

Agilent AN 369-5 Multi-frequency C-V Measurement of Semiconductors

Application Note

Agilent E4980A and 4284A Precision LCR Meters

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.
- 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 E4980A and 4284A solving these problems.

Solutions Offered by the E4980A and 4284A

1. Wide Frequency Range Measurements from 20 Hz to 2 MHz.

The program listing shown in the 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 E4980A and the 4284A can single-handedy 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 and 3.) The extension cable and the prober cause additional errors that greatly influence the test value. The E4980A and 4284A's 2m/4mCable Length Operation function with 16048D/E test leads, Option 006 for 4284A, minimizes additional errors caused by using 2m/4m extension cables. The E4980A and 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.



Figure 2. Cable extension and prober connection in four-terminal pair (4TP) configuration



Figure 3. Cable extension and prober connection in two-terminal pair (2TP) configuration

3. Highly Accurate Internal Bias

Insufficient accuracy and stability of the bias voltage applied to a device prevents accurate C-V measurements. The E4980A and 4284A ensure the application of a stable bias voltage with a maximum accuracy of 0.1% (Option 001). This minimizes measurement errors due to bias voltage errors.

Table 1. E4980A Option 001 DC Bias Capability

Range	Resolution	Accuracy*
±0 to 5 V	330 µV	± 0.1% + 2 mV
±5.001 to 10 V	1 mV	± 0.1% + 2 mV
±10.002 to 20 V	2 mV	± 0.1% + 2 mV
±20.005 to 40 V	5 mV	± 0.1% + 2 mV

Table 2. 4284A Option 001 DC Bias Capability

Range	Resolution	Accuracy*
±0.000 to 5 V	1 mV	± 0.1% + 1 mV
±4.002 to 8 V	2 mV	± 0.1% + 2 mV
±8.005 to 20 V	5 mV	± 0.1% + 5 mV
±20.01 to 40 V	10 mV	± 0.1% + 10 mV

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

Conclusion

The E4980A and 4284A feature 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. Because the E4980A and 4284A can perform all of the low and high frequency C-V measurements singlehandedly, it will greatly contribute to the lowering of capital costs.

