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TABLE OF CONTENTS

PLENARY SESSION: Invited Papers

Monday, December 10, 9:00 a.m.
Continental Ballroom

Chairman: H. Geipel

- 1.1 MICROELECTRONICS: End of the Beginning or Beginning of the End?, G. H. Heilmeier, *Texas Instruments, Inc., Dallas, TX* 2
- 1.2 TRENDS IN MEGABIT DRAMs, S. Asai, *Hitachi Central Research Laboratory, Tokyo, Japan* 6
- 1.3 GaAs IC TECHNOLOGY—Impact on the Semiconductor Industry, C. A. Liechti, *Rockwell International, Thousand Oaks, CA* 13

SESSION 2: Detectors, Sensors and Displays— High Density Image Sensors

Monday, December 10, 1:00 p.m.
Continental Ballroom 1,2,3

Co-Chairmen: R. D. McGrath
E. Oda

- 1:00 p.m.
INTRODUCTION
- 1:05 p.m.
2.1 CHARGE COUPLED DEVICES FOR X-RAY IMAGING (Invited Paper), M. Wadsworth and R. McGrath, *Texas Instruments, Dallas, TX* 20
- 1:30 p.m.
2.2 A DESIGN CONSIDERATION ON P-WELL STRUCTURE FOR SOLID-STATE IMAGE SENSORS, A. Kohno, Y. Ishihara, and N. Teranishi, *NEC Corporation, Kawasaki, JAPAN* 24
- 1:55 p.m.
2.3 THE PINNED PHOTODIODE FOR AN INTERLINE-TRANSFER CCD IMAGE SENSOR, B. Burkey, W. Chang, J. Littlehale, T.H. Lee, T. Tredwell, J. Lavine, and E. Trabka, *Eastman Kodak Company, Rochester, NY* 28
- 2:20 p.m.
2.4 ELIMINATION OF FIXED PATTERN NOISE IN SUPER-8 FORMAT CCD IMAGE SENSOR BY THE USE OF EPITAXIAL WAFERS, Y. Hiroshima, S. Matsumoto, K. Senda, T. Kuriyama, K. Horii, T. Kuroda, T. Kunii, and H. Mizuno, *Matsushita Electronics Corporation, Osaka, JAPAN* 32
- 2:45 p.m.
2.5 SOLID STATE COLOR IMAGER WITH BURIED OXIDE WALL FABRICATED BY LOW PRESSURE SELECTIVE EPITAXY, S. Hine, S. Nagao, N. Tsubouchi, and H. Nakata, *Mitsubishi Electric Corporation, Hyogo, JAPAN* 36
- 3:10 p.m.
2.6 THE ACCORDIAN IMAGER: AN ULTRA HIGH DENSITY FRAME TRANSFER CCD, A. Theuvsen, C. Weijtens, L. Esser, J. Cox, H. Duyvelaar, and W. Keur, *Philips Research Laboratories, THE NETHERLANDS* 40
- 3:35 p.m.
2.7 A SINGLE CHIP 1/4" FRAME TRANSFER CCD COLOR IMAGE SENSOR, N. Mitani, T. Furusawa, Y. Tsuchihashi, Y. Kitamura, Y. Kiriya, and Y. Rai, *Sanyo Electric Co., Ltd., Gifu Prefecture, JAPAN* 44

SESSION 3: Integrated Circuits—MOS Process Technologies

Monday, December 10, 1:00 p.m.
Continental Ballroom 4,5

Co-Chairmen: E. Demoulin
R. J. Smith

- 1:00 p.m.
INTRODUCTION

- 1:05 p.m.
3.1 RELIABILITY IN MOS INTEGRATED CIRCUITS (Invited Paper), M. Woods and B. Euzent, *Intel Corporation, Santa Clara, CA* 50
- 1:30 p.m.
3.2 A DOUBLE LAYER METAL CMOS III TECHNOLOGY, R. Smith, G. Sery, J. McCollum, J. Orton, B. Mantha, J. Smudski, T. Chi, S. Smith, P. Dishaw, and K. Kokkonen, *Intel Corporation, Santa Clara, CA* 56
- 1:55 p.m.
3.3 Hi-CMOS III TECHNOLOGY, S. Meguro, S. Ikeda, K. Nagasawa, A. Koike, T. Yasui, Y. Sakai and T. Hayashida, *Hitachi, Ltd., Tokyo, JAPAN* 59
- 2:20 p.m.
3.4 TWIN TUB III-A THIRD GENERATION CMOS TECHNOLOGY, J. Agraz-Guerena, R. Ashton, W. Bertram, R. Melin, R. Sun, and J. Clemens, *AT&T Bell Laboratories, Allentown, PA* 63
- 2:45 p.m.
3.5 A NEW FULL CMOS SRAM CELL STRUCTURE, O. Kudoh, H. Ooka, I. Sakai, M. Saitoh, J. Ozaki, and M. Kikuchi, *NEC Corporation, Kanagawa, JAPAN* 67
- 3:10 p.m.
3.6 A MANUFACTURABLE 1.2 MICRON DOUBLE POLY, DOUBLE LEVEL METAL CMOS PROCESS FOR A ONE MEGABIT DRAM, T. Harrington, M. Bayless, B. Waller, and T. Chan, *United Technologies Mostek, Carrollton, TX* 71
- 3:35 p.m.
3.7 NMOS PROCESS INTEGRATION FOR A 1M WORD $\times$ 1 BIT DRAM, T. Shibata, T. Moriya, K. Kurosawa, T. Mitsuno, K. Okumura, Y. Horiike, K. Yamada, and M. Muromachi, *Toshiba Corporation, Kawasaki, JAPAN* 75

