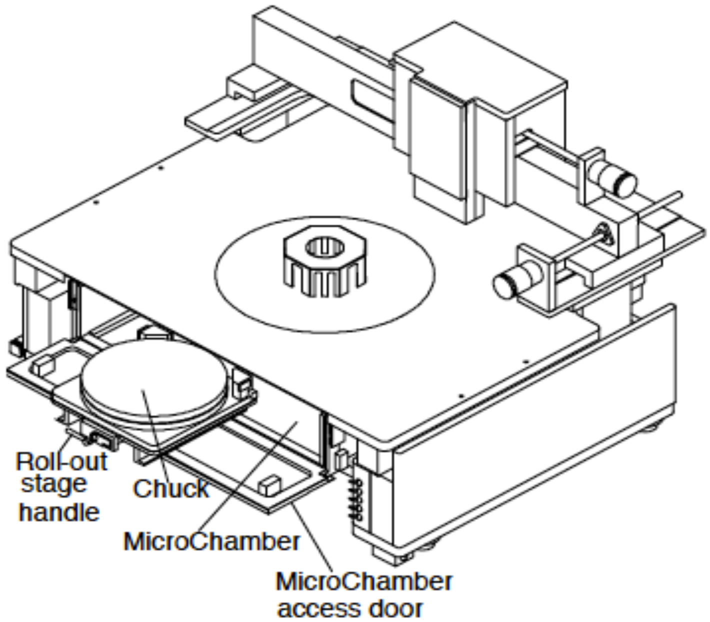


Figure 1-4: Probe Station (Right Side View)

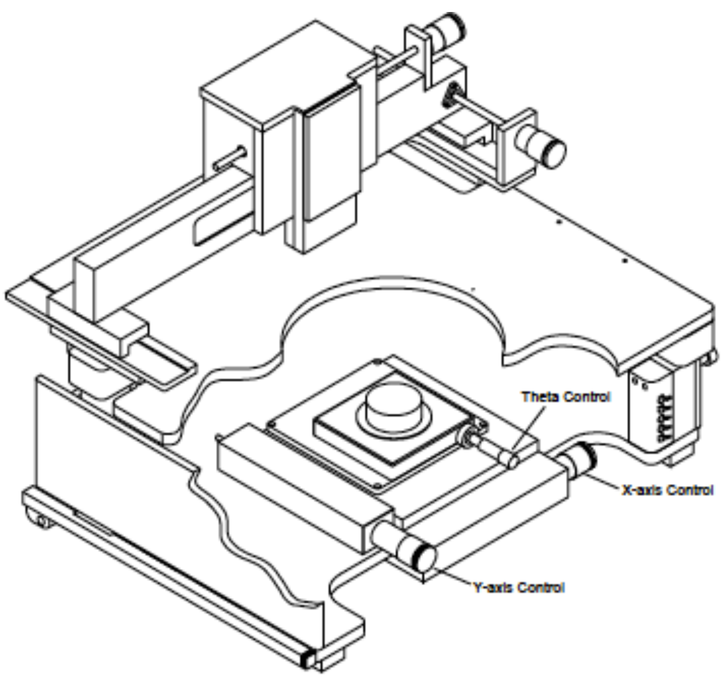


Figure 1-5 Probe Station (Left Side View)

EQUIPMENT CONFIGURATION & SPECIFICATIONS

Probe Station: Probe Station includes a microscope/video system, vibration isolation table, probe card holders, RF and DC probes, needles and probe cards, RF and DC cables and adapters, RF and DC probe positioners, calibration software and standards, vacuum pump for holding the wafer or die, and air dryer for fast purge

Platen System: This system offers 4 DC and 2 RF positioners. Four DC positioners are required for I-V characterizations.

Thermo Chuck Platform: 6-inch/150mm RF/Microwave wafer chuck (Ni).
Chuck provides an ultra low capacitance for swept measurement without capacitive error currents, and helps to measure the current in low femtoAmp range

MicroChamber: The chamber offers EMI shielding (≥20dB at 0.5-3 GHz, ≥30 dB at 3-20GHz) for low noise measurements, a sealed environment for moisture free low temperature measurements, low volume for the fastest purge, and light tight (light attenuation ≥120dB) to eliminate the need for a dark box. The EMI shielding feature is important in RF measurement that will be performed by Co-PI Jiang. The light-shielding feature is important for users who will test electro-optic devices.

Microscope: Zoom 2 microscope; 10:1 and 50:1 optical zoom ratios; broad fields-of-view; manual zoom, Focus and illumination functions; 5X high-resolution objective lens; eyepiece-equipped with 10x Ocular lenses

Probe Positioners: It is a kind of joystick, which handles the movement of probe in X-Y-Z axis. It has the adjustable, articulate arm for probing over and around components. These positioners have vacuum mounted base, which are compatible with most board fixtures, and they have the friction locking mechanics for rapid movement and rigid placement. Large dynamic positioning ranges 50um typical placement accuracy.

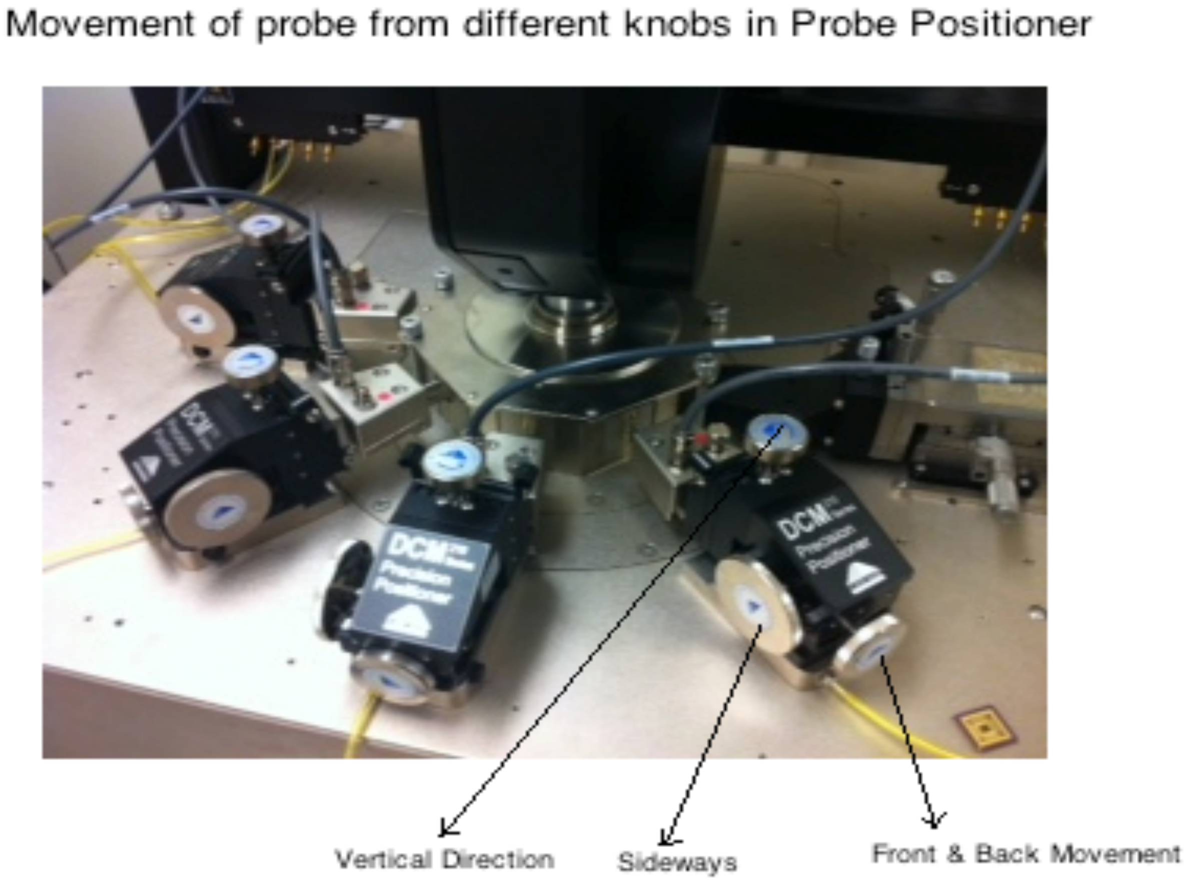


Figure 1-6 Probe Positioners (Top View)

Optical Probe and Probe Holder: Two micro-probe holders (left and right) are provided for convenient mounting of fiber probe tips. A multi configurable optical (light wave) probe is also included for photonic device measurement and characterization discussed in Man's research. It features user replaceable fiber pigtails, allowing the probe to be optimized for a variety of light delivery and light collection applications.

Mechanical Performance: The manual probes can move in X and Y direction. The X-Y stage can travel for 203 mm×203 mm with resolution of 5 mm/turn. The theta stage travels ±5.7° with resolution of 0.8°/turn.

Vibration Isolation Table: Working with increasingly small scales of reference in the Cascade MicroTech 11000B means that any vibration however minute, even from the equipment itself, will seriously degrade a probe station's performance. Slight vibrations caused from footsteps or from surrounding will cause the probes to jump and miss their contacts and the microscope image will be blurred. The Vibration Isolation Tables creates a vibration less environment by choosing a platform that suits the environmental conditions and enables stable probing at all times. The table is specifically designed to work in the general working conditions as well as for very sensitive measurements such as in the submicron range.

Digital Imaging System :It offers easy probe set-up and navigation. It simultaneously displays up to three cameras and provide optical magnifications. It offers a wide field of view for easy navigation; high optical magnification for precise probe alignment (0.4 µm resolution in X-Y direction); and live motion frame rates to avoid damage to probes or wafer

1.4 Semiconductor Parameter Analyzer

The semiconductor parameter analyzer, the Agilent B1500A provides a highly accurate laboratory bench-top solution for advanced device characterization. It is a highly versatile piece of equipment that can serve the diverse and expanding needs within the SFSU Engineering and Physics research. Other labs are integrated with the probe station to offer a complete Nano-scale test and characterization Lab. The probe station can be connected to SFSU's existing equipment's outlined in the Facilities section, thereby also optimizing the use of the existing equipment.

It is an integrated instrument that supports both I-V and CV measurements and also fast high-voltage pulsing. Microsoft Windows user interface supports Agilent's Easy EXPERT software, which provides a new, more in-built task-oriented approach to device characterization. Because of its extremely low current, low-voltage, and integrated capacitance measurement capabilities, the Agilent B1500A can be used for a wide range of semiconductor device characterization. It is also an excellent solution for non-volatile memory cell characterization and high-speed device characterization. Advanced Negative Biased temperature Instability (NBTI) measurement can be performed which is a key reliability issue in MOSFETs.

