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Application Note Series

Using the Model 4200-CVU-PWR C-V Power Package to Make High Voltage and High Current C-V Measurements with the Model 4200-SCS Semiconductor Characterization System

Introduction

Traditional capacitance-voltage (C-V) testing of semiconductor materials is typically limited to about 30V and 10mA DC bias. However, many applications, such as characterizing C-V parameters of LD MOS structures, low κ interlayer dielectrics, MEMs devices, organic TFT displays, and photodiodes, require higher voltage or higher current C-V measurements. For these applications, a separate high voltage DC power supply and a capacitance meter are required to make the measurements.

The Model 4200-CVU-PWR C-V Power Package for the Model 4200-SCS allows making C-V measurements with a DC voltage bias of up to ±200V or 400V differential (0 to ±400V) and a current output of up to 300mA. Using this package, the Model 4200-CVU Capacitance-Voltage Unit measures the capacitance and either one or two 4200-SMUs (or 4210-SMUs for current up to 300mA) are used to supply the DC bias or sweep voltage. The C-V Power Package includes two bias tees that enable coupling of the AC signals from the 4200-CVU and the DC signals from the 4200-SMU. Along with the hardware, the C-V Power Package includes interactive software to control the high voltage C-V measurements using the KITE software. This application note explains how to implement and optimize high voltage C-V tests using the Model 4200-CVU-PWR C-V Power Package. It assumes the reader is familiar with making C-V measurements with the Keithley 4200-SCS with the 4200-CVU at the level outlined in [1] and [2].

Making Connectons To The Device

The Model 4200-CVU-PWR C-V Power Package comes with two Model 4205-RBT Remote Bias Tees. The desired voltage output will determine if one or two bias tees are required in the test circuit. For C-V measurements with an applied voltage bias up to ±200V, one bias tee is required. For C-V measurements with a voltage differential up to 400V (for example: 0 to 400V or –100 to 300V), two bias tees are required.

To make C-V measurements with an applied voltage bias up to ±200V, one 4200-SMU Source-Measure Unit, one 4200-CVU Capacitance-Voltage Unit, and one 4205-RBT Remote Bias Tee are connected to the device as shown in *Figure 1*. The 4200-SMU sources the DC voltage and the 4200-CVU measures the capacitance of the device under test (DUT). The 4205-RBT allows coupling of the AC signals from the CVU and the DC signal from the SMU.

In this setup, either the CVL1 (LPOT and LCUR) or CVH1 (HPOT and HCUR) can be connected to the AC Input of the bias tee. By default, the AC ammeter is connected to the CVL1

terminals and it is best that the AC ammeter be connected to the gate of the device if applicable. If this is the case, then the HCUR and HPOT (or CVH1) terminals of the 4200-CVU are connected to the other side of the device or to the chuck. The DC bias is supplied by the 4200-SMU, with the Force and Sense from the SMU connected to the Force and Sense terminals of the bias tee. The SMU LO terminals and the CVU CVH1 terminals are referenced internally to the system output common.
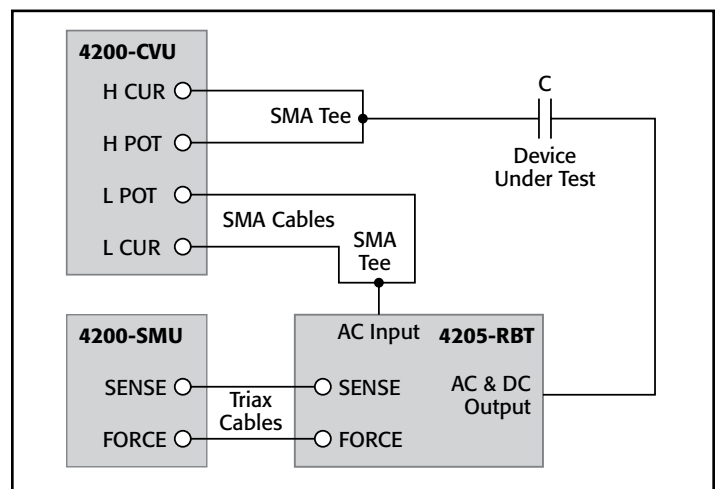

Figure 1. Device Connections for High Voltage C-V Measurements Using One Bias Tee

For C-V measurements that require up to 400V differential, two Model 4205-RBT Remote Bias Tees and two 4200-SMUs are required in addition to the 4200-CVU Capacitance Voltage Unit. This configuration is shown in *Figure 2*. Using this configuration, 4200-SMU 1 and the CVL1 terminals of the 4200-CVU are connected through one 4205-RBT Remote Bias Tee to one side of the device. The other side of the device is connected through a second 4205-RBT bias tee to both the 4200-SMU 2 and the CVH1 terminals of the 4200-CVU. This setup allows 400V differential measurements, for example, 0 to 400V, –100 to 300V, or –400V to 0V.

Using the KITE Software to Control High Voltage C-V Measurements

The *hivcvulib* user library contains two modules, *SweepV* and *CvsT*, for controlling the high voltage C-V measurements. These modules can be used with either the one or two bias tee configurations.

