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RESEARCH TRIANGLE INSTITUTE

Second Quarterly Technical Report

INVESTIGATION OF LOW TEMPERATURE MULTILEVEL DIELECTRICS FOR APPLICATION FOR RADIATION TOLERANT, SUBMICRON-SCALED IC TECHNOLOGY

Period Covered: 1 April 1989 to 30 June 1989

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The following report details the progress on ONR contract number N-00014-86-0421 during the period from April 1, 1989 to June 30, 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University.

During this quarter work has proceeded in mapping out the nitride deposition parameter space. The new ultra high purity reactor is on line and in use. Nitride results show a 2 order of magnitude improvement.

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1.0 INTRODUCTION

The following report details the progress on ONR Contract Number N-00014-86-0421 during the period from 1 April 1989 to 30 June 1989. This program entails a joint effort between Research Triangle Institute and North Carolina State University. Funding is being provided by the Innovative Science and Technology Office of the Strategic Defense Initiative.

During this quarter work has proceeded in mapping out the nitride deposition parameter space. This work is described in section 2.0. The new ultra-high purity reactor is on line and in use. Nitride results showing a 2 order of magnitude improvement over results from the original reactor are given. This work is described in section 3.0. Section 4.0 includes the summary and preview.

2.0 NITRIDE DEPOSITION WORK

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A great deal of effort has been put into characterization of the remote plasma-enhanced nitride deposition process using N_2 as the nitrogen source. The data base ~~listing in Appendix A~~ includes deposition conditions and characterizations of the deposited films. The deposition variables include temperature, pressure, and gas flow rates. The characterizations include deposition rate, etch rate, refractive index (from elipsometry), dielectric constant, infrared data, flatband shift, and hydrogen content. This data base allows correlation of data according to any combination of parameters in the data base. This function can be used to verify the possibility of improbability of various suspected correlations. This capability is illustrated in Figure 1, "Growth rate vs. Silane Flow Rate". Note the parameters listed under the title.

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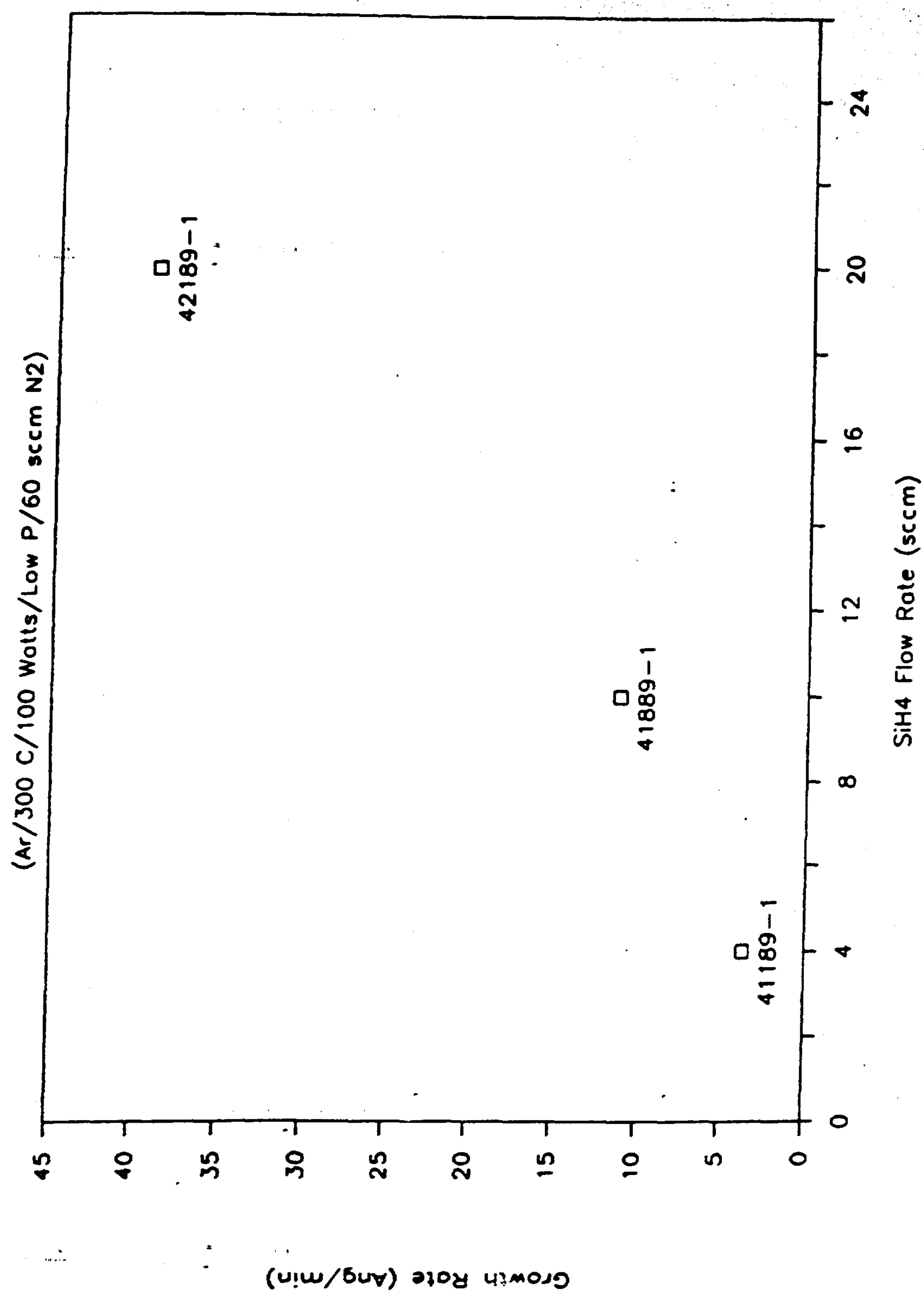

