

User Manual

DC Probe Station

High Frequency Test Laboratory

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TABLE OF CONTENT

- 1. Before Starting**
- 2. Cascade Summit 12K Probe Station**
- 3. Agilent 4156C Precision Semiconductor Parameter Analyzer**
- 4. Agilent 4294A Precision Impedance Analyzer**
- 5. Temptronic TPO3000 ThermoChuck System**
- 6. Pulsed I-V Measurements**
- 7. Finish Up**

1. Before Getting Started

Fig. 1.1 shows that this tool is configured around a Cascade Summit 12K probe station, including four Kelvin probes each mounted on a Cascade 208 or 210 probe positioner, an Agilent 4156C precision semiconductor parameter analyzer, an Agilent 4294A precision impedance analyzer, a Temptronic TPO3000 200-mm ThermoChuck system, a Kinetic Systems 1201 vibration-isolation table, and a personal computer (PC) running Keysight IC-CAP on Windows 10. For users interested in exploring the full capacity of the tool, ask the HFTL manager for manuals provided by manufacturers of individual instruments. **If you have any question or doubt about the following instructions, discuss it with the HFTL manager before you unilaterally bend the rules!**

- 1.1 Study this manual before arranging for the HFTL manager to give you one-on-one in-person training on the tool! Make sure it is the latest version posted on the CNF website <https://www.cnfusers.cornell.edu/node/670>, because revisions are frequent.
- 1.2 You will need to have your own sample and know what you like to do with it, so you may regard it as your first measurement session. You will be charged for the training time, so you will save time and money if you study this manual well before the training.
- 1.3 Schedule in advance with the HFTL manager for your first measurement session. After you successfully complete the training and become a qualified user of this tool, for additional measurement sessions, you still need to make sure the HFTL manager, the tool owner, or an expert user is available. **Currently, HFTL does not allow unsupervised use!**
- 1.4 You will be given access to the Coral workstation dedicated to HFTL, as well as the PC dedicated to this tool. Each time you use the tool, make sure to log on and off both the workstation and the PC, so you can be charged accordingly.
- 1.5 Log on the workstation using the net/guest ID and password used to establish your CNF user project/account. If you have not gone through the CNF orientation and safety training, you may ask CNF for a special permission to access HFTL tools only without access to the CNS clean room. Since the same Coral workstation controls the access to several HFTL probe stations, after you enable your use of the DC probe station, log off the workstation so that others can use the it to enable their use of other probe stations. Even after you log off the workstation, the charging clock will continue ticking until, after you finish your measurement, you log onto the workstation to disable your use of the DC probe station.
- 1.6 Log on the PC as "User." No password needed.

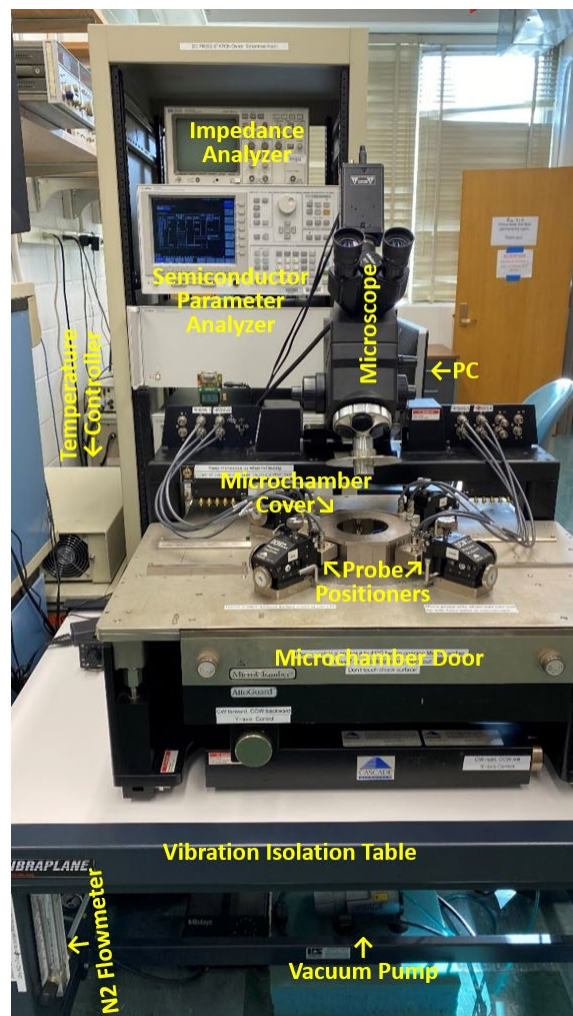


Fig. 1.1. DC probe station.

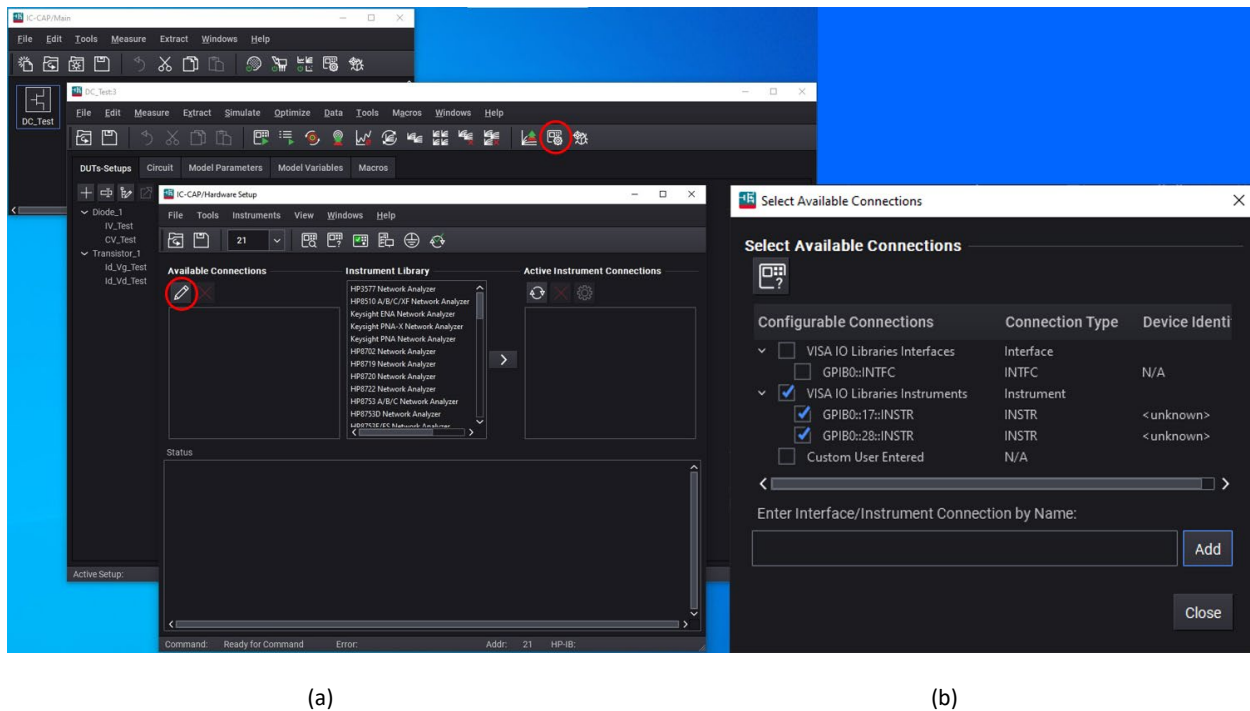





Fig. 1.2. IC-CAP hardware setup.

- 1.7 Set up your own folder under your net/guest ID such as "D:\User\NetID" if you don't have it set up before. **Save all files or data in this folder only!** Otherwise, they may be deleted by the tool owner without notice. **Do not touch another user's folder!**
- 1.8 From the PC desktop, copy the "DC_Test.mdl" template to your own folder "D:\Users\NetID." Because "DC_Test.mdl" is frequently updated by the tool owner, it is recommended that you make a fresh copy to your folder each time you use the tool.
- 1.9 On the PC desktop, click on the IC-CAP icon to open it. If it cannot be opened, make sure the PC is connected to the internet. Each time IC-CAP is opened, the PC must fetch the IC-CAP license from the server via the internet. On the top menu of IC-CAP, click on "File," then go to your own directory "D:\User\NetID" to open your own copy of "DC_Test.mdl." It provides the basic test setup.
- 1.10 In the top menu of "DC_Test.mdl," click on  to "Open Hardware Setup" as shown in Fig. 1.2(a).
- 1.11 Under "Available Connections," click on  to "Select Available Connections" and check "VISA IO Libraries Instruments." Confirm that "GPIB0::17::INSTR" and "GPIB0::28::INSTR" are checked as shown in Fig. 1.2(b). Close the window and get back to the home screen of "DC_Test."
- 1.12 Under "Active Instrument Connections," click on  to "Rebuild Active Instrument." Once it is finished, confirm that both "Keysight4294" and "HP4156" are listed under "Active Instrument Connections" as shown in Fig. 1.3. (The names are historical, because HP became Agilent, then Agilent became Keysight). Close the "IC-CAP/Hardware Setup" window and get back to the home screen of "DC_Test."
- 1.13 **Other than carefully adjusting the microscope, the wafer chuck, the vacuum switches, the probe positioners, and the z-lever, never touch or lean on the probe station!** Otherwise, it may damage the sample or probes. Keep in mind that any rough motion will set off vibrations to allow the probes to scratch the sample if they come in contact. The z-lever can be used to conveniently lift the probes from the sample. The z-lever may become your best friend.

1.14 Everything on the probe station is delicate. **Do not force them outside their normal range of movement and permanently damage them!**

1.15 **Never touch the wafer chuck surface with bare hands or metal tweezers!** When working with Si MOSFETs or other oxide devices, ground yourself with the wristband to avoid damaging them. If you can feel a static shock by touching a metal, you should definitely ground yourself regardless what you are working with.

1.16 If you accidentally drop or lose the sample, a screw, or anything else in the microchamber, ask the tool owner to fish it out. **Don't attempt to disassemble the microchamber yourself!**

1.17 **Never change the hardware configuration of the tool except for switching between the 4156C and the 4294A!** Please understand that it is impossible to manage a shared facility with a variable configuration customized for a smart or dumb user. If you encounter anything unexpected during the measurement, report it to the tool owner and record it on the workstation before you log off. Users violating these rules will be removed from the list of qualified users.

1.18 **Never change the probe yourself!** If you think the probe is dirty, worn out, or damaged, ask the tool owner or an expert user to clean or replace it.

1.19 The hardware configuration of the tool includes cables, probe positioners, and other pieces of hardware not listed at the beginning of this manual. Usually, the four probes there, each capable of forcing and sensing a current or voltage, are more than enough. Eight triaxial cables connect the four probes to the two connector panels on the left and right sides of the probe station as shown in Fig. 1.4 and Fig. 1.5, respectively. Between the two cables on each probe, the cable on the dotted (red or white) side connects to the high (force) side of the connector panel; the other cable connects to the low (sense) side of the connector panel. Normally, as shown in Fig. 1.1, the southwest probe is connected to "HRSMU1," the northwest probe is connected to "HRSMU2," the northeast probe is connected to "HRSMU3," and the southeast probe is connected to "HRSMU4."

1.20 Typically, for testing a p-n diode, the n-side is connected to the southwest probe (HRSMU1) while the p-side is connected to the southeast probe (HRSMU4). For testing a field-effect transistor, its source, gate, and drain are connected to the southwest (HRSMU1), northwest (HRSMU2), and southeast (HRSMU4) probes. Even when you switch between the 4156C and the 4294A, you need only to reconnect the front side of the connector panels. **Never change the connection on the probes or the back of the connector panels except for electrically isolating the chuck as in the following steps or in Step 4.2!**

1.21 For testing the current-voltage (I-V) characteristics of a diode with only a top contact while grounding the substrate to the wafer chuck, electrically isolate the chuck by: 1) Locate the two chuck bias connectors behind the left (when viewed from front) side of the probe station and hidden below [Fig. 1.6(a)]. 2) Remove both BNC grounding caps and BNC-to-triaxial adaptors to expose the triaxial connectors [Fig. 1.6(b)]. **Don't lose the caps and adaptors, because they need to be put back later!** 3) Locate the "HRSMU1/F" and "HRSMU1/S" cables on the backside of the

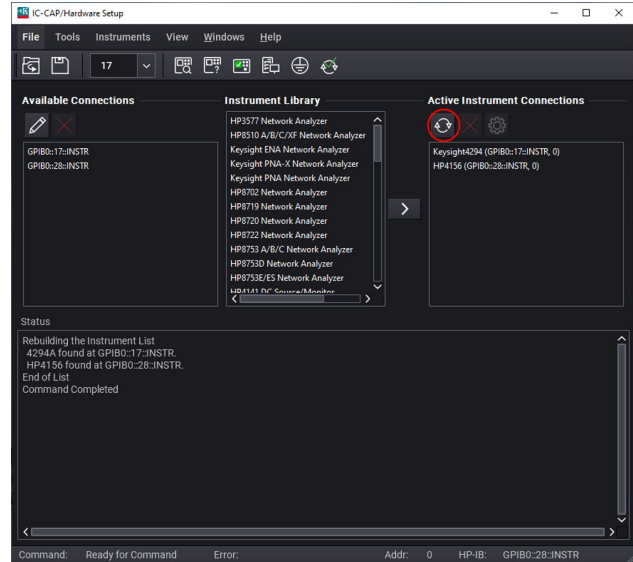


Fig. 1.3. Active instrument connections.