SESSION 4: Solid State Devices—Hot Carriers in MOSFETs

Monday, December 10, 1:00 p.m.
Continental Ballroom 6,7,8,9

Co-Chairmen: J. Y. Chen
L. E. Clark

- 1:00 p.m.
INTRODUCTION
- 1:05 p.m.
4.1 HOT CARRIERS IN SMALL GEOMETRY CMOS, L. Akers, *Arizona State University, Tempe, AZ*; M. Holly, C. Lund, *Motorola, Inc., Phoenix, AZ* 80
- 1:30 p.m.
4.2 A STUDY OF AVALANCHE BREAKDOWN IN SCALED n-MOSFETs, S. Laux, *IBM T.J. Watson Research Center, Yorktown Heights, NY*; F. Gaensslen, *IBM Corporation, Purchase, NY* 84
- 1:55 p.m.
4.3 ENHANCEMENT OF HOT-ELECTRON CURRENTS IN GRADED-GATE-OXIDE (GGO) MOSFETs, P. Ko, S. Tam, and C. Hu, *University of California, Berkeley, CA*; S. Wong, *Hewlett Packard, Palo Alto, CA*; C. Sodini, *MIT, Cambridge, MA* 88
- 2:20 p.m.
4.4 LOW VOLTAGE HOT-ELECTRON EFFECTS IN SHORT CHANNEL MOSFETs, B. Ricco, E. Sangiorgi, and D. Cantarelli, *University of Bologna, Bologna, ITALY* 92
- 2:45 p.m.
4.5 A COMPARATIVE STUDY OF TUNNELING SUBSTRATE HOT-ELECTRON AND CHANNEL HOT-ELECTRON INJECTION INDUCED DEGRADATION IN THIN-GATE MOSFETs, F. C. Hsu and K. Y. Chiu, *Hewlett Packard Labs., Palo Alto, CA* 94
- 3:10 p.m.
4.6 HOT CARRIER EFFECTS IN MOS TRANSISTORS, T. Poorter and P. Zoestbergen, *Philips Research Laboratories, Eindhoven, THE NETHERLANDS* 100

3:35 p.m.	4.7	HOT CARRIER DEGRADATION MECHANISM IN N-MOSFETs, K.R. Hofmann, <i>Siemens Research and Technology Laboratories, Princeton, NJ</i> , W. Weber, C. Werner, and G. Dorda, <i>Siemens AG, Munich, FRG</i>	104
SESSION 5: Device Technology—Interconnects 109			
Monday, December 10, 1:00 p.m. <i>Imperial Ballroom</i>			
Co-Chairmen: P. Roitman A. N. Saxena			
1:00 p.m.		INTRODUCTION	
1:05 p.m.	5.1	SILICIDES FOR CONTACTS AND INTERCONNECTS (Invited Paper), C. Ting, <i>IBM Thomas J. Watson Research Center, Yorktown Heights, NY</i>	110
1:30 p.m.	5.2	LAYERED AND HOMOGENEOUS FILMS OF ALUMINUM AND ALUMINUM/SILICON WITH TITANIUM, ZIRCONIUM, AND TUNGSTEN FOR MULTILAYER INTERCONNECTS, D. Gardner, R. Beyers, T. Michalka, K. Saraswat, T. Barbee, Jr., and J. Meindl, <i>Stanford University, Stanford, CA</i>	114
1:55 p.m.	5.3	A NEW DEVICE INTERCONNECT SCHEME FOR SUB-MICRON VLSI, D. Chen, S. Wong, P. Vande Voorde, P. Merchant, T. Cass, J. Amano, and K. Y. Chiu, <i>Hewlett Packard Labs., Palo Alto, CA</i>	118
2:20 p.m.	5.4	TUNGSTEN GATE TECHNOLOGY USING WET HYDROGEN OXIDATION, N. Kobayashi, S. Iwata, N. Yamamoto, T. Mizutani, and K. Yagi, <i>Hitachi, Tokyo, JAPAN</i>	122
2:45 p.m.	5.5	MULTILEVEL INTERCONNECTION TECHNOLOGY (Invited Paper), P. Ghate, <i>Texas Instruments, Dallas, TX</i>	126
3:10 p.m.	5.6	SELF-ALIGNED TITANIUM SILICIDATION OF SUB-MICRON MOS DEVICES BY RAPID LAMP ANNEALING, K. Tsukamoto, T. Okamoto, M. Shimizu, T. Matsukawa, and H. Nakata, <i>Mitsubishi Electric Corp., Hyogo, JAPAN</i>	130
3:35 p.m.	5.7	Mo/TiW CONTRACT FOR VLSI APPLICATIONS, M. Kim, S. Cohen, D. Brown, P. Piacente, and B. Gorowitz, <i>General Electric Company, Schenectady, NY</i>	134
4:00 p.m.	5.8	ION IMPLANTED DOUBLE LEVEL METAL PROCESS, Y. Kamei, M. Kameda, and H. Nakayama, <i>RICOH Company, Ltd., Osaka, JAPAN</i>	138
SESSION 6: Device Technology—Insulators 143			
Monday, December 10, 1:00 p.m. <i>Hilton Plaza</i>			
Co-Chairmen: A. Reisman J. Shott			
1:00 p.m.		INTRODUCTION	
1:05 p.m.	6.1	A NEW SiO ₂ GROWTH BY FLUORINE-ENHANCED THERMAL OXIDATION, M. Morita, S. Aritome, M. Tsukude, and M. Hirose, <i>Hiroshima University, Higashihiroshima, JAPAN</i>	144
1:30 p.m.	6.2	ELECTRIC FIELD AND CURRENT DEPENDENCE OF SiO ₂ INTRINSIC BREAKDOWN, A. Modelli, <i>SGS-Ates, Milano, ITALY</i> , B. Ricco, <i>University of Bologna, Bologna, ITALY</i>	148
1:55 p.m.	6.3	CHARACTERIZATIONS OF VERY THIN GATE-OXIDE MOS DEVICES, M.S. Liang, J.Y. Choi, P.K. Ko, and C. Hu, <i>University of California, Berkeley, CA</i>	152
2:20 p.m.	6.4	STUDIES OF TRAPPING AND CONDUCTION IN ULTRATHIN SiO ₂ GATE INSULATORS, M. Moslehi and K. Saraswat, <i>Stanford University, Stanford, CA</i>	157
2:45 p.m.	6.5	OXIDIZED SILICON NITRIDE FILMS IN THIN INSULATOR MIS STRUCTURE, A. Faigon and J. Shappir, <i>University of Jerusalem, Jerusalem, ISRAEL</i>	161
3:10 p.m.	6.6	ULTRATHIN THERMAL SILICON NITRIDE AND NITROXIDE GATE INSULATORS FOR VLSI, M. Moslehi and K. Saraswat, <i>Stanford University, Stanford, CA</i>	165
3:35 p.m.	6.7	ELECTRICAL AND STRUCTURAL CHARACTERISTICS OF THIN NITRIDED GATE OXIDES PREPARED BY RAPID THERMAL NITRIDIZATION, J. Nulman, J. Krusius, and L. Rathbun, <i>Cornell University, Ithaca, NY</i>	169
4:00 p.m.	6.8	STACKED SiO ₂ /Si ₃ N ₄ /SiO ₂ DIELECTRIC LAYER FOR RELIABLE MEMORY CAPACITOR, T. Watanabe, A. Menjoh, M. Ishikawa, and J. Kumagai, <i>Toshiba Corporation, Kawasaki-city, JAPAN</i>	173
SESSION 7: Quantum Electronics and Compound Semiconductor Devices—High Speed Compound Semiconductor Devices and Device Physics 177			
Monday, December 10, 1:00 p.m. <i>Pacific Room</i>			
Co-Chairmen: D. R. Meyer K. H. Hsieh			
1:00 p.m.		INTRODUCTION	
1:05 p.m.	7.1	PHASE NONLINEARITY OF BURIED-LAYER GaAs MESFETs, J. Abeles and S.A. Schwarz, <i>Bell Communications Research, C.W. Tu, S.H. Wemple, and T.M. Brennan, AT&T Bell Laboratories, Murray Hill, NJ</i>	178
1:30 p.m.	7.2	LOW FREQUENCY OSCILLATIONS IN UNDOPED GaAs AS A PROBE TO DEEP LEVEL PARAMETERS, H. Goronkin, <i>Motorola Inc., Phoenix, AZ</i> , G. Maracas, <i>Arizona State University, Tempe, AZ</i>	182
1:55 p.m.	7.3	TRAPEZOIDAL-GROOVE SCHOTTKY-GATE VERTICAL CHANNEL GaAs FET (GaAs STATIC INDUCTION TRANSISTOR), P. Campbell, W. Garwacki, A. Sears, P. Menditto, and B. Baliga, <i>General Electric Company, Schenectady, NY</i>	186
2:20 p.m.	7.4	InP HIGH POWER MISFET, K. Nagahama, T. Nishimura, N. Hayafuji, T. Murotani, and K. Fujikawa, <i>Mitsubishi Electric Corporation, Hyogo, JAPAN</i>	190
2:45 p.m.	7.5	A NEW SELF-ALIGN TECHNOLOGY FOR LOW NOISE GaAs MESFETs—SIDEWALL ASSISTED PATTERN INVERSION TECHNOLOGY, M. Hagio, S. Katsu, H. Takagi, M. Kazurumura, G. Kano, I. Teramoto, and H. Mizuno, <i>Matsushita Electronics Corporation, Osaka, JAPAN</i>	194
3:10 p.m.	7.6	GaAs/AlGaAs HETEROJUNCTION BIPOLAR TRANSISTORS WITH VERY LOW BASE SHEET RESISTANCE, S. Kofol, N. Moll, E. Gowen, and J. Miller, <i>Hewlett-Packard Laboratories, Palo Alto, CA</i>	198
3:35 p.m.	7.7	NEW LATERAL GaAs TRANSISTOR, K. Taira, M. Dohsen, J. Kasahara, M. Arai, and N. Watanabe, <i>Sony Corporation, Yokohama, JAPAN</i> , M. Wada, Y. Kato, <i>Sony Corporation, Kanagawa, JAPAN</i>	201