Using one bias tee, the *SweepV* module allows the user to sweep a DC voltage across the DUT using the 4200-SMU and
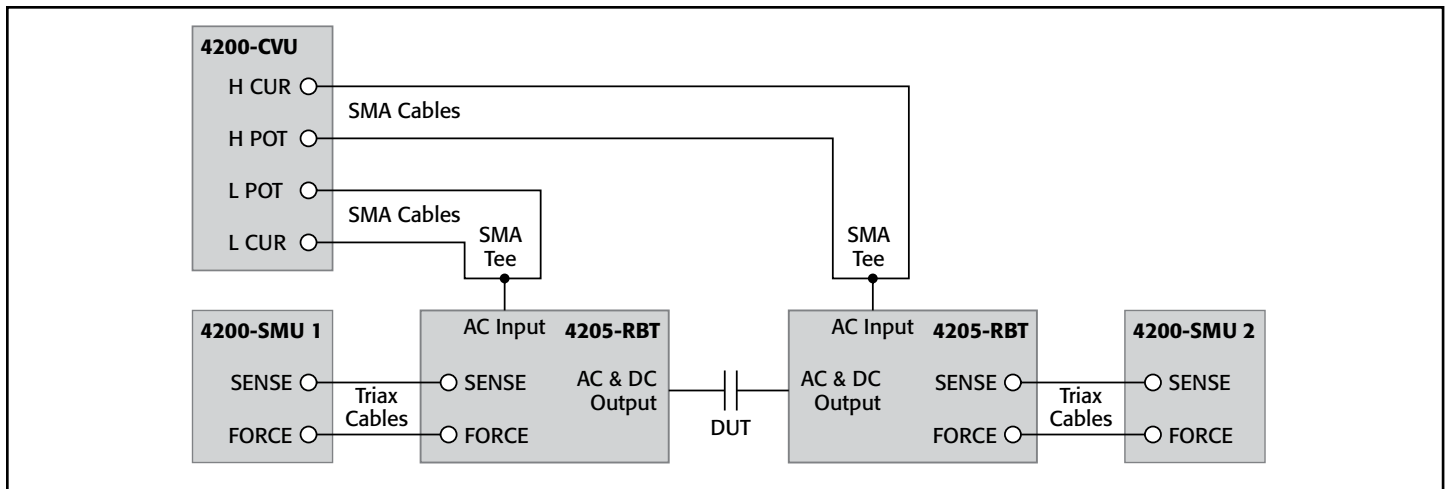
Figure 2. High Voltage C-V Measurements Using Two Remote Bias Tees

measure the capacitance using the 4200-CVU. If two bias tees are used with the *SweepV* module, then one SMU is used to sweep the DC voltage and the other SMU is used to apply an offset DC bias (as shown in *Figure 2*).

The *CvsT* module provides capacitance measurements as a function of time at a user-specified DC bias. This module can also be used with either one or two bias tees. With one bias tee and one SMU, capacitance measurements can be made with up to 200V DC bias. With two bias tees and two SMUs, capacitance measurements can be made up to 400V DC.

These modules can be opened up in a project using a User Test Module (UTM). However, a project has already been created that uses these test modules. This project, called *CVU_highV*, can be found at the following location on the 4200-SCS:

C:\S4200\kiuser\Projects_CV

The *CVU_highV* project uses both the *SweepV* and *CvsT* modules to make measurements on devices.

Setting up the Parameters in the *SweepV* Module

Table 1 lists the adjustable parameters for the *SweepV* module. This module has settings for the 4200-CVU and up to five 4200-SMUs in the test circuit. One SMU is used for the voltage sweep in the C-V measurements. Up to four other SMUs can be used to output a DC bias. One SMU can also be used to measure current.

Here is a description of the input parameters:

OpenCompensate: If desired, an offset correction can be performed. First, go to the Tools Menu and select CVU Connection Compensation. Then click on the Measure Open button. After this compensation procedure is performed, it can be enabled in this module by setting the OpenCompensate parameter value to 1.

ShortCompensate: For lower impedance devices, a short compensation should be performed. This is especially true for the two bias tee configuration. First, short the CVH1 and CVL1 terminals. In the Tools Menu, select CVU Connection

Table 1. List of Adjustable Parameters in *SweepV* module

Parameter	Range	Description
OpenCompensate	0 or 1	Enables/Disables Open Compensation for CVU
ShortCompensate	0 or 1	Enables/Disables Short Compensation for CVU
CVUCableLen	0, 1.5m, 3m	Set cable length for CVU
SweepSMU	1-8	SMU number that will force voltage in CV sweep
MeasISMU	1-8	SMU number that will measure current during the CV sweep
StartV	–200 to +200	Start voltage for sweep
StopV	–200 to +200	Stop voltage for sweep
StepV	–200 to +200	Step voltage for sweep
SweepDelay	0 to 10 seconds	Time between voltage steps
PresoakV	–200 to +200	Voltage bias prior to start of sweep
PresoakTime	0 to 600 seconds	Time to apply soak voltage
SMU1Bias	–200 to +200	Voltage forced by SMU1 during sweep (ignored with SMU1 is SweepSMU)
SMU2Bias	–200 to +200	Voltage forced by SMU2 during sweep (ignored with SMU2 is SweepSMU)
SMU3Bias	–200 to +200	Voltage forced by SMU3 during sweep (ignored with SMU3 is SweepSMU)
SMU4Bias	–200 to +200	Voltage forced by SMU4 during sweep (ignored with SMU4 is SweepSMU)
Frequency	10e3 to 10e6	Test frequency
ACVoltage	0.01 to 0.1V	AC test voltage of CVU
Speed	0 fast, 1 normal, 2 quiet	Speed of CVU
CVRange	0=Auto, 1μA, 30μA, 1mA	CVU measure range

Compensation and then click on the Measure Short button. After this compensation procedure is performed, short compensation can be enabled in the *SweepV* module by setting the ShortCompensate parameter value to 1.

CVUCableLen: Input the length of the CVU cables. By default, this is set to 1.5m, the length of the SMA cables that come with the 4200-CVU, Keithley P/N CA-447A.