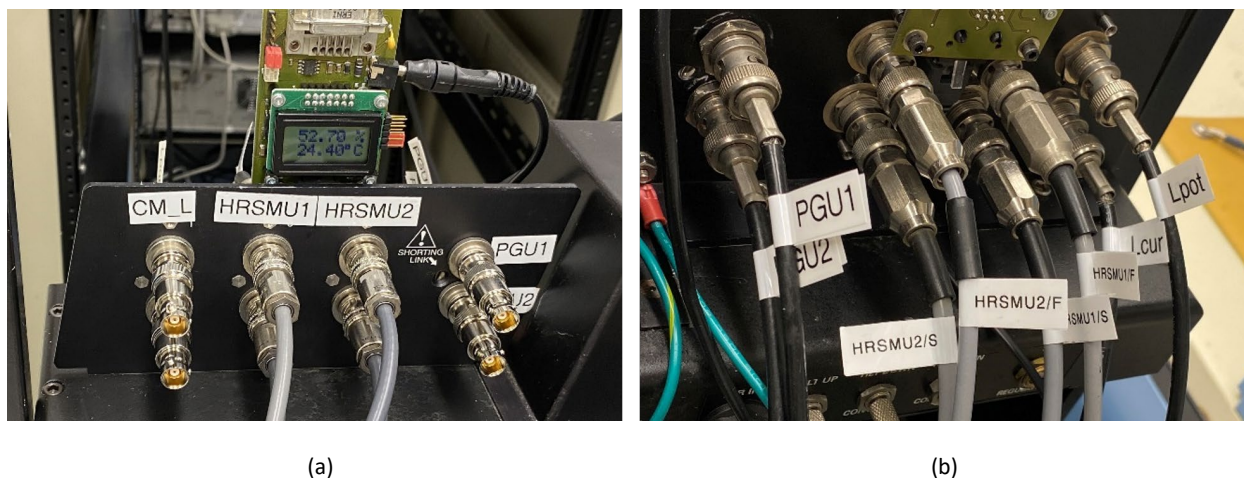


Fig. 1.4. Normal configuration of the (a) front and (b) back of the left connector panel.

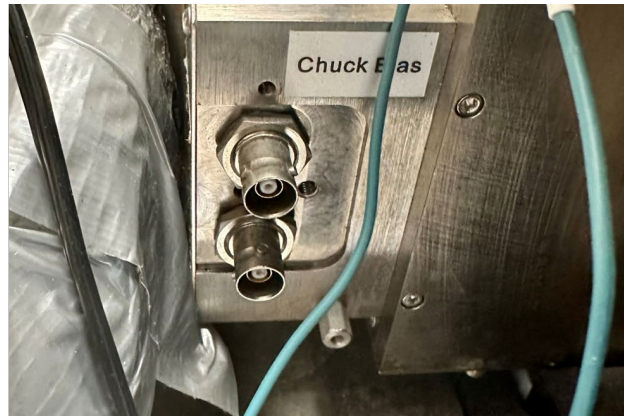


Fig. 1.5. Normal configuration of the (a) front and (b) back of the right connector panel.

- left (viewed from the front) connector panel [Fig. 1.7(a)], which are connected to "HRSMU1" on the frontside. 4) Disconnect the cables and reconnect them to the chuck bias [Fig. 1.7(b)]. **After you are finished with your measurements, remember to reconnect these cables to "HRSMU1" and the triaxial-to-BNC adaptors and BNC caps to the chuck bias, because many users do not check behind the connector panels!**
- 1.22 For testing the current-voltage (I-V) characteristics of a field-effect transistor with only the gate and drain contacts on the top of the chip while grounding the source through the substrate to the wafer chuck, follow the above step to connect the "HRSMU1/F" and "HRSMU1/S" cables to the chuck bias. Similarly, for testing the current-voltage (I-V) characteristics of a field-effect transistor with only the source and drain contacts on the top of the chip while gating through the substrate in contact with the wafer chuck, follow the above step except to connect "HRSMU2/F" and "HRSMU2/S" to the chuck bias instead of "HRSMU1/F" and "HRSMU1/S".
 - 1.23 For testing the capacitance-voltage (C-V) characteristics of a diode with only a top contact while grounding the substrate to the wafer chuck, see Step 4.2.

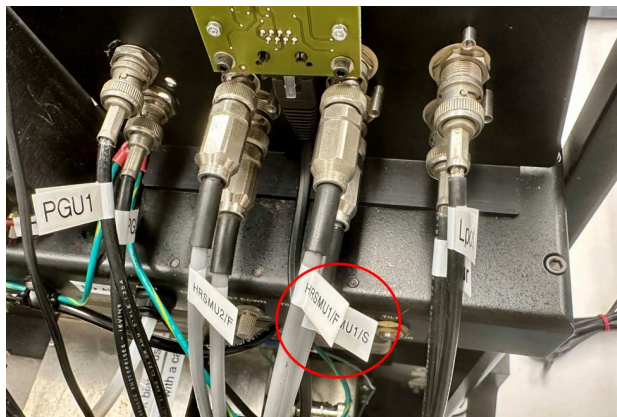


(a)

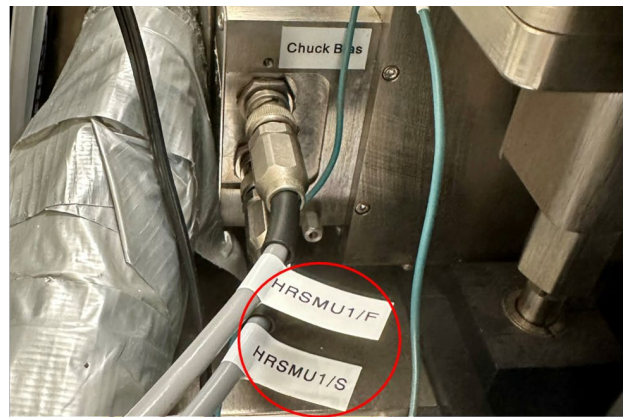


(b)

Fig. 1.6. (a) Grounded and (b) open configurations of the chuck bias.



(a)



(b)

Fig. 1.7. Moving the "HRSMU1/F" and "HRSMU1/S" cables from (a) the backside of the left (viewed from the front) connector panel to (b) the chuck bias.

2. Cascade Summit 12K Probe Station

The probe station is equipped with an electrically-shielded and light-tight microchamber for controlled sample environment. Although it is by no means a vacuum enclosure, it is sufficiently tight for flushing out the room air with dry nitrogen to prevent frost formation at temperatures as low as -50°C . The 200-mm wafer chuck is triaxially guarded, ideal for ultra-low-leakage current-voltage (I-V) and capacitance-voltage (C-V) measurements. The chuck is normally grounded except in Steps 1.21, 1.22 or 4.2. Follow these steps to load the sample and to contact it with probes:

- 2.1 Remove the dust cover and store it in the top-right drawer of the workbench left of the probe station.
- 2.2 Confirm the hardware configuration according to Fig. 1.4 and Fig. 1.5.
- 2.3 Make sure the microscope is lifted up as shown in Fig. 2.1. This way, through the top opening of the microchamber, you can peek with bare eyes at the probes inside. If the microscope is down, lift it by flipping the switch near the left end of the bridge the microscope is mounted on. This heavy-duty bridge spans the width of the probe station and supports the microscope with high stability.
- 2.4 With bare eyes, make sure the probes are safely above the chuck and away from each other by at least a few millimeters. If necessary, gently adjust the probe positioner while observing how the probe moves. By acquainting with the probe configuration and movement with bare eyes, later you will have a better feel for them when viewed through the microscope. Good eye-hand coordination can be learned. **Never adjust the probe positioners without simultaneously observing the probe movement with bare eyes, through the microscope, or on the TV monitor!** The probe positioners are magnetically attached to the platen and further secured by tapes. **Never tear the tapes to move or dismount the probe positioners!** The platen is the large metal plate spanning the width and depth of the probe station.
- 2.5 Make sure the z-lever (Fig. 2.1) is up, which lifts the platen, including the probe positioners and microchamber cover, away from the chuck. Lowering the z-lever lowers the platen and brings the probes closer to the chuck.
- 2.6 Unlock the microchamber access door by turning the two knobs on the left and right ends of the door (Fig. 2.1). Allow the door to flip down while remaining hinged.
- 2.7 Reach into the microchamber and rotate the roll-out stage handle [Fig. 2.2(a)] counterclockwise to unlock the stage. Pull the stage out until it locks outside the microchamber. **Never pull out the stage with the z-lever down! Never touch the chuck surface with bare hands!**
- 2.8 Using plastic tweezers or plastic-tipped metal tweezers, place your sample at the center of the chuck and align it with the x-axis of the chuck, make sure that the x-axis of the chuck itself is aligned with the edge of the microchamber. If necessary, turn the θ control directly under the chuck to align its x-axis with the edge of the microchamber. **Never scratch the chuck surface with metal tweezers!**

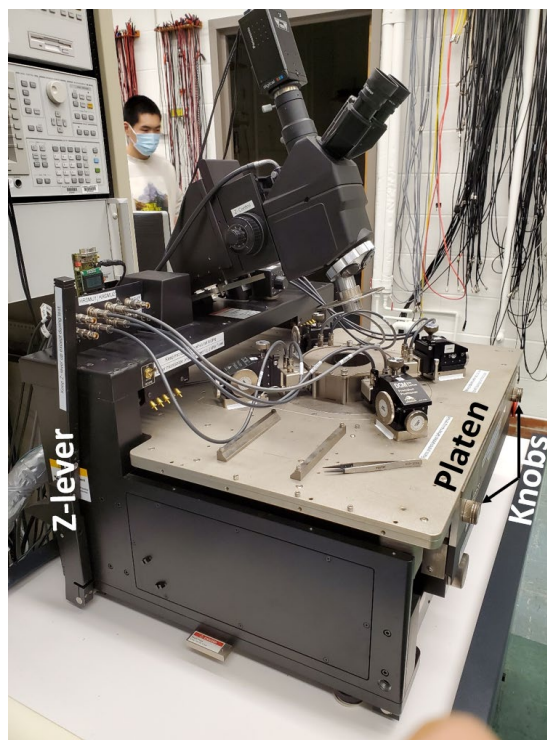


Fig. 2.1. Z-lever for platen and doorknobs for microchamber.

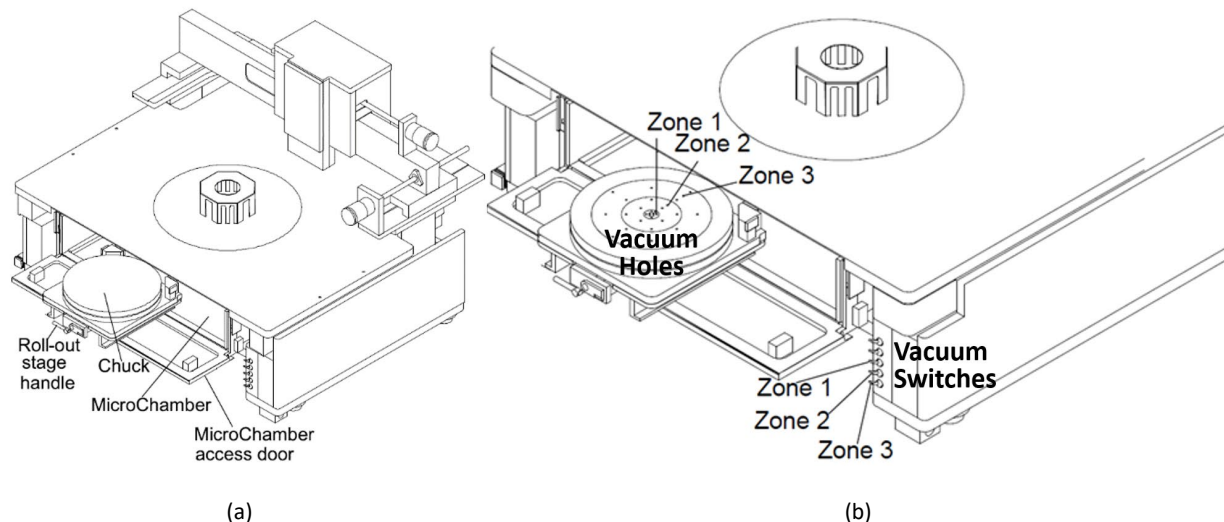


Fig. 2.2. (a) Access and (b) vacuum control of the wafer chuck.

