Multi-frequency C-V Measurements of Semiconductors

Application Note 369-5

**HP 4284A
Precision LCR Meter**

Introduction

Parameters such as the capacitance of the oxide layer (Cox) and the density of substrate impurities (Nsub) that are required in the evaluation of the manufacturing process of MOS type semiconductors can be derived by using measured C-V characteristics. To make an accurate evaluation of these processes. precise C-V measurements are required. Such measurements entail the following difficulties.

Difficulties

1. There is no single instrument that can make C-V measurements from low to high frequencies.
2. It is difficult to compensate for the additional errors that occur when cable extensions or a prober are used.
3. The accuracy and reliability of the DC bias voltage are not sufficient to perform repeatable C-V measurements.

In the following discussion we will show how C-V measurements are performed with the HP 4284A solving these problems.

Solutions Offered by HP 4284A

1. Wide Frequency Range Measurements from 20 Hz - 1 MHz.

The program listing shown in appendix was used to measure the C-V characteristics at 10 kHz, 100 kHz and 1 MHz of the MOS device whose characteristics are shown in Figure 1. Thus the HP 4284A can single handedly perform C-V measurements in both the low and high frequency ranges. This allows it to measure high-loss devices (semiconductors on large diameter wafers, etc.), which are difficult to measure at 1 MHz, at low frequencies (10 kHz, 100 kHz, etc.).
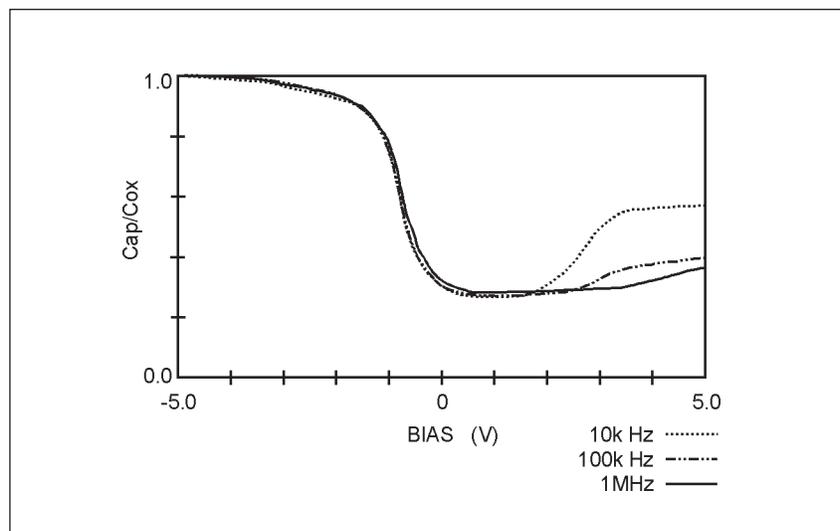

Figure 1. Multi-Frequency C-V Characteristics of a Semiconductor

2. Compensation Functions for Cable Extensions and Probers.

In order to test semiconductor devices on a wafer, an extension cable and a prober are required. (See Figure 2) The extension cable and the prober cause additional errors that greatly influence the test value. The HP 4284A's 2m/4m Cable Length Operation function (opt.006 with HP 16048D/E Test Leads) minimizes additional errors caused by using 2m/4m extension cables. The HP 4284A's OPEN/SHORT/LOAD compensation functions minimize errors caused by a prober. This powerful compensation function ensures highly accurate C-V measurements even when a prober is used.

