

Capacitance-voltage measurements

Capacitance-voltage measurements of MOS capacitors and diodes are done using the probe station and HP 4280 CV meter in the lab.

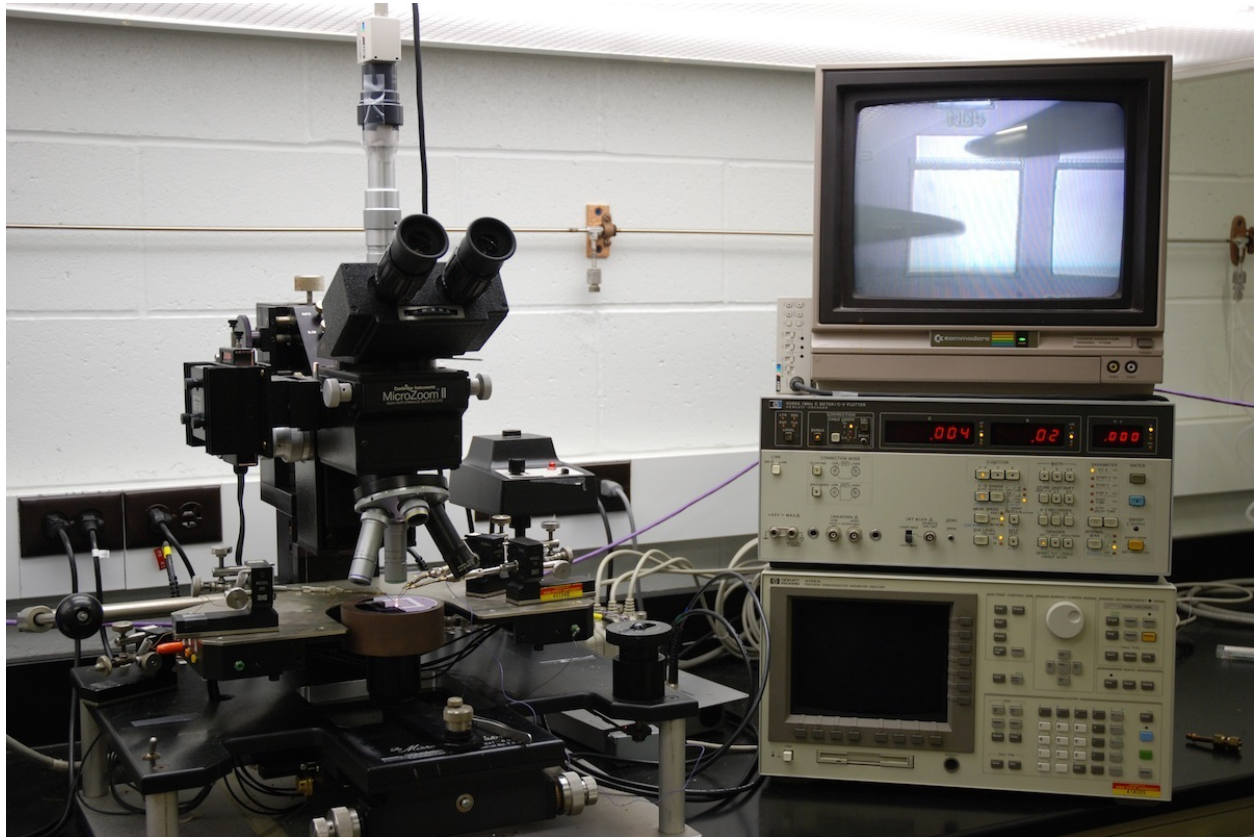


Figure 1. The test set-up for capacitance voltage measurements. Note the CyMOS capacitor contacted by probes on the video monitor.

The probe station is used to contact the two electrodes for the capacitor and is used in exactly the same manner as when probing transistors. See the transistor measurement notes for details on using the probe station, if you have forgotten.