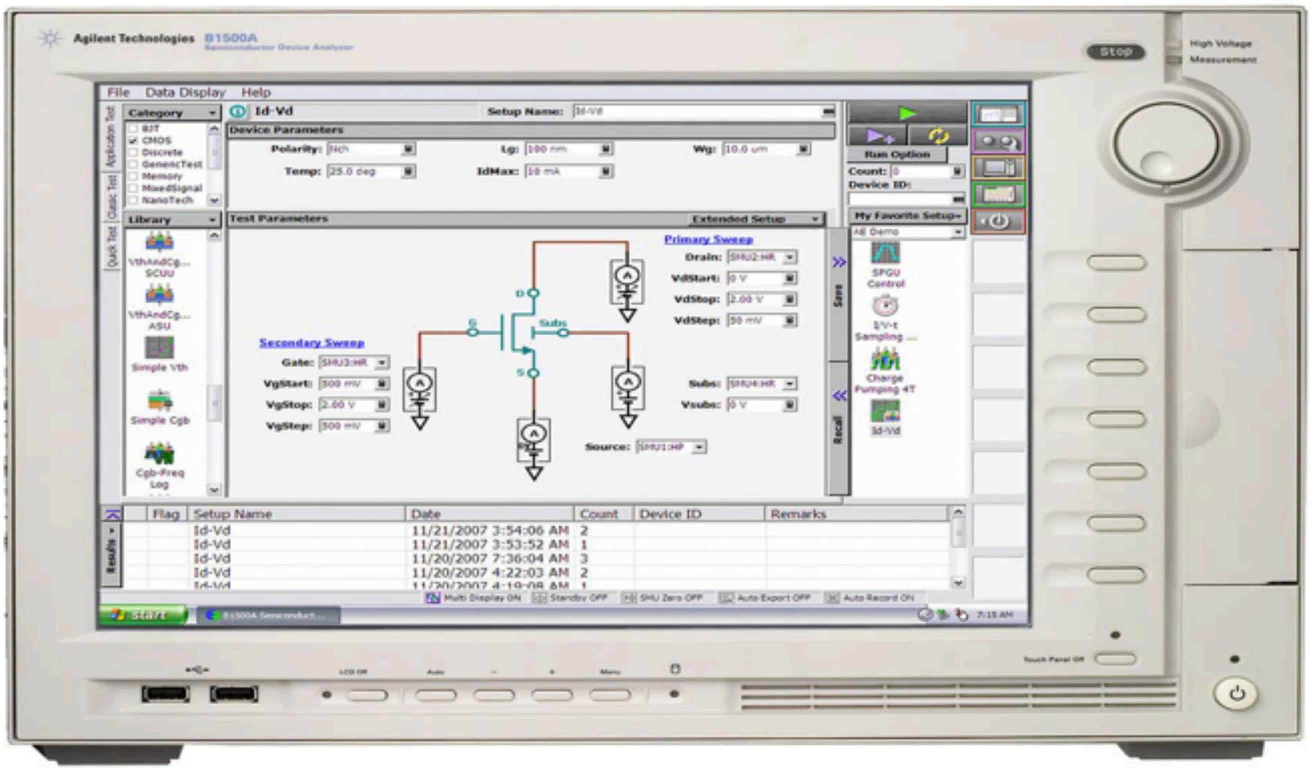


Figure 1-7 Semiconductor parameter Analyzer

Key Features & Specifications

General features

- Instrument with Microsoft Windows OS and Easy EXPERT software already installed.
- Single instrument for current-voltage (I-V), capacitance-voltage (CV), pulse generation, fast I-V, and time-domain measurement.
- Ten module slots for source monitor units (SMUs) and other module types (MFCMU, HV-SPGU and WGFMU)
- Offline data analysis and application test development via Easy EXPERT software.

Measurement capabilities

- 1× High Power Source/Monitor Unit (HPSMU): +/- 200 V and +/- 1 A measurement range and 2 μV and 10 fA measurement resolution
- 1× Medium Power Source/Monitor Unit (MPSMU): +/- 100 V and +/- 100 mA measurement range and 0.5 μV and 10 fA measurement resolution
- 1× High Resolution Source/Monitor Unit (HRSMU): +/- 100 V and +/- 100 mA measurement range and 0.5 μV and 1 fA measurement resolution
- 1× Multi frequency capacitance measurement unit (MFCMU): 1 KHz to 5 MHz measurement range
- 1× High Voltage Semiconductor Pulse Generator Unit (SPGU): This unit is capable of producing pulses in the +/- 40 V voltage range, output current of +/- 200 mA, minimum pulse width of 50 nS and minimum pulse period of 100 nS

1.5 Temperature Control Unit

For temperature control of the micro-chamber, the system includes the ESPEC ETC-200L temperature control unit that provides rapid temperature adjustment and a precise environment for probing semiconductor devices in the range of -60 °C to +200 °C. The main components of the system are: Controller, Chiller, and Thermal Chuck. The controller and chiller are standalone units, external to the probing station. The thermal chuck is built into the probing station. These control units are high precision, reliable instrument in the industry. Performing with exceptional temperatures stability and uniformity across the entire chuck surface. This temperature control unit makes testing at range of temperature simple and convenient.

Figure 1-8 Temperature Control Unit

A Link describing about the different equipment's:

http://www.youtube.com/watch?v=tSJEG7lFoIc

Chapter2: Setup and Probing of Device under Test

2.1 Preparation and floating table:

Testing at room temperature or above.

Step1: Connect the cable from Air Compressor to switch on.

Step2: Switch on the Master valve (on the inside part of wooden case), which allow the flow of compressed air.

Step3: Secondary valve needs to be in off state.

Step 4: Now move the Microscope up, so that the MicroChamber easily visible. Open the MicroChamber from the front side.

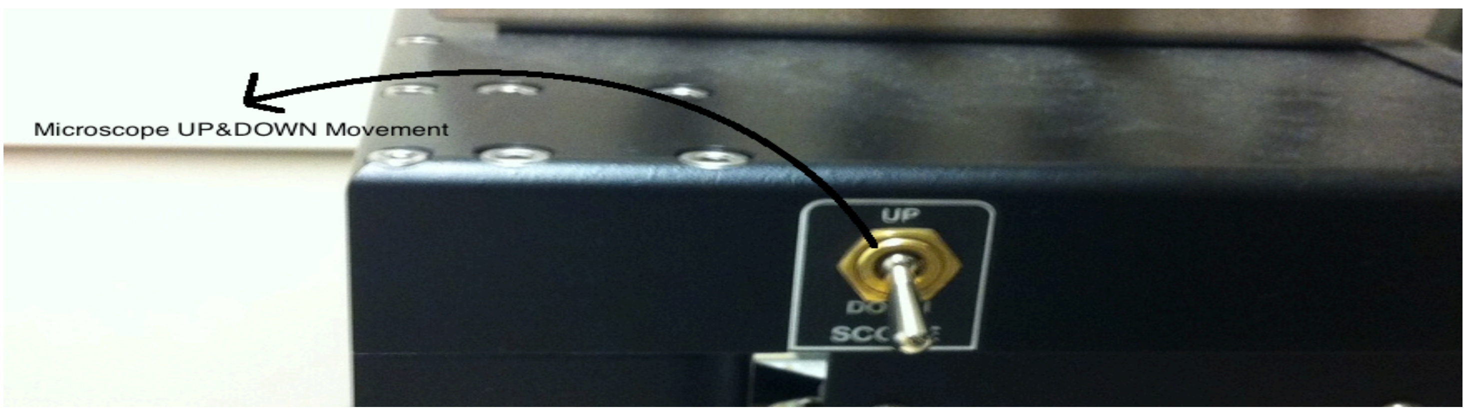


Figure 2-1 Microscope movement knob

***Note**: While moving the MicroChamber out, lower the chamber from side handle on left side of instrument by moving it up and make sure all connection from probes are disconnected.*

Step 5: When MicroChamber is safely opened place the device under test at the center position.

Step 6: Close the MicroChamber carefully.

Step7: Switch on the vacuum and the Digital Imaging System computer.

Figure 2-2 Vacuum and Digital Imaging Switch

Caution: *Student should never lean on the Vibration Isolation Table (Floating Table). Leaning will cause vibrations in the MicroChamber and will affect the test results. Purpose of this table is to isolate any vibration in the surrounding.*

Testing at below room temperature

Step1: Connect the cable from Air Compressor to switch on.

Step2: Switch on the Master valve (on the inside part of wooden case), which allow the flow of compressed air.

Step3: Secondary valve needs to be in on state.

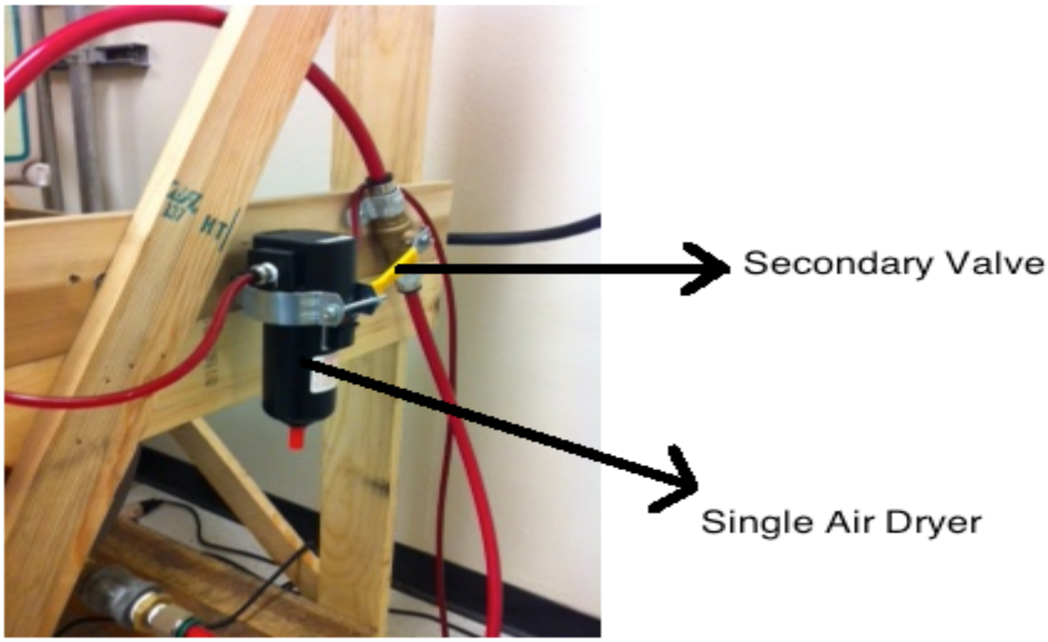
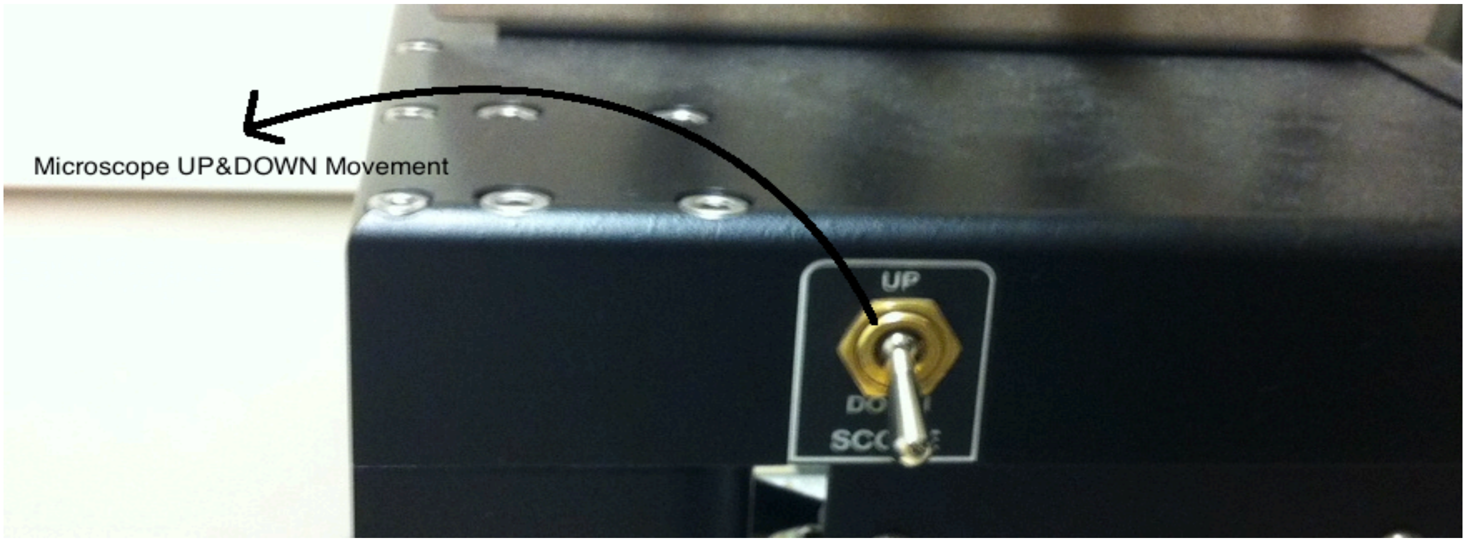


Figure 2-3 Secondary Valve

<u>*Step 4:*</u> Air dryer needs to be switched on.