3. Highly Accurate Internal Bias

Insuddicient accuracy and stability of the bias voltage applied to a device prevent accurate C-V measurements. The HP 4284A ensures the application of a stable bias voltage with a maximum accuracy of 0.1% + 1 mV. (Opt.001) This minimizes measurement errors due to bias voltage errors.
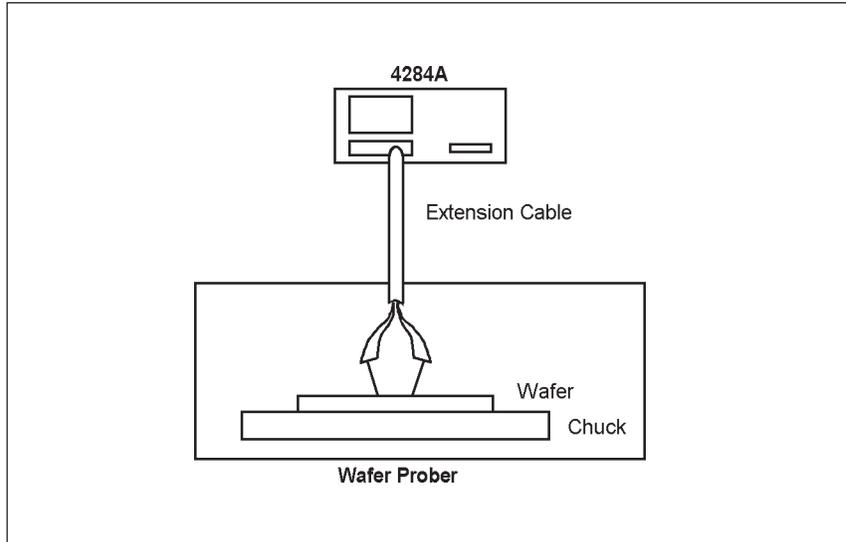
Figure2. Extension Cable and Prober

Table 1. HP 4284A Opt.001 DC Bias Capability

Range	Resolution	Accuracy*
±(0.000 to 4.000)V	1mV	±(0.1% + 1mV)
±(4.002 to 8.000)V	2mV	±(0.1% + 2mV)
±(8.005 to 20.000)V	5mV	±(0.1% + 5mV)
±(20.01 to 40.000)V	10mV	±(0.1% + 10mV)

*This can only be used when the test signal level is < 2 Vrms.

Conclusion

The HP 4284A features a wide frequency range, powerful compensation functions and highly accurate bias characteristics. This versatility of the meter guarantees highly accurate C-V measurements, and higher efficiency in the evaluation of semiconductor processes. Since the HP 4284 can perform all of the low and high frequency C-V measurements singlehandedly, it will greatly contribute to the lowering of capital costs.