The 4280 meter does most of the heavy lifting for the C-V measurements. It applies a fixed DC voltage (bias) across the leads of the capacitor. In addition, the meter applies a small AC voltage ($10 \text{ mV}_{\text{RMS}}$ or $30 \text{ mV}_{\text{RMS}}$) across the capacitor and measures the corresponding AC current. From the voltage and current, the impedance of the capacitor can be calculated. The impedance is interpreted in terms of a parallel combination of a capacitance and a conductance, which are displayed on the front panel. The AC frequency is fixed at 1 MHz. For MOS capacitors, this is clearly in the high-frequency measurement regime, as so you should expect to see only the high-frequency branch of the MOS C-V curve.

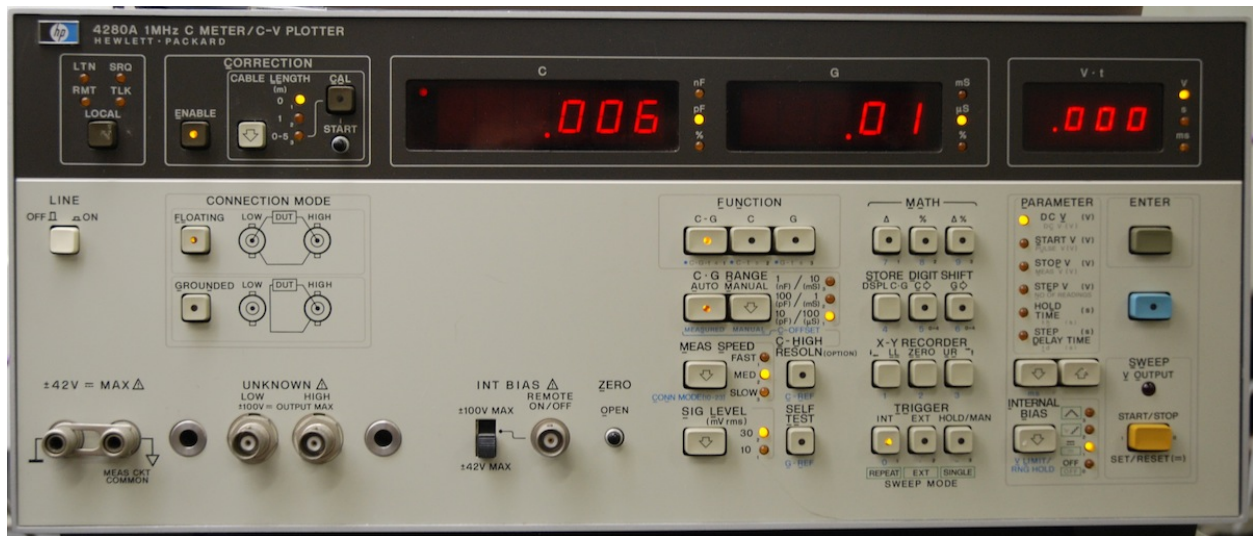


Figure 2. Front panel of the Hewlett-Packard 4280 capacitance-voltage meter.