Step 5: Now adjust the knob, which allows how much airflow is required. It has to be between 1-2 units.

Step 6: Now move the Microscope up and open the MicroChamber from the front side.



Note: *While moving the MicroChamber out, lower the chamber from side handle on left side of instrument by moving it up and make sure all connection from probes are disconnected.*

Step 7: When MicroChamber is safely opened place the device under test at the center position.

Step 8: Close the MicroChamber carefully.

Step 9: Switch on the vacuum and the Digital Imaging System computer.

Caution: *Student should never lean on the Vibration Isolation Table (Floating Table). Leaning will cause vibrations in the MicroChamber and will affect the test results. Purpose of the table is to isolate any vibration in the surrounding.*

2.2 Placement of device under test and role of vacuum system

After following the steps in section 2.1

Step 1: Placing of device under test at the correct position is very important.

Step 2: Expected Height and the position at which the probe make the contact with the device under test is key in proper placing of device.

Step 3: Vacuum is switched on. The area under the vacuum zone can be fixed from the switches provided.

Vacuum is switched on so that probe positioners and the device under test placed on the Thermo Chuck Platform remain stable and isolate any effect of vibrations from the surrounding.

The vacuum switches are connected through tubes with probe positioners and make them stable in their movement.

After switching on the vacuum and placing the probe positioners at the required positions, setup should look like the above Figure.

Note: At this point probes from probe positioners and device under test all need to be at same level. If it doesn't happen then device under test needs to be placed on the chuck, which is provided separately.

2.3 Probing Techniques and use of Microscope

Step1: Try moving the probes fixed with the probe holder as close to the center of device under test. During this step Microscope can be open.

Step 2: Close the microscope.

Step 3: View from the microscope in the Digital Imaging System. Try moving around the Microscope Adjustment knob unless something is visible.

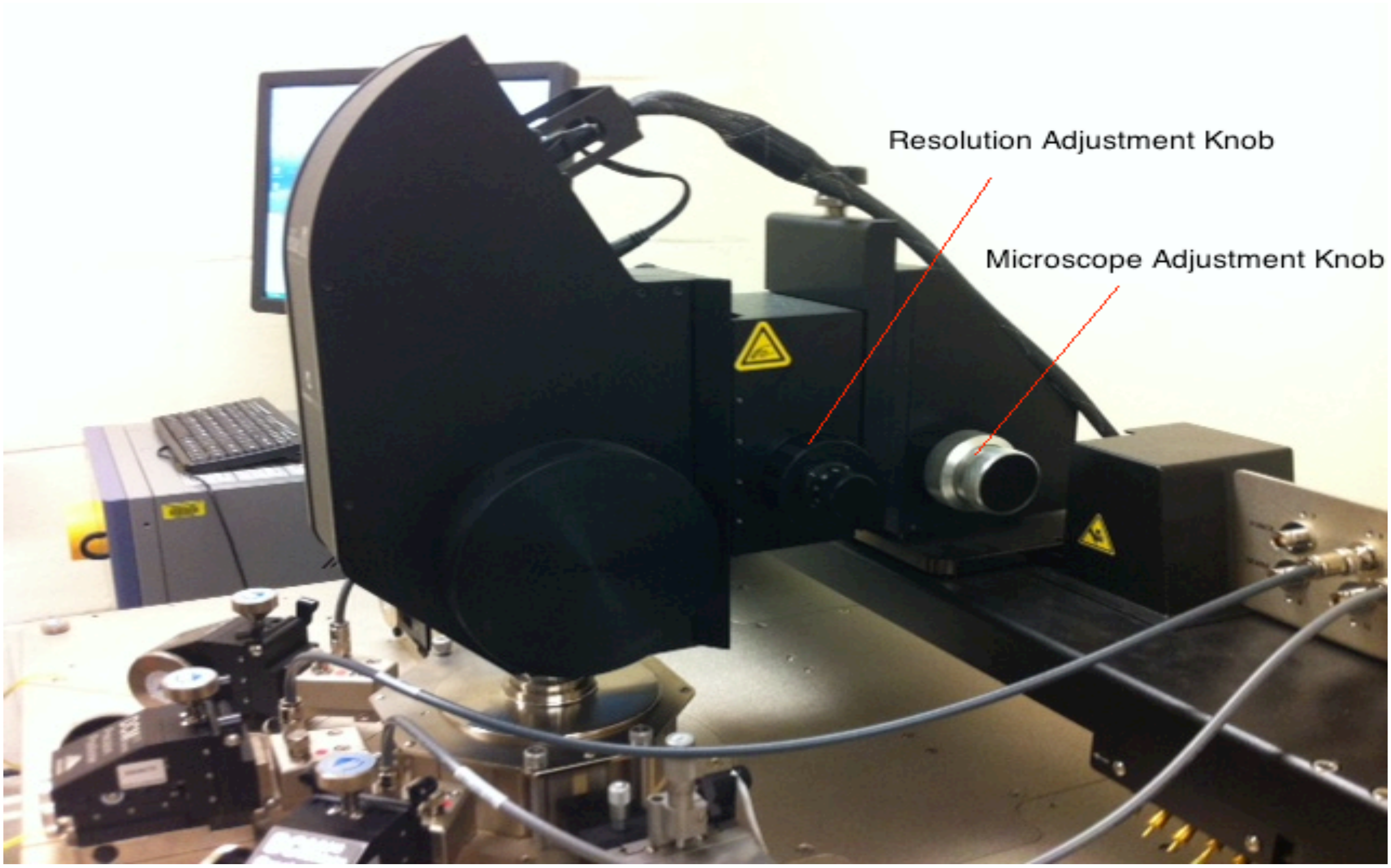


Figure 2-5 Microscope (Side View)

<u>*Step 4*</u>: *Try to focus the chip using the resolution adjustment knob.*

Step 3 & Step 4 are simultaneously performed .As the practice grows it will become easier.

<u>*Step 5:*</u> Try to focus and play around the Microscope knob unless a clear picture is formed in the screen.

<u>*Step 6:*</u> After having the clear focus of the device under test. Next step is to find any probes in the screen.
Probes are mostly unfocused since the probe and device under test are at different heights and resolution knob has been adjusted according to the device.
During this step darker portion signifies the focus part and the lighter part is unfocused.

Step 7: Obtaining the same level of focus means probe and the device under test needs to be at same level. This step of having at same level is the critical in probing.

Watch video for better understanding.

Step 8: For adjusting at same level and probing of device needs lot of practice. During this process student need to get familiar with the movements of probe positioners. Multiple knobs have to moved and viewed simultaneously in the screen.

Step 9: Try to probe at same time if using multiple probe positioners.

Caution: *During this step all probe positioners need to be operated together. If one pin is probed perfectly and others are still not focused any movement inside the chamber will break the chip.*

2.4 Temperature Control Unit Operations.

To operate the variation in temperature control unit,

Procedure1: Small touch screen is provided on the center of screen.

1. Touch the constant setup menu. Then click on the chuck temperature and then the numeric keypad will appear.
2. Now press the operation/stop button on bottom of screen to start the temperature control unit.
3. To monitor the change touch the Monitor on the screen.

Figure 2-6 Interface of Temperature Control Unit

Procedure 2: Temperature control menu is available in the Nucleus software. Click to set the temperature and start.

Chapter3: Measurement using Source Monitor Units (SMU)

3.1 Introduction to SMU

SMU, which is a Source/Measure Unit, or is a source and measurement resource for test applications having high accuracy, high resolution and measurement flexibility. SMUs are sometimes also referred to as source monitor units. An SMU can precisely force voltage or current and simultaneously measure voltage and/or current.

Source/monitor unit, SMU, can simultaneously perform DC voltage or current output and measurement. Typical SMU has the Force, Guard, Sense, and Circuit Common terminals as shown below. Normally the Force, Guard, and Sense terminals have same potential. Voltage marked around the terminals indicates the Protection Limits.

3.2 Connection between probe station and SMU

Both Force and Sense must be connected to a terminal of a device under test for the Kelvin connection, which is effective way for high current measurement and low resistance measurement. For the non-Kelvin connection only Force is connected. Do not connect Sense. It must be open.

When a Kelvin connection is used, current is supplied via a pair of force connections. These generate a voltage drop across the impedance to be measured according to Ohm's law $V=RI$. The current generated currently has a voltage drop across the force wires themselves. To avoid the voltage drop across that in the measurement, a pair of sense connections is made adjacent to the target impedance. The accuracy of the technique comes from the fact that almost no current flows in the sense wires, so the voltage drop $V=RI$ is extremely low.

It is conventional to arrange the sense wires as the inside pair, while the force wires are the outside pair. If the force and sense connections are exchanged, accuracy can be affected, because more of the lead resistance is included in the measurement. In some arrangements, the force wires are very large, compared to the sense wires, which can be very small. If force and sense wires are exchanged at the instrument end, the sense wire could burn up from carrying the force current.

Kelvin connection works like ammeter and voltmeter connected in parallel to the device under test.

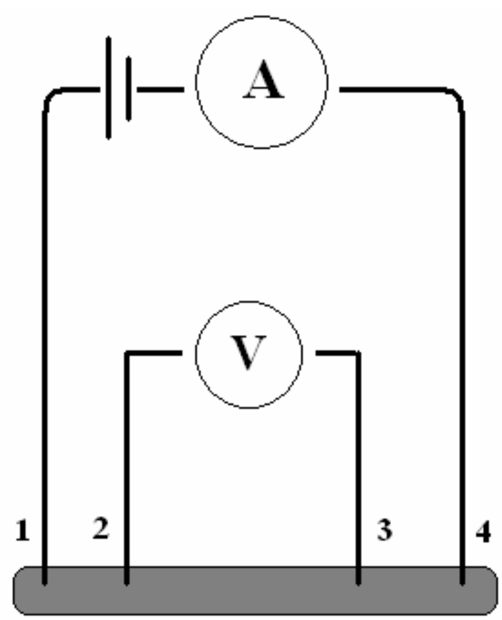


Figure 3-1 Kelvin Connection

How the connection is established from the Parameter Analyzer to Probe Station

Step 1:Connecting cables to SMU

Step 2: Connect other end of cable to the back side of probe station

Step 3:Connect the cable on front side of probe station.

Step 4:Connect the probe positioners

3.3. Measuring I-V characteristics of 2 terminal devices

Measuring I-V character, where the cable from an SMU connects to the input terminal of the probe positioners. The measurement center conductor and guard shield are routed to the DUT via the shielded probe needle.