FIGURE 1: Growth rate vs. SiH_4 rate.

3.0 NEW ULTRA-HIGH PURITY REMOTE PLASMA DEPOSITION SYSTEM

A new ultra-high purity deposition system is now on line and operating at RTI. This reactor takes advantage of the insights we have gained into the oxide and nitride deposition processes. The reactor has an all quartz deposition region for high purity. and a long flow tube type design to minimize eddie current flows. The all-quartz construction of the reaction zone allows us to use external heaters to heat the sample. which greatly simplifies the internal construction of the reactor and eliminates many sources of contamination. The reaction zone is heated with infra-red lamps. This radiation should couple very well into any water-related byproducts and help to drive them off of the reactor walls so they can be transported out of the reaction zone. The gas delivery lines are very short to minimize contamination from the lines, and each gas will be filtered at its injection point with a .05 micron filter. All-metal sealed leak valves are used for flow control so that the gas lines are entirely UHV compatible and bakeable. The system provides much latitude for adjustment of sample position and plasma region position. We believe this system will allow us to make major strides in the development of high-quality, highly reliable dielectrics.

Already the new system is proving its viability in the area of nitride deposition. The charge to breakdown data shown in Figure 2 is from a nitride deposited at 300 °C in the new system. This nitride film passed a total charge of over 400 C/cm^2 before breaking down. The total voltage shift was less than 0.1 Volt. The best nitride films out of the original reactor had total charge to breakdown values of 1 C/cm^2. **This** exciting new result we attribute to the overall improved purity in the new **reactor.**