- 2.9 Turn on the vacuum pump under the vibration-isolation table. The switch is on the power cord right next to the pump as shown in Fig. 2.3(a).
- 2.10 Depending on the sample size, configure the switches on the lower-right of the probe station [Fig. 2.2(b)] to apply vacuum to the holes in different zones of the chuck. For small samples (< 3" dia.), switch on (flip right) Zone 1 (13 mm dia.) only. For $\geq 3"$ samples, switch on both Zone 1 and Zone 2 (75 mm dia.). For $\geq 6"$ samples, switch on Zone 1, Zone 2, and Zone 3 (150 mm dia.). Leave the top switch off for the auxiliary chuck.
- 2.11 Gently nudge the sample with tweezers to confirm the friction caused by vacuum. Otherwise, switch off the vacuum, inspect the sample bottom to make sure it is clean, smooth and flat, place the sample on the wafer chuck again and switch back the vacuum. If the problem persists, discuss it with the tool owner or an expert user.
- 2.12 Push the roll-out stage all the way inside the microchamber and rotate the handle clockwise to lock it.
- 2.13 Close the microchamber access door and lock it with the doorknob.
- 2.14 Gently lower the z-lever while observing with bare eyes the probes remain safely above the sample. Otherwise, lift the z-lever and coarsely adjust the probe positioners.
- 2.15 Lower the microscope using the switch on the left end of the bridge. The response is purposely delayed to soften the mechanical impact. **Never lower the microscope with the z-lever up!** Otherwise, the microscope may crash into the microchamber cover and cause damage.
- 2.16 Make sure the skirt of the microscope objective is resting on the center of the microchamber cover. Then, you can use the microscope as a reference to center the sample and probes. If the sample is too far off the center of the microchamber, it may not be reachable by the probes.
- 2.17 Turn on the microscope light. The switch is on the right side of the bridge the microscope is mounted on. Adjust the light intensity for the best contrast under the microscope. If a good contrast cannot be obtained even at the lowest light intensity, it can be further lowered by increasing the zoom control located on the right side of the microscope near the front. The light intensity may have to be readjusted for the best contrast on the TV monitor.
- 2.18 Focus the microscope on the sample. **Keep the microscope objective safely above the sample and probes!** The 2X objective has a long working distance of approximately 3 cm and should never be allowed to come within a few millimeters of the sample or probes.

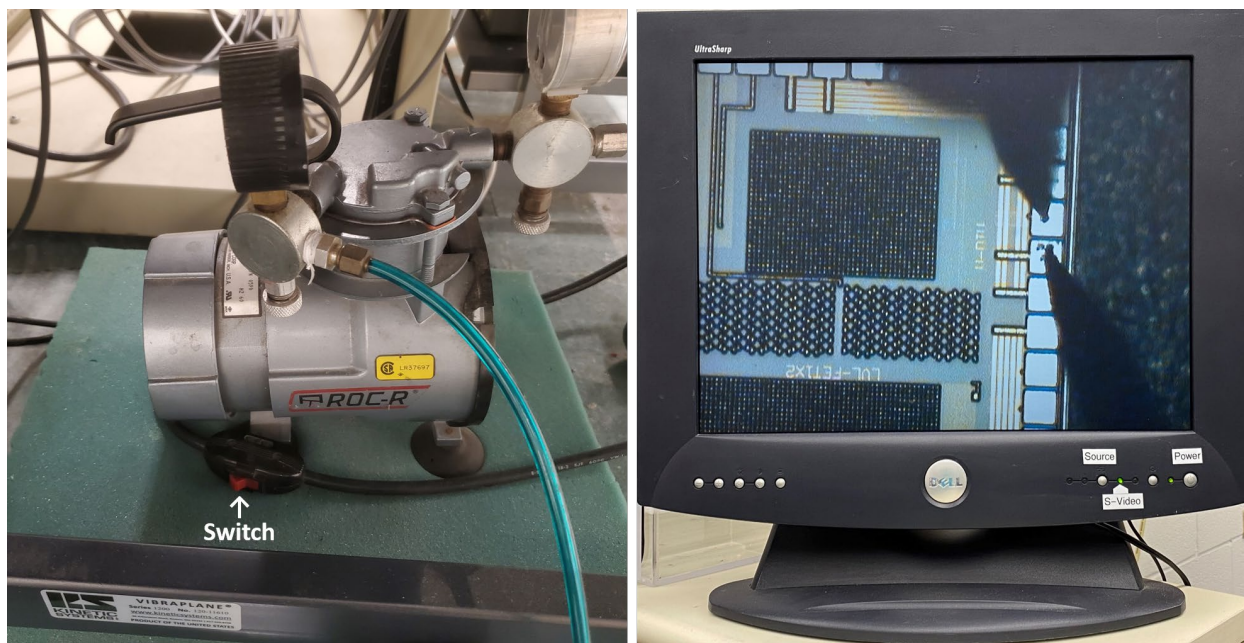


Fig. 2.3. (a) Vacuum pump and (b) TV monitor.

- 2.19 When the sample is in focus under the microscope, its image should also be displayed by the TV monitor on the shelf left of the probe station. Make sure it is on and with "3:S-Video" selected as the source [Fig. 2.3(b)].
- 2.20 Locate through the microscope the sample as well as the probe tips. If necessary, enlarge the field of view by reducing the zoom ratio from 2X toward 1X. If not all probe tips can be seen through the microscope, lift the microscope and coarsely adjust the probe positioners under bare eyes, before lowering the microscope again.
- 2.21 Using the x and y controls on the bottom of the probe station to move the wafer chuck so that the desired die on the sample appears under the microscope.
- 2.22 Finetune the probe positioners to land the probes on the contact pads of the device-under-test (DUT). The probe is contacting the probe pad when it starts to skate sideways when lowered.
- 2.23 Turn off the microscope light so that it will not interfere with the measurement. Keep in mind that, despite the vibration-isolation table, even a gentle motion such as lifting the microscope can vibrate the probes off the DUT and scratch it without you knowing it in real time. Avoid any such motion during measurement.
- 2.24 Follow Sec. 3 for I-V measurements, Sec. 4 for C-V measurements, Sec. 5 for heated or cooled measurements, and Sec. 6 for pulsed I-V measurements.

3. Agilent 4156C Precision Semiconductor Parameter Analyzer

As shown in Fig. 3.1, this electronic instrument measures and analyzes the I-V characteristics of a semiconductor device, whether 2-, 3-, or 4-terminal. It has four high-resolution source/monitor units (HRSMUs, ± 100 V, 0.1 A), two voltage source units (VSUs, ± 20 V max), and two voltage measurement units (VMUs, ± 20 V max). A 41501B SMU and Pulse Generator Expander is attached to the 4156C. The 41501B contains two pulse generator units (PGUs, ± 40 V max with 100-V/ μ s slew rate), one high-power source/monitor unit (HPSMU, ± 200 V, 0.5 A), and one ground unit (GNDU). The 4156C is designed for Kelvin connections. HRSMUs, HPSMUs, and GNDU output terminals use triaxial connectors whereas VSU, VMU, and PGU output terminals use BNC connectors.

If you want to apply more than 40 V, ask the tool owner or an expert user to connect interlock terminals of the 41501B and the probe station with a BNC cable! Otherwise, the output voltage is automatically limited to 40 V to minimize high-voltage danger. The 4156C is controlled by the IC-CAP program on the PC. Follow these steps to use the 4156C:

- 3.1 If the 4156C is off, turn it on and wait for about 30 min for it to warm up. Normally it is left on 24/7.
- 3.2 For pulsed (as opposed to CW) I-V measurements, go to Sec. 6.
- 3.3 For temperature-controlled I-V measurements, go to Sec. 5.
- 3.4 Make sure the frontside of the connector panels are connected to the 4156C instead of the 4294A as shown in Fig. 1.4 and Fig. 1.5.
- 3.5 From the PC desktop, open "IC-CAP" if it is not already open from Steps 1.9–1.12.
- 3.6 For measuring a p-n diode, it is recommended to contact its n- and p-terminals with the southwest and southeast probes, respectively, as in Step 1.20. On the "DC_Test" home screen and under "Diode_1," select "IV_Test." The top menu selection of "Measure/Simulate" should automatically be displayed as shown in Fig. 3.2. For example, it shows that the input of HRSMU1 is set to 0 V. The input of HPSMU4 is swept from -5 V to 5 V in 0.1-V steps. The output current is measured also by HPSMU4. "Mode" defines the input/output in current or voltage. You can customize these parameters, but leave "Type" in "M." When the input is in voltage, set "Compliance" to a low limit such as 100 mA to avoid burning out the DUT, or, worse, the test setup!
- 3.7 For measuring a field-effect transistor, it is recommended to contact its source, gate and drain terminals with the southwest, northwest and southeast probes, respectively, as in Step 1.20. In the left menu of "DC_Test" and under "Transistor_1," select "Id_Vg_Test." The top menu selection of "Measure/Simulate" is displayed as shown in Fig. 3.3. It shows that the input of HRSMU1 is set to 0 V. The input of HRSMU2 is swept from 0 to -5 V in 100-mV steps. The input of HRSMU4 is set at 1 V. The output current is measured also by HRSMU4. Fig. 3.4 illustrates the "Measure/Simulate" display for "Id-Vd_Test," which measures the output characteristics by stepping both the gate and drain voltages.

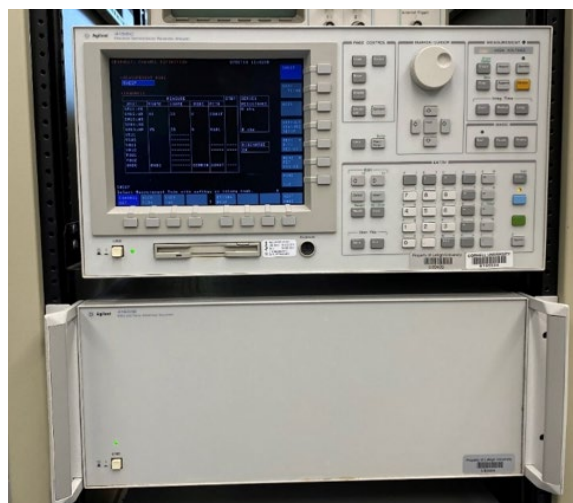


Fig. 3.1. Agilent 4156C precision semiconductor parameter analyzer.

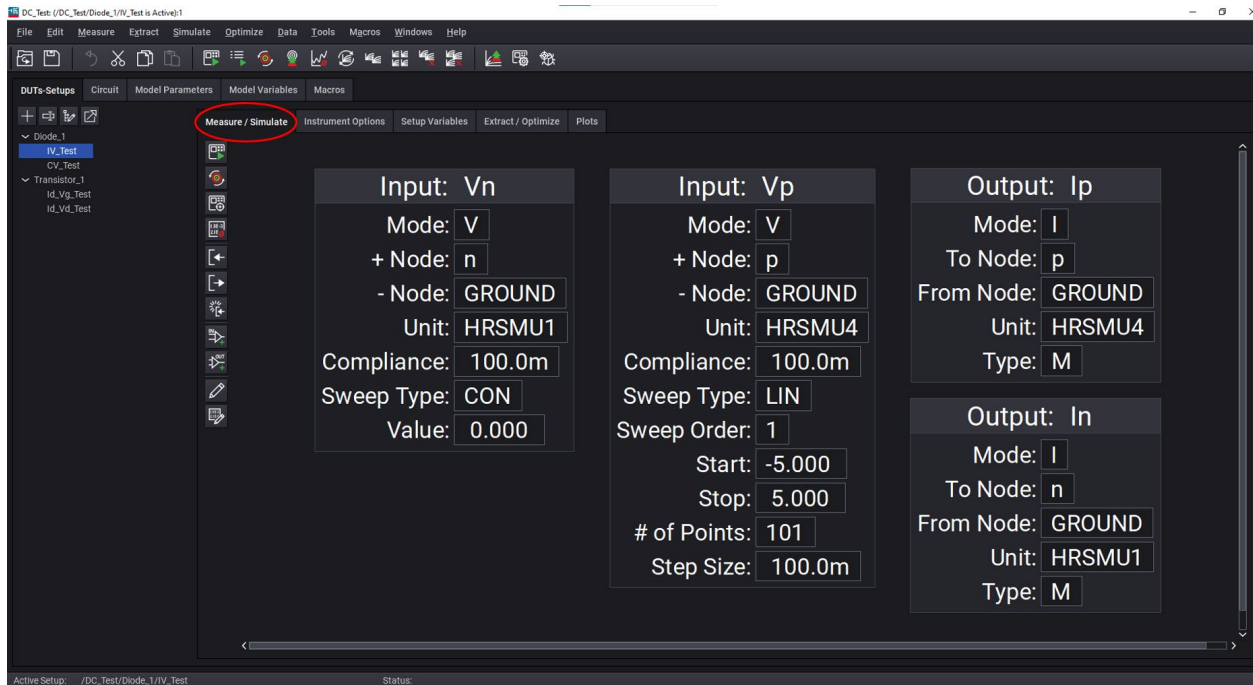


Fig. 3.2. Template for measuring the diode I-V characteristic.