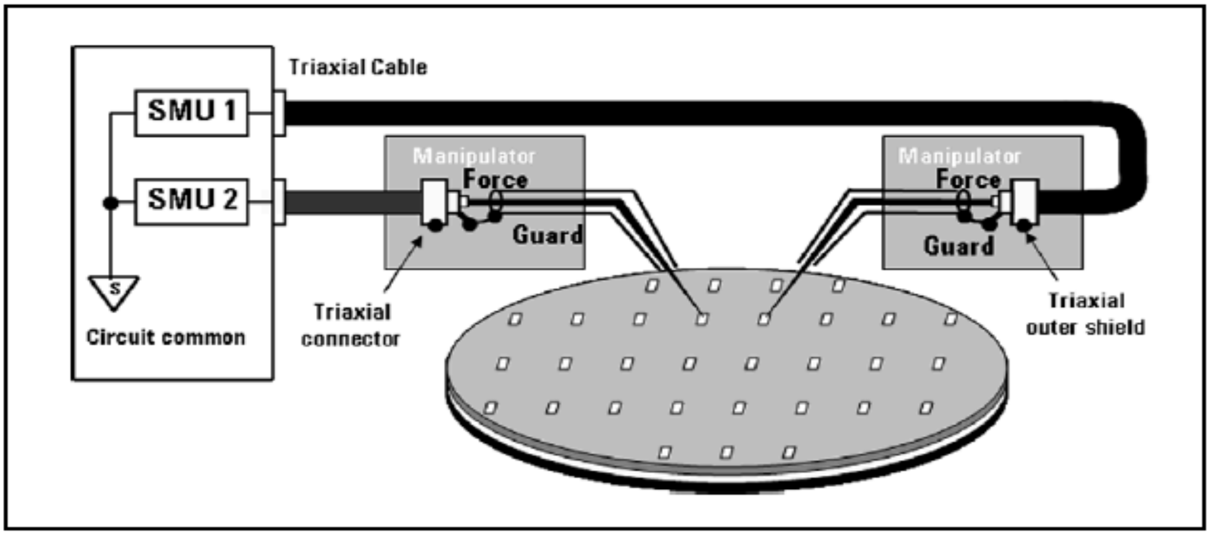


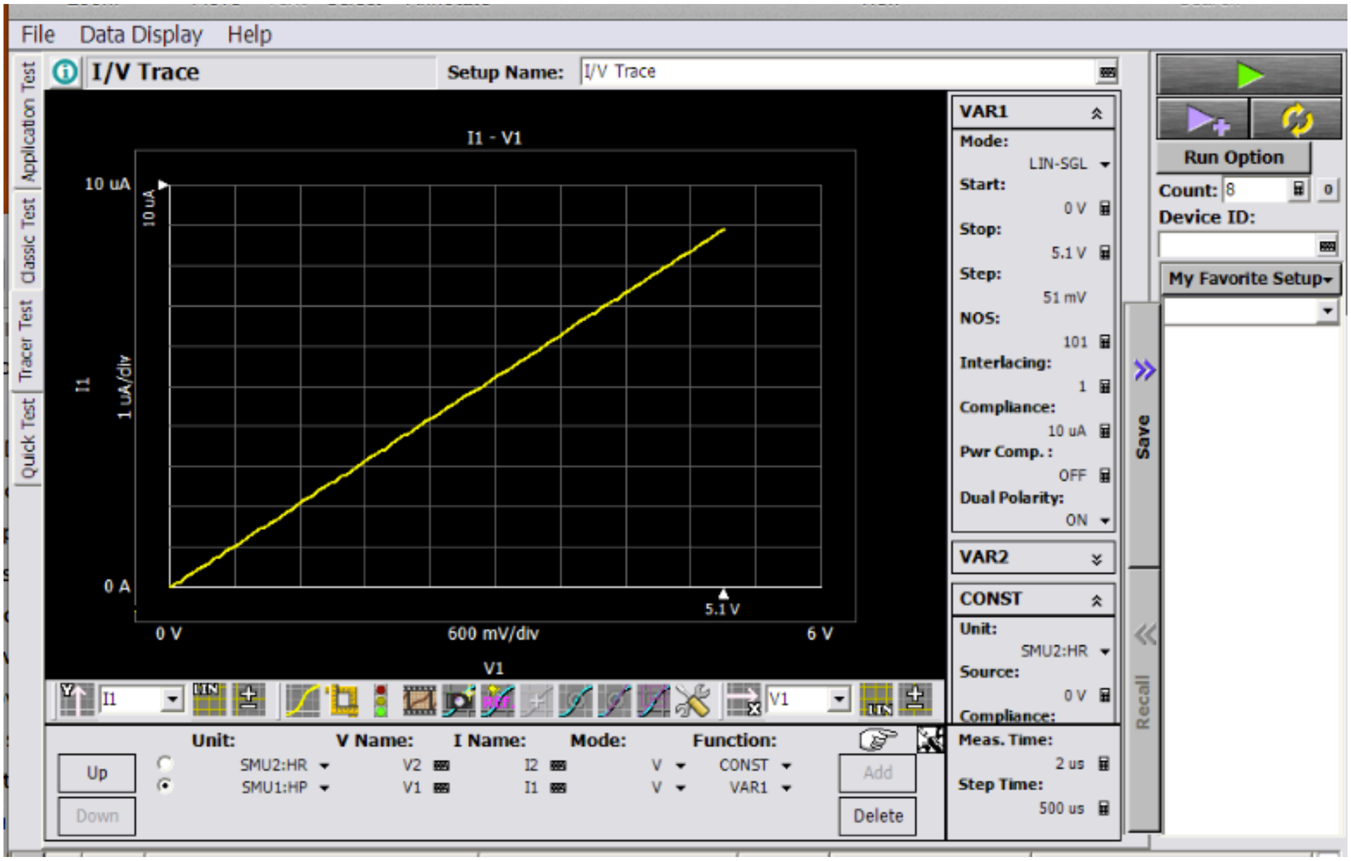
Figure 3-2 Non-Kelvin setup for I-V measurement

Example 1: Simple resistor device I-V characterization

Connecting the two terminal of resistor is very simple, since probing the resistor doesn't require the use of microscope. But that is not the core purpose of using probe station, as it has the capability measuring characteristics of Nano scale devices.

This experiment will basically train in getting used to the instruments different parts like the movements of the probe positioners and involvement of the parameter analyze.

Results of I-V characteristic of resistor



This is the screen capture of the result for I-V characteristics measured for the high resistor.

Procedure for measurement:

Name the workspace and continue.
To measure I-V characteristics click on the tracer test in the Agilent Easy Expert.

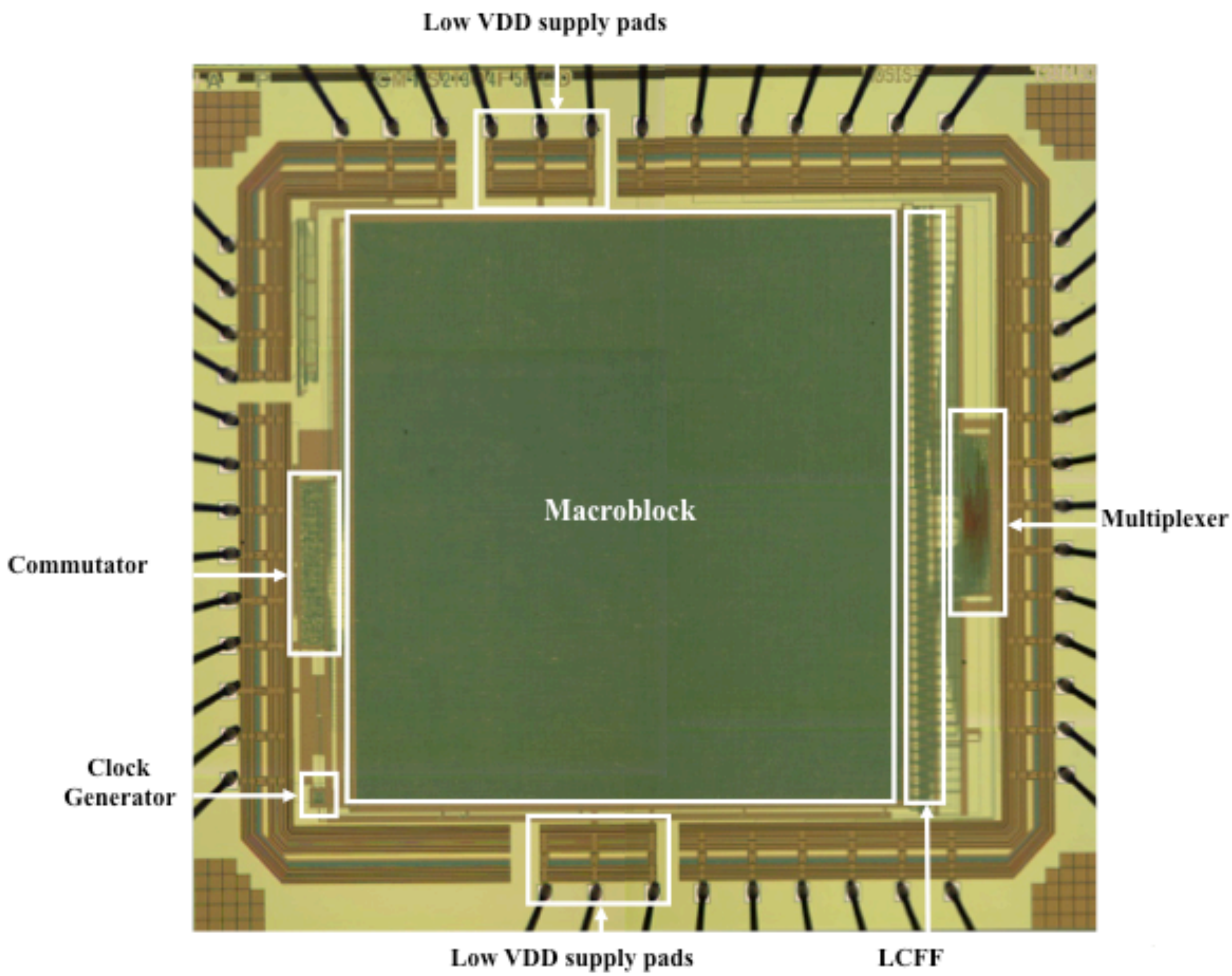
- *Add the SMU.*
- *For this experiment 2 SMU are used, which are connected to the probe via probe positioners.*
- *We can set the function of the SMU. For the two terminal device. One SMU is set as variable (V) and other as constant (GND).*
- *After setting the SMU, set the parameter of measurement on right side like start point, stop voltage, number of steps and others.*
- *Click the green play on right side of screen.*