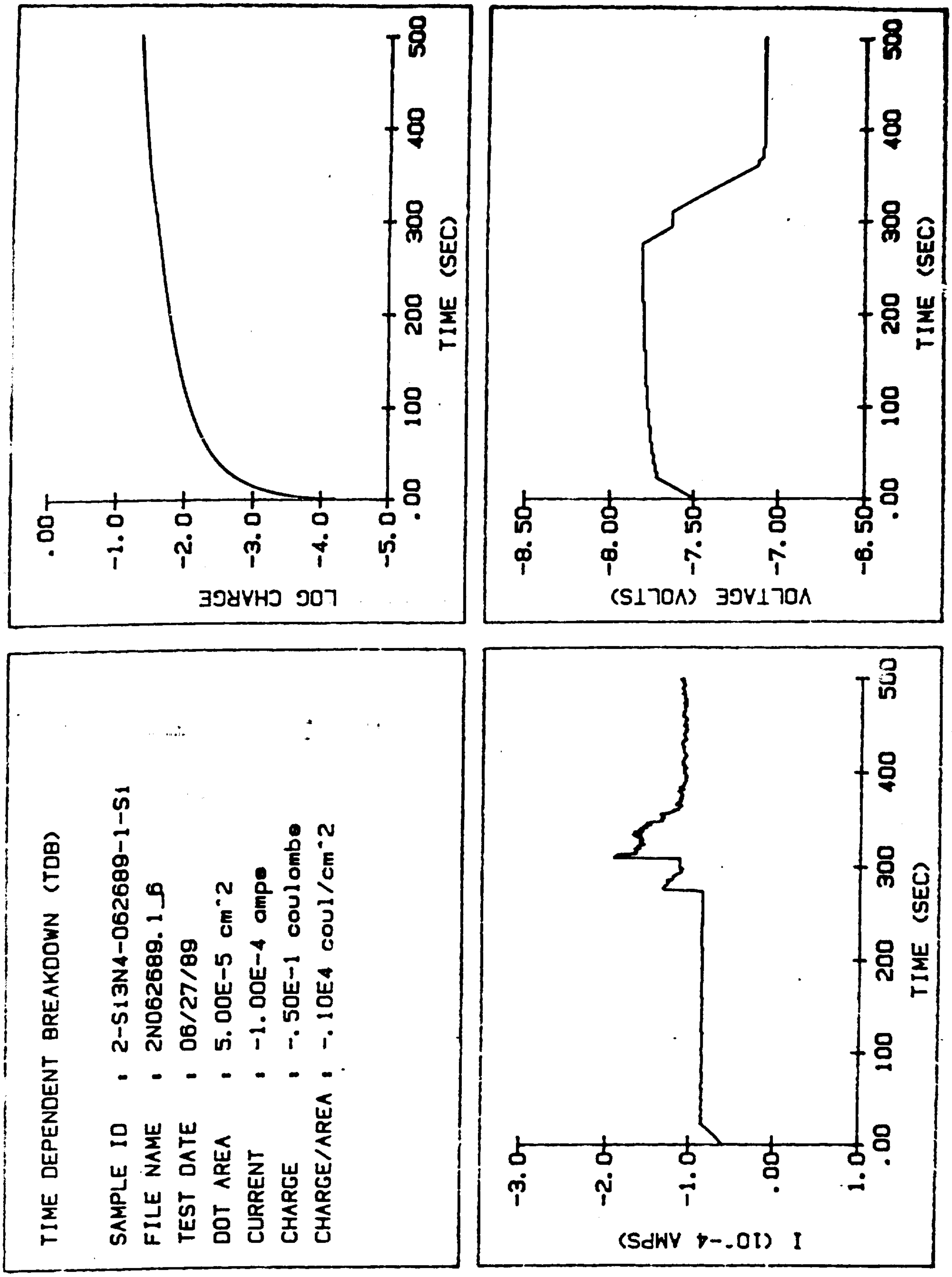

FIGURE 2: Time dependent breakdown measurement for Si_3N_4 film ($\sim$ 10 nm thick) deposited at 300 °C using the new ultra-high purity reactor.

4.0 SUMMARY AND PREVIEW

During this quarter the nitride deposition process parameter space has been intensively investigated. The data has been entered into a data base for convenient evaluation. Possible correlations of deposition parameters with material characteristics are being evaluated.

The new ultra-high purity deposition system has been brought on line and is being exercised. This system has already shown the capability of improving the quality of the deposited materials in the nitride deposition area. A Si_3N_4 film has been deposited which passed 400 C/cm^2 before breaking down. This result is a 2 order of magnitude improvement over results obtained in the original system.

During the next quarter we will report additional results from deposition studies conducted using the new ultra-high purity reactor. These studies will include both oxide and nitride depositions.