Appendix 1. Agilent E4980A Sample Program List

10 !	Agilent E4980A C-V MEASUREMENT SAMPLE PROGRAM	
20	CCLEAR	
/0	PRINT CHR\$(12)	
50	DIM C(3 101) Cn/3 101) Vhias(101)	
00	INTEGER H1 H2 H3 Tm	
70	DIM D(101 4)	
80	ASSIGN MAA TO 717 FORMAT ON	Ι DEFINE Ι/Ο ΡΔΤΗ
an	ASSIGN @Pat TO 717-EOBMAT OFF	
100	REMOTE @Ad	
110	OUTPUT @Ad." *Pet"	
120		
120		
140		
140		
150		! DEFINE BUFFER IN E4980A
100		! ENABLE BUFFER TRAINSFER
1/0	OUTFUT WAG, APER SHUR	SET INTEG TIME TO SHORT
100		
190	PRINT "CONNECT OUT AND PRESS CONTINUE"	
200	PAUSE	
210	PRINT CHRS(12)	! CLEAR DISPLAY
220	Holdtime=10	! HULD TIME = TUSEC
230	Delaytime=.1	! DELAY TIME = 100msec
240	Vbias(1)=-5	START BIAS VULIAGE
250		100mV BIAS STEP
260	UUTPUT @Ad;"TRIG:DEL "&VAL\$(Delaytime)	! SET DELAY TIME
2/0	OUTPUT @Ad;"OUTP:DC:ISOL:STAT ON"	! DCI ISOLATION ON
280	OUTPUT @Ad;"BIAS:STATE ON"	! BIAS ON
290	FreqS(1)=" 1MHz"	
300	Freq\$(2)=" 100KHz"	
310	FreqS(3)=" 10KHz"	
320	FOR I=1 TO 3	
330	OUTPUT @Ad;"FREQ"&Freq\$(I)	! FREQUENCY SETTING
340	OUTPUT @Ad;"BIAS:VOLT "&VALS(Vbias(1))	! SET START BIAS VOLTAGE
350	PRINT TABXY(5,15);"HOLD TIME 10SEC"	
360	WAIT Holdtime	! HOLD TIME
370	PRINT TABXY(5,15);"MEASURING at "&Freq\$(I)	
380	FOR J=1 TO 101	
390	OUTPUT @Ad;"trig"	! TRIGGER E4980A
400	IF J=101 THEN 430	
410	Vbias(J+1)=Vbias(J)+Vstep	! CHANGE BIAS VOLTAGE
420	OUTPUT @Ad;"BIAS:VOLT "&VALS(Vbias(J+1)) ! SET BIAS VOLTAG	ìΕ
430	NEXT J	
440	OUTPUT @Ad;"MEM:READ? DBUF"	! READ BUFFER
450	ENTER @Pat;H1,H2,H3,D(*),Tm	
460	FOR J=1 TO 101	
470	C(I,J)=D(J,1)	
480	NEXT J	
490	IF MAX(C(*))=0 THEN Err	CHECK IF MAX C VALUE IS 0
500	FOR J=1 TO 101	
510	Cn(I,J)=C(I,J)/MAX(C(*))	! NORMALIZE C VALUE
520	NEXT J	
530	OUTPUT @Ad;"MEM:CLE DBUF;FILL DBUF"	! CLEAR DATA IN BUFFER
540	PRINT CHR\$(12)	! CLEAR DISPLAY
550	NEXT I	
560	OUTPUT @Ad;"BIAS:STATE OFF"	! BIAS OFF
570	GOSUB Plotting	
580	GOTO Ending	
590	!	
600	! ************************************	
610	! THE FOLLOWINGS ARE FOR PLOTTING THE MEASUREMENT DATA TO) CRT.
620	!	
630	Plotting: DEG	! SET ANGLE UNIT TO DEGREE
640	GRAPHICS ON	
650	VIEWPORT 8,150,17,100	PLOT NUMBERS AND LABELS
660	WINDOW 0,100,0,100	!
670	LDIR 0	!
680	LORG 2	!
690	CSIZE 4	!
700	MOVE 45,15	!
710	LABEL "BIAS (V)"	!
720	MOVE 8.23	!
730	LABEL "-5.0"	!
740	MOVE 49,23	!
750	LABEL "0"	!
760	MOVE 84.23	!
770	LABEL "5.0"	!
780	MOVE 5.98	!

Appendix 1. Agilent E4980A Sample Program List continued...