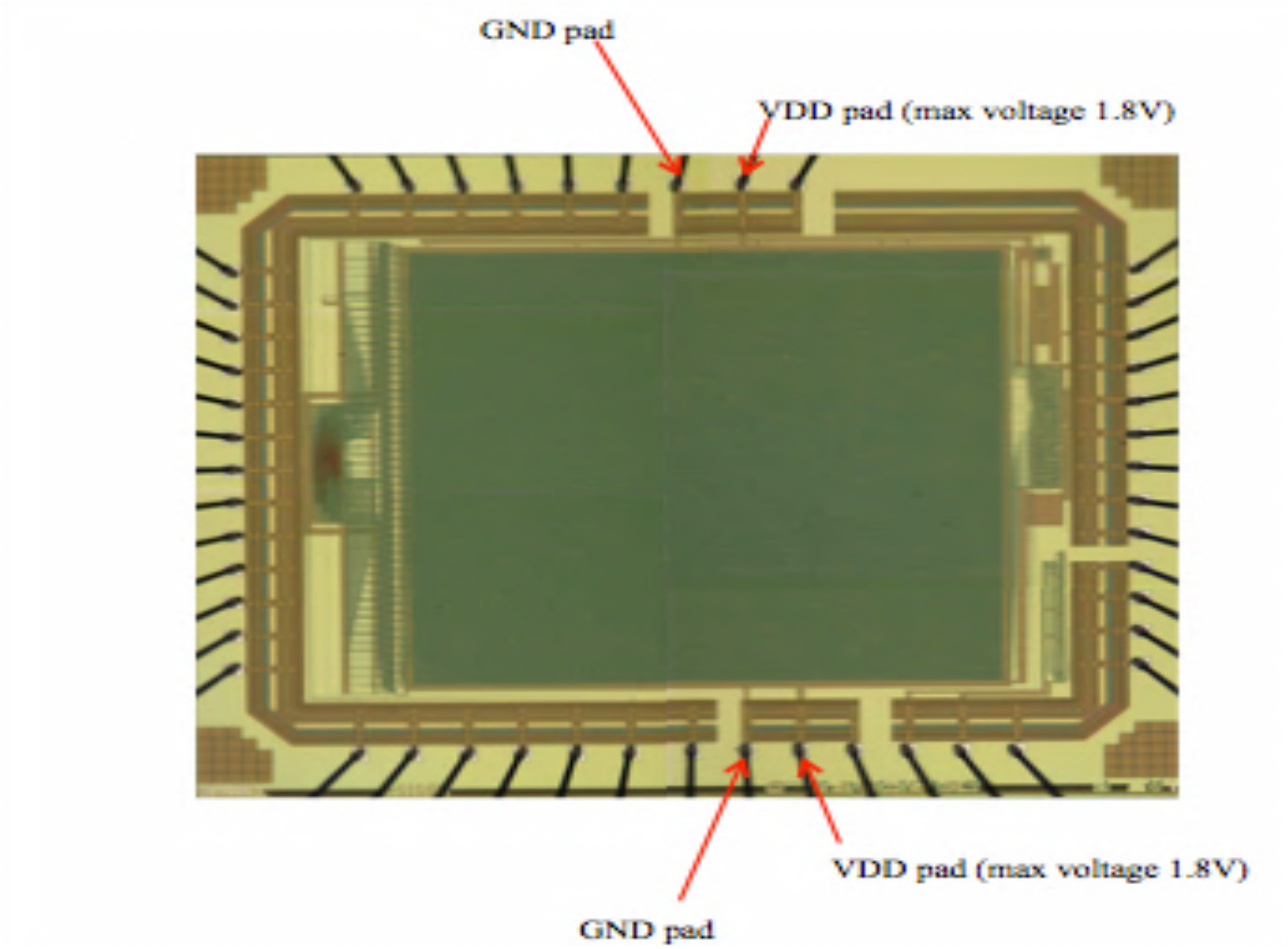
Example 2: Leakage vs. Voltage characterization of a Chip

This example will be performed on a device, which is in the Nano scale.

While doing this experiment all the parts are involved together and student need to be extremely careful with the movements of probe positioners. Since any wrong movement of probe positioners can break the device.

Chip Diagrams





How to probe:

After carefully placing the probes on VDD and GND, which are connected to SMU 1 and SMU 2 respectively.

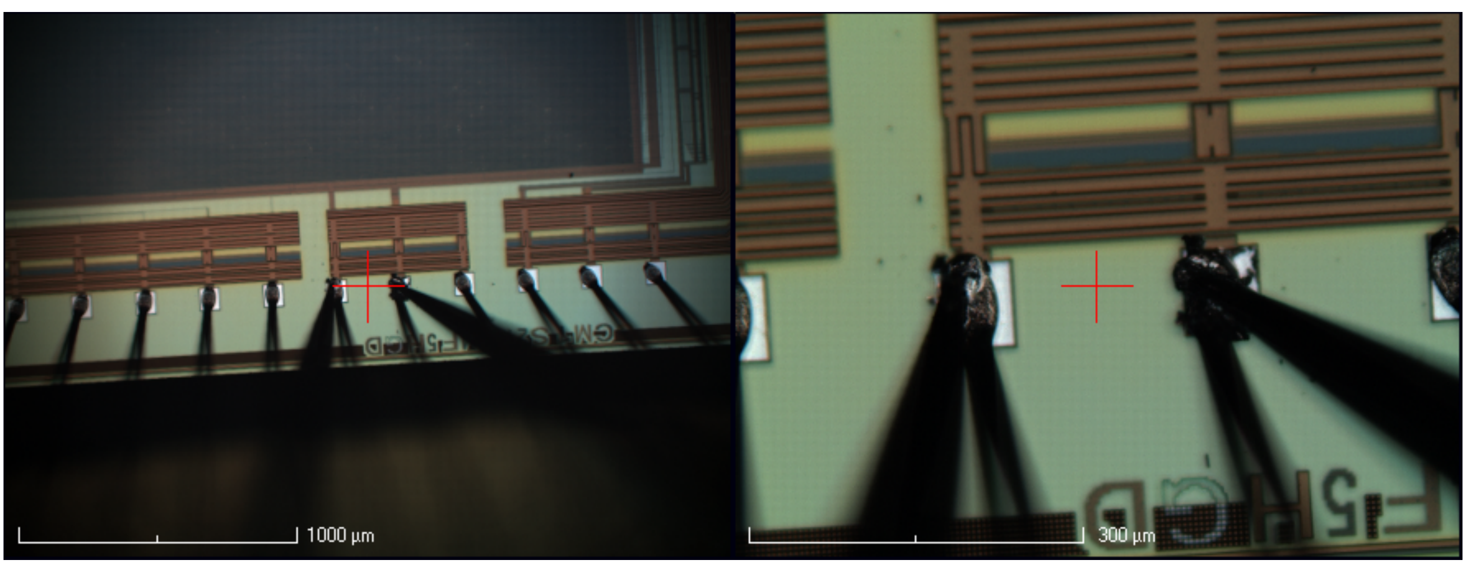


Figure 3.5 Zoom view of the chip observed in the Digital Imaging System.

Procedure for measurement:

Name the workspace and continue.

To measure I-V characteristics click on the tracer test in the Agilent Easy Expert

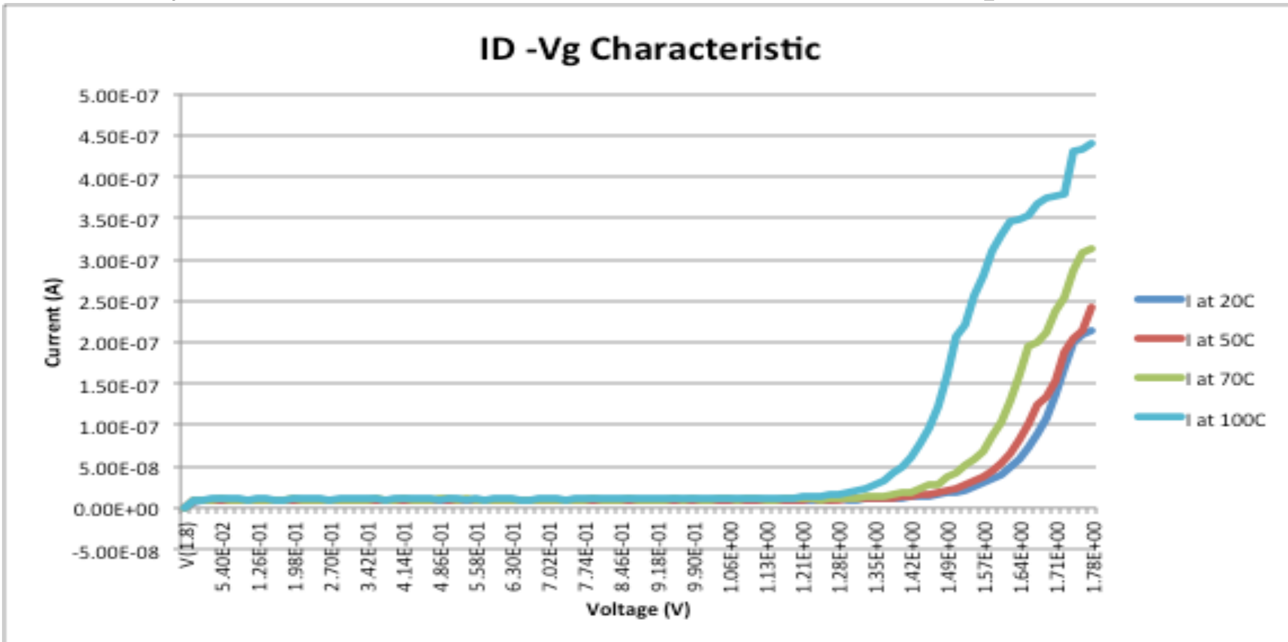
- Add the SMU and set the mode as V.
- For this experiment SMU 1 and SMU 2 are used, which are connected to the probe via probe positioners.
- We can set the function of the SMU. SMU 1 is set as variable (V) and SMU 2 as constant (GND).
- After setting the SMU, set the parameter of measurement on right side like start point, stop voltage, number of steps and others.
- Click the green play icon on right side of screen.

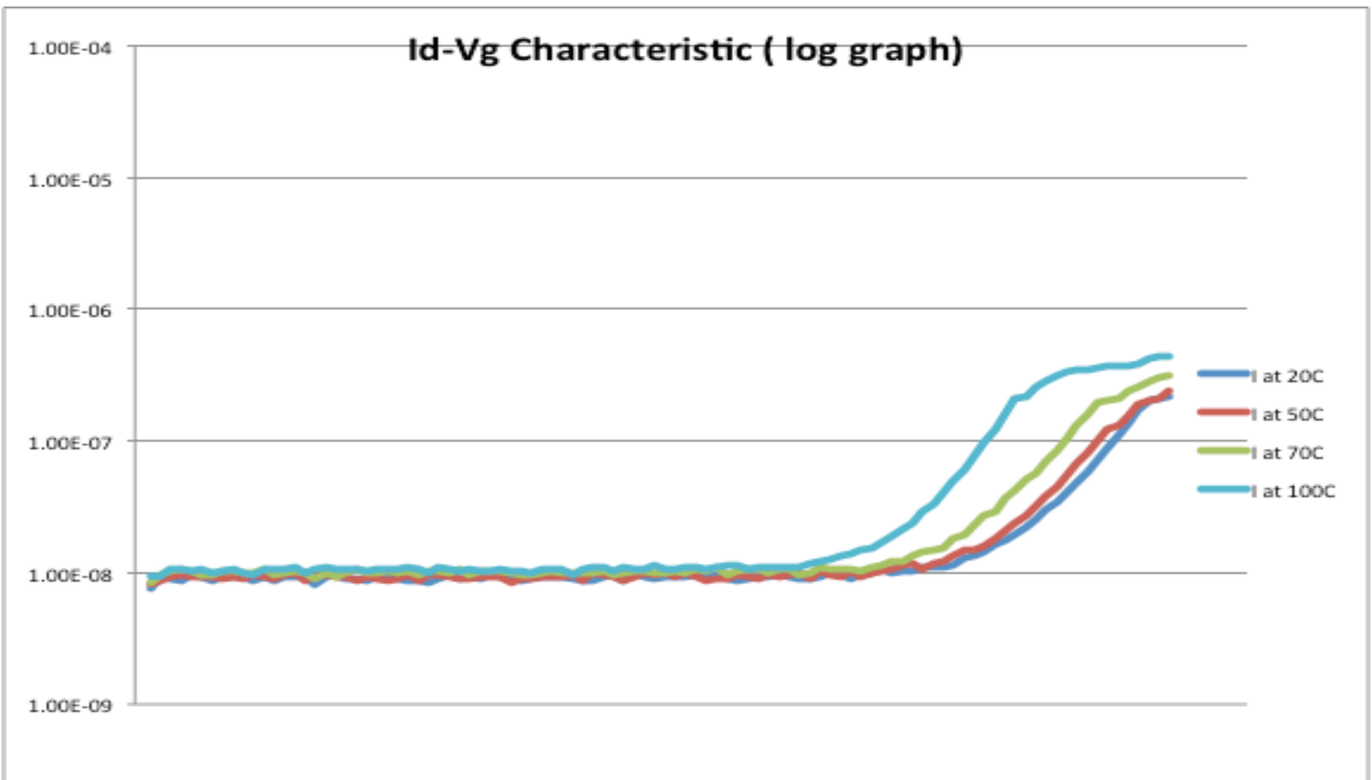
Measure I-V Characteristics with function of Temperature.