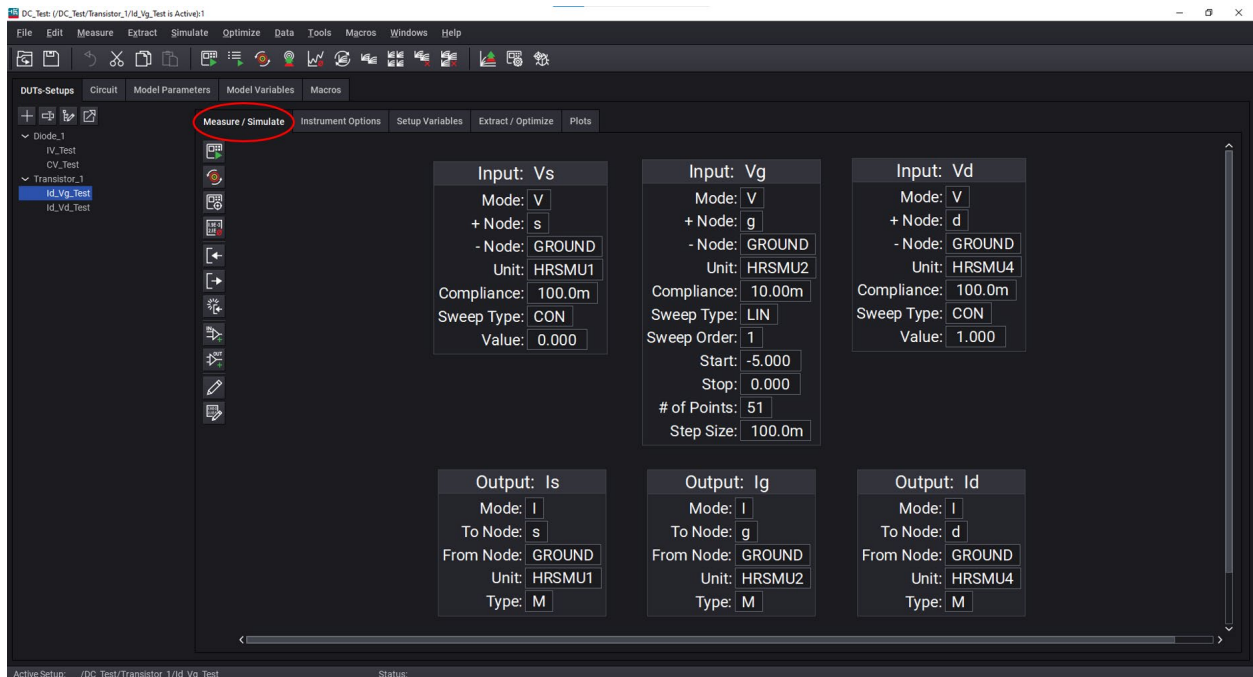



Fig. 3.3. Template for measuring the transistor transfer characteristic.



Fig. 3.4. Template for measuring transistor output characteristics.

- 3.8 If you need more inputs/outputs, "copy" an input/output panel in Figs. 3.2–3.4, "paste," then double-click it to customize. As listed in the beginning of Sec. 3, the available units are HRSMU1, HRSMU2, HRSMU3, HRSMU4, HPSMU5, PGU1, and PGU2. Normally, HRSMU1, HRSMU2, HRSMU3, and HRSMU4 are preferred due to their high resolution. Their voltage capacity (± 100 V max) should be sufficient in most cases, except that their currents are limited to 0.1 A. HPSMU5 is used only for higher power measurements and PGU1 and PGU2 are used only for pulsed measurements. Nevertheless, with four probes, you are limited to a maximum of four inputs and four outputs. You can switch between HRSMU, HPSMU, and PGU on the frontside of the left and right connector panels. **Before you leave the probe station, always leave the connector panels in the same configuration as in Fig. 1.4 and Fig. 1.5!**
- 3.9 Start the measurement by clicking on  on the left menu of Figs. 3.2–3.4, the cursor on the screen starts spinning and the message "Measure in Progress" appears on the bottom of the window.
- 3.10 After the cursor stops spinning and the message "Measure Complete" appears, you can click on "Plots" on the top menu to check the result. Fig. 3.5 illustrates the setup for plotting an I-V characteristic of a diode in an XY graph. Fig. 3.6 and Fig. 3.7 illustrate the setups for plotting the transfer and output characteristics, respectively, of a transistor. Again, you can customize them or copy/paste/double-click to setup another plot.

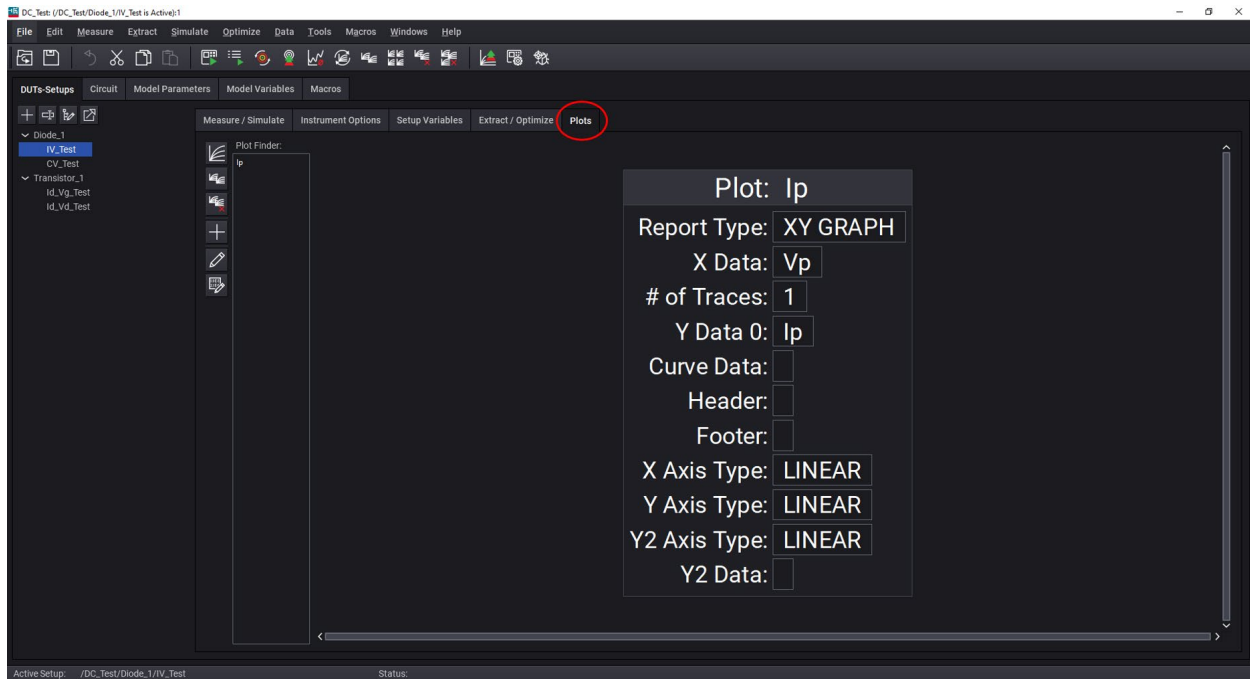


Fig. 3.5. Plotting the I-V characteristic measured on a diode.

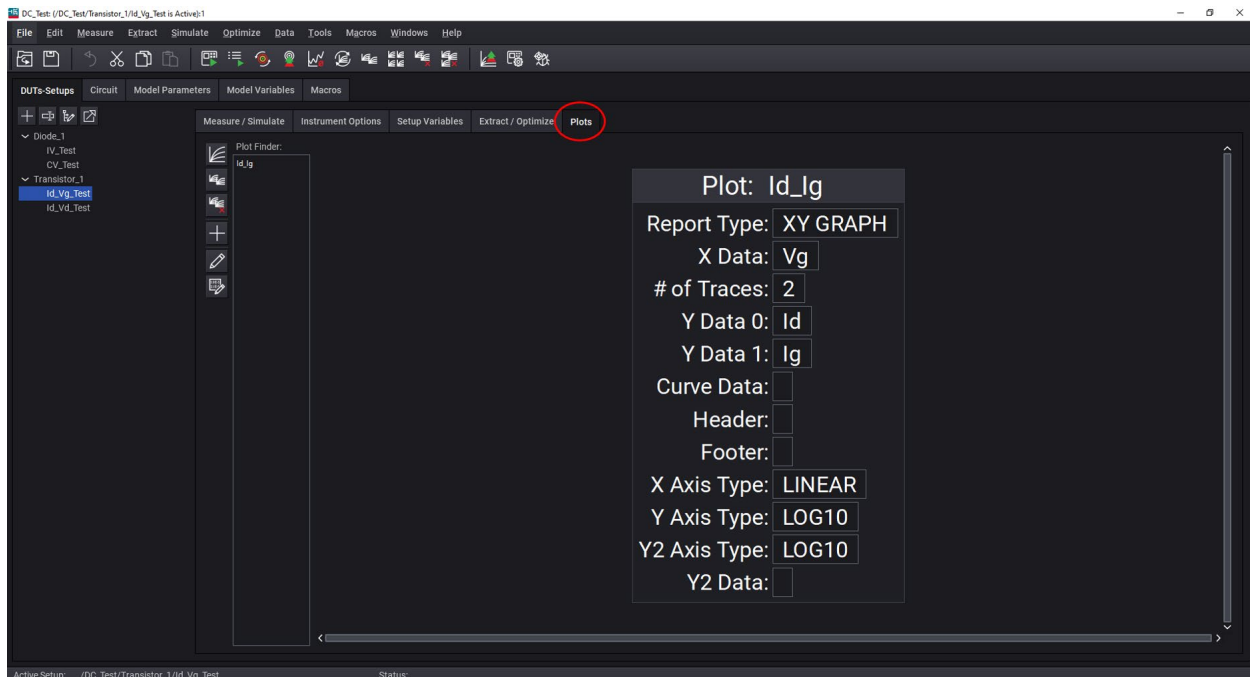


Fig. 3.6. Plotting the transfer characteristic measured on a transistor.