190	LABEL "1.0"	1
800	MOVE 65,5	!
810	LABEL " 1MHz"	!
820	MOVE 65,10	!
830	LABEL "TUUKHZ"	1
040 850		1
860	MOVE 78.5	:
870	DBAW 88.5	!
880	LINE TYPE 8	!
890	MOVE 78,10	!
900	DRAW 88,10	!
910	LINE TYPE 3	!
920	MOVE 78,15	!
930	DRAW 88,15	!
940	LINE TYPE 1	!
950	LUIK 90 MOVE 2 FE	!
900 970	ABEL "Can/Cox"	1
980		:
990	MOVE 5.28	!
1000	LABEL "0.0"	!
1010	MOVE 5,98	!
1020	LABEL "1.0"	! END PLOT NUMBERS AND LABELS
1030		!
1040	VIEWPORT 25,125,40,95	! DRAW AXES
1050	FRAME	!
1060	WINDOW -5,5,0,1	
10/0	AXES 1,.2,-5,0	! END DRAW AXES
1080		
1100	MOVE Vhias(1) Cn(I 1)	
1110	FOR J=2 TO 101	!
1120	DRAW Vbias(J),Cn(I,J)	!
1130	NEXT J	!
1140	LINE TYPE 3	!
1150	IF I=1 THEN LINE TYPE 8	!
1160	NEXT I	! END PLOT DATA
1170	LINE TYPE 1	
1180	RETURN	
1100		
1190		
1190 1200 1210	I Corr: I SUBROUTINE FOR CORRECTION	NTION .
1190 1200 1210 1220	!	STION.
1190 1200 1210 1220 1230	I SUBROUTINE FOR CORRECTION SUBROUTINE FOR CORRECTION THE FOLLOWINGS ARE FOR PERFORMING OPEN/SHORT COMPENSA UITPUT @Ad;"DISP:PAGE CSETUP"	ITION. 9 GO TO CORRECTION SETUP PAGE
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1190 1200 1210 1220 1230 1240 1250	! Corr: ! **********************************	ATION. ! GO TO CORRECTION SETUP PAGE ! CABLE LENGTH 1m, SINGLE COMPEN MODE ! SPOT FREQ.1 = 1MHz
1190 1200 1210 1220 1230 1240 1250 1260	! Corr: ! **********************************	NTION. ! Go to correction setup page ! Cable Length 1m, single compen mode ! Spot Freq 1 = 1 MHz ! Spot Freq 2 = 100kHz
1190 1200 1210 1220 1230 1240 1250 1260 1270	! Corr: ! **********************************	TION. ! Go to correction setup page ! Cable Length 1m, single compen mode ! Spot Freq 1 = 1 MHz ! Spot Freq 2 = 100kHz ! Spot Freq 3 = 10kHz
1190 1200 1210 1220 1230 1240 1250 1260 1270 1280	!	TION. ! Go to correction setup page ! Cable Length 1m, single compen mode ! SPOT FREQ 1 = 1 MHz ! SPOT FREQ 2 = 100kHz ! SPOT FREQ 3 = 10kHz ! LOAD COMPEN OFF
1190 1200 1210 1220 1230 1240 1250 1260 1260 1270 1280 1290	! SUBROUTINE FOR CORRECTION	NTION. I GO TO CORRECTION SETUP PAGE I CABLE LENGTH 1m, SINGLE COMPEN MODE I SPOT FREQ 1 = 1 MHz I SPOT FREQ 2 = 100kHz I SPOT FREQ 3 = 10kHz I LOAD COMPEN OFF
1190 1200 1210 1220 1230 1240 1250 1260 1260 1270 1280 1290 1300	! SUBROUTINE FOR CORRECTION	ITION. I GO TO CORRECTION SETUP PAGE I CABLE LENGTH 1m, SINGLE COMPEN MODE I SPOT FREQ 1 = 1MHz I SPOT FREQ 2 = 100kHz I SPOT FREQ 3 = 10kHz I LOAD COMPEN OFF
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1190 1200 1210 1220 1230 1260 1260 1270 1280 1300 1300 1300 1300 1300 1300 1300 13	!	I CONFIRM SHORT COMPEN AT SPOT FREQ 1 PERFORM SHORT COMPEN AT SPOT FREQ 1 PERFORM SHORT COMPEN AT SPOT FREQ 1 PERFORM OPEN COMPEN AT SPOT FREQ 2 PERFORM OPEN COMPEN AT SPOT FREQ 2 PERFORM OPEN COMPEN AT SPOT FREQ 3 CONFIRM OPEN MEASUREMENT COMPLETED PERFORM SHORT COMPEN AT SPOT FREQ 1 PERFORM SHORT COMPEN AT SPOT FREQ 2 PERFORM SHORT COMPEN AT SPOT FREQ 3 CONFIRM SHORT COMPEN AT SPOT FREQ 3 I CONFIRM SHORT MEASUREMENT COMPLETED SHORT COMPEN ON GO TO MEASUREMENT PAGE I CLEAR DISPLAY
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Appendix 2. Agilent 4284A Sample program list