- Follow the steps in section 2.4 Temperature Control Unit Operations to vary the temperature.
- Measure the I-V characteristic at room temperature and save the result.
- Increase the temperature. While the temperature is increasing probes will move from its original position due to expansion and contraction properties of material.

  Note: During the temperature change movement of probes can break the pins in the chip. Be careful while temperature is changing.
- Try to reposition the probes when temperature is set as similar to earlier.
- Save the results of I-V characteristic at different temperature and extract the results as text file.

Results of I-V characteristics with variation in Temperature





Conclusion:

According to the Test results with the increase in temperature leakage current increases.

Example 3: Four-Point Probe Resistance Measurement

In sheet resistance measurement several resistances need to be considered. The probe has a probe resistance Rp. At the interface between the probe tip and the semiconductor, there is a probe contact resistance, Rcp. When the current flows from the small tip into the semiconductor and spreads out in the semiconductor, there will be a spreading resistance; Rsp. Finally the semiconductor itself has a sheet resistance Rs. The use of four-point probe equivalent circuit for the measurement of sheet resistance is shown.

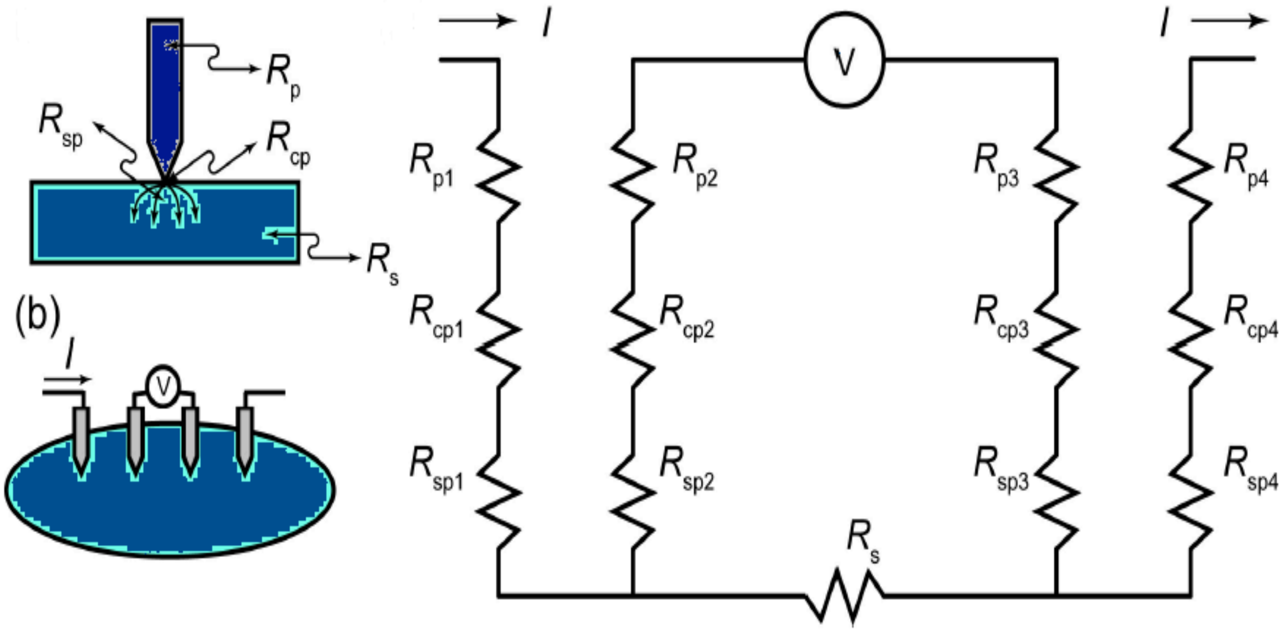


Figure 3-3 Four-point probe measurement of semiconductor sheet resistance

Two probes carry the current and the other two probes sense the voltage. Each probe has a probe resistance Rp, a probe contact resistance Rcp and a spreading resistance Rsp associated with it. However, these parasitic resistances can be neglected for the two voltage probes because the voltage is measured with a high impedance voltmeter, which draws very little current. Thus the voltage drops across these parasitic resistances are insignificantly small. The voltage reading from the voltmeter is approximately equal to the voltage drop across the semiconductor sheet resistance. By using the four-point probe method, the semiconductor sheet resistance can be calculated:

$$Rs = F\ V/I$$

Where V is the voltage reading from the voltmeter, I is the current carried by the two current carrying probes, and F is a correction factor. For collinear or in-line probes with equal probe spacing, the correction factor F can be written as a product of three separate correction factors:

$$F = F1.F2.F3$$

F1 corrects for finite sample thickness, F2 corrects for finite lateral sample dimensions, and F3 corrects for placement of the probes with finite distances from the sample edges. For very thin samples with the probes being far from the sample edge, F2 and F3 are approximately equal to one (1.0), and the expression of the semiconductor sheet resistance becomes:

$$Rs = kV/I$$

$$\text{Where } k= \pi/\ln 2$$

The four-point probe method can eliminate the effect introduced by the probe resistance, probe contact resistance and spreading resistance. Therefore it has more accuracy than the two-point probe method.

How to probe:

Sheet resistance measurement can be performed using the kelvin connection measurement. Resistance measurement is usually performed on very thin conductive material. In this setup all four probe points are placed approximately on a straight line. Centre probes together make the sense connection for voltmeter and external two forms the current forcing source as per the kelvin connections.