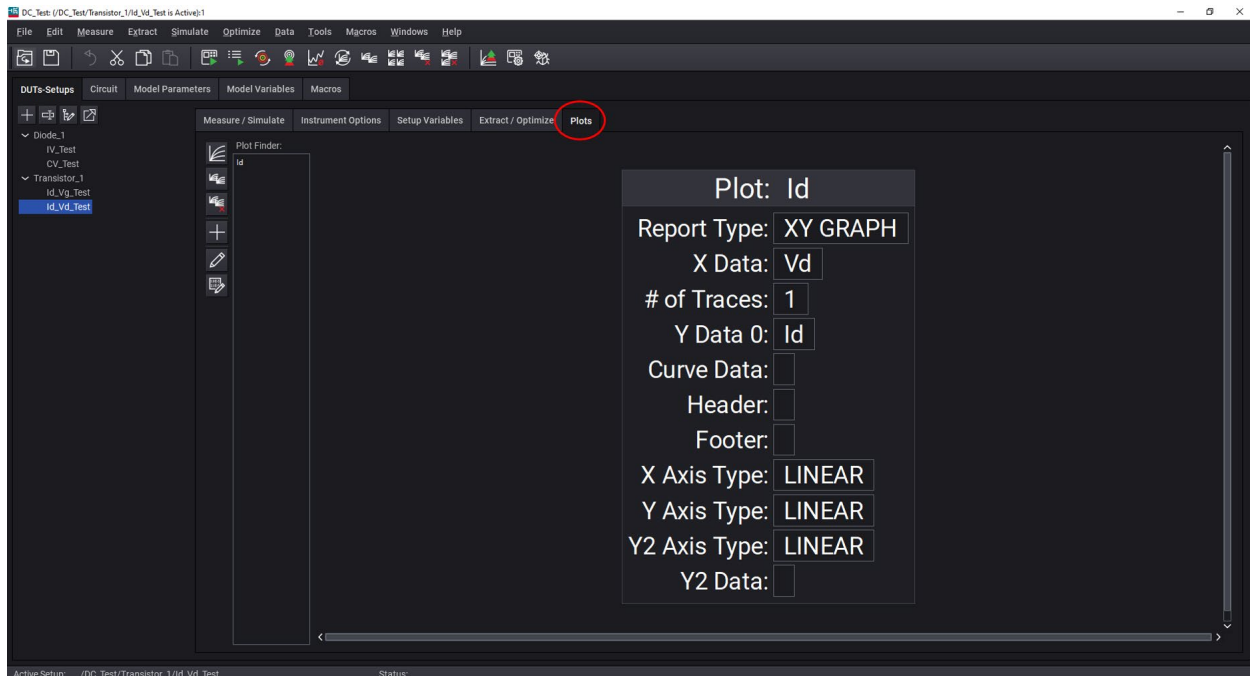





Fig. 3.7. Plotting output characteristics measured on a transistor.

- 3.11 Click on  on the left menu to "Display Plot" as shown in Fig. 3.8. If the plot appears reasonable, you can click on "File" on the top left corner, then "Save Image" into your own folder after naming the file. Close the image window. To save the numerical data, go back to "Measure/Simulate" on the top menu, click on  on the left menu to "Export Data." On the popup window as shown in Fig. 3.9, ".csv" is recommended for "Data File Type" because it can be easily imported by Excel, etc. Under "File Name," "Browse" your own folder to save data there under a unique file name. Leave "Data Type" as "Measured." Add "Comment" as you wish. Click on "OK" to save the data.
Do not mess with someone else's folder!
- 3.12 After finishing probing the DUT and before probing another device on the same sample, lift the z-lever to lift the probes safely above the sample and move the wafer chuck to locate the new DUT, before lowering the z-lever to bring the probes above the new DUT. If necessary, readjusting the probe positioners for proper contact with the new DUT. **Never move the wafer chuck with the probes contacting the sample!**
- 3.13 Repeat the measurement on a new DUT by repeating Steps 3.9–3.12.
- 3.14 **Make sure your project is saved on the PC!** IC-CAP will not auto-save your project. To do so, click on  on the top menu of the "DC_Test" home screen. (You could also click on "File" as in Step 3.11. This illustrates the many ways IC-CAP skins a cat.) Fig. 3.10 pops up. It is recommended the "Select File Type" remains ".mdl" but "File Name" points to your own folder. Click on "OK" to save the project. if no more measurement will be done, exit IC-CAP by closing all windows. Leave the PC on.
- 3.15 After all devices are measured, go to Sec. 4 for C-V measurements, Sec. 5 for heated/cooled measurements, Sec. 6 for pulsed I-V measurements, or Sec. 7 to finish up.

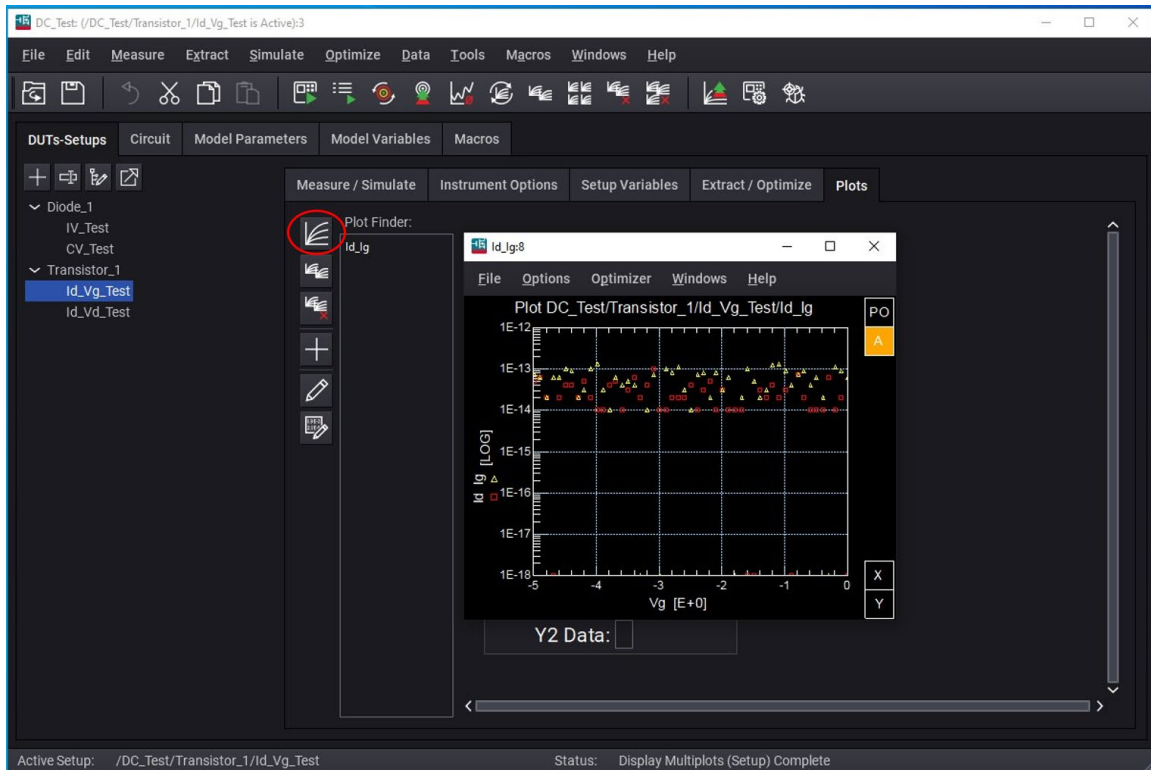


Fig. 3.8. Plot of transfer characteristics measured on a transistor.

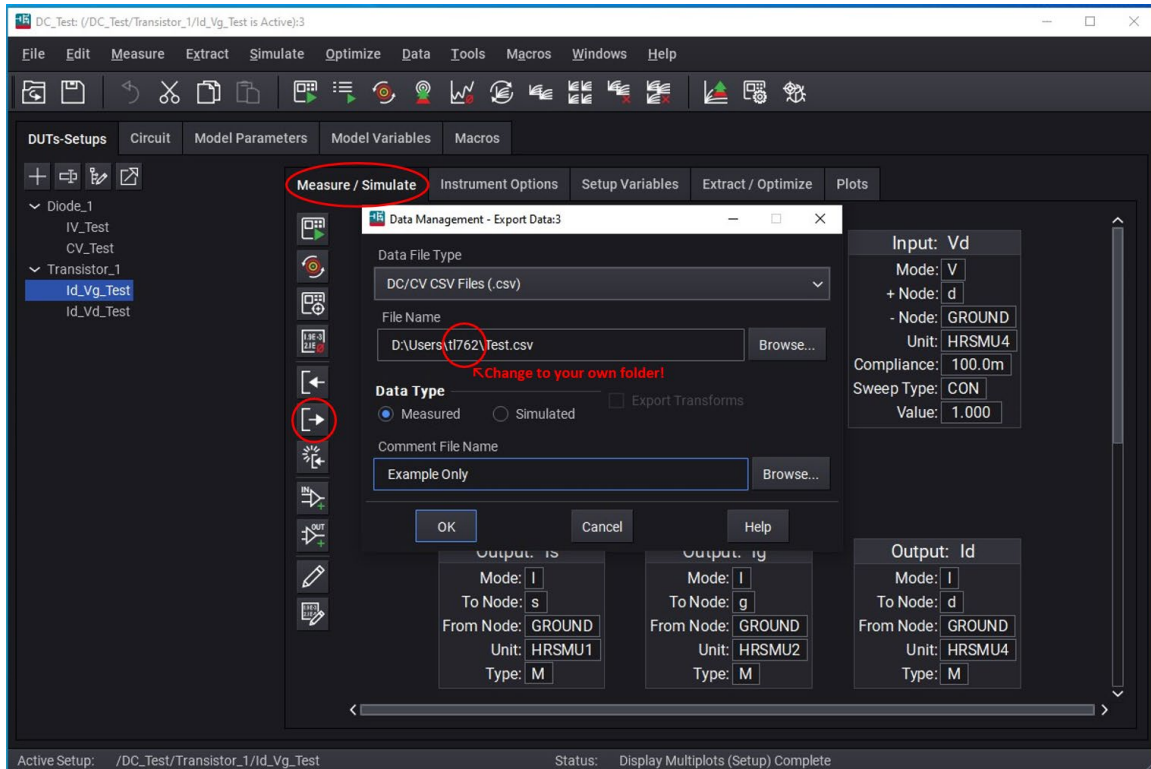


Fig. 3.9. Saving measured data.

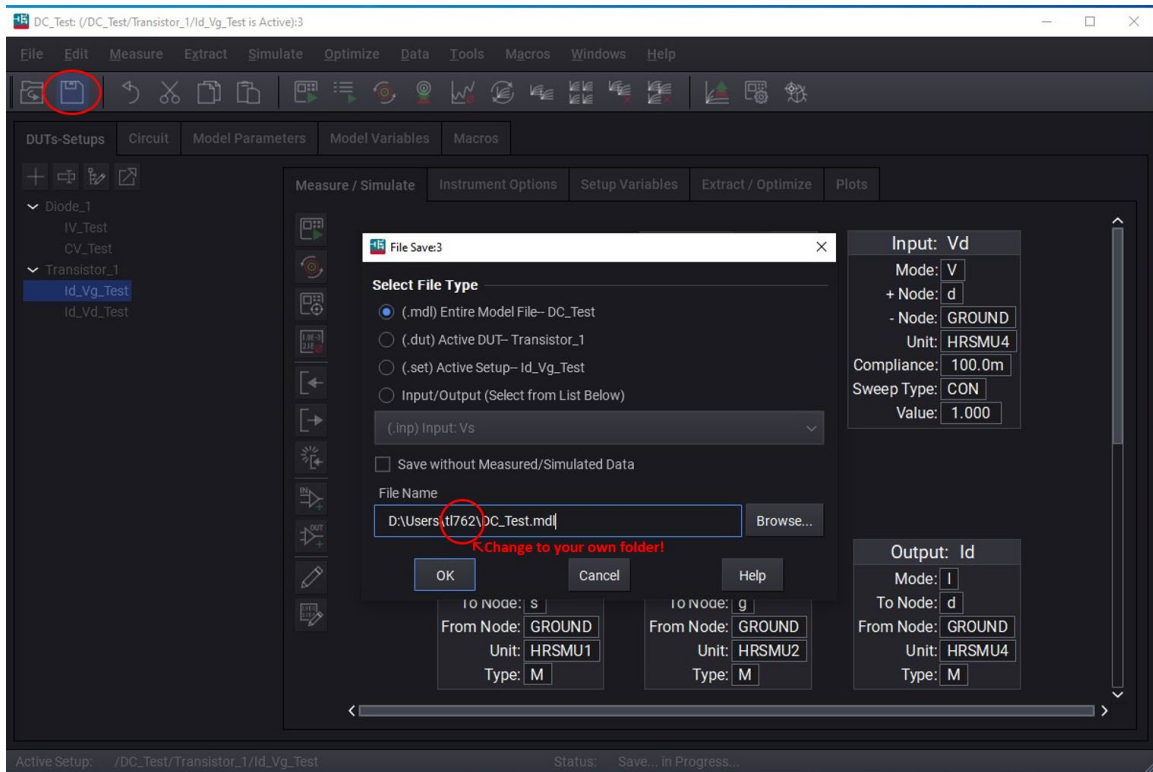


Fig. 3.10. Saving a DC_Test project.