SweepSMU: This is the number of the SMU that will force the sweep voltage in the C-V sweep. The Force HI and Sense HI terminals of this SMU are connected to the Force and Sense terminals of the Model 4205-RBT Remote Bias Tee.

MeasISMU: The user inputs the number of the SMU that will measure current in the circuit. If the SMU that is measuring current is not the SMU that is used to sweep voltage (SweepSMU), then the current range is set to limited autorange to the 100nA range. If the SMU that is measuring current is the same as the SweepSMU, then the current range is set to limited autorange on the $10\mu A$ range. If this is the case, additional sweep delay time needs to be added to ensure a settled reading. It also may be necessary to use PreSoakV and PreSoakTime to charge up the device to the first step in the sweep prior to taking the current measurements.

StartV, StopV, StepV: Input the start, stop, and step size voltages for the C-V sweep.

SweepDelay: The time between steps in the voltage sweep. Allow an adequate delay time to ensure the device reaches equilibrium. If measuring current through the bias tee, additional SweepDelay time may need to be added to ensure optimal results.

PreSoakV: This is the voltage bias output by the SweepSMU prior to the start of the voltage sweep.

PresoakTime: This is the length of the time in seconds for the PreSoakV voltage to be applied to the device. You can verify how much time is required for the device to reach equilibrium by using the *CvsT* module in the *hivcvulib*. This module measures the capacitance as a function of a time while the device is biased with a constant DC voltage. The settling time can be observed from the graph.

SMU1Bias, SMU2Bias, SMU3Bias, SMU4Bias: In addition to an SMU supplying a voltage for the C-V sweep, up to four more SMUs can be used to bias other parts of the test circuit.

Frequency: Test frequency of CVU, which can be set to 10kHz, 20kHz, 30kHz, 40kHz, 50kHz, 60kHz, 70kHz, 80kHz, 90kHz, 100kHz, 200kHz, 300kHz, 400kHz, 500kHz, 600kHz, 700kHz, 800kHz, 900kHz, 1MHz, 2MHz, 3MHz, 4MHz, 5MHz, 6MHz, 7MHz, 8MHz, 9MHz, and 10MHz. For higher capacitance values, the test frequency may need to be lowered through the bias tee to avoid errors due to resonance.

ACVoltage: The amplitude of the AC voltage output of the CVU.

Speed: The speed time can be set as: 0 = FAST, 1 = NORMAL, and 2 = QUIET. The FAST mode has the fastest time but the highest noise. The NORMAL mode is the most common setting, which allows sufficient settling times for most measurements. The QUIET mode ensures high accuracy but a slower settling time. The QUIET mode allows more time for DC settling and provides longer integration time.

CVRange: This is the AC ammeter measurement range of the CVU. The input values are 0 for autorange, $1\mu A$, $30\mu A$, and 1mA ranges.

Setting Up the Parameters in the *CvsT* Module

Table 2 lists the adjustable parameters for the *CvsT* module. This module has settings for the CVU and up to five SMUs in the test circuit. One or two SMUs can be connected to one or two bias tees to output voltage. It is not necessary to specify which SMUs are connected to the bias tees. This is done through the hardware configuration, and then the user inputs in the UTM how much voltage those particular SMUs will output. Two or three other SMUs can also output voltage in the circuit. One SMU can be used to measure current.

Table 2. List of Adjustable Parameters for *CvsT* Module

Parameter	Range	Notes
OpenCompensate	0 or 1	Enables/Disables Open Compensation for CVU
ShortCompensate	0 or 1	Enables/Disables Short Compensation for CVU
CVUCableLen	0, 1.5m, 3m	Set cable length for CVU
MeasISMU	1-8	SMU number that will measure current
SampleCount	1 to 10000	Number of Measurements
Interval	0 to 60	Time between readings
SMU1Bias	−200 to +200	Voltage forced by SMU1
SMU2Bias	−200 to +200	Voltage forced by SMU2
SMU3Bias	−200 to +200	Voltage forced by SMU3
SMU4Bias	−200 to +200	Voltage forced by SMU4
Frequency	10^3 to 10^6	Test Frequency
ACVoltage	0.01 to 0.1V	AC test voltage of CVU
Speed	0 fast, 1 normal, 2 quiet	Speed of CVU
CVRange	0=Auto, $1\mu A$, $30\mu A$, 1mA	CVU measure range

Here is a description of the input parameters for the *CvsT* module:

OpenCompensate: If desired, an offset correction can be performed. First, go to the Tools Menu and select CVU Connection Compensation. Then click on the Measure Open button. After this compensation procedure is performed, it can be enabled in this module by setting the OpenCompensate parameter value to 1.

ShortCompensate: For lower impedance devices, a short compensation should be performed. This is especially true for the two bias tee configuration. First, short the CVH1 and CVL1 terminals. In the Tools Menu, select CVU Connection Compensation and then click on the Measure Short button. After this compensation procedure is performed, short compensation can be enabled in the *CvsT* module by setting the ShortCompensate parameter value to 1.

CVUCableLen: Input the length of the CVU cables. By default, this is set to 1.5m, the length of the SMA cables that come with the 4200-CVU, Keithley P/N CA-447A.

MeasISMU: The user inputs the number of the SMU that will measure current in the circuit. The current range is set to limited autorange to the 100nA range.

SampleCount: Enter the number of capacitance measurements from 1 to 10000.

Interval: This is the time between readings in seconds.

SMU1Bias, SMU2Bias, SMU3Bias, SMU4Bias: Up to four SMUs can be used to bias the test circuit. One or two of these SMUs is

connected through a bias tee(s) to supply voltage to the DUT for the C-V measurement.