Appendix. Sample Program

```
10   ! ******* HP 4284A C-V MEASUREMENT SAMPLE PROGRAM *********
20   !
30     GCLEAR
40     PRINT CHR$(12)                        ! CLEAR DISPLAY
50     DIM C(3,128),Cn(3,128),Vbias(128)
60     REAL Datab(1:513) BUFFER
70     DIM Dum$[6] BUFFER
80     ASSIGN @Ad TO 717;FORMAT ON           ! DEFINE I/O PATH
90     ASSIGN @Pat TO 717;FORMAT OFF         ! DEFINE I/O PATH
100    ASSIGN @Dummy TO BUFFER Dum$          ! DEFINE BUFFER FOR HEADER
110    ASSIGN @Buff TO BUFFER Datab(*)       ! DEFINE BUFFER FOR DATA
120    REMOTE @Ad                            ! SET HP4284A TO REMOTE MODE
130    OUTPUT @Ad;"*RST"                     ! RESET HP4284A
140    OUTPUT @Ad;"VOLT:LEV 0.3V"            ! SET OSC LEVEL TO 300mV
150    OUTPUT @Ad;"OUTP:HPOW ON"             ! BIAS OPTION ON
160    OUTPUT @Ad;"TRIG:SOUR BUS"            ! HP-IB TRIGGER MODE
170    OUTPUT @Ad;"FORM:DATA REAL"           ! BINARY DATA TRANSFER
180    OUTPUT @Ad;"MEM:DIM DBUF,101"         ! DEFINE BUFFER IN HP4284A
190    OUTPUT @Ad;"MEM:FILL DBUF"            ! ENABLE BUFFER TRANSFER
200    OUTPUT @Ad;"APER SHOR"                ! SET INTEG TIME TO SHORT
210    GOSUB Corr
220    PRINT "CONNECT DUT AND PRESS CONTINUE"
230    PAUSE
240    PRINT CHR$(12)                        ! CLEAR DISPLAY
250    Holdtime=10                           ! HOLD TIME = 10sec
260    Delaytime=.1                          ! DELAY TIME = 100msec
270    Vbias(1)=-5                           ! START BIAS VOLTAGE
280    Vstep=.1                              ! 100mV BIAS STEP
290    OUTPUT @Ad;"TRIG:DEL "&VAL$(Delaytime)  ! SET DELAY TIME
300    OUTPUT @Ad;"BIAS:STATE ON"            ! BIAS ON
310    Freq$(1)=" 1MHz"
320    Freq$(2)=" 100KHz"
330    Freq$(3)=" 10KHz"
340    FOR I=1 TO 3
350      OUTPUT @Ad;"FREQ"&Freq$(I)          ! FREQUENCY SETTING
360      OUTPUT @Ad;"BIAS:VOLT "&VAL$(Vbias(1))  ! SET START BIAS VOLTAGE
370      PRINT TABXY(5,15);"HOLD TIME 10SEC"
380      WAIT Holdtime                       ! HOLD TIME
390      PRINT TABXY(5,15);"MEASURING at "&Freq$(I)
400      FOR J=1 TO 101
410        OUTPUT @Ad;"TRIG"                 ! TRIGGER HP4284A
420        IF J=101 THEN 450
430        Vbias(J+1)=Vbias(J)+Vstep         ! CHANGE BIAS VOLTAGE
440        OUTPUT @Ad;"BIAS:VOLT "&VAL$(Vbias(J+1))! SET BIAS VOLTAGE
450      NEXT J
460      RESET @Dummy
470      RESET @Buff
480      OUTPUT @Ad;"MEM:READ? DBUF"         ! READ BUFFER
490      TRANSFER @Pat TO @Dummy;COUNT 6,WAIT   ! TRANSFER HEADER
500      TRANSFER @Pat TO @Buff;COUNT 101*4*8+1,WAIT ! TRANSFER DATA
510      FOR J=1 TO 101
520        C(I,J)=Datab(J*4-3)
530      NEXT J
540      IF MAX(C(*))=0 THEN Err             ! CHECK IF MAX C VALUE IS 0
550      FOR J=1 TO 101
560        Cn(I,J)=C(I,J)/MAX(C(*))          ! NORMALIZE C VALUE
570    ! PRINT Cn(I,J)                       ! PRINT NORMALIZED C VALUE
580      NEXT J
590      OUTPUT @Ad;"MEM:CLE DBUF;FILL DBUF" ! CLEAR DATA IN BUFFER
600      PRINT CHR$(12)                      ! CLEAR DISPLAY
610    NEXT I
620    OUTPUT @Ad;"BIAS:STATE OFF"           ! BIAS OFF
630    GOSUB Plotting
640    GOTO Ending
650    !
660    ! *********************  PLOT C-V  ***********************
670    ! THE FOLLOWINGS ARE FOR PLOTTING THE MEASUREMENT DATA TO CRT.
680    !
690 Plotting:DEG                             ! SET ANGLE UNIT TO DEGREE
700    GRAPHICS ON
710    VIEWPORT 8,150,17,100                 ! PLOT NUMBERS AND LABELS
720    WINDOW 0,100,0,100                    !
730    LDIR 0                                !
740    LORG 2                                !
750    CSIZE 4                               !
760    MOVE 50,15                            !
770    LABEL "BIAS (V)"                      !
780    MOVE 8,23                             !
790    LABEL "-5.0"                          !
800    MOVE 54,23                            !