10 ! ******* Agilent 4284A C-V MEASUREMENT SAMPLE PROGRAM ******* 20 OPTION BASE 1 30 GCLEAR 40 PRINT CHR\$(12) ! CLEAR DISPLAY 50 DIM C(3,101),Cn(3,101),Vbias(101) 60 INTEGER H1,H2,H3,Tm 70 DIM D(101,4) 80 ASSIGN @Ad TO 717;FORMAT ON I DEFINE I/0 PATH 90 ASSIGN @Pat TO 717;FORMAT OFF ! DEFINE I/0 PATH 100 REMOTE @Ad ! SET 4284A TO REMOTE MODE 110 OUTPUT @Ad;" *Rst" ! RESET 4284A 120 OUTPUT @Ad;"VOLT:LEV 0.02V" ! SET OSC LEVEL TO 20mV **! BIAS OPTION ON** 130 OUTPUT @Ad;"OUTP:HPOW ON" 140 OUTPUT @Ad;"TRIG:SOUR BUS" I GPIB TRIGGER MODE 150 OUTPUT @Ad;"FORM:DATA REAL" **! BINARY DATA TRANSFER** 160 OUTPUT @Ad:"MEM:DIM DBUE.101" ! DEFINE BUFFER IN 4284A ! ENABLE BUFFER TRANSFER 170 OUTPUT @Ad;"MEM:FILL DBUF" 180 OUTPUT @Ad;"APER SHOR" **! SET INTEG TIME TO SHORT** 190 GOSUB Corr 200 PRINT "CONNECT OUT AND PRESS CONTINUE" 210 PAUSE 220 PRINT CHR\$(12) ! CLEAR DISPLAY 230 Holdtime=10 ! HOLD TIME = 10sec 240 Delaytime=.1 ! DELAY TIME = 100msec 250 Vbias(1)=-5 **! START BIAS VOLTAGE** 260 Vstep=.1 100mV BIAS STEP 270 OUTPUT @Ad;"TRIG:DEL "&VAL\$(Delaytime) ! SET DELAY TIME 280 OUTPUT @Ad;"OUTP:DC:ISOL ON" ! DC BIAS ISOLATION ON 290 OUTPUT @Ad;"BIAS:STATE ON" ! BIAS ON 300 Freq\$(1)=" 1MHz" 310 Freq\$(2)=" 100KHz" 320 Freq\$(3)=" 10KHz" FOR I=1 TO 3 330 OUTPUT @Ad;"FREQ"&Freq\$(I) **! FREQUENCY SETTING** 340 OUTPUT @Ad;"BIAS:VOLT "&VAL\$(Vbias(1)) 350 ! SET START BIAS VOLTAGE PRINT TABXY(5,15);"HOLD TIME 10SEC" 360 370 WAIT Holdtime ! HOLD TIME PRINT TABXY(5,15);"MEASURING at "&Freq\$(I) 380 FOR J=1 TO 101 390 OUTPUT @Ad;"trig" ! TRIGGER 4284A 400 IF J=101 THEN 440 410 Vbias(J+1)=Vbias(J)+Vstep OUTPUT @Ad;"BIAS:VOLT "&VALS(Vbias(J+1)) ! CHANGE BIAS VOLTAGE 420 430 **I SET BIAS VOLTAGE** 440 NEXT J OUTPUT @Ad;"MEM:READ? DBUF" **! READ BUFFER** 450 ENTER @Pat;H1,H2,H3,D(*),Tm 460 FOR J=1 TO 101 470 480 C(I,J)=D(J,1)NEXT J 490 500 IF MAX(C(*))=0 THEN Err ! CHECK IF MAX C VALUE IS 0 510 FOR J=1 TO 101 ! NORMALIZE C VALUE 520 Cn(I,J)=C(I,J)/MAX(C(*)) 530 PRINT Cn(I,J) **! PRINT NORMALIZED C VALUE** 540 NEXT J OUTPUT @Ad;"MEM:CLE DBUF;FILL DBUF" 550 ! CLEAR DATA IN BUFFER 560 PRINT CHR\$(12) ! CLEAR DISPLAY 570 NEXT I 580 OUTPUT @Ad;"BIAS:STATE OFF" **! BIAS OFF** 590 GOSUB Plotting 600 GOTO Ending 610 620 630 ! THE FOLLOWINGS ARE FOR PLOTTING THE MEASUREMENT DATA TO CRT. 640 650 Plotting: DEG ! SET ANGLE UNIT TO DEGREE GRAPHICS ON 660 VIEWPORT 8,150,17,100 PLOT NUMBERS AND LABELS 670 WINDOW 0,100,0,100 680 690 LDIR 0 700 LORG 2 710 CSIZE 4 720 MOVE 45,15 730 LABEL "BIAS (V)" 740 MOVE 8 23 750 LABEL "-5.0" 760 MOVE 49.23 770 LABEL "0"