4. Agilent 4294A Precision Impedance Analyzer

This electronic instrument measures and analyzes the impedance/admittance of a device (Fig. 4.1). It includes two pairs of cables with BNC connectors labeled as LPOT and LCUR for the voltage and current Kelvin connections to the low-potential side, and HPOT and HCUR for the Kelvin connection to the high-potential side. Like the 4156C, it is also controlled by IC-CAP except for pulsed measurements. To use the 4294A, first make sure the z-lever is up and the probes are fully raised and retracted by adjusting the probe positioners. Then follow the same steps as in Sec. 3 except:

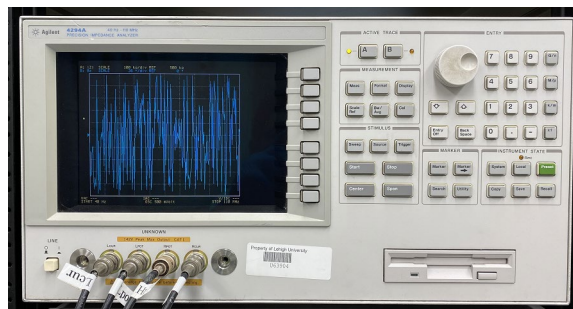

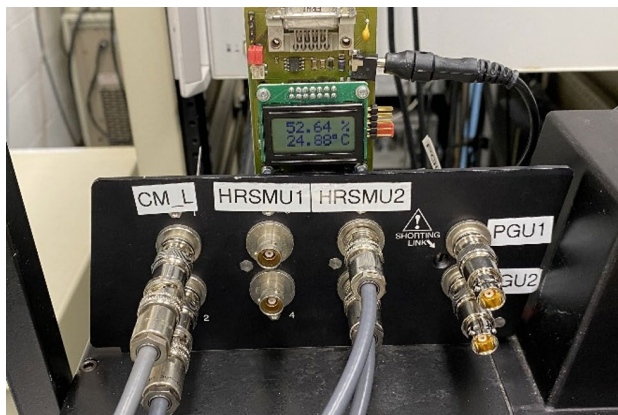
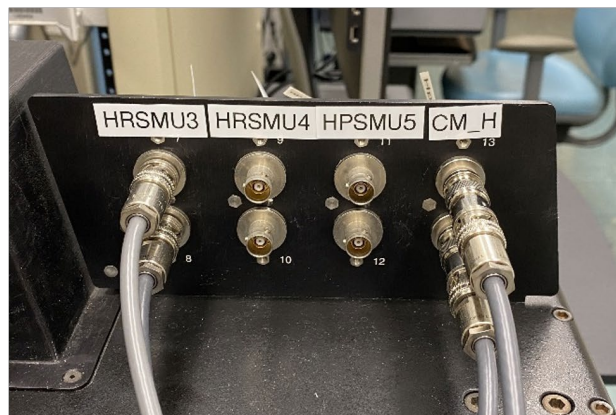


Fig. 4.1. Agilent 4294A precision impedance analyzer.

- 4.1 Make sure the connector panels are connected to the 4294A (instead of the 4156C) as shown in Fig. 4.2, i.e., with the southwest probe connected to "CM_L" (instead of HRSM1) and the southeast probe connected to "CM_H" (instead of HRSM4).
- 4.2 For measuring a pn diode with only a top contact while grounded through the substrate to the wafer chuck, electrically isolate the chuck by: 1) Locate the two chuck bias connectors behind the left (when viewed from the front) side of the probe station and hidden below [Fig. 4.3(a)]. 2) Remove the BNC grounding caps while leaving the BNC-to-triaxial adaptors in place [Fig. 4.3(b)]. **Don't lose the caps, because they need to be put back later!** 3) Locate the "Lpot" and "Lcur" cables on the backside of the left (viewed from front) connector panel [Fig. 4.4(a)], which are connected to "CM_L" on the frontside. 4) Disconnect the cables and reconnect them to the chuck bias [Fig. 4.4(b)]. **Remember to reconnect these cables back to "CM_L" when all measurements are done, because many users do not check behind the connector panels!**
- 4.3 For temperature-controlled C-V measurement, go to Sec. 5 before continuing to Step 4.4.
- 4.4 Open "IC-CAP" on the PC desktop if it is not already open. Under "DC_Test.mdl" copied to your own folder, select "CV_Test" under "Diode_1" as shown in Fig. 4.5. For example, the input of the CM unit (Vpn) is swept from 0 to 1 V in 100 mV steps while the output of the same unit is measured in capacitance (Cpn) and conductance (Gpn). "CM" is the only available unit. Leave "Type" in "B." The default measurement frequency is 1 MHz. If another frequency is desired, click on "Instrument Options" and change "Meas Freq" as shown in Fig. 4.6.
- 4.5 Click on  on the left menu shown in Fig. 4.5 to calibrate. After the message "You are about to download the current measurement setup into the Keysight4294.1000.0" pops up, click on "OK." If you change the measurement parameters as in Step. 4.4, you may have to recalibrate.
- 4.6 After the message "Disconnect Measurement Leads from DUT Now" pops up, click on "OK" because the probes should have been up.
- 4.7 After the message "You may now re-connect the DUT" pops up, center the desired DUT by moving the chuck. Lower the z-lever and readjusting the probes to contact the DUT. Click on "OK."
- 4.8 Follow Steps 3.9–3.12 to measure, plot, and save the C-V characteristics of the DUT.
- 4.9 After finishing probing the DUT and before probing another device on the same sample, lift the z-lever to lift the probes safely above the sample and move the wafer chuck to locate the new DUT. If necessary, readjusting the probe positioners for proper contact with the new DUT. **Never move the wafer chuck with the probes contacting the sample!**
- 4.10 Repeat the measurement on a new DUT by repeating Step 4.8.
- 4.11 **Make sure your project is saved on the PC by following Step 3.14!** IC-CAP will not auto-save your project. Exit IC-CAP if no more measurement will be done.



(a)



(b)

Fig. 4.2. Connecting the 4294A to the frontside of the (a) left and (b) right connector panels.

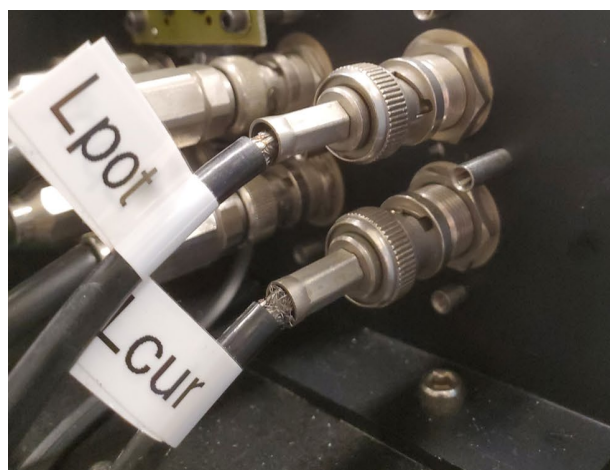


(a)



(b)

Fig. 4.3. Chuck bias connectors (a) with and (b) without BNC caps.



(a)



(b)

Fig. 4.4. "Lpot" and "Lcur" cables connected to (a) backside of left (viewed from front) connector panel and (b) chuck bias.

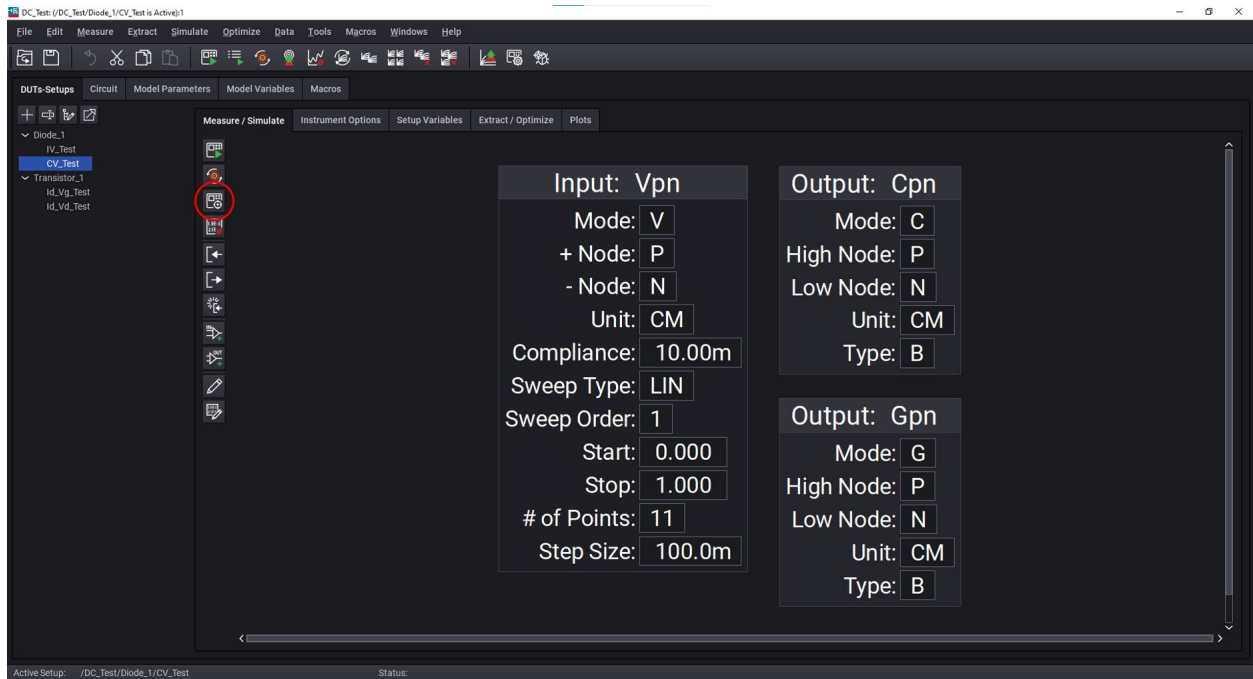


Fig. 4.5. Template for C-V measurements.

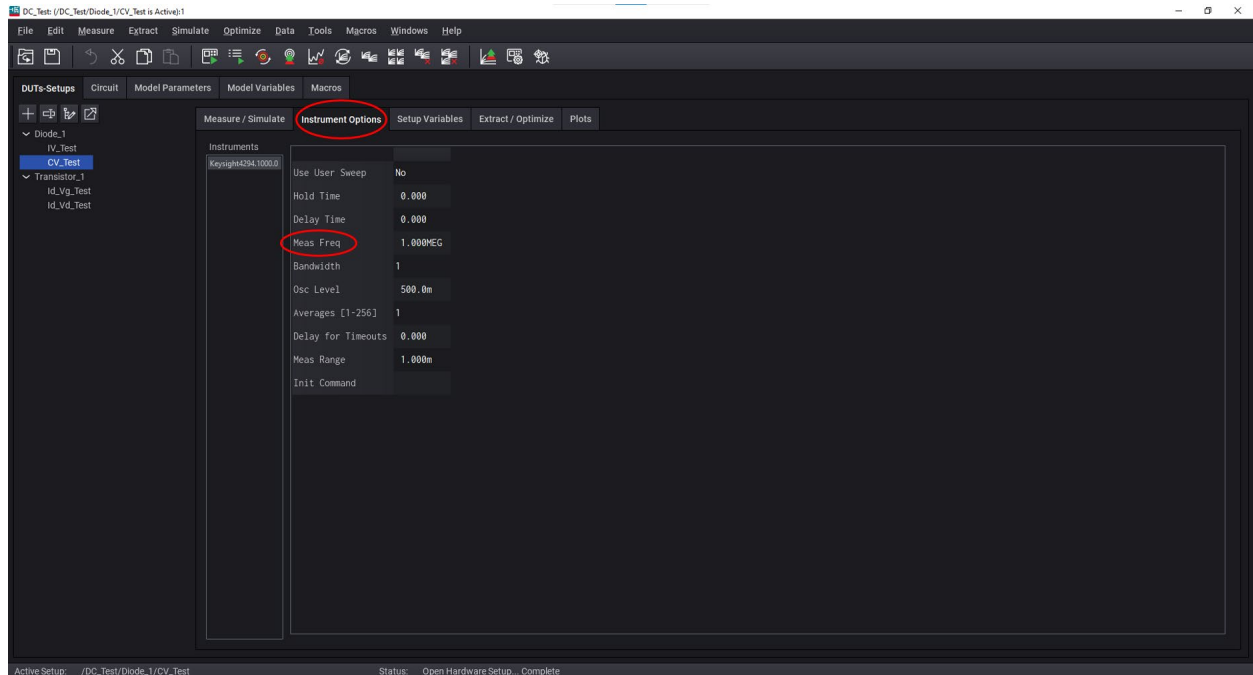


Fig. 4.6. Template for setting measurement frequency.