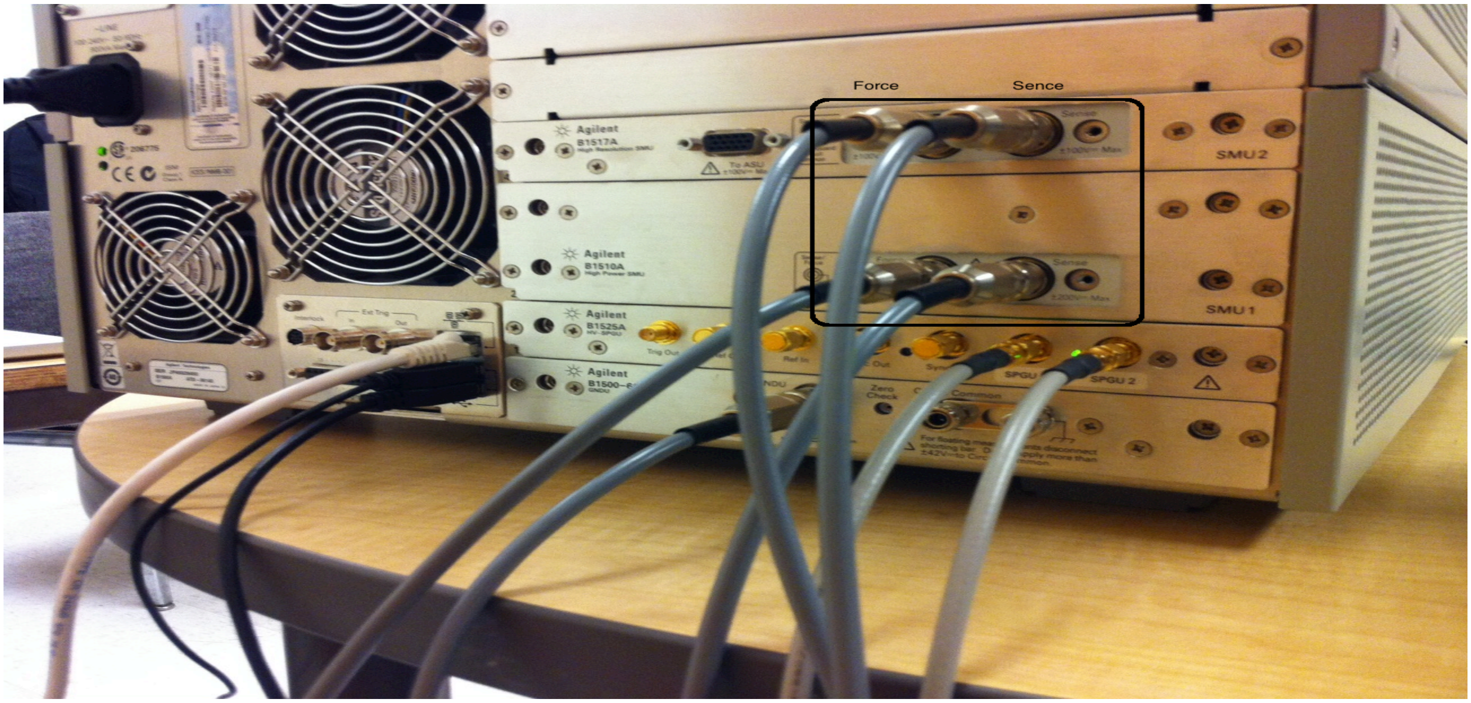


Figure 3-4 Picture of connection

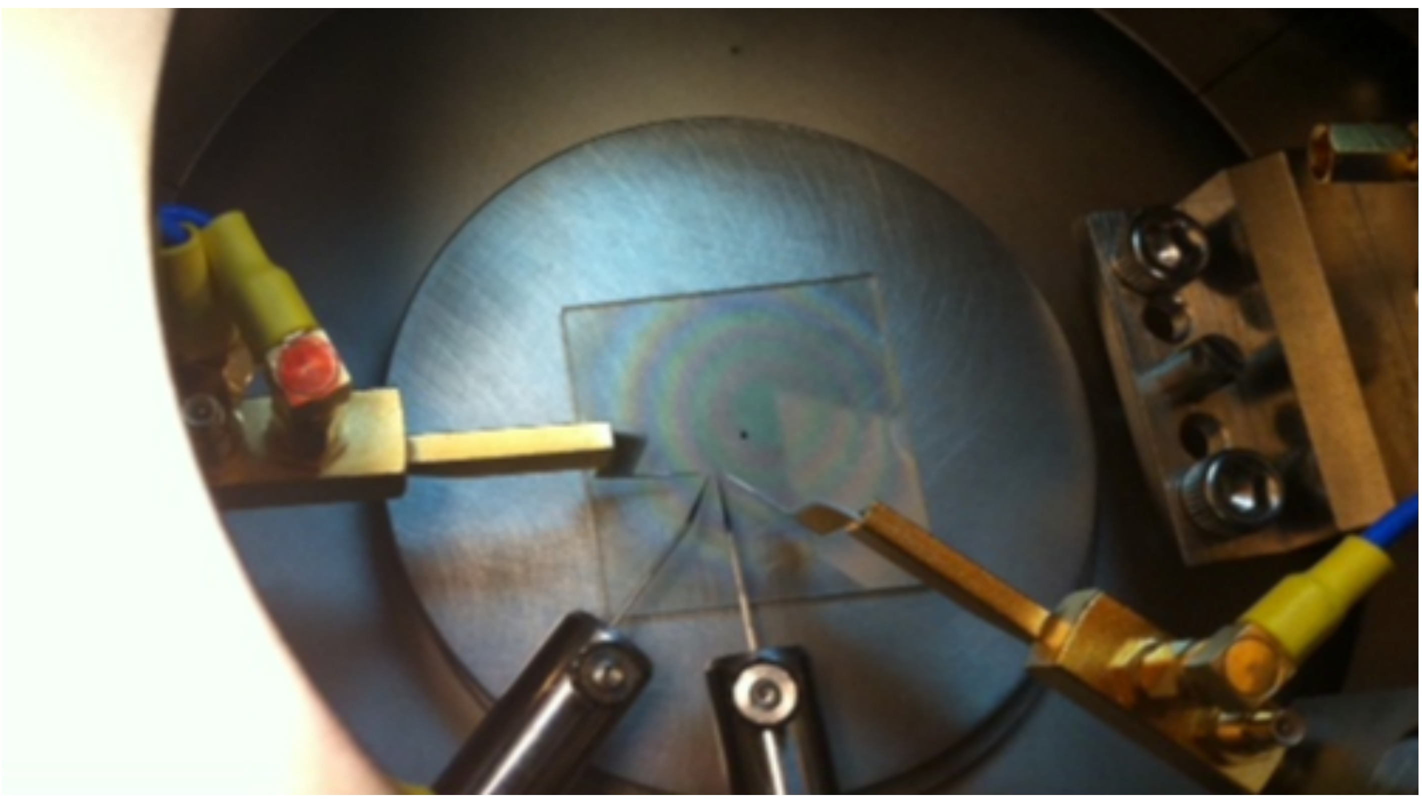
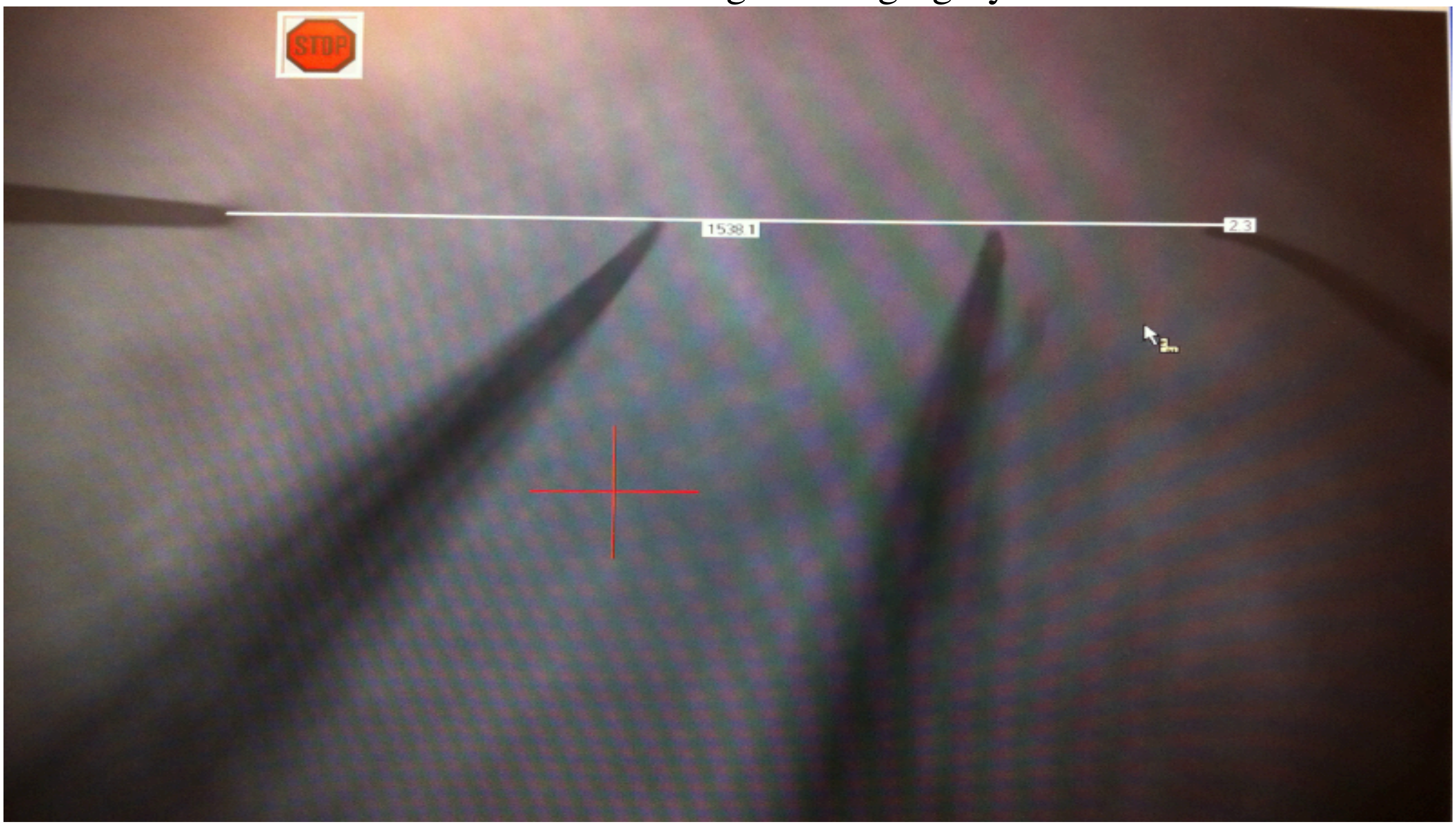


Figure 3-5 Inside View of Chamber

Zoom view of the sheet observed in the Digital Imaging System.

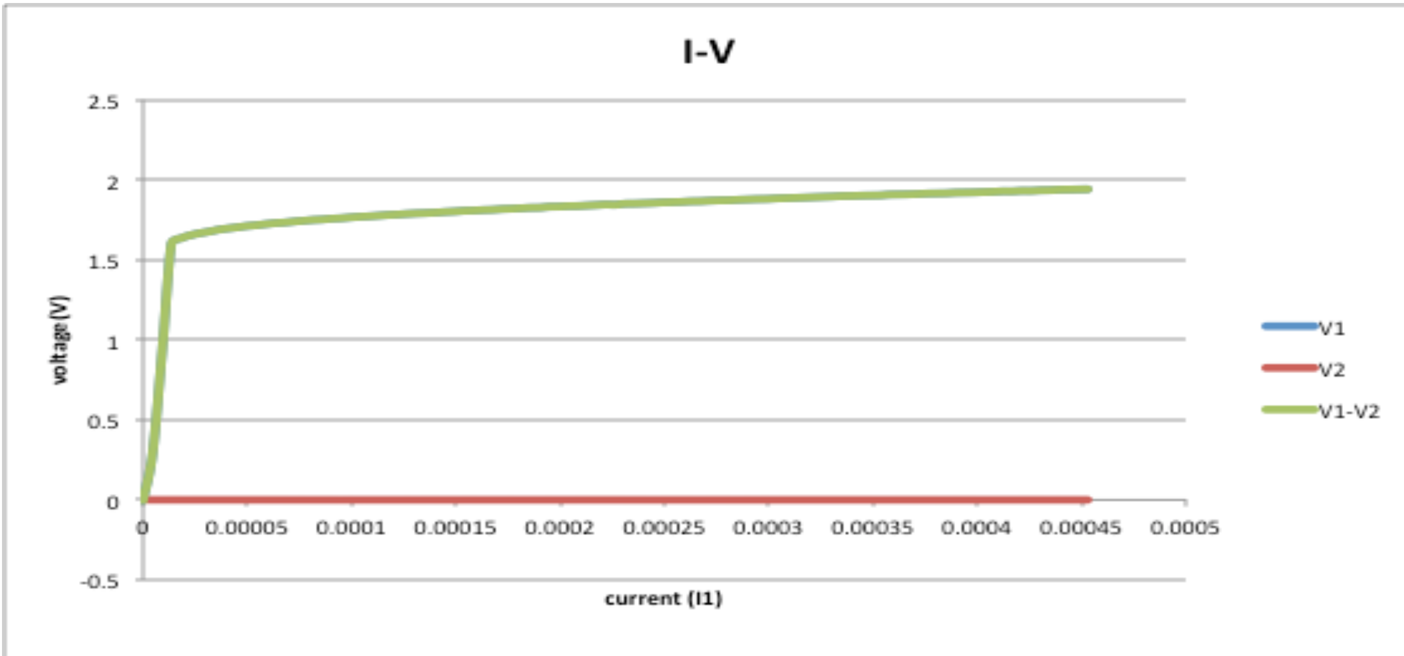


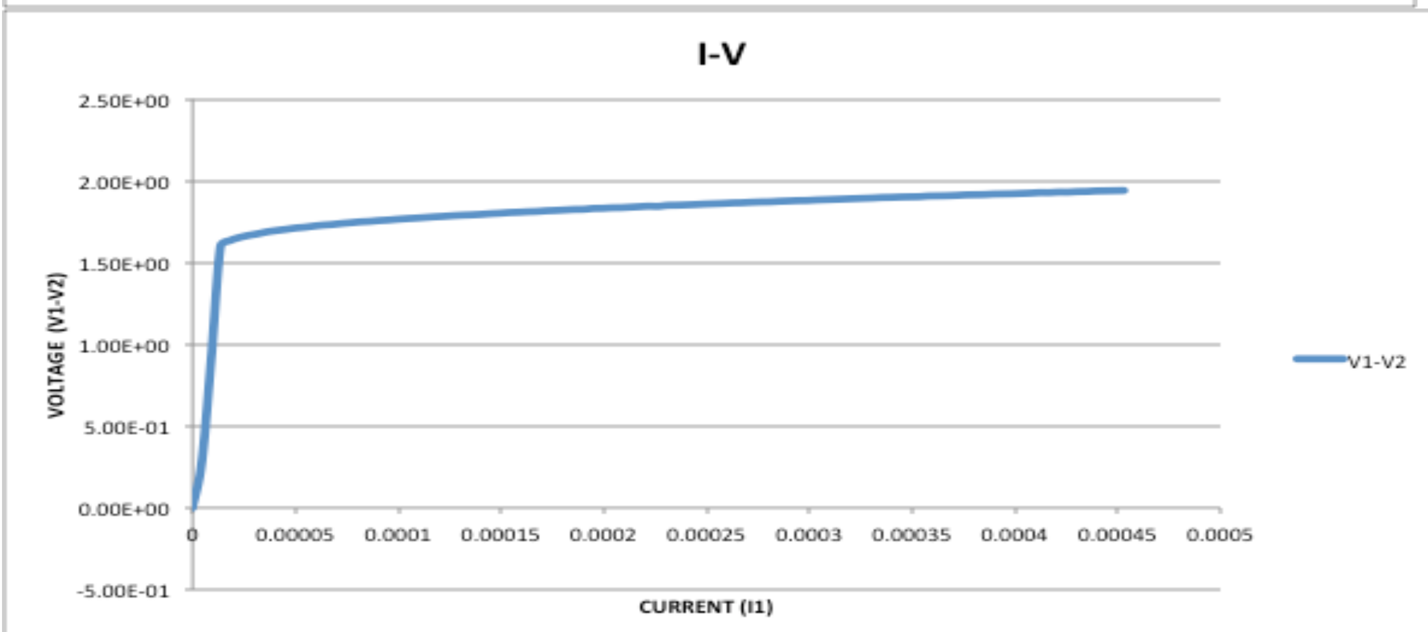
Procedure for measurement:

To measure sheet resistance follow the procedure in section 3.2 for probe connection with SMU.