APPENDIX A

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions Temp. (C)	Power Watts)	Press. (Torr)	Plasma Feed Ar (sccm)	He	N2	Ring Feed SiH4 (sccm)	N2	H2	Ar/He	Film Thickness (A)
32889-2	300	30	Low P	400			10	60			491.4
32989-2	300	30	Low P	400			10	60	100		585.0
33189-2	300	30	Low P	400			4	60			
40389-2	300	30	0.30	400			10	60			1598.4
40689-2	300	30	0.30	400			2	60			320.0
40789-1	300	30	0.30	400			4	60		100	1327.0
40789-2	300	30	Low P	400			4	60	100		470.0
41089-1	300	30	Low P	400			2	60			too thin
41189-1	300	100	Low P	400			4	60			876.0
41189-2	350	30	Low P	400			4	60			542.0
41289-1	300	30	Low P	400			4	60			645.0
41289-2	300	100	Low P	400			4	30			678.3
41389-1	300	30	0.30	400			4	60			770.0
41389-2	300	30	0.20	400			4	60			1026.0
41489-1	300	30	Low P	400			4	30			461.6
41789-1	300	30	Low P	400			4	60			510.0
41889-1	300	100	Low P	400			10	60			1350.0
41989-1	300	100	Low P	400			10	60			2200.0
42189-1	300	100	Low P	400			20	60			2340.0
42189-2	300	100	0.30	400			4	60			970.0
42489-1	300	100	Low P	400			10	100			2000.0
42489-2	300	100	Low P	400			10	100			2750.0
42689-2	300	100	Low P	400			10	20			2150.0
50289-1	300	30	0.07	400		20	4				430.0
50289-2	300	30	0.07	400			4	20			600.0
50389-1	300	30	0.07	400		20	10				653.0
50389-2	300	30	0.07	400			10	20			730.0

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions Temp. (C)	Power Watts)	Press. (Torr)	Plasma Feed Ar (sccm)	He	N2	Ring Feed SiH4 (sccm)	N2	H2	Ar/He	Film Thickness (A)
50389-3	300	10	0.07	400		20	4				431.0
50489-1	300	30	0.10		500	10	10				750.0
50589-1	300	30	0.10		500		10	10			565.0
50589-2	300	30	0.10		500	10	4				250.0
50589-3	300	30	0.20		500	40	10				605.0
50889-1	300	30	0.10		500	40	10				410.0
50889-2	300	30	0.10		200	40	10				230.0
50889-3	300	30	0.10		100	40	10				100.0
50989-1	300	30	0.10		200	40	4				160.0
50989-2	300	30	0.30		200	40	10				0.0
51089-1	300	30	Low P		400		10	5			555.0
51089-2	300	30	Low P		400		10	20			315.0
51089-3	300	30	Low P		400		10	40			307.5
51189-1	300	30	Low P		200		10	40			464.0
51189-2	400	30	Low P		300		10	40			225.0
51189-3	400	30	Low P		300		4	40			
51289-1	400	30	Low P		200	40	4				175.0
51289-2	400	30	Low P		200		10	100			558.0
51589-1	350	100	Low P		200	100	10				567.0
51589-2	350	100	Low P		200		10	100			588.0
51589-3	350	200	Low P		200		10	100			913.0
51689-1	350	200	Low P		200	100	10				570.0
51689-2	350	200	Low P		200	100	4	100			519.0
51689-3	350	200	Low P		500		10	100			820.5

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Conditions			Plasma Feed			Ring Feed				Film
	Temp. (C)	Power Watts)	Press. (Torr)	Ar (sccm)	He	N2	SiH4 (sccm)	N2	H2	Ar/He	Thickness (A)
51789-1	350	200	Low P		500	100	10				680.0
51789-2	400	200	Low P		200		10	100			627.0
51789-3	400	200	0.08	200			4	100			473.0
51889-1	300	200	0.08	200			10	40			533.0
51889-2	300	200	0.08	500			10	40			1014.0
51889-3	300	200	0.08	500			10	100			
51989-1	400	200	0.08	300			10	100			
51989-2	400	200	0.07	300			10	100			
51989-3	400	200	0.08	300			10	100			