SESSION 8: Detectors, Sensors and Displays—Technologies for Integrated Sensors 205

Tuesday, December 11, 9:00 a.m.
Continental Ballroom 1,2,3

Co-Chairmen: K. E. Petersen
P. W. Barth

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 8.1 **INTEGRATING SENSORS AND ELECTRONICS, NEW CHALLENGES FOR SILICON** (Invited Paper), R. Muller, University of California, Berkeley, CA 206

9:30 a.m.

- 8.2 **FABRICATION TECHNOLOGY FOR A CHRONIC IN-VIVO PRESSURE SENSOR**, B. Burns, P. Barth, and J. Angell, Stanford University, Stanford, CA 210

9:55 a.m.

- 8.3 **INTEGRATED RESONANT-MICROBRIDGE VAPOR SENSOR**, R. Howe, Carnegie-Mellon University, Pittsburgh, PA, R. Muller, University of California, Berkeley, CA 213

10:20 a.m.

- 8.4 **MONOLITHIC SILICON FABRICATION TECHNOLOGY FOR FLEXIBLE CIRCUIT AND SENSOR ARRAYS**, P. Barth, S. Bernard, and J. Angell, Stanford University, Stanford, CA 217

10:45 a.m.

- 8.5 **MUTUAL CAPACITIVE NORMAL-AND SHEAR-SENSITIVE TACTILE SENSOR**, L. S. Fan, R. White, and R. Muller, University of California, Berkeley, CA 220

11:10 a.m.

- 8.6 **PLANAR PROCESSED POLYSILICON SEALED CAVITIES FOR PRESSURE TRANSDUCER ARRAYS**, H. Guckel and D. Burns, University of Wisconsin, Madison, WI 223

SESSION 9: Integrated Circuits—Random Access Memories

Tuesday, December 11, 9:00 a.m.
Continental Ballroom 4,5

Co-Chairpersons: L. Razouk
M. Y. Tsai

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 9.1 **POLYSILICON TRANSISTORS IN VLSI MOS MEMORIES**, (Invited Paper), H. Shichijo, S. Malhi, W. Richardson, G. Pollack, A. Shah, L. Hite, S. Banerjee, M. Elahy, R. Sundaresan, R. Womack, H. Lam, and P. Chatterjee, Texas Instruments Inc., Dallas, TX 228

9:30 a.m.

- 9.2 **SCALING CONSIDERATION AND DIELECTRIC BREAKDOWN IMPROVEMENT OF CORRUGATED CAPACITOR CELL (CCC) FOR FUTURE DRAM**, H. Sunami, T. Kure, K. Yagi, K. Yamaguchi, and S. Shimizu, Hitachi, Tokyo, JAPAN 232

9:55 a.m.

- 9.3 **BURIED ISOLATION CAPACITOR (BIC) CELL FOR MEGABIT MOS DYNAMIC RAM**, K. Nakamura, M. Yanagisawa, Y. Nio, K. Okamura, and M. Kikuchi, NEC Corporation, Kanagawa, JAPAN 236

10:20 a.m.

- 9.4 **AN ISOLATION-MERGED VERTICAL CAPACITOR CELL FOR LARGE CAPACITY DRAM**, S. Nakajima, K. Miura, K. Minegishi, and T. Morie, Nippon Telegraph and Telephone Public Corporation, Kanagawa, JAPAN 240

10:45 a.m.

- 9.5 **A FOLDED CAPACITOR CELL (F.C.C.) FOR FUTURE MEGABIT DRAMS**, M. Wada, K. Hieda, and S. Watanabe, Toshiba Corporation, Kawasaki, JAPAN 244

11:10 a.m.

- 9.6 **TRENCH CAPACITOR LEAKAGE IN MEGABIT DRAMS**, M. Elahy, H. Shichijo, P. Chatterjee, A. Shah, S. Banerjee, and R. Womack, Texas Instruments Inc., Dallas, TX 248

11:35 a.m.