- 4.12 **Raise the z-lever and the probes before reconnecting the cables to the 4156C as shown in Fig. 1.4 and Fig. 1.5!** Make sure the triax-to-coax adapters remain on "CM_L" and "CM_H" as shown in the figures. If you followed Step 4.2 to move the "Lpot" and "Lcur" cables to the chuck bias, remember to return them to "CM_L" on the backside of the left connector panel [Fig. 4.4(a)] and recap the chuck bias [Fig. 4.3(a)]. **Don't surprise the next user who does not check behind the connector panels!**
- 4.13 After all devices are measured, go to Sec. 3 for I-V measurements, Sec. 5 for heated/cooled measurements, Sec. 6 for pulsed I-V measurements, or Sec. 7 to finish up.

5. Temptronic TPO3000 ThermoChuck System

This heater/refrigerator can control the wafer chuck temperature between $-50\text{ }^{\circ}\text{C}$ and $+200\text{ }^{\circ}\text{C}$ (Fig. 5.1). It is located left of the probe station facing back. It is normally off because most measurements are performed at the room temperature. The probe station is equipped with an electrically shielded and light-tight microchamber for controlled sample environment. Although it is by no means a vacuum enclosure, it is sufficiently tight for flushing out the room air with dry nitrogen to prevent frost formation at temperatures as low as $-50\text{ }^{\circ}\text{C}$. Follow these steps to manually control the temperature of the wafer chuck, either by heating or cooling.

- 5.1 Before any heated or cooled measurement, first follow Sec. 3 or Sec. 4 to perform a room-temperature measurement to make sure the setup and the DUT are performing as expected. Keep in mind that heating or cooling can take tens of minutes.
- 5.2 If you need to do both heated and cooled measurements, it is better to do the heated measurement first to help remove the moisture from inside the microchamber to prevent frost formation during cooling later.
- 5.3 Seal the microchamber by 1) closing the access door, 2) lowering the z-lever, and 3) lowering the microscope. Lowering the z-lever seals the gap between the probe platen and the bottom half of the microchamber that houses the wafer chuck. The objective lens of the microscope should have a skirt attached to seal the top half of the microchamber while the microscope is moved around. **Never lower the microscope with the z-level up!**
- 5.4 Turn on (counterclockwise) the N_2 flow meter on the left-front leg of the vibration-isolation table to purge the microchamber under 7 standard cubic feet per minute (SCFM).
- 5.5 Purge the microchamber until the humidity drops to below 10%. Humidity and temperature in the microchamber are read from the little display above the left connector panel as shown in Fig. 1.4(a). Do not confuse the microchamber temperature with the chuck temperature, the latter is displayed on the Temptronic controller only.
- 5.6 After purging to below 10%, reduce the flow to 3 SCFM if the desired chuck temperature is below $41\text{ }^{\circ}\text{C}$, and 2 SCFM if it is above $41\text{ }^{\circ}\text{C}$.
- 5.7 **Never heat up or cool down the chuck with the probes contacting the sample!** Otherwise, the difference in thermal expansion can cause the probe and sample to move against each other damaging both.
- 5.8 Turn on the Temptronic controller on top of the Temptronic refrigerator (Fig. 5.2).
- 5.9 For several minutes, the Temptronic controller will display "Wait." The refrigerator is more than 20 years old and cannot be rushed. **Be patient and gentle!**
- 5.10 After the "Wait" message disappears, "TA" should illuminate and gradually approaches the default setting of 41, while "T1" and "T2" display "100" and " -50 ," respectively.



Fig. 5.1. Temptronic TPO3000 ThermoChuck system.



Fig. 5.2. Temptronic temperature controller.

- 5.11 After "TA" exceeds 40 and "AT TEMP" illuminates, press "T1" and use "↑" and "↓" on the keypad to set it to the desired chuck temperature if it is above 41 °C; press "T2" and use "↑" and "↓" to set it to the desired chuck temperature if it is below 41 °C. **Do not touch other keys of the keypad by removing its cardboard cover!**
- 5.12 **For temperatures below 41 °C, make sure the sample is not frosted by frequently checking it through the microscope!** If you see any frost, press "TA" to return to the default temperature of 41 °C and alert the tool owner or an expert user, before causing further damage.
- 5.13 Wait until the Temptronic controller verifies that the desired chuck temperature is reached by illuminating "AT TEMP," before contacting the sample with probes to begin the measurement. Be patient. It takes time for the temperatures of the chuck and sample to equilibrate in any case. Even after the chuck is "AT TEMP" and before starting the measurement, it is best to wait a few minutes for the sample temperature to approach that of the chuck. Keep in mind that the temperature controller senses the temperature of the chuck, not the temperature of the sample.
- 5.14 **Always lift the probes by the probe positioners before changing to the next device or temperature!** Do not lift the z-lever because it opens the seal between the platen and the bottom half of the microchamber.
- 5.15 **Follow Sec. 3 or Sec. 4 to perform I-V or C-V measurement.**
- 5.16 After finishing the at-temperature measurement, press "TA" to return the chuck temperature to the default setting of 41 °C.
- 5.17 **Wait for as many minutes as needed for the chuck temperature to exceed 40 °C and "AT TEMP" illuminates again!** Then, shut down the Temptronic controller, stop the N₂ flow, and open the microchamber. The chuck needs to return to 41 °C instead of 25 °C to prevent the formation of frost, which may ruin not only the test setup, but also your sample. Temptronic uses both heating and cooling to accurately control the temperature even if it is set at the room temperature. The < -50 °C refrigerant continues to circulate below the chuck until its temperature exceeds 40 °C. If you open the microchamber before the chuck temperature exceeds 41 °C, frost will form on the body of the chuck even if its top is above freezing.
- 5.18 It is usually a good idea to repeat the measurement at the room temperature both before and after a heated or cooled measurement to confirm the sample is not degraded by the temperature cycle.
- 5.19 Often it is convenient to switch from a temperature-controlled I-V measurement to a C-V measurement (or vice versa) at the same temperature. In this case, lift the probes by the probe positioners. **Do not lift the microscope or the z-lever because it will open the microchamber to air and may damage the sample or the setup.** Next, follow Sec. 3 for I-V measurement or Sec. 4 for C-V measurement. Switching between I-V and C-V measurements requires switching the cables

connecting the probes to the connector panels. Such rough movement can damage the sample or the probes if they are close.

- 5.20 After finishing all measurements, I-V or C-V, room temperature or heated/cooled, go to Sec. 7 to finish up.

6. Pulsed I-V Measurements

Pulsed measurements are based on the Agilent 4156C precision semiconductor parameter analyzer, but controlled by Metrics MTW4156 program instead of the Keysight IC-CAP program. **Please first read Sec. 3 about the CW operation of the Agilent 4156C if you are not familiar with it.** Note that, although the pulse generator units (PGU1 and PGU2) are capable of 100 V/ μ s slew rate, the minimum measurement (integration) time of the source/monitor units is 0.6 ms. Therefore, the Agilent 4156C is more suitable for millimeter-second pulsed I-V measurements than microsecond pulsed I-V measurements.

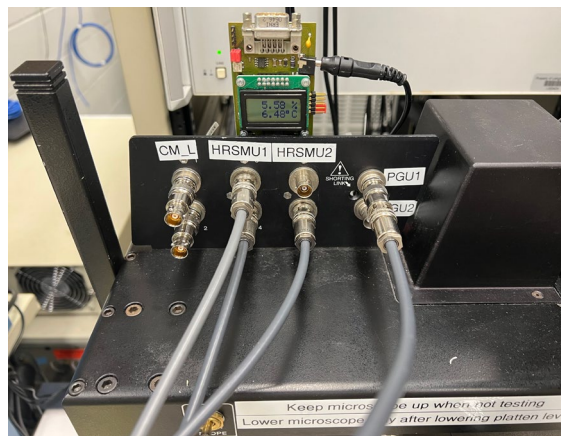

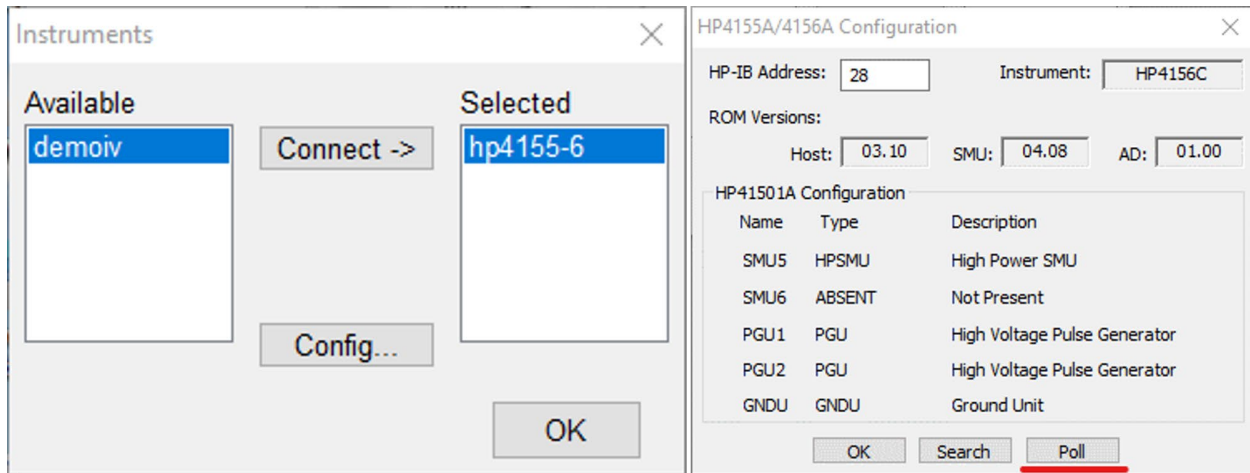


Fig. 6.1. Pulsed configuration on the front side of the left connector panel.

- 6.1 **Make sure the z-lever is up!**
- 6.2 Make sure the connector panels on the left and right of the probe station are connected to the 4156C (instead of the 4294A) as shown in Fig. 1.4 and Fig. 1.5.
- 6.3 Move the top cable connected to the northwest probe from HRSMU2 to PGU1 as shown in Fig. 6.1. **Don't disturb any other connection!**
- 6.4 If the 4156C is off, turn it on and wait for about 30 min for it to warm up. Normally it is left on 24/7.
- 6.5 For temperature-controlled pulsed I-V measurements, go to Sec. 5 before continuing to the next step.
- 6.6 Open "MTW4156" on the PC desktop. Click on "Instruments" and "Select Instrument" as shown in Fig. 6.2(a). Fig. 6.2(b) pops up. Under "Available," click on "hp4155-6." (If hp4155-6 is not available, discuss it with the tool owner or an expert user.) Click on "Connect" and "hp4155-56" should move right under "Selected" as shown in Fig. 6.2(b). Click on "Config" and Fig. 6.2(c) should pop up. Click on "Poll," wait a few seconds, then click on "OK" on both Fig. 6.2(b) and Fig. 6.2(c) to close the windows.
- 6.7 On the top menu of MTW4156, click on  to set up the measurement. Select "NEW" to name the setup, then click on "OK."
- 6.8 In the "Setup Editor" window shown in Fig. 6.3, click on "Devices" to choose the device type to be measured. Click on "OK" and the device diagram with the proper number of terminals appears. For example, the JFET diagram in Fig. 6.3 has three terminals of source, gate, and drain, respectively. If you choose MOSFETs, then a bulk terminal will be added so that there are four terminals altogether.
- 6.9 In "Setup Editor," click on "Sources" and scroll down to "HP4155-6.PGU1," click on it then the device terminal to connect them. In case you make a mistake, repeating the same step on the same terminal will remove the source assignment there. Assign the SMUs to the other terminals as shown in Fig. 6.3. Click on "Done."
- 6.10 In "Setup Editor," click on "Options" to open "Mainframe Setup" as shown in Fig. 6.4(a). Check "Sample/Stress Enable" and select "Sample" mode. Under "Type," select linear or log. Setup "Hold Time," "Interval," and "No. Samples." For example, Fig. 6.4(a) shows zero hold time so that sampling occurs immediately after the pulse. Then, sampling is repeated every 4 ms. "Integration" on the lower right shows that the shortest possible integration time is 0.6 ms, which means that it takes 0.6 ms to complete a sampling measurement. Therefore, the interval should be set at least twice of the integration time such as 1.2 ms. Click on "OK".



(a)



(b)

(c)

Fig. 6.2. Configuring the Agilent 4156C.