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Time (min)	Growth Rate (A/min)	Etch Thickness (A)	Etch Time (sec)	Etch Rate (A/sec)	Optical Thickness (A)	Refract. Index (n)	Concentration [Si-H] cm-3	Concentration [N-H]
32889-2	45	10.92	96.5	5	19.30	537.0	1.734		
32989-2	90	6.50	77.5	5	15.50	606.0	1.794		1.94E+22
33189-2	120	0.00		5	0.00	442.5	1.802		2.16E+22
40389-2	120	13.32	80.0	5	16.00	1455.5	1.812		
40689-2	180	1.78	235.0	10	23.50	299.0	2.000	1.00E+21	1.33E+22
40789-1	180	7.37	1150.0		ERR	1342.5	1.668		
40789-2	210	2.24	455.0	5	91.00	567.3	1.713		1.09E+22
41089-1	240	0.00		5	0.00	280.0	2.000		1.57E+22
41189-1	240	3.65	57.5	120	0.48	859.3	1.899		
41189-2	180	3.01	75.0	30	2.50	663.0	1.819		5.63E+21
41289-1	180	3.58	228.0	30	7.60	608.5	1.809		5.50E+21
41289-2	180	3.77	130.0	180	0.72	735.0	1.896		6.17E+21
41389-1	180	4.28	113.3	5	22.66	928.0	1.680		5.16E+21
41389-2	180	5.70	511.6	5	102.32	867.0	1.702		9.46E+21
41489-1	180	2.56	461.0	5	92.20	662.0	1.820		7.08E+21
41789-1	180	2.83	45.0	10	4.50	631.0	1.785		1.80E+22
41889-1	120	11.25	322.5	30	10.75	2342.0	2.000		2.50E+22
41989-1		ERR		5					
42189-1	60	39.00	30.0	5	6.00	1904.5	2.000		
42189-2	180	5.39	450.0	5	90.00	882.0	1.727		5.32E+21
42489-1	120	16.67	40.0	5	8.00	1715.7	2.000		1.13E+22
42489-2	120	22.92		5					4.47E+21
42689-2	128	16.80	60.0	10	6.00	1766.0	2.000		6.22E+21
50289-1	180	2.39		5	0.00				
50289-2	180	3.33		5	0.00	670.0	1.808		
50389-1	60	10.88		5	0.00	664.0	1.747		
50389-2	60	12.17		5	0.00	758.0	1.743		

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth		Etch			Optical	Refract.	Concentration	
	Time (min)	Rate (A/min)	Thickness (A)	Time (sec)	Rate (A/sec)	Thickness (A)	Index (n)	[Si-H] cm-3	[N-H]
50389-3	180	2.39		5	0.00	474.0	1.790		
50489-1	120	6.25		5	0.00	793.0	1.803		
50589-1	90	6.28		5	0.00	584.5	1.801		
50589-2	180	1.39			ERR	341.0	2.000		
50589-3	120	5.04			ERR	548.0	1.811		
50889-1	90	4.56			ERR	417.0	1.794		
50889-2	60	3.83			ERR	245.0	2.000		
50889-3	60	1.67			ERR	156.0	2.000		
50989-1	180	0.89		5	0.00	250.0	2.000		
50989-2	90	0.00		5	0.00	30.0	2.000		
51089-1	90	6.17		5	0.00	607.0	1.830		
51089-2	60	5.25		5	0.00	304.0	2.000		
51089-3	60	5.13		5	0.00	280.0	2.000		
51189-1	90	5.16		5	0.00	464.0	1.826		
51189-2	60	3.75		5	0.00	233.0	2.000		
51189-3	180	0.00		5	0.00	188.0	2.000		
51289-1	210	0.83		5	0.00	245.0	2.000		
51289-2	120	4.65		5	0.00	558.0	1.845		
51589-1	90	6.30		5	0.00	567.0	1.867		
51589-2	90	6.53		5	0.00	588.0	1.860		
51589-3	180	5.07	360.8	120	3.01	913.0	1.867		
51689-1	90	6.33		5	0.00	570.0	1.880		
51689-2	210	2.47		5	0.00	519.0	1.926		
51689-3	90	9.12	283.0	20	14.15	800.5	1.857		