- 9.7 **A NEW SOFT ERROR MECHANISM OF DYNAMIC MEMORY WITH GROUNDED CELL PLATE**, H. Ishiuchi, Y. Okada, N. Sekiguchi, T. Tanaka, and O. Ozawa, Toshiba Corporation, Kawasaki, JAPAN 252

SESSION 10: Solid State Devices—High Voltage Integrated Circuits and Composite Devices 257

Tuesday, December 11, 9:00 a.m.
Continental Ballroom 6,7,8,9

Co-Chairmen: J. E. Kohl
H. Sakuma

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 10.1 **COMPARISON OF HIGH VOLTAGE DEVICES FOR POWER INTEGRATED CIRCUITS**, R. Jayaraman, V. Rumennik, B. Singer, and E. Stupp, Philips Laboratories, Briarcliff Manor, NY 258

9:30 a.m.

- 10.2 **NEW HIGH VOLTAGE IC TECHNOLOGY** (Invited Paper), E. Wildi, T. Chow, and M. Adler, General Electric Company, Schenectady, NY; M. Cornell and G. Pifer, General Electric Company, Syracuse, NY 262

9:55 a.m.

- 10.3 **850V NMOS DRIVER WITH ACTIVE OUTPUTS**, R. Martin, Xerox PARC, Palo Alto, CA; S. Buhler and G. Lao, Xerox Microelectronics Center, El Segundo, CA 266

10:20 a.m.

- 10.4 **RECENT ADVANCES IN DISCRETE POWER TRANSISTORS** (Invited Paper), L. A. Goodman, RCA Labs., Princeton, NJ 270

10:45 a.m.

- 10.5 **INSULATED GATE TRANSISTOR MODELING AND OPTIMIZATION**, H. Yilmaz, W. Van Dell, K. Owyang, and M. Chang, General Electric Company, Syracuse, NY 274

11:10 a.m.

- 10.6 **COMPARISON OF N AND P CHANNEL INSULATED GATE TRANSISTORS**, M. Chang, G. Pifer, H. Yilmaz, and R. Dyer, General Electric Company, Syracuse, NY; B. Baliga, T. Chow, and M. Adler, General Electric Company, Schenectady, NY 278

11:35 a.m.

- 10.7 **MOS CONTROLLED THYRISTORS (MCT's)**, V. Temple, General Electric Company, Schenectady, NY 282

SESSION 11: Integrated Circuits—Analysis and Characterization of Integrated CMOS Structures 287

Tuesday, December 11, 9:00 a.m.
Imperial Ballroom

Co-Chairmen: W. Fichtner
C. G. Sodini

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 11.1 **COMPUTER-AIDS FOR ANALYSIS AND SCALING OF EXTRINSIC DEVICES** (Invited Paper), M. Pinto, R. Dutton, H. Iwai, and C. S. Rafferty, Stanford University, Stanford, CA 288

9:30 a.m.

- 11.2 **ANALYSIS OF LATCHUP SUSCEPTIBILITY IN CMOS CIRCUITS**, J. Hall, K. Fung, J. Seitchik, L. Arledge, and P. Yang, Texas Instruments, Inc., Dallas, TX 292

9:55 a.m.

- 11.3 **RECENT DEVELOPMENTS IN CMOS LATCHUP** (Invited Paper), R. R. Troutman, IBM Corporation, Essex Junction, VT 296

10:20 a.m.

- 11.4 **AN ANALYTICAL MODEL FOR INTRINSIC CAPACITANCES OF SHORT-CHANNEL MOSFETs**, B. J. Sheu and P. K. Ko, University of California, Berkeley, CA 300

10:45 a.m.

- 11.5 PERFORMANCE OF CMOS CIRCUITS WITH LDD-TYPE NMOSFET's FOR HIGH DENSITY STATIC RAMS, H. Momose, M. Saitoh, H. Shibata, T. Maeda, H. Sasaki, H. Satoh and T. Ohtani, *Toshiba Corporation, Kawasaki, JAPAN* 304

11:10 a.m.

- 11.6 SUBMICRON CCD MEMORY STRUCTURES FABRICATED BY ELECTRON-BEAM LITHOGRAPHY, J. Slotboom, J. Bartsen, J. Dil, M. Pelgrom, J. de Klerk, C. Juffermans, and R. Verhaar, *Philips Research Laboratories, THE NETHERLANDS*; D. Vinton, J. Swetman, *Philips Research Laboratories, Redhill, ENGLAND* 308

SESSION 12: Electron Tubes—Cathode and Electron Guns—Design and Performance 313

Tuesday, December 11, 9:00 a.m.
Hilton Plaza

Co-Chairmen: R. L. Metivier
W. C. Wood

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 12.1 HIGH CURRENT DENSITY CATHODES—AN UPDATE, M. Feinleib, and M. Green, *Varian Associates, Inc., Palo Alto, CA* 314

9:30 a.m.

- 12.2 DISPENSER CATHODE LIFE PREDICTION MODEL, R. Longo, E. Adler, and L. Falce, *Hughes Aircraft Co., Torrance, CA* 318

9:55 a.m.

- 12.3 AN IMPROVED DISPENSER CATHODE, T. Sakurai, K. Sato, and C. Kimura, *New Japan Radio Co., Ltd., Tokyo, JAPAN* 322

10:20 a.m.

- 12.4 A PRESSED MULTI-LAYER NICKEL MATRIX CATHODE, E. Zhang, Y. You, Y. Cheng, and W. Cai, *Institute of Electronics, Beijing, CHINA* 326

11:10 a.m.

- 12.5 A DUAL APERTURE/MODULATING ANODE ELECTRON GUN FOR HIGH PRECISION MILLIMETER WAVE APPLICATIONS, G. Firman and T. Grant, *Varian Associates, Palo Alto, CA*

11:10 a.m.

- 12.6 HIGH RELIABILITY TWTS FOR SATELLITE APPLICATIONS, A. Shroff and G. Firman, *THOMSON-CSF, Boulogne-Eiillancourt, FRANCE* 330

11:35 a.m.

- 12.7 A POWERFUL QUALITY ASSURANCE TECHNIQUE FOR DISPENSER CATHODES AND ELECTRON GUNS, T. Grant, *Varian Associates, Palo Alto, CA* 334

SESSION 13: Quantum Electronics and Compound Semiconductor Devices—III-V HETEROSTRUCTURE DEVICES FOR HIGH SPEED ICs. 339

Tuesday, December 11, 9:00 a.m.
Franciscan Room

Co-Chairmen: H. Goronkin
C.T. Lee

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 13.1 MATERIAL AND DEVICE CONSIDERATIONS FOR HEMT LSI (Invited Paper), A. Shibatomi, J. Saito, M. Abe, T. Mimura, K. Nishiuchi, and M. Kobayashi, *Fijitsu Limited, Atsugi, JAPAN* 340

9:30 a.m.