780 MOVE 84,23 790 LABEL "5.0"

800	MOVE 5,98	!
810 820	LABEL "1.0"	1
830	LABEL " 1MHz"	1
840	MOVE 65,10	!
850	LABEL "100kHz"	!
860	NUVE 65,15	1
880	MOVE 78,5	!
890	DRAW 88,5	!
900	LINE TYPE 8	!
910	NIUVE 78,10 DRAW 88.10	1
930	LINE TYPE 3	!
940	MOVE 78,15	!
950	DRAW 88,15	1
970	LDIR 90	: !
980	MOVE 3,55	!
990	LABEL "Cap/Cox"	!
1000	LDIR U MOVE 5.28	!
1020	LABEL "0.0"	!
1030	MOVE 5,98	!
1040	LABEL "1.0"	! END PLOT NUMBERS AND LABELS
1050	! VIEW/PORT 25.125.40.95	I DRAW AXES
1070	FRAME	1
1080	WINDOW -5,5,0,1	!
1090	AXES 1,.2,-5,0	! END DRAW AXES
1100		
1120	MOVE Vbias(1),Cn(I,1)	!
1130	FOR J=2 TO 101	!
1140	DRAW Vbias(J),Cn(I,J)	!
1150	NEXT J LINE TYPE 3	!
1170	IF I=1 THEN LINE TYPE 8	!
1180	NEXT I	! END PLOT DATA
1190	LINE TYPE 1	
1200	RETURN	
1220	Corr: ! ************ SUBROUTINE FOR CORRECTION ***********	
1230	! THE FOLLOWINGS ARE FOR PERFORMING OPEN/SHORT COMPENSATION.	
1240		
1250	UUTPUT @Ad;"DISP:PAGE CSETUP" OUTPUT @Ad:"CORR:LENG 1:METH SING"	I GO TO CORRECTION SETUP PAGE
1200	OUTPUT @Ad;"CORR:SPOT1:FREQ.1MHz;STAT ON"	! SPOT FREQ 1 = 1MHz
1280	OUTPUT @Ad;"CORR:SPOT2:FREQ 100KHz;STAT ON"	! SPOT FREQ 2 = 100kHz
1290	OUTPUT @Ad;"CORR:SPOT3:FREQ 10KHz;STAT ON"	! SPOT FREQ 3 = 10kHz
1300	PRINT "OPEN COMPENSATION"	! LUAD COMPEN OFF
1320	PRINT TABXY(5,15);"PRESS CONTINUE"	
1330	PAUSE	
1340	PRINT TABXY(5,15);" "	
1350	OUTPUT @Ad;"CORR:SPOTI:OPEN" OUTPUT @Ad:"CORR:SPOT2:OPEN"	PERFORM OPEN COMPEN AT SPOT FREU T
1370	OUTPUT @Ad;"CORR:SPOT3:OPEN"	PERFORM OPEN COMPEN AT SPOT FREQ 3
1380	OUTPUT @Ad;"*0PC?"	! CONFIRM OPEN MEASUREMENT COMPLETED
1390	ENTER @Ad;A\$	
1400	UUTPUT @Ad;"CURR:UPEN:STAT UN" PRINT CHR\$(12)	
1420	PRINT "SHORT COMPENSATION"	
1430	PRINT TABXY(5,15);"PRESS CONTINUE"	
1440	PAUSE	
1450	PRINT TABAY(5,15);" OLITPLIT @Ad:"CORR:SPOT1:SHOR"	PERFORM SHORT COMPEN AT SPOT FRED 1
1470	OUTPUT @Ad;"CORR:SPOT2:SHOR"	PERFORM SHORT COMPEN AT SPOT FREQ 2
1480	OUTPUT @Ad;"CORR:SPOT3:SHOR"	PERFORM SHORT COMPEN AT SPOT FREQ 3
1490	OUTPUT @Ad;"*OPC?"	! CONFIRM SHORT MEASUREMENT COMPLETED
1500 1510	EINTEN WAU;AN OUTPUT @Ad:"COBR:SHOR:STAT ON"	! SHORT COMPEN ON
1520	OUTPUT @Ad;"DISP:PAGE MEAS"	! GO TO MEASUREMENT PAGE
1530	PRINT CHRS(12)	! CLEAR DISPLAY
1540	RETURN	
1560	: 	
1570	Err: PRINT "C-V MEASUREMENT FAILED."	
1580	Ending: END	

Appendix 2. Agilent 4284A Sample program list continued...



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