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Growth Time (min)	Growth Rate (A/min)	Etch Thickness (A)	Etch Time (sec)	Etch Rate (A/sec)	Optical Thickness (A)	Refract. Index (n)	Concentration [Si-H] cm-3	Concentration [N-H]
51789-1	90	7.56		5	0.00	668.0	1.849		
51789-2	90	6.97		5	0.00	627.0	1.880		
51789-3	180	2.63	938.0	120	7.82	473.0	1.932		
51889-1	90	5.92			ERR	533.0	1.882		
51889-2	120	8.45	50.0	20	2.50				
51889-3	120	0.00			ERR				
51989-1	210	0.00			ERR				
51989-2	90	0.00			ERR				
51989-3	210	0.00			ERR				

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
32889-2				0.00
32989-2				0.00
33189-2				0.00
40389-2	125.0	-3.15	1.0E-07	10.96
40689-2	124.2	-1.40	1.0E-07	2.18
40789-1	140.0	-1.15	5.0E-08	10.19
40789-2	350.0	-2.00	1.0E-07	9.02
41089-1	335.0	-2.25		0.00
41189-1	218.0	-2.60	1.0E-08	10.47
41189-2	140.0	-15.60	1.0E-09	4.16
41289-1	223.0	-1.95	1.0E-08	7.89
41289-2	102.1	-21.50	1.0E-09	3.80
41389-1	295.0	-1.15	1.0E-08	12.46
41389-2	234.7	-1.60	1.0E-07	13.21
41489-1	298.0	-1.25	1.0E-07	7.55
41789-1	220.0	-1.60	1.0E-08	6.15
41889-1	138.0	-2.05	1.0E-07	10.22
41989-1	103.0	-1.25	1.0E-08	12.43
42189-1	115.2	-1.30	1.0E-07	14.79
42189-2	255.0	-1.30	1.0E-07	13.57
42489-1	150.0	-1.75	1.0E-07	16.46
42489-2	120.0	-2.20	1.0E-07	18.10
42689-2			1.0E-07	0.00
50289-1			1.0E-07	0.00
50289-2	218.0	-2.10	1.0E-07	7.17
50389-1	300.0	-1.60	1.0E-07	10.75
50389-2	370.4	-1.35	1.0E-07	14.83

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
50389-3	255.0	-1.72	1.0E-07	6.03
50489-1	127.0	-5.00	1.0E-09	5.22
50589-1	230.0	-6.30	1.0E-09	7.13
50589-2				0.00
50589-3				0.00
50889-1				0.00
50889-2				0.00
50889-3				0.00
50989-1	377.4	-3.10	5.0E-09	3.31
50989-2				0.00
51089-1			1.0E-08	0.00
51089-2	307.1	-5.55	5.0E-08	5.31
51089-3	292.7	-5.15	5.0E-09	4.94
51189-1	251.0	-1.90	2.0E-08	6.39
51189-2	467.0	-4.60	9.0E-11	5.76
51189-3	596.0	-5.30	9.0E-11	0.00
51289-1	469.0	-6.45	5.0E-07	4.50
51289-2	204.0	-9.60	3.0E-09	6.24
51589-1	195.3	-3.30	6.0E-08	6.07
51589-2	191.5	-3.08	6.0E-08	6.18
51589-3	133.0	-3.95	6.0E-08	6.66
51689-1	211.0	-3.45	8.0E-08	6.60
51689-2	202.0	-15.00	1.0E-06	5.75
51689-3	157.8	-3.00	1.0E-07	7.10

SILICON NITRIDE DEPOSITION PROCESS OPTIMIZATION

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Sample	Accum. Cap. pF	Flat-Band Voltage Shift (V)	I-V Ledge (Log I)	Epsilon-R Si3N4
51789-1				0.00
51789-2	195.0	-3.55	8.0E-08	6.71
51789-3	182.0	-13.00	5.0E-11	4.72
51889-1	206.0	-4.35	5.0E-08	6.02
51889-2				0.00
51889-3				0.00
51989-1				0.00
51989-2				0.00
51989-3				0.00