Frequency: Test frequency of CVU which can be set to 10kHz, 20kHz, 30kHz, 40kHz, 50kHz, 60kHz, 70kHz, 80kHz, 90kHz, 100kHz, 200kHz, 300kHz, 400kHz, 500kHz, 600kHz, 700kHz, 800kHz, 900kHz, 1MHz, 2MHz, 3MHz, 4MHz, 5MHz, 6MHz, 7MHz, 8MHz, 9MHz, and 10MHz. For higher capacitance values, the test frequency may need to be lowered through the bias tee to avoid errors due to resonance.

ACVoltage: The amplitude of the AC voltage output of the CVU.

Speed: The speed time can be set as: 0 = FAST, 1 = NORMAL, and 2 = QUIET. The FAST mode has the fastest time but the highest noise. The NORMAL mode is the most common setting, which allows sufficient settling times for most measurements. The QUIET mode ensures high accuracy but a slower settling time. The QUIET mode allows more time for DC settling and provides longer integration time.

CVRange: This is the AC ammeter measurement range of the CVU. The input values are 0 for autorange, $1\mu A$, $30\mu A$, and 1mA ranges.

Applications for High Voltage Capacitance Measurements

Even though the user can set up new UTMs for testing many types of devices, the *CVU_highV* project comes with UTMs already configured for four types of devices: zener diodes, MOScaps, capacitors, and Schottky diodes. The project tree for the *CVU_highV* project is shown in *Figure 3*. A description of the specific tests follows.
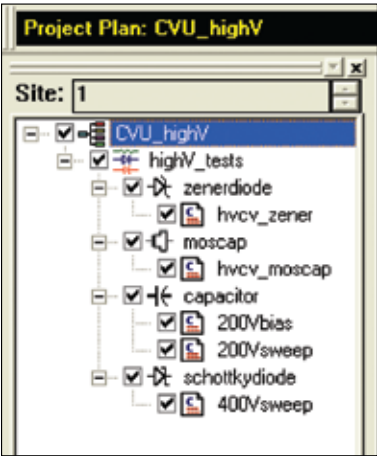

Figure 3. Project Tree for *CVU_highV* Project

Zener Diode Testing

To make high voltage C-V measurements on a zener diode, connect the zener diode to the 4200 system as shown in *Figure 4*. In this configuration, the anode is connected to the CVH1 terminals of the 4200-CVU and the cathode is connected to the AC and DC Output terminal of the 4205-RBT Remote Bias Tee. This connects the Force and Sense HI terminals of the SMU
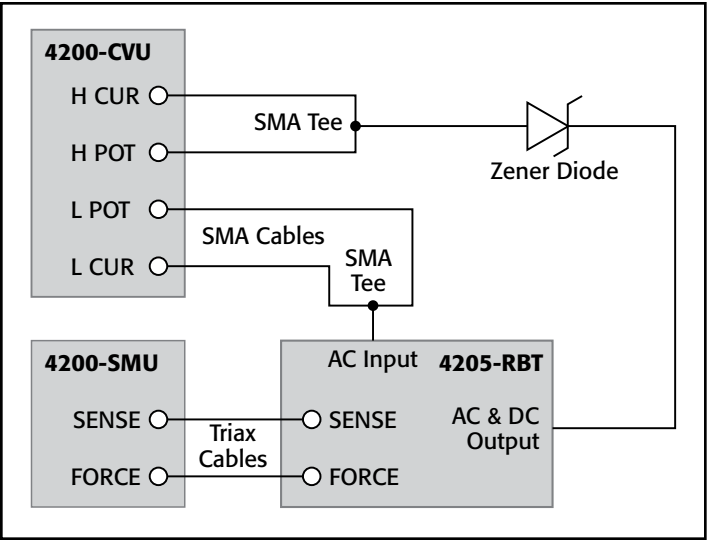

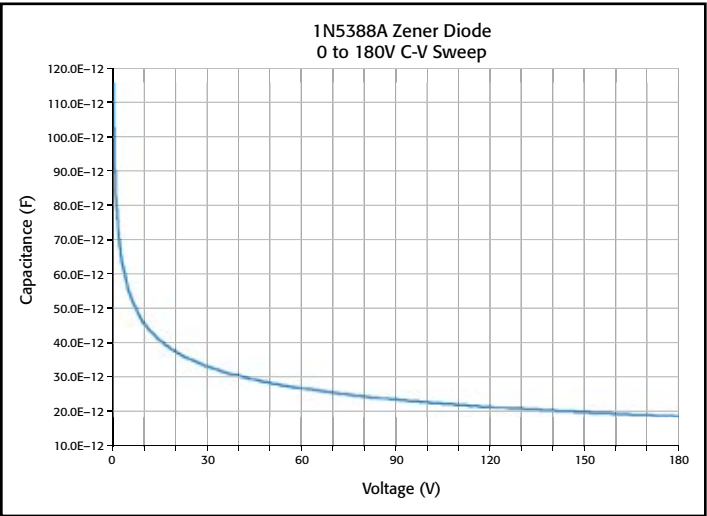Figure 4. High Voltage C-V Connections for Zener Diode