- 13.2 A GaAs 12x12 BIT EXPANDABLE PARALLEL MULTIPLIER LSI USING SIDEWALL-ASSISTED CLOSELY-SPACED ELECTRODE TECHNOLOGY, T. Furutsuka, K. Takahashi, M. Ishikawa, S. Yano, and A. Higashisaka, *NEC Corporation, Kawasaki, JAPAN* 344

9:55 a.m.

- 13.3 PULSE DOPED MODFET's, M. Hueschen, N. Moll, E. Gowen, and J. Miller, *Hewlett-Packard Laboratories, Palo Alto, CA* 348

10:20 a.m.

- 13.4 GaAs/Ga AlAs DOUBLE HETEROSTRUCTURE HIGH ELECTRON MOBILITY TRANSISTORS, N. Sheng, C. Lee, R. Chen, and D. Miller, *Rockwell International Corporation, Thousand Oaks, CA* 352

10:45 a.m.

- 13.5 HIGH TRANSCONDUCTANCE InAlAs/InGaAs DOUBLE HETEROSTRUCTURE MESFETS WITH IN SITU ALUMINUM OXIDE GATE BARRIER, T. Chang, R. Behringer, R. Howard, A. Liao, L. Jackel, E. Caridi, W. Skocpol, and R. Epworth, *AT&T Bell Labs., Holmdel, NJ* 356

11:10 a.m.

- 13.6 MICROWAVE CHARACTERIZATION OF VERY HIGH TRANSCONDUCTANCE MODFET, L. Camnitz, P. Tasker, H. Lee, D. van der Merwe, and L. Eastman, *Cornell University, Ithaca, NY* 360

11:35 a.m.

- 13.7 TWO-DIMENSIONAL TRANSIENT SIMULATION OF THE HIGH ELECTRON MOBILITY TRANSISTOR, D. Widiger, I. Kizilyalli, K. Hess, and J. Coleman, *University of Illinois, Urbana, IL* 364

SESSION 14: Detectors, Sensors and Displays—Infrared Detectors 369

Tuesday, December 11, 2:15 p.m.
Continental Ballroom 1,2,3

Co-Chairmen: P. H. Zimmerman
W. M. Scott

2:15 p.m.

INTRODUCTION

2:20 p.m.

- 14.1 RECENT ADVANCES IN PLATINUM SILICIDE INFRARED FOCAL PLANE ARRAYS (Invited Paper), F. Shepherd, *Rome Air Development Center, Hanscom AFB, MA* 370

2:45 p.m.

- 14.2 MONOLITHIC INTRINSIC NMOS HgCdTe IRCCDs WITH ON-CHIP SIGNAL PROCESSING, T. Koch and J. Phillips, *Santa Barbara Research Center, Goleta, CA* 374

3:10 p.m.

- 14.3 DEVELOPMENT OF AN IMPROVED 16 x 64 InSb CID Array, C. Wei, H. Woodbury, and S. C-H. Wang, *General Electric Company, Schenectady, NY* 378

3:35 p.m.

- 14.4 FULLY-INTEGRATED ZnO ON SILICON PYROELECTRIC INFRARED DETECTOR ARRAY, D. Polla, R. Muller and R. White, *University of California, Berkeley, CA* 382

4:00 p.m.

- 14.5 GROWTH AND CHARACTERIZATION OF AS GROWN p-n JUNCTIONS FABRICATED IN MULTILAYER LIQUID PHASE EPITAXIAL (Hg,Cd)Te, P. Nayar, P. Ward, P. Colter, S. Hampton, I. Slawinski, L. Fishman, C. Callahan, and H. Vydyanath, *Aerojet ElectroSystems Co., Azusa, CA* 385

4:25 p.m.

- 14.6 SURFACE LEAKAGE CURRENT MECHANISMS IN HgCdTe GATE CONTROLLED PHOTODIODES, J. Rosbeck and E. Blazejewski, *Santa Barbara Research Center, Goleta, CA* 389

4:50 p.m.

- 14.7 Hg DIFFUSED Hg_{1-x}Cd_xTe PHOTODIODES FOR LWIR DIRECT DETECTION APPLICATIONS, R. Briggs and J. Shanley, *Honeywell, Inc., Lexington, MA* 393

SESSION 15: Device Technology—Advanced CMOS TECHNOLOGY 397

Tuesday, December 11, 2:15 p.m.
Continental Ballroom 4,5

Co-Chairmen: R. W. Mauntel
J. Manoliu

2:15 p.m.

INTRODUCTION

- 2:20 p.m.
15.1 CHARACTERIZATION AND MODELING OF A LATCH-UP FREE 1 MICRON CMOS TECHNOLOGY, Y. Taur, W. Chang and R. Dennard, *IBM Thomas J. Watson Research Center, Yorktown Heights, NY* 398
- 2:45 p.m.
15.2 LATCHUP FREE CMOS USING GUARDED SCHOTTKY BARRIER PMOS, S. Swirhun, E. Sangiorgi, R. Swanson, K. Saraswat and R. Dutton, *Stanford University, Stanford, CA*, and A. Weeks, *VLSI Technology, San Jose, CA* 402
- 3:10 p.m.
15.3 A NEW METHOD FOR PREVENTING CMOS LATCH-UP, K. Terrill, P. Byrne, H. Zappe, N. Cheung and C. Hu, *University of California, Berkeley, CA* 406
- 3:35 p.m.
15.4 REDUCED N⁺/P⁺-SPACING WITH HIGH LATCHUP HARDNESS IN SELF-ALIGNED DOUBLE WELL CMOS TECHNOLOGY, U. Schwabe, E. Jacobs and D. Takacs, *Siemens AG, Munich, FRG*, J. Winnerl and E. Lange, *Technical University Munich, Munich, FRG* 410
- 4:00 p.m.
15.5 DEEP SUBMICRON MOSFET CHARACTERISTICS WITH 5 nm GATE OXIDE, T. Kobayashi, S. Horiguchi and K. Kiuchi, *Nippon Telegraph and Telephone Public Corporation, Kanagawa, JAPAN* 414
- 4:25 p.m.
15.6 A FINE-LINE CMOS TECHNOLOGY THAT USES P+ POLYSILICON/SILICIDE GATES FOR NMOS AND PMOS DEVICES, L. Parrillo, S. Hillenius, R. Field, E. Hu, W. Fichtner and M. L. Chen, *AT&T Bell Laboratories, Murray Hill, NJ* 418
- 4:50 p.m.
15.7 HIGH PERFORMANCE SUBHALF-MICROMETER P-CHANNEL TRANSISTORS FOR CMOS VLSI, A. Schmitz, P. Vasudev and J. Chen, *Hughes Research Laboratories, Malibu, CA* 423