- *Name the workspace and continue.*
- *To measure the resistance we need to plot the I-V characteristics. Click on the tracer test in the Agilent Easy Expert*
- Add the SMU1 and set the mode as I and add SMU2 and set the mode as V.
- For this experiment both force and sense of SMU 1 and SMU 2 are used, which are connected to the probe via probe positioners.
- We can set the function of the SMU. SMU 1 is set as variable (V) and SMU 2 as constant (GND).
- After setting the SMU, set the parameter of measurement on right side like start point, stop voltage, number of steps and others.
- Click the green play icon on right side of screen.
- Measure the I-V characteristic at room temperature and save the results of I-V characteristic and extract the results as text file.

Results of I-V characteristics to find the approximate resistance:





CONCLUSION:

Approximate resistance of the sheet can be found by using

$$Rs = kV/I$$

Where V/I is effectively $\Delta V / \Delta I$

Chapter4: Measurement using Semiconductor Pulse Generator Units (SPGU)

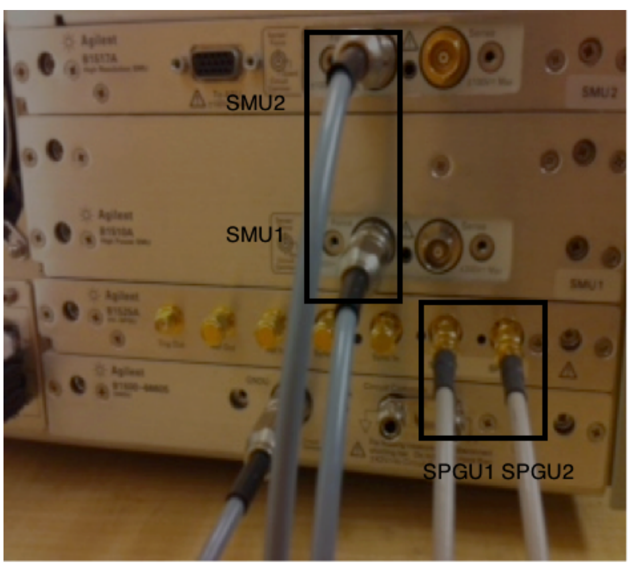
4.1. Introduction to SPGU

A Pulse generator is an electronic circuit *or* a piece of electronic test equipment used to generate rectangular pulses. Pulse generator unit capable of generating pulses with width under approximately 10 ns programmable pulse widths and supports high voltage pulse generation (up to ±40 V) for high power and memory device testing.

4.2. Connection between probe station and SPGU

Step 1:Connecting cables to SPGU & SMU

Step 2: Connect other end of cable to the back side of probe station



Step 3:Connect the cable on front side of probe station.

Step 4:Connect the probe positioners

4.3. Reliability Test Using SPGU and SMU

After following the steps explained in the *Example 3: Leakage vs. Voltage characterization of a Chip in section 3.3*

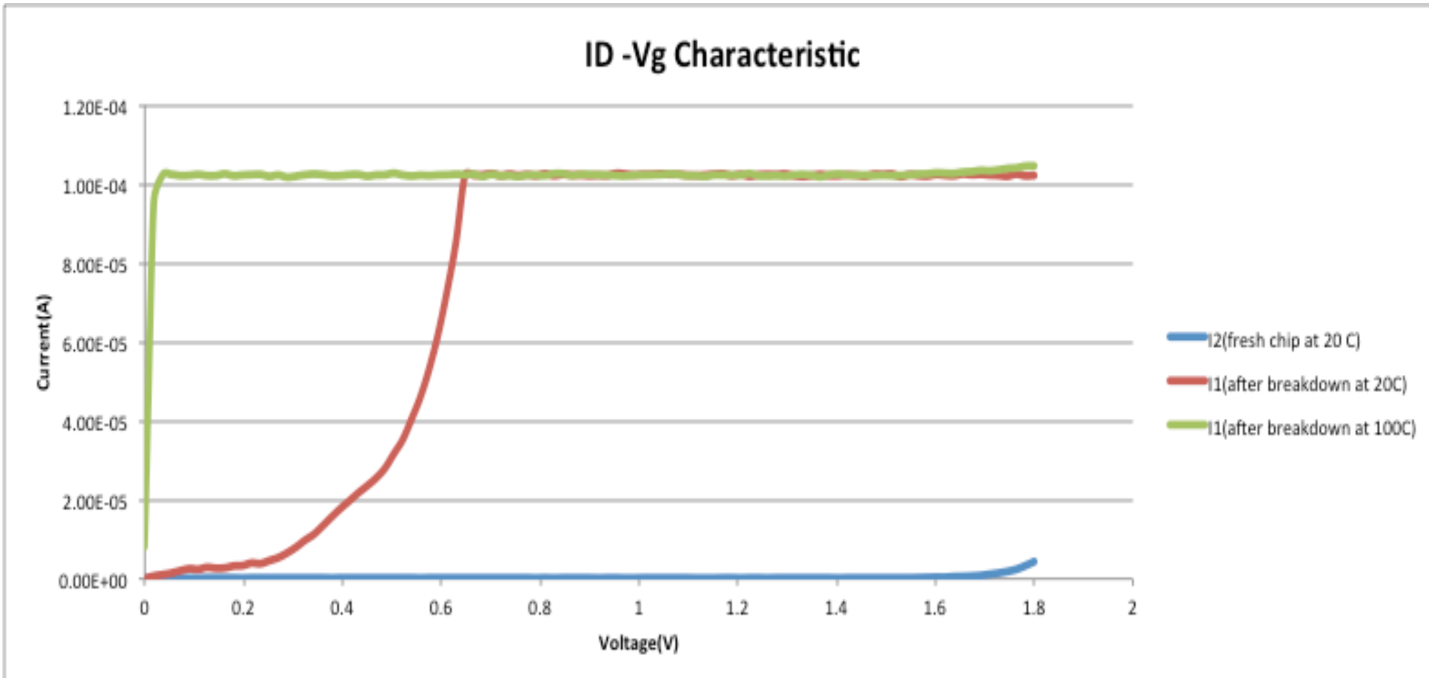
Purpose of the test:
We are using the fresh chip to find the reliability characteristics of the chip by applying the high voltage pulse from the SPGU. Applying pulse is basically applying stress to have breakdown of transistor. Increasing the temperature to more than 100 degree C to enhance the breakdown. Raising the voltage and temperature can accelerate transistor breakdown effect.

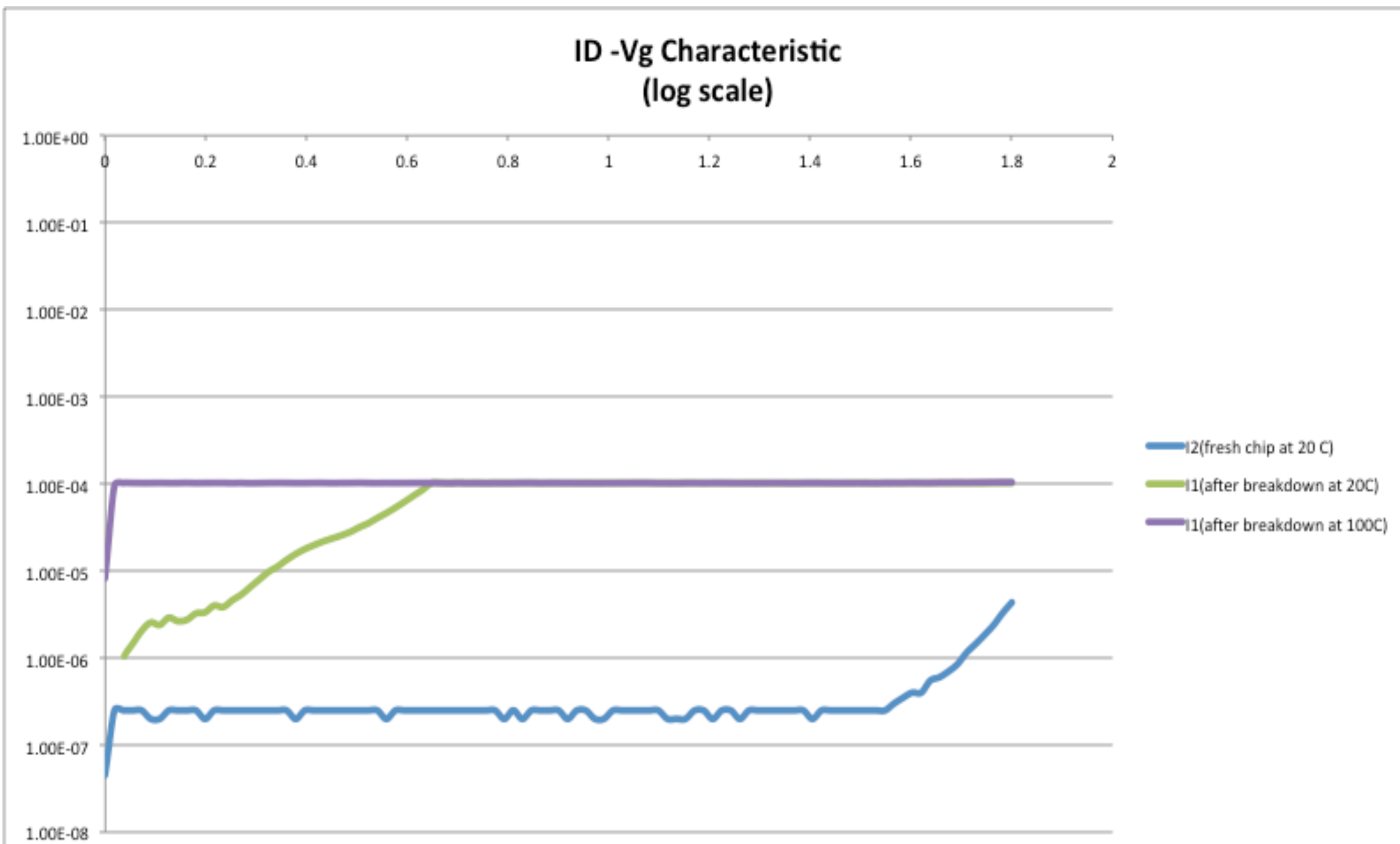
Example: Measuring breakdown characteristics of a chip

Procedure for measurement:

- In this experiment initially I-V characteristics of the fresh chip was measured and saved as in example2 at room temperature.
- Now replace the cable from the SMU 1 and SMU 2 with the SPGU1 and SPGU2 respectively.
- Click the SPGU CONTROL under the classic test in Agilent Easy Expert.
- Add both the SPGU and set the mode as pulse.
- Now click the Pulse/ALWG under the SPGU setup.
- SPGU Pulse setup will open.
- Set the period, duration of the pulse, pulse peak and duty cycle of the pulse.
- Set SPGU1 as Pulse source and SPGU 2 as GND.
- Temperature control unit is used to increase the temperature (140° C)
- After the parameters are set click the green play icon and wait for the required interval.
- After applying pulse (stress) for required time decrease the temperature to the 20°C and connect SMU1 and SMU 2 replacing SPGU 1 and SPGU 2 respectively.
- Measure the I-V characteristics of stressed chip at room temperature (20° **C**).

Chip shows the breakdown effect after applying stress of 3.5V from SPGU for 1hr at 140°C with 90% duty cycle with 1ms period on the fresh chip.





Conclusion:

The leakage vs. voltage plot of a chip before and after shows significant change as a result of breakdown.

Reference:

[1] http://www.home.agilent.com/agilent/home.jspx?cc=US&lc=eng
[2]
http://www.home.agilent.com/agilent/facet.jspx?k=b1500a&neighborhood=ETM&kt=1&cc=US&lc=eng&homesearch=Search&searchbtn=Search

[3] http://www.cascademicrotech.com/products