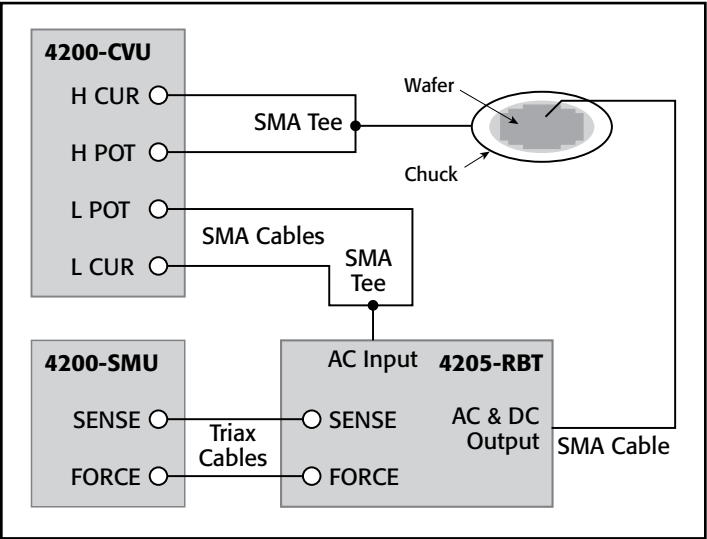Figure 5. Results of C-V Sweep of Zener Diode

Figure 6. High Voltage C-V Connections for MOScap Testing

(DC bias) and the AC ammeter of the CVU to the cathode.

The UTM for testing zener diodes is called ***hvcv_zener***. This UTM is set up to reverse bias the zener diode from 0 to 180V in 1V steps. The capacitance as a function of voltage is plotted in the Graph tab. For displaying the capacitance and voltage measurements over a wide range, a log-log or semi-log graph can be generated instead. The C-V measurement results of a 1N5388A zener diode are shown in ***Figure*** 5.

MOScap Testing

The connections for making high voltage capacitance-voltage measurements on a MOScap are shown in ***Figure 6***. In this application, the LPOT and LCUR (or CVL1) are connected to the AC Input of the bias tee. By default, the AC ammeter is internally connected to the CVL1 terminals, and it is best that the ammeter be connected to the gate of the device as shown. The HCUR and HPOT (CVH1) terminals of the 4200-CVU are connected to the chuck. The DC bias is supplied by the 4200-SMU, which gets connected to the gate through the bias tee. Connecting the Force HI terminal of the SMU to the gate through the bias tee will ensure the proper polarity of the gate voltage.

The UTM for performing high voltage C-V measurements on MOScaps is called ***hvcv_moscap*** and is located under the "moscap" device in the project tree. This UTM sweeps the gate voltage from 10V to –90V in 0.5V steps. The results are graphed as shown in ***Figure*** 7.

Once the C-V measurements are made, various MOScap parameters can be derived. The ***hvcv_moscap*** UTM includes formulas for extracting several parameters including threshold voltage, oxide thickness, flatband capacitance, doping concentration, etc. These parameters are calculated in the Formulator and the calculated values appear in the Sheet tab. These formulas are listed in ***Table 3***. The specific details about these formulas can be found in Keithley Application Note Number 2896, "C-V Characterization of MOS Capacitors Using the Model 4200-SCS Semiconductor Characterization System."

Table 3. Formulas for *hvcv_moscap* UTM

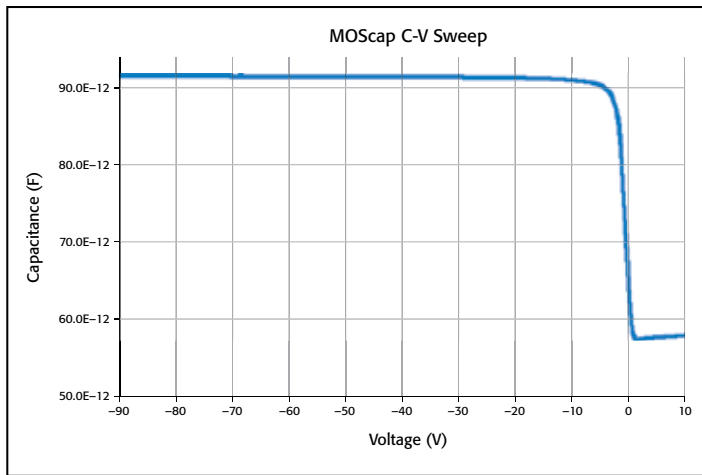| Formula Name, Units	Description	Simplified Equations
RS, Ω	Series resistance calculation	$$RS = \frac{\left(\frac{G}{2\pi fC}\right)^2}{\left[1+\left(\frac{G}{2\pi fC}\right)^2\right]G}$$ where C = capacitance in strong accumulation
AR	Intermediate parameter for calculation of corrected capacitance	$a = G - (G^2 + (2\pi fC)^2)R_S$
CADJ, F	Corrected capacitance by compensating for series resistance	$C_{ADJ} = \dfrac{(G^2+(2\pi fC)^2)C}{a^2+(2\pi fC)^2}$
COX, F	Oxide Capacitance	C_{ox} = set to the maximum capacitance in accumulation.
CMIN, F	Minimum capacitance	$N = \left|\dfrac{-2}{q\varepsilon_s A^2 \dfrac{d(1/C^2)}{dV}}\right|$
INVCSQR, $\dfrac{1}{F^2}$	Inverse square of capacitance	$INVCSQR = \dfrac{1}{C^2}$
TOXNM, nm	Calculated thickness of oxide	$T_{ox\,(nm)} = \dfrac{(1xE^7)A\varepsilon_{ox}}{C_{ox}}$ where $1\times E^7$ = units conversion from cm to nm ε_{ox} = permittivity of oxide (F/cm) A = gate area (cm²)
NDOPING, $\dfrac{1}{cm^3}$	Doping density	
DEPTHM (w), m	Depletion depth	$W = A\varepsilon_s\left(\dfrac{1}{C} - \dfrac{1}{C_{OX}}\right)\left(1xE^{-2}\right)$ $1\times E^{-2}$ = units conversion from cm to m
N90W	Doping density at 90% of maximum depletion depth	
DEBYEM (λ), m	Debye length	$\lambda = \left(\dfrac{\varepsilon_s kT}{q^2 N}\right)^{1/2}\left(1xE^{-2}\right)$ where N=N at 90% W_{MAX} (or N90W) $1\times E^{-2}$ = units conversion from cm to m
CFB (C_{FB}), F	Flatband capacitance	$C_{FB} = \dfrac{C_{ox}\left(\varepsilon_s A/\lambda\right)\left(1xE^2\right)}{C_{ox}+(\varepsilon_s A/\lambda)\left(1xE^2\right)}$
VFB (V_{FB}), V	Flatband voltage	Once C_{FB} is derived, V_{FB} is interpolated from the closest V_{GS} values.
PHIB (ϕ_B), V	Bulk potential	$\phi_B = \pm\dfrac{kT}{q}\ln\left(\dfrac{N_{BULK}}{N_i}\right)$
VTH, V	Threshold voltage	$V_{TH} = V_{FB} \pm\left[\dfrac{A}{C_{OX}}\sqrt{4\varepsilon_s q|N_{BULK}\phi_B|} + 2|\phi_B|\right]$
WMS (W_{MS}), V	Work function difference between metal and semiconductor	$W_{MS} = W_M - \left[W_S + \dfrac{E_{BG}}{2} - \phi_B\right]$ W_M and W_S are defined in the constants table in the Formulator
QEFF (Q_{EFF}), $\dfrac{C}{cm^2}$	Effective oxide charge	$Q_{EFF} = \dfrac{C_{OX}\left(W_{MS}-V_{FB}\right)}{A}$
BEST_LO	Index from DEPTHM array that is three Debye lengths from the surface	
BEST_HI	Index from DEPTHM array that is 95% of maximum depletion length, or twice the screening length in the semiconductor, whichever is larger	
NAVG (N_{AVG}), $\dfrac{1}{cm^3}$	Average doping	Calculated between index BEST_HI and BEST_LO
MAXINVSQR	Finds row position of maximum point on $\dfrac{1}{C^2}$ curve	
VFBPOS	Finds row position of flatband voltage	
NSLOPE	Finds slope of $\dfrac{1}{C^2}$ curve	
NSUB, $\dfrac{1}{cm^3}$	Calculated substrate doping concentration from slope	