SESSION 16: Solid State Devices—Thyristors and High Frequency Power MOSFETs 427

Tuesday, December 11, 2:15 p.m.
 Continental Ballroom 6,7,8,9

Co-Chairmen: D. L. Blackburn
 M. Kurata

- 2:15 p.m.
 INTRODUCTION
- 2:20 p.m.
16.1 TURN-ON RELIABILITY BREAKTHROUGH IN LIGHT TRIGGERED THYRISTORS, V. Temple, *General Electric Company, Schenectady, NY* 428
- 2:45 p.m.
16.2 A NEW TRIGGERED MODE FOR LIGHT TRIGGERING THYRISTORS, Y. C. Kao and S. G. Leslie, *Westinghouse R&D Center, Pittsburgh, PA* 432
- 3:10 p.m.
16.3 A VERY HIGH SENSITIVITY AND VERY HIGH SPEED LIGHT TRIGGERED AND LIGHT QUENCHED STATIC INDUCTION THYRISTOR (LTQSITH), J. Nishizawa and K. Nonaka, *Tohoku University, Sendai, JAPAN*, T. Tamamushi, *Semiconductor Research Institute, Sendai, JAPAN* 435
- 3:35 p.m.
16.4 A HIGHLY INTERDIGITATED GTO POWER SWITCH WITH RECESSED GATE STRUCTURE, P. Roggwiller, J. Gobrecht, J. Voboril and B. Broich, *Brown Boveri Research Center, Baden, SWITZERLAND* 439
- 4:00 p.m.
16.5 NUMERICAL SIMULATION OF THE GTO THYRISTOR, E. Palm and F. Van de Wiele, *Universite de Catholique de Louvain, Louvain-la-Neuve, BELGIUM* 443
- 4:25 p.m.
16.6 A 900 MHz 100W VD-MOSFET WITH SILICIDE GATE SELF-ALIGNED CHANNEL, H. Esaki and O. Ishikawa, *Matsushita Elec. Ind. Co., Ltd., Osaka, JAPAN* 447
- 4:50 p.m.
16.7 VHF HIGH POWER VD² MOSFET, H. Yoshida, Y. Shibata and Y. Usunaga, *NEC Corp., Kawasaki City, Kanagawa, JAPAN* 451

SESSION 17: Integrated Circuits—Non-Volatile Memory Technology 455

Tuesday, December 11, 2:15 p.m.
 Imperial Ballroom

Co-Chairmen: D. C. Guterman
 C. Hu

- 2:15 p.m.
 INTRODUCTION
- 2:20 p.m.
17.1 TECHNOLOGY REQUIREMENTS FOR MEGA BIT CMOS EPROMS, K. Yoshikawa, M. Sato, S. Mori, Y. Mikata, T. Yanase, K. Kanzaki and H. Nozawa, *Toshiba Corporation, Kawasaki, JAPAN* 456
- 2:45 p.m.
17.2 A HIGH PERFORMANCE CMOS PROCESS FOR THE NEXT GENERATION EPROM, J. Lien, S. Longcor, K. Chang, L. Shen, P. Manos, D. Chan, T. Lee and S. Nallamothu, *Advanced Micro Devices, Sunnyvale, CA* 460
- 3:10 p.m.
17.3 A NEW FLASH E² PROM CELL USING TRIPLE POLYSILICON TECHNOLOGY, F. Masuoka, M. Asano, H. Iwahashi, T. Komuro and S. Tanaka, *Toshiba Corp., Kawasaki, JAPAN* 464
- 3:35 p.m.
17.4 DESIGN OF AN E² PROM MEMORY CELL LESS THAN 100 SQUARE MICRONS USING 1 MICRON TECHNOLOGY, S. Lai, Y. Hu, S. Tam, G. Lum and V. Dham, *Intel Corp., Santa Clara, CA* 468
- 4:00 p.m.
17.5 A SHIELDED SUBSTRATE INJECTOR MOS (SSIMOS) EEPROM CELL, R. Stewart, A. Ipri, L. Faraone, J. Cartwright and K. Schlesier, *RCA Laboratories, Princeton, NJ* 472
- 4:25 p.m.
17.6 CONDUCTION IN THERMAL OXIDES GROWN ON POLYSILICON AND ITS INFLUENCE ON FLOATING GATE EEPROM DEGRADATION, G. Groeseneken and H. Maes, *Katholieke Universiteit Leuven, Heverlee, BELGIUM* 476
- 4:50 p.m.
17.7 ENDURANCE MODEL FOR TEXTURED POLY FLOATING GATE MEMORIES, H. Wegener, *Xicor, Inc., Milpitas, CA* 480

SESSION 18: Electron Tubes—Traveling Wave Tubes 485

Tuesday, December 11, 2:15 p.m.
 Hilton Plaza

Co-Chairmen: R. W. Herriott
 R. Harper

- 2:15 p.m.
 INTRODUCTION
- 2:20 p.m.
18.1 SLOW-WAVE STRUCTURES IN MICROWAVE TUBES (Invited Paper), B. Epsztajn, *THOMSON-CSF, Boulogne Billancourt, FRANCE* 486
- 2:45 p.m.
18.2 A HIGHLY EFFICIENT, LINEAR, HIGH POWER X-BAND COUPLED CAVITY TWT FOR ECM-RESISTANT AIRBORNE RADAR, K. Amboss, W. Harman and I. Tammaru, *Hughes Electron Dynamics Division, Torrance, CA* 490
- 3:10 p.m.
18.3 RECENT PROGRESS IN MILLIMETER-WAVE TUNNELADDER TWT's, D. Wilson, Jr., A. Jacquez and D. Andker, *Varian Associates, Palo Alto, CA* 494
- 4:00 p.m.
18.4 BI-PERIODIC FREE-LADDER MILLIMETER WAVE COMMUNICATION TWT, K. Wile and M. Cant, *Varian Canada, Inc., Orono, ONTARIO, Canada*, L. F. Farnham and D. A. Carter, *Varian Associates, Inc., Palo Alto, CA*
- 4:00 p.m.
18.5 750W HELIX TWT FOR 14GHz EARTH STATIONS, G. Fleury, D. Henry, J. Kuntzmann and S. LeFur, *THOMSON-CSF, Boulogne Billancourt, FRANCE* 498

4:50 p.m.

- 18.6 A 40 WATT, $f_c = 4$ GHz PAVE LIN WAVE TUBE S. Tipton, G. Ball and J. Bourne, *English Electric Valve Co., Ltd., Wiltam, Essex, ENGLAND*

4:50 p.m.

- 18.7 RECENT ADVANCES IN AN EHF HELIX TWTS, R. Ohtomo, G. Wada, J. Benton and M. Pohlenz, *Hughes Aircraft Company, Torrance, CA* 502

5:15 p.m.