810    LABEL "0"                             !
820    MOVE 94,23                            !
830    LABEL "5.0"                           !
840    MOVE 5,28                             !
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850   LABEL "0.0"                    !
860   MOVE 5,98                      !
870   LABEL "1.0"                    !
880   MOVE 75,5                      !
890   LABEL "  1MHz"                 !
900   MOVE 75,10                     !
910   LABEL "100kHz"                 !
920   MOVE 75,15                     !
930   LABEL " 10kHz"                 !
940   MOVE 88,5                      !
950   DRAW 98,5                      !
960   LINE TYPE 8                    !
970   MOVE 88,10                     !
980   DRAW 98,10                     !
990   LINE TYPE 3                    !
1000  MOVE 88,15                     !
1010  DRAW 98,15                     !
1020  LINE TYPE 1                    !
1030  LDIR 90                        !
1040  MOVE 3,55                      !
1050  LABEL "Cap/Cox"               !
1060  LDIR 0                         !
1070  MOVE 5,28                      !
1080  LABEL "0.0"                    !
1090  MOVE 5,98                      !
1100  LABEL "1.0"                    ! END PLOT NUMBERS AND LABELS
1110 !
1120  VIEWPORT 23,125,40,100         ! DRAW AXES
1130  FRAME                          !
1140  WINDOW -5,5,0,1                !
1150  AXES 1,.2,-5,0                 ! END DRAW AXES
1160 !
1170  FOR I=1 TO 3                   ! PLOT DATA
1180    MOVE Vbias(1),Cn(I,1)        !
1190    FOR J=2 TO 101               !
1200      DRAW Vbias(J),Cn(I,J)      !
1210    NEXT J                       !
1220    LINE TYPE 3                  !
1230    IF I=1 THEN LINE TYPE 8      !
1240  NEXT I                         ! END PLOT DATA
1250  LINE TYPE 1
1260  RETURN
1270 !
1280 Corr:!   ************* SUBROUTINE FOR CORRECTION  ***************
1290     ! THE FOLLOWINGS ARE FOR PERFORMING OPEN/SHORT COMPENSATION.
1300     !
1310  OUTPUT @Ad;"DISP:PAGE CSETUP"       ! GO TO CORRECTION SETUP PAGE
1320  OUTPUT @Ad;"CORR:LENG 0;METH SING" ! CABLE LENGTH 0m, SINGLE COMPEN MODE
1330  OUTPUT @Ad;"CORR:SPOT1:FREQ 1MAHz;STAT ON"  ! SPOT FREQ 1 = 1MHz
1340  OUTPUT @Ad;"CORR:SPOT2:FREQ 100KHz;STAT ON" ! SPOT FREQ 2 = 100kHz
1350  OUTPUT @Ad;"CORR:SPOT3:FREQ 10KHz;STAT ON"  ! SPOT FREQ 3 = 10kHz
1360  OUTPUT @Ad;"CORR:LOAD:STAT OFF"        ! LOAD COMPEN OFF
1370  PRINT "OPEN COMPENSATION"
1380  PRINT TABXY(5,15);"PRESS CONTINUE"
1390  PAUSE
1400  PRINT TABXY(5,15);"            "
1410  OUTPUT @Ad;"CORR:SPOT1:OPEN"        ! PERFORM OPEN COMPEN AT SPOT FREQ 1
1420  OUTPUT @Ad;"CORR:SPOT2:OPEN"        ! PERFORM OPEN COMPEN AT SPOT FREQ 2
1430  OUTPUT @Ad;"CORR:SPOT3:OPEN"        ! PERFORM OPEN COMPEN AT SPOT FREQ 3
1440  OUTPUT @Ad;"*OPC?"                  ! CONFIRM OPEN MEASUREMENT COMPLETED
1450  ENTER @Ad;A$
1460  OUTPUT @Ad;"CORR:OPEN:STAT ON"      ! OPEN COMPEN ON
1470  PRINT CHR$(12)                      ! CLEAR DISPLAY
1480  PRINT "SHORT COMPENSATION"
1490  PRINT TABXY(5,15);"PRESS CONTINUE"
1500  PAUSE
1510  PRINT TABXY(5,15);"            "
1520  OUTPUT @Ad;"CORR:SPOT1:SHOR"        ! PERFORM SHORT COMPEN AT SPOT FREQ 1
1530  OUTPUT @Ad;"CORR:SPOT2:SHOR"        ! PERFORM SHORT COMPEN AT SPOT FREQ 2
1540  OUTPUT @Ad;"CORR:SPOT3:SHOR"        ! PERFORM SHORT COMPEN AT SPOT FREQ 3
1550  OUTPUT @Ad;"*OPC?"                  ! CONFIRM SHORT MEASUREMENT COMPLETED
1560  ENTER @Ad;A$
1570  OUTPUT @Ad;"CORR:SHOR:STAT ON"      ! SHORT COMPEN ON
1580  OUTPUT @Ad;"DISP:PAGE MEAS"         ! GO TO MEASUREMENT PAGE
1590  PRINT CHR$(12)                      ! CLEAR DISPLAY
1600  RETURN
1610 !
1620 !    *********************************************************
1630 Err:PRINT "C-V MEASUREMENT WAS FAILED."
1640 Ending:END
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