Figure 7. High Voltage C-V Sweep of MOScap

In addition to the equations for the derived parameters in the Formulator, several constants have been added to the Constants Table in the Formulator. These constants are listed in *Table 4*. The user will need to adjust these constants in the Formulator based on the MOScap device being tested.

Table 4. Constants for *hvcv_moscap* UTM

Constant	Description	Default Value	Units
AREA	Gate Area of Device	10.8E-3	cm^2
EOX (ε_{ox})	Permittivity of Oxide	340.0E-15	F/cm
ES (ε_s)	Semiconductor Permittivity	1.04E-12	F/cm
NI (N_i)	Intrinsic Carrier Concentration	14.5E+09	cm^{-3}
DOPETYPE	–1 for 1 for P-type, N-type	1E+00	
WM (W_M)	Metal Work Function	4.15E+00	V
WS (W_S)	Silicon Electron Affinity	4.05E+00	V
EBG (E_{BG})	Semiconductor Energy Gap	1.12E+00	eV
TEMP	Test Temperature	293E+00	K

Capacitor Testing

Two test modules exist for testing capacitors: one applies a constant 200V bias and the other sweeps the voltage from –200V to 200V. To perform these tests, the capacitor is connected to the test system using one bias tee as previously shown in *Figure 1*.

High voltage capacitance vs. time measurements can be made using the *200vbias* UTM, which was created using the *CvsT* module. This module applies 200V to a 100pF capacitor, measures the capacitance as a function of time, and plots the data in the graph. The results are shown in *Figure 8*. This module can be used to determine how much settling time to use during an actual C-V sweep.

In the 200Vsweep UTM, the CVU measures the capacitance while an SMU sweeps the test voltage from –200V to +200V. The results of the C-V sweep of the 100pF capacitor are shown in *Figure 9*.

Schottky Diode Testing

Using two bias tees and two SMUs, C-V measurements can be made up to 400V. An example of this configuration is shown in *Figure 10*. In this setup, the 4200-CVU, two 4205-RBTs, and two
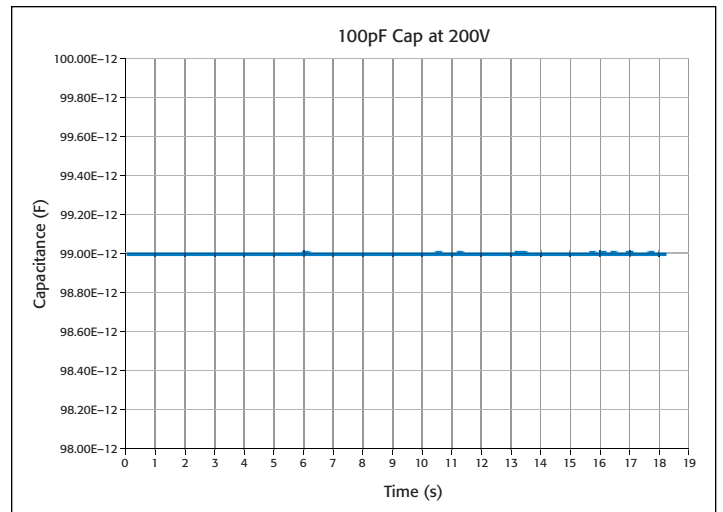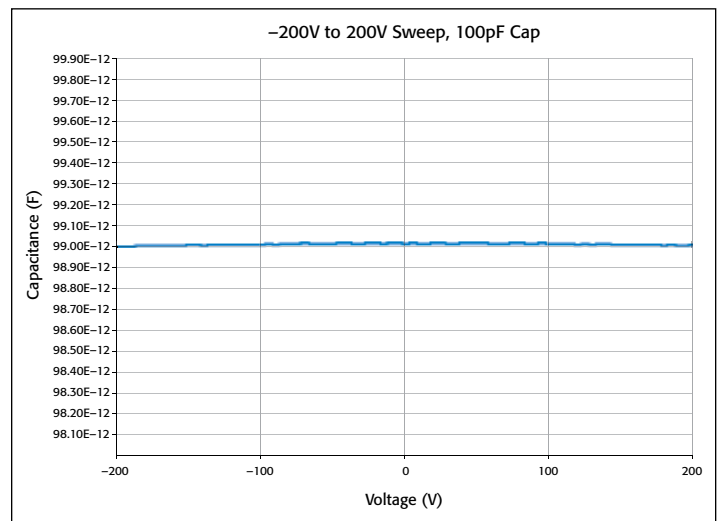