- 18.8 44 GHz HELIX TWT's FOR SATELLITE COMMUNICATION SYSTEMS, A. Jacquez, *Varian Associates, Palo Alto, CA* 506

SESSION 19: Quantum Electronics and Compound Semiconductor Devices—Lasers and Heterostructures 509

Tuesday, December 11, 2:15 p.m.
Franciscan Room

Co-Chairmen: J. J. Coleman
L. Figueroa

2:15 p.m.

INTRODUCTION

2:20 p.m.

- 19.1 FREQUENCY CONTROL OF SEMICONDUCTORS LASERS (Invited Paper), S. Wang, *University of California, Berkeley, CA* 510

2:45 p.m.

- 19.2 SINGLE LONGITUDINAL MODE DISTRIBUTED FEED-BACK DOUBLE CHANNEL PLANAR BURIED HETEROSTRUCTURE 1.55 μ m IN GaAsP/InP LASERS, D. Wilt, R. Yen, T. Wessel, P. Besomi, R. Brown, T. Cella, N. Dutta and P. Anthony, *AT&T Bell Laboratories, Murray Hill, NJ* 514

3:10 p.m.

- 19.3 IMPROVED HIGH POWER TWIN CHANNEL LASER WITH BLOCKING LAYER, C. Morrison, L. Zinkiewicz, A. Burghard and L. Figueroa, *TRW, Inc., Redondo Beach, CA* 517

3:35 p.m.

- 19.4 MONOLITHIC INTEGRATION OF A QUANTUM-WELL LASER AND A DRIVER CIRCUIT ON A GaAs SUBSTRATE, O. Wada, T. Sanada, S. Yamakoshi, H. Hamaguchi, T. Fujii, T. Horimatsu and T. Sakurai, *Fujitsu Limited, Atsugi, JAPAN* 520

4:00 p.m.

- 19.5 InGaAs/GaAs, STRAINED-LAYER SUPERLATTICE (SLS), JUNCTION PHOTODETECTORS, LED's, INJECTION LASERS's, AND FET's FOR OPTOELECTRONIC IC APPLICATIONS (Invited Paper), T. Zipperian, L. Dawson, C. Barnes, J. Wiczer and G. Osbourn, *Sandia National Labs., Albuquerque, NM* 524

4:25 p.m.

- 19.6 AlAs/GaAs SUPERLATTICE BARRIER UNIPOLAR DIODE STRUCTURES, T. Drummond and H. Hjalmarson, *Sandia National Labs., Albuquerque, NM*; P. Pearah, H. Morkoc, *Univ. of Illinois, Urbana, IL* 528

4:50 p.m.

- 19.7 CHARACTERIZATION OF DOUBLE HETEROJUNCTION GaAs/AlGaAs HOT ELECTRON TRANSISTORS, N. Yokoyama, K. Imamura, T. Ohshima, H. Nishi, S. Muto, K. Kon-do and S. Hiaymizu, *Fujitsu Limited, Atsugi, JAPAN* 532

SESSION 20: Evening Panel Discussion 537

Tuesday, December 11, 8:00 p.m.
Continental Ballroom 4

Panel Moderator: Billy Crowder
IBM Corporation
East Fishkill, NY

SESSION 21: Evening Panel Discussion 539

Tuesday, December 11, 8:00 p.m.
Continental Ballroom 5

Panel Organizer: John Shott
Stanford University
Stanford, CA

Panel Moderator: Brian Reid
Stanford University
Stanford, CA

SESSION 22: Evening Panel Discussion 539

Tuesday 11, 8:00 p.m.
Continental Ballroom 6

Panel Moderator: David R. Myers
Sandia National Laboratories
Albuquerque, NM

SESSION 23: Evening Panel Discussion 543

Tuesday, December 11, 8:00 p.m.
Continental Ballroom 7,8,9

Panel Moderator: Robert K. Parker
Naval Research Laboratory
Washington, D.C.

SESSION 24: Evening Panel Discussion 545

Tuesday, December 11, 8:00 p.m.
Imperial Ballroom

Panel Moderators: John Barnes
Motorola, Inc.
Austin, TX
Wolfgang Fichtner
AT&T Bell Laboratories
Murray Hill, NJ

SESSION 25: Detectors, Sensors and Displays—New Sensor Technologies and Characterization Methods 547

Wednesday, December 12, 9:00 a.m.
Continental Ballroom 1,2,3

Co-Chairmen: W. E. Tennant
R. S. Muller

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 25.1 HIGH-GAIN PHOTODETECTORS IN THIN-FILM TRANSISTORS FABRICATED FROM LASER-CRYSTALLIZED SILICON ON FUSED SILICA, A. Chiang and N. Johnson, *Xerox Palo Alto Research Center, Palo Alto, CA* 548

9:30 a.m.

- 25.2 A HALF INCH SIZE CCD IMAGE SENSOR OVERLAID WITH A HYDROGENATED AMORPHOUS SILICON, T. Chikamura, T. Kameda, D. Ishiko, M. Yoshino, M. Nakayama, K. Yano, Y. Aoki, A. Ueno, T. Yamada and T. Ishihara, *Matsushita Industrial Co. Ltd., Osaka, JAPAN* 552

9:55 a.m.

- 25.3 CHARACTERIZATION OF DARK CURRENT IN CCD IMAGERS, G. Hawkins, L. Rivaud and J. Kyan, *Eastman Kodak Company, Rochester, NY* 556

10:20 a.m.

- 25.4 ELECTRON-BEAM INDUCED CURRENT MEASUREMENT OF HgCdTe HETEROJUNCTION INFRARED DETECTORS, S. Price, *Santa Barbara Research Center, Goleta, CA* 560

10:45 a.m.

- 25.5 A.C. CHARACTERIZATION AND MODELING OF LATERAL BIPOLAR MAGNETOTRANSISTORS, A. Andreou and C. Westgate, *The Johns Hopkins University, Baltimore, MD* 564

- 11:10 a.m.
25.6 SENSITIVITY AND NOISE OF A LATERAL BIPOLAR MAGNETOTRANSISTOR IN CMOS TECHNOLOGY, R. S. Popovic, *LGZ Landis and Gyr Zug Corp., Zug, SWITZERLAND*; R. Widmer, *Swiss Federal Institut of Technology, Zurich, SWITZERLAND* 568

SESSION 26: Device Technology—Advanced Isolation Technologies 573

Wednesday, December 12, 9:00 a.m.

Continental Ballroom 4,5

Co-Chairmen: W. G. Oldham
T. Shibata

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 26.1 TRENCH ISOLATION PROSPECTS FOR APPLICATION IN CMOS VLSI**, (Invited Paper) R. Rung, *Hewlett Packard Co., Corvallis, OR* 574

9:30 a.m.