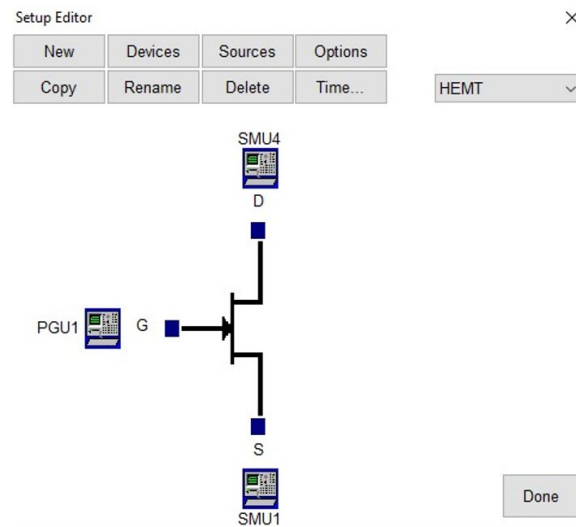
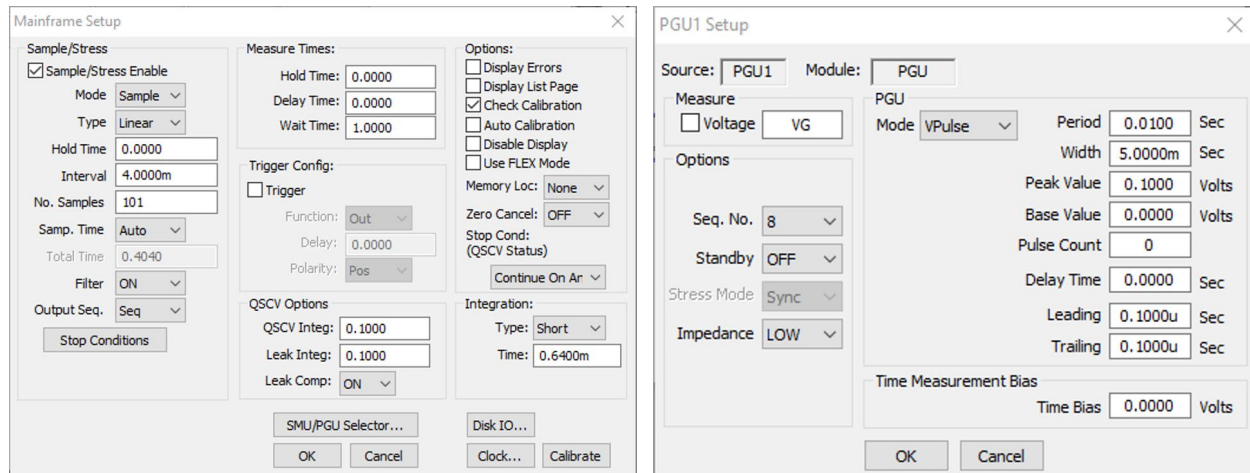






Fig. 6.3. Setup editor with sources assigned to a JFET.



(a)

(b)

Fig. 6.4. Mainframe setup for (a) sample and (b) pulse.

- 6.11 In "Setup Editor," click on "PGU1" on the device diagram to define the pulses as shown in Fig. 6.4(b). For the source "Impedance," choose "LOW" in most cases, so that most of the applied voltage falls on the DUT. Choose "50 ohm" if the DUT is matched to 50 ohm, so that reflection or ringing can be minimized. For "Mode," choose "VPulse" and enter the parameters of the pulse without exceeding the limits of the PGU (± 40 V, 100 V/ μ s). Fig. 6.4(b) illustrates the case with a period of 0.01 s and a width of 5 ms for a duty cycle of 50%. When "Pulse Count" is set to zero, the pulse will be repeated indefinitely, which is a little counterintuitive. Otherwise, pulsing will stop when the pulse count reaches the set value. Click on "OK." When "Delay Time" is set to zero, the pulse will be applied immediately as soon as you click on  as in Step. 6.14. Although the slew rate is 100 V/ μ s, you can slow down the rise/fall time of the pulse by giving "Leading" or "Trailing" a longer time.
- 6.12 Click on the SMUs assigned to other device terminals. Check on "Voltage" or "Current" or both to allow them to be measured. Fig. 6.5(a) illustrates the measurement of the source current with the source grounded. Fig. 6.5(b) illustrates the measurement of the drain current under a drain voltage of 1 V. Since PGU can only generate and cannot measure, you can get an idea of the gate current by comparing the measured source and drain currents. **Make sure the compliance is set low such as 0.1 A!** Click on "OK" to close the "PGU" or "SMU" setup windows and "Done" to close the "Setup Editor" window.
- 6.13 Lower the z-lever then finetune the probes to contact the DUT.
- 6.14 On the top menu of MTW4156 as shown in Fig. 6.2(a), ready the measurement by clicking on , choose the setup you named, and click on  to start a single measurement as shown in Fig. 6.6(a).
- 6.15 After the measurement-in-progress message appears on the bottom of the window and disappears to indicate that the measurement is finished, click on  on the top menu of MTW4156 to plot the data. On the popup window shown in Fig. 6.6(b), choose the appropriate axis and data range, click on "Apply" and "Done," a plot appears. If the plot does not appear to be satisfactory, change the measurement setup by repeating Steps 6.11–6.12 and remeasure as in Step 6.14. Repeating the measurement updates the data.
- 6.16 To save the desirable data, go to the top menu of MTW4156 as shown in Fig. 6.2(a), click on "File," then "Export." Select your own folder in Drive D under "User." Click on "Save."

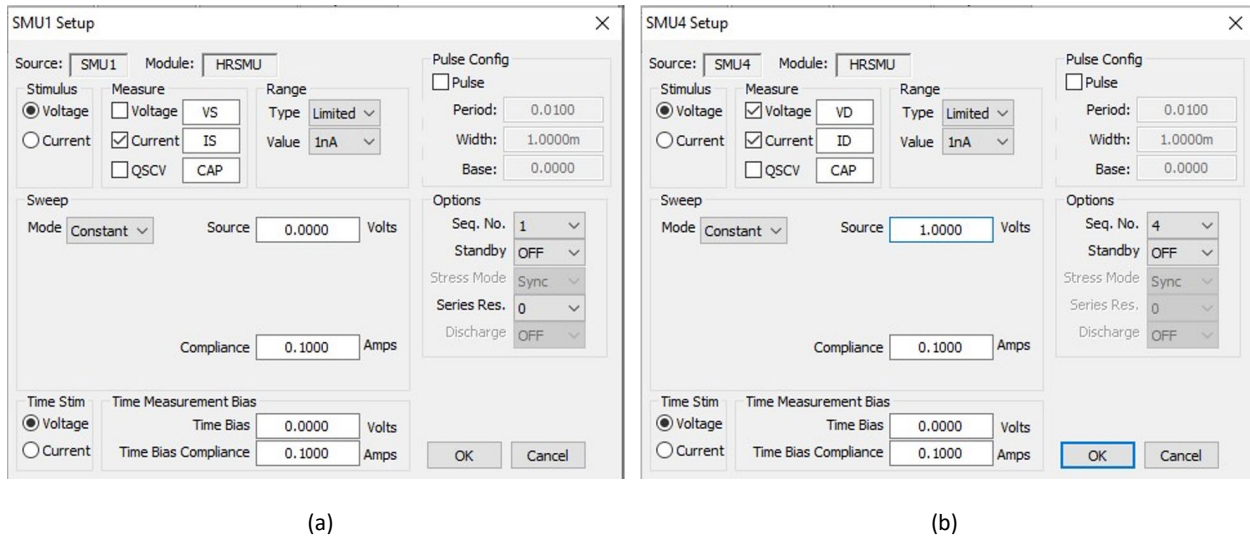


Fig. 6.5. Mainframe setup for SMUs connected to (a) source and (b) drain terminals of a JFET.

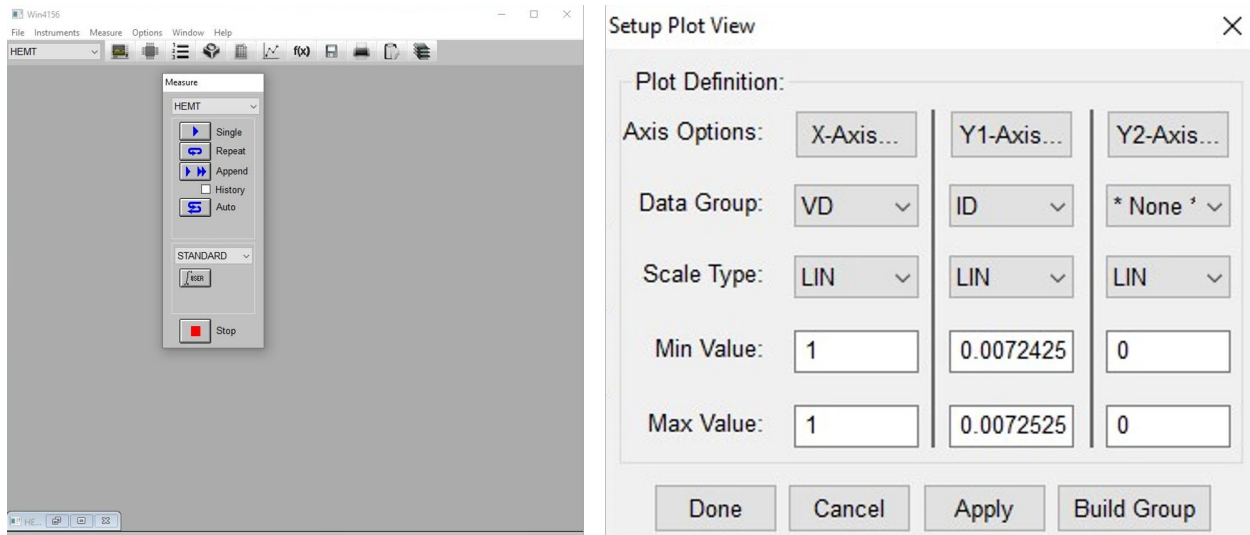


Fig. 6.6. (a) Measure window and (b) Setup plot view.

- 6.17 After finishing probing the DUT and before probing another device on the same sample, lift the z-lever to lift the probes safely above the sample and move the wafer chuck to locate the new DUT, before lowering the z-lever to bring the probes above the new DUT. If necessary, readjusting the probe positioners for proper contact with the new DUT. **Never move the chuck with the probes contacting the sample!**
- 6.18 Measure the new DUT by repeating Steps 6.14–6.17.
- 6.19 After finishing measuring all devices on the sample, lift the z-lever and probes before reversing Step 6.3 by moving the top cable connected to the northwest probe from PGU1 back to HRSMU2.
- 6.20 Close the “MTW4156” window as shown in Fig. 6.2(a) and follow Sec. 7 to finish up.

7. Finish Up

- 7.1 After all desired dice are probed, gently lift the probes while keeping them in sight through the microscope. Save coarse probe movement to when you can see them with bare eyes as in Step 7.5.
- 7.2 Turn off the microscope light.
- 7.3 Lift the microscope.
- 7.4 Lift the z-lever.
- 7.5 While observing with bare eyes, retract further the probes to make sure they are at least a few millimeters above the chuck and away from each other.
- 7.6 Unlock and open the microchamber access door.
- 7.7 Reach into the microchamber and rotate the roll-out stage handle counterclockwise to unlock the stage. Pull the stage out until it locks halfway outside the microchamber.
- 7.8 Turn off the vacuum pump and leave the vacuum switch on Zone 1 (13 mm) only.
- 7.9 Using plastic tweezers or plastic-tipped tweezers, remove the sample. If you plan to remeasure the same sample in the near future, it can be stored in the nitrogen-flushed dry box to the right of the probe station. Make sure you clearly mark your name, date, and the device type such as "GaN HEMT." The dry box will be periodically cleaned by the tool owner and anything not clearly marked will be removed without notice.
- 7.10 Push the roll-out stage all the way inside the microchamber and rotate the handle clockwise to lock it.
- 7.11 Close the microchamber access door and lock it.
- 7.12 As a courtesy to the next user, return the x, y, and θ movements of the chuck to their central settings, so that the pattern of vacuum holes on the chuck appear centered in the microchamber.
- 7.13 Confirm the hardware configuration is returned to normal as shown in Fig. 1.4, and Fig. 1.5.
- 7.14 Make sure the microscope is up, the z-lever is up, and the probes are up and retracted.
- 7.15 Replace the dust cover on the probe station. The dust cover should have been stored in the top-right drawer of the workbench left of the probe station.
- 7.16 **Make sure your "Test_DC" project is saved on the PC under your own folder by following Step 3.14!** IC-CAP will not auto-save your project.
- 7.17 Log off IC-CAP and the PC
- 7.18 Log onto the Coral workstation again and disable the DC probe station. Otherwise, the charge will continue to accumulate until you return to disable the DC probe station.
- 7.19 Record any issues/problems before logging off the workstation.