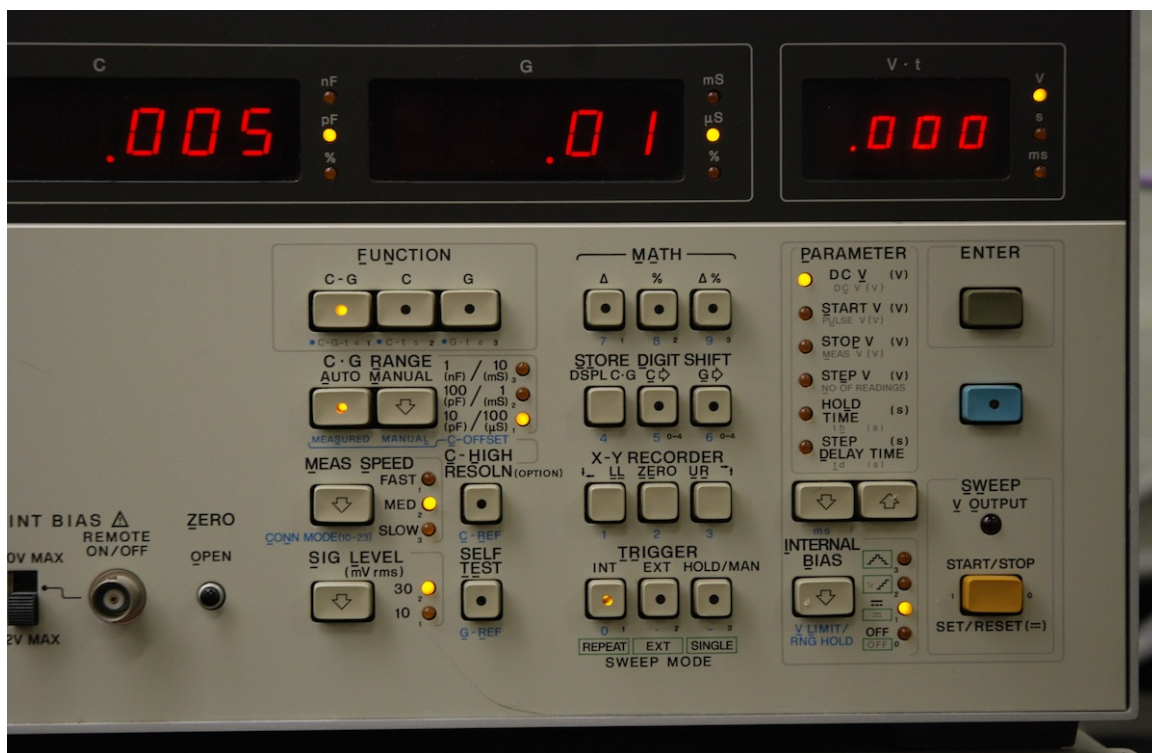


Figure 3. Detail of front panel buttons of the C-V meter.