Figure 8. Capacitance vs. Time Measurements

Figure 9. ±200 C-V Sweep on 100pF Capacitor

4200-SMUs are connected to a Schottky diode. In the *400Vsweep* UTM, capacitance measurements are made as a 0 to 400V sweep is generated across a Schottky diode. To generate the 0 to 400V sweep, SMU1 sweeps from –200V to 200V while SMU2 outputs a constant –200V bias. This results in a high voltage C-V sweep as shown in the graph in *Figure 11*.

Optimizing Measurements

When making high voltage C-V measurements, as with making C-V measurements in general, various techniques can be used to optimize measurement accuracy. These techniques include choosing the proper speed modes, allowing sufficient settling time, and taking steps to reduce the effects of stray capacitance.

The two modules in the *hivcvulib* library include an adjustable Speed parameter. The Speed parameter can be set as: 0 = FAST, 1 = NORMAL, and 2 = QUIET. The FAST mode has the fastest time but the highest noise. The NORMAL mode is the most common setting, which allows sufficient settling times for most measurements. The QUIET mode ensures high accuracy but
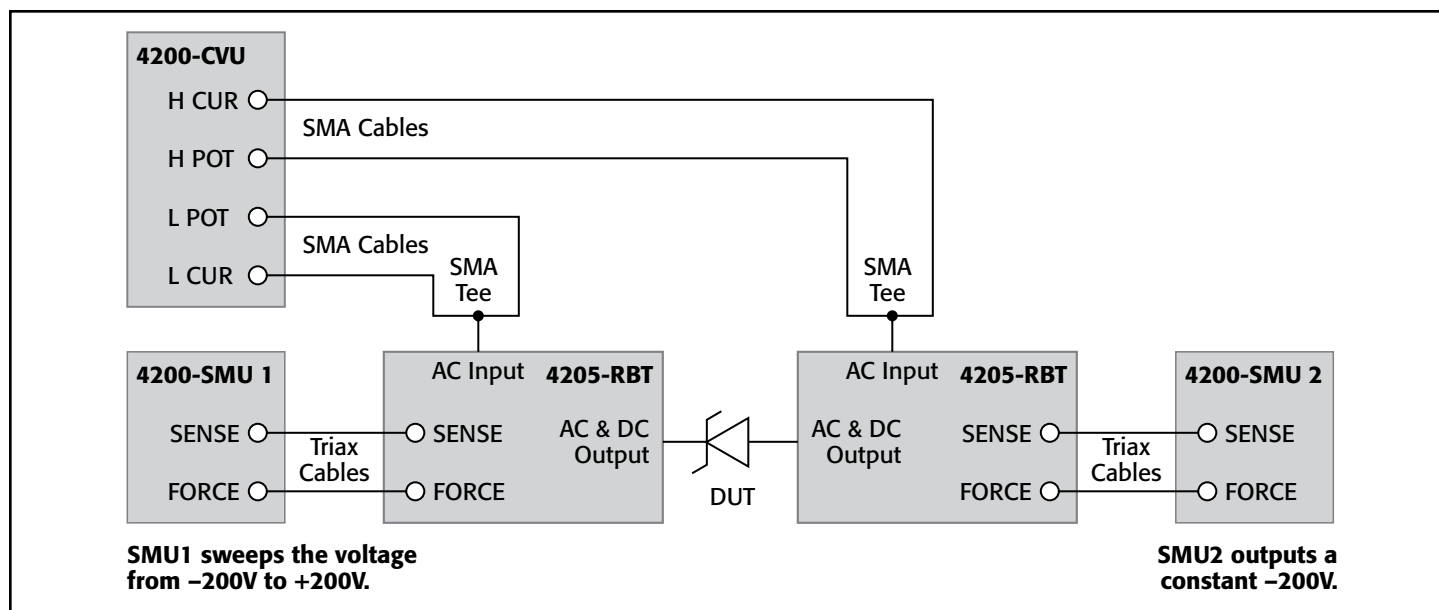
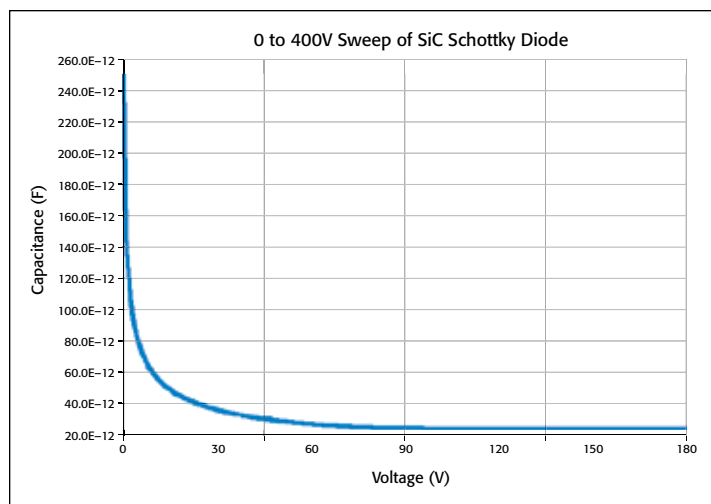**Figure 10. High Voltage C-V Connections for Schottky Diode Test**