- 26.2 A NEW TRENCH ISOLATION TECHNOLOGY AS A REPLACEMENT OF LOCOS**, H. Mikoshiba, T. Homma and K. Hamano, *NEC Corporation, Kanagawa, JAPAN* 578

9:55 a.m.

- 26.3 NEW TECHNIQUE FOR ELIMINATION OF THE BIRD'S HEAD AND BIRD'S BEAK**, G. Burton, P. Tuntasood, F. Chien, R. Kovacs, and M. Vora, *Fairchild Research Center, Palo Alto, CA* 582

10:20 a.m.

- 26.4 DEFECT GENERATION IN TRENCH ISOLATION**, C. Teng, C. Slawinski, and W. Hunter, *Texas Instruments Incorporated, Dallas, TX* 586

10:45 a.m.

- 26.5 A FULLY SCALED SUBMICRON DIRECT WRITE E-BEAM CMOS TECHNOLOGY FOR ULSI DIGITAL APPLICATIONS**, R. Lutze, H. Vyas and J. Huang, *Honeywell Inc., Plymouth, MN* 590

11:10 a.m.

- 26.6 APPLICATION OF SELECTIVE SILICON EPITAXIAL GROWTH FOR CMOS TECHNOLOGY**, S. Nagao, K. Higashitani, Y. Akasaka and H. Nakata, *Mitsubishi Electric Corp., Itami, JAPAN* 593

SESSION 27: Solid State Devices—Advanced MOS Devices and Models 597

Wednesday, December 12, 9:00 a.m.

Continental Ballroom 6,7,8,9

Co-Chairmen: S. Diehl-Nagle
P. Sullivan

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 27.1 CRYOGENIC BEHAVIOR OF SCALED CMOS DEVICES**, J. Schrankler, J. Huang, R. Lutze, H. Vyas and G. Kirchner, *Honeywell Inc., Plymouth, MN* 598

9:30 a.m.

- 27.2 1.5 MICRON GATE CMOS OPERATED AT 77°**, I. Kato, H. Oka, S. Hijiyama and T. Nakamura, *Fijitsu Labs., Ltd., Atsugi, JAPAN* 601

9:55 a.m.

- 27.3 EFFECTS OF SURFACE ROUGHNESS ON INVERSION LAYER TRANSPORT** (Invited Paper), D. Ferry, *Arizona State University, Tempe, AZ* 605

10:20 a.m.

- 27.4 A NEW p-CHANNEL MOSFET STRUCTURE WITH SCHOTTKY-CLAMPED SOURCE AND DRAIN**, C. S. Oh, Y. Koh and C. Kim, *Institute of Science and Technology, Seoul, KOREA* 609

10:45 a.m.

- 27.5 SCALING OF COMPENSATED MOSFETS TOWARDS SUBMICRON DIMENSIONS**, F. M. Klaassen, J. J. J. Bastiaens, W. Hes and M. Sprokel, *Phillips Research Laboratories, Eindhoven, THE NETHERLANDS* 613

11:10 a.m.

- 27.6 A SMALL-SIGNAL HIGH-FREQUENCY MODEL FOR THE FOUR-TERMINAL INTRINSIC MOSFET VALID IN ALL REGIONS OF OPERATION**, M. Bagheri and Y. Tividis, *Columbia University, New York, NY* 617

11:35 a.m.

- 27.7 TWO-DIMENSIONAL MOSFET SIMULATION WITH ENERGY TRANSPORT PHENOMENA**, M. Fukuma and R. Uebbing, *NEC Corporation, Kawasaki, JAPAN* 621

SESSION 28: Device Technology—Advanced Technologies 625

Wednesday, December 12, 9:00 a.m.

Imperial Ballroom

Co-Chairmen: J. T. Clemens
R. R. Troutman

9:00 a.m.

INTRODUCTION

9:30 a.m.

- 28.2 PROCESS CONSIDERATIONS IN RESTRUCTURABLE VLSI FOR WAFER-SCALE INTEGRATION**, P. Wyatt, J. Raffel, G. Chapman, B. Mathur, J. Burns and T. Herndon, *MIT, Lincoln Lab., Lexington, MA* 626

9:55 a.m.

- 28.3 SILICON NITRIDE FILMS BY PLASMA CVD FROM SiH₄-N₂ and SiF₄-N₂-H₂ GAS MIXTURES**, S. Fujita, H. Toyoshima, T. Ohishi and A. Sasaki, *Kyoto University, Kyoto, JAPAN*; N. Zhou, *The Northwest Telecommunication Engineering Institute, Xi'an, THE PEOPLE'S REPUBLIC OF CHINA* 630

10:20 a.m.

- 28.4 ELEVATED SOURCE/DRAIN MOSFET**, S. Wong, D. Bradbury, D. Chen and K. Y. Chiu, *Hewlett Packard Labs., Palo Alto, CA* 634

10:45 a.m.

- 28.5 MULTIPLE SELF-ALIGNMENT MOS TECHNOLOGY MUSA/MOST**, H. Horie, T. Fukano, T. Ito and H. Ishikawa, *Fujitsu Laboratories Ltd., Atsugi, JAPAN* 638

11:10 a.m.

- 28.6 N- and P-WELL PROCESS COMPATIBILITY IN A 1 MICRON CMOS TECHNOLOGY**, E. Jacobs, D. Takacs and U. Schwabe, *SIEMENS AG, Munich, FRG* 642

11:35 a.m.

- 28.7 A HIGHLY RELIABLE N-MOS PROCESS FOR ONE MEGABIT DYNAMIC RANDOM ACCESS MEMORY**, T. Matsukawa, M. Inuishi, J. Mitsushashi, M. Hirayama, K. Tsukamoto, S. Uoya, T. Yoshihara and H. Nakata, *Mitsubishi Electric Corporation, Hyogo, JAPAN* 647

SESSION 29: Electron Tubes—Klystrons, Collectors, and Computations 651

Wednesday, December 12, 9:00 a.m.

Hilton Plaza

Co-Chairmen: A. Staprans
R. K. Parker

9:00 a.m.

INTRODUCTION

9:05 a.m.

- 29.1 DEVELOPMENT OF 2 GHz, 1MW KLYSTRON FOR PLASMA HEATING**, S. Miyake, H. Ohno, H. Ishihara, S. Hosoi, and T. Okamoto, *Toshiba Corporation, Kawasaki-City, JAPAN*; T. Nagashima, K. Uehara, T. Imai, T. Fujii, K. Sakamoto, Y. Ikeda and M. Saigusa, *Japan Atomic Energy Research Institute, JAPAN* 652

9:30 a.m.

- 29.2 A WIDEBAND 3 MW