Setup and measurement

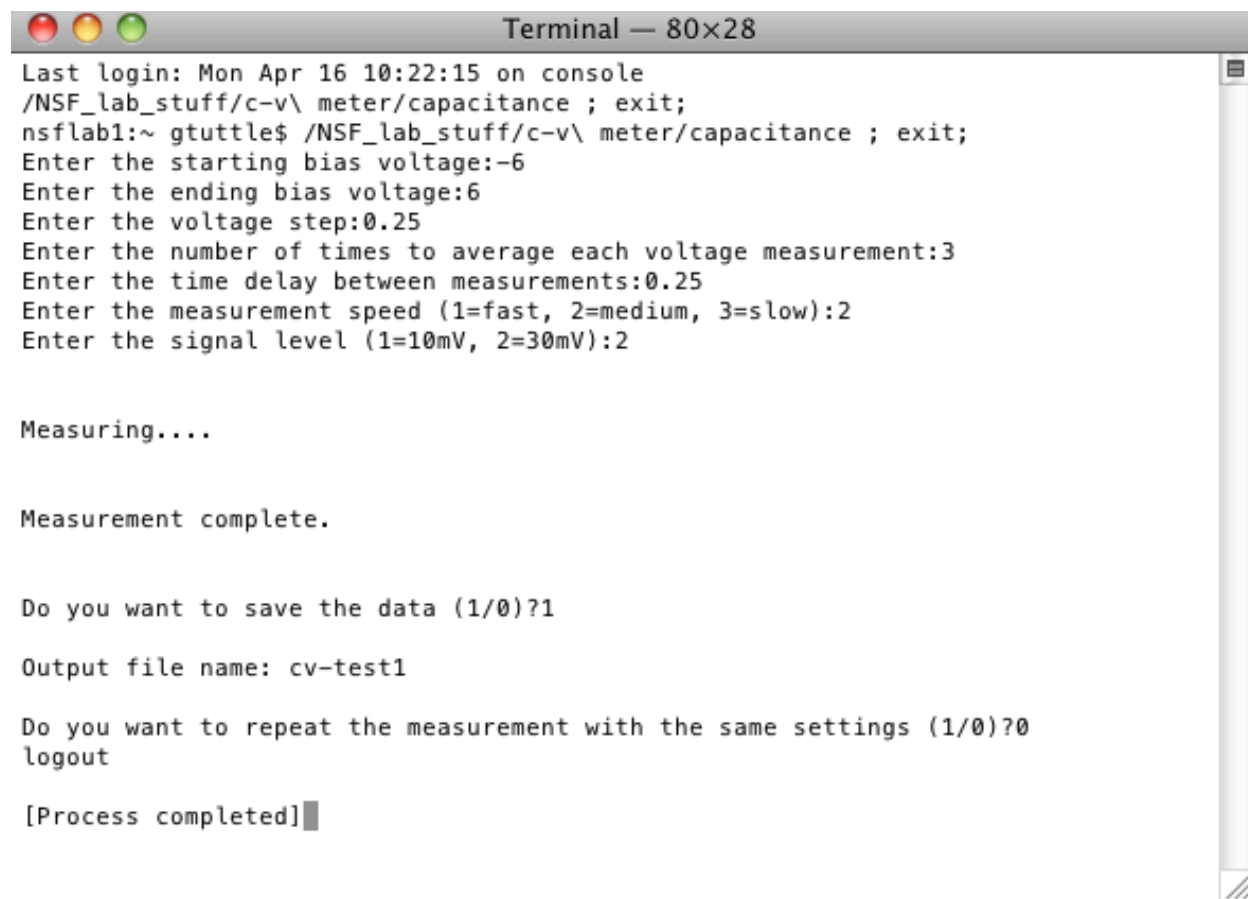
1. Place the wafer with the capacitors to be tested on the chuck of the probe station.
2. Determine which probes will be used for the positive and negative contacts to the capacitor and connect them to two of the BNC connectors at the back of the probe station. Connect a coaxial cable from the BNC connector corresponding to the negative capacitor contact to the LOW input connector on the 4280. Connect a second coaxial cable from the BNC corresponding to the positive capacitor contact to the HIGH input connector on the 4280. (The connectors are near the lower left corner of the 4280. They can be seen in Fig. 2.)
3. Select the following settings:
 - a. Connection Mode - floating,
 - b. Function - C-G,
 - c. C-G Range - auto,
 - d. Meas Speed - medium,
 - e. Sig Level - 30.
4. Lower the probes onto the device contacts. Assuming everything is OK, you should see a capacitance value on the left-hand display of the meter. This value includes the device capacitance and all of the stray capacitances of the cables, wires, probes, etc.
5. To remove the unwanted stray capacitances, lift *one* of the probes off the device contact. The value on the capacitance display will be due to the stray capacitances. It should be quite small, usually much less than 1 pF. Push the small black Zero button to zero the stray capacitance. Lower the probe back into contact on the capacitor. The displayed capacitance value should be due entirely to the device.
6. To apply a DC voltage bias:
 - a. Select the DC V option in the parameter section of the front panel. (See Fig. 3.)
 - b. Enter the desired voltage value using the keys in math section of the front panel. Note that you must push the blue option key first in order for the math keys to operate in the number mode. Push the gray ENTER key when finished. The entered voltage will be shown in the right-hand display. Note that the voltage is not yet being applied to the capacitor.
 - c. To actually apply the DC voltage to the capacitor, push the gold START/STOP key. The red LED indicates that the voltage is being applied to the capacitor. Pushing the START/STOP removes the voltage from the capacitor.
 - d. If a different voltage is desired, enter it with the math keys (don't forget the blue button first) and push the ENTER button. If the red LED is on, the voltage is applied immediately once the ENTER button is pressed. If the LED isn't on, you will need to push the START/STOP button again to apply the voltage.