Figure 11. Results of High Voltage C-V Sweep of Schottky Diode

a slower settling time. The QUIET mode allows more time for DC settling and provides longer integration time.

Choosing an appropriate PreSoak Time and SweepDelay Time is important for many applications. The condition of a device when all internal capacitances are fully charged after an applied step voltage is referred to as "equilibrium." If capacitance measurements are made before a device is in equilibrium, inaccurate results may be produced. To choose the delay times for the *SweepV* module, make a measurement of capacitance vs. time in the *CvsT* module. Observe the settling time on the graph. Use this time as the PresoakTime for the PreSoakV or the SweepDelay time applied to each step in the sweep in the *SweepV* module.

When making C-V measurements, it is important to take steps to reduce the effects of stray capacitance, which include offset compensation and proper connections.

To correct for offsets, use Open and Short Compensation. Open Compensation corrects for large impedance, small capacitance offsets. Short Compensation corrects for low impedance, high capacitance offsets. Open and Short Compensation are explained in greater detail in Section 15 of the Model 4200-SCS Reference Manual.

To avoid noisy measurements and stray capacitance, the AC ammeter terminal (LCUR) should always be connected to the terminal of the device that has the least amount of capacitance to ground. When measuring MOScaps, always connect the CVL1 terminals (LCUR and LPOT) to the gate and the CVH1 terminals (HCUR and HPOT) to the chuck.

Because the bias tee unavoidably adds some external parasitics to the measurement circuit, care must be taken when making measurements especially at higher capacitances using higher test frequencies (>1MHz). If measurement errors are suspected, make C-V measurements without the bias tee, and then make measurements through the bias tee with the same test conditions (frequency, voltage, speed, interval time, etc.). The measurements without the bias tee are made using an ITM and will be limited to ±30V. If there are discrepancies, try lowering the test frequency, if possible, and use the Quiet speed mode. Increasing the settling time may ensure the device has reached equilibrium.

Test System Safety

Many electrical test systems or instruments are capable of measuring or sourcing hazardous voltage and power levels. It is also possible, under single fault conditions (e.g., a programming error or an instrument failure), to output hazardous levels even when the system indicates no hazard is present. These high voltage and power levels make it essential to protect operators from any of these hazards at all times. Protection methods include:

- Design test fixtures to prevent operator contact with any hazardous circuit.
- Make sure the device under test is fully enclosed to protect the operator from any flying debris.
- Double insulate all electrical connections that an operator could touch. Double insulation ensures the operator is still protected, even if one insulation layer fails.
- Use high reliability, fail-safe interlock switches to disconnect power sources when a test fixture cover is opened.
- Where possible, use automated handlers so operators do not require access to the inside of the test fixture or have a need to open guards.
- Provide proper training to all users of the system so they understand all potential hazards and know how to protect themselves from injury.

It is the responsibility of the test system designers, integrators, and installers to make sure operator and maintenance personnel protection is in place and effective.

Conclusion

Using the Model 4200-CVU-PWR C-V Power Package for the Model 4200-SCS allows making C-V measurements with a DC voltage bias of up to ±200V or 400V differential and a current output of up to 300mA. To achieve the higher test voltage and current, this package couples the AC and DC signals from the 4200-CVU and 4200-SMU (or 4210-SMU) using the Model 4205-RBT Remote Bias Tees. Software that allows making either high voltage C-V sweeps or capacitance measurements at a constant DC voltage is included with the package. Example tests are included for a zener diode, MOS capacitor, capacitor, and Schottky diode. These tests can be easily modified to measure other devices or new tests can be created by opening a UTM in

another project. Like C-V measurements in general, high voltage C-V measurements require using appropriate measurement techniques and connections to ensure optimal results.

Appendix
Ordering Information

Model 4200-CVU-PWR C-V Power Package

Includes:

2 ea. Model 4205-RBT

2 ea. SMA F-M-F Tee adaptors CS-1391

2 ea. Male SMA to Female BNC adapter CS-1252

2 ea. SMA to SSMC Y-Cables 4200-PRB-C

CVU Power Package Typical Performance Parameters

Measurement Parameters: Cp-Gp, DCV, timestamp

Capacitance Range: from fF to nF

Measurement Terminals: two-wire SMA with BNC adapters (CVU), Triax (SMU)

Test Signal: 100kHz to 10MHz, 10mV to 100mV AC

DC voltage source: ±200V with 5mV resolution (400V differential)

DC current: 100mA (MPSMU) or 300mA (HPSMU) maximum

Typical Cp Accuracy @ 1MHz: 1.0%

DC current sensitivity: 10nA/V

Number of SMU bias terminals supported: 4

References

1. Model 4200-SCS Reference Manual
2. Keithley Application Note 2896, "C-V Characterization of MOS Capacitors Using the Model 4200-SCS Semiconductor Characterization System"

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A   G R E A T E R   M E A S U R E   O F   C O N F I D E N C E