Automating the measurement

The 4280 can be programmed in a rudimentary fashion using the keys in the parameter section of the front panel. The DC voltage can be ramped in one direction or it can ramp up and then back down. You can use these functions if you'd like – they are easy enough to figure out on your own.

However, it is probably easier to use the *capacitance* program on the Mac to automate the measurements, since the program will also record the data for you in an Excel-ready format. To use the program:

1. Make sure the GPIB interface box is powered on and all the cables are connected.
2. Double-click on the capacitance program icon.
(Macintosh HD -> NSF_lab_stuff -> c-v meter -> capacitance.)
3. A old-style command-line window opens. Answer the questions in order to enter the parameters for the measurement:
 - a. starting bias voltage,
 - b. ending bias voltage,
 - c. voltage step,
 - d. number of times to average for each step,
 - e. time delay between each voltage measurement,
 - f. measurement speed, and
 - g. signal level.
4. After the signal level has been entered, the measurement starts. You will be able to see the applied DC voltage and measured capacitance displays changing on the meter during the measurement.
5. Once the measurement is completed, the program will ask if you would like to save the data. (1 = yes and 0 = no). If you choose “1”, then the program will ask you to enter a file name. The file will be stored in the user home folder on the hard disk. The file is in CSV (comma separated variable) format and can be opened directly in Excel. The file includes the applied DC voltage, the measured capacitance, and the measured conductance.
6. The program will ask if you would like to repeat the measurement (1 = yes and 0 = no). If you choose “1”, the measurement repeats. Otherwise, the program will end.

A screenshot of a terminal window titled "Terminal — 80x28". The window shows a series of commands and prompts for a C-V measurement. The prompts include: "Last login: Mon Apr 16 10:22:15 on console", "/NSF_lab_stuff/c-v\ meter/capacitance ; exit;", "nsflab1:~ gtuttle\$ /NSF_lab_stuff/c-v\ meter/capacitance ; exit;", "Enter the starting bias voltage:-6", "Enter the ending bias voltage:6", "Enter the voltage step:0.25", "Enter the number of times to average each voltage measurement:3", "Enter the time delay between measurements:0.25", "Enter the measurement speed (1=fast, 2=medium, 3=slow):2", and "Enter the signal level (1=10mV, 2=30mV):2". The output shows "Measuring....", "Measurement complete.", "Do you want to save the data (1/0)?1", "Output file name: cv-test1", "Do you want to repeat the measurement with the same settings (1/0)?0", "logout", and "[Process completed]".

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Terminal — 80x28
Last login: Mon Apr 16 10:22:15 on console
/NSF_lab_stuff/c-v\ meter/capacitance ; exit;
nsflab1:~ gtuttle$ /NSF_lab_stuff/c-v\ meter/capacitance ; exit;
Enter the starting bias voltage:-6
Enter the ending bias voltage:6
Enter the voltage step:0.25
Enter the number of times to average each voltage measurement:3
Enter the time delay between measurements:0.25
Enter the measurement speed (1=fast, 2=medium, 3=slow):2
Enter the signal level (1=10mV, 2=30mV):2

Measuring....

Measurement complete.

Do you want to save the data (1/0)?1
Output file name: cv-test1

Do you want to repeat the measurement with the same settings (1/0)?0
logout

[Process completed]
```

Figure 4. A screen shot from a typical C-V measurement using the *capacitance* program.

Conductance

Generally, we do not need the conductance data, but it can serve as an indicator of possible problems with the measurement. Usually the conductance should be very small, indicating that there is little current leaking across the capacitor and that most of the current is displacement current. If the conductance (G) is on the same order as the reactance (ωC), it might indicate that there is a problem with the capacitor. (A reverse-biased diode may be going into breakdown or there may be a shunt path across a MOS capacitor.) An easy thing to check is the G/C ratio. If G/C becomes bigger than about 10^6 rad/s, there might be a problem. In that case, it may be a good idea to look at the I-V characteristic of the device to see if there is significant DC current flowing at the biases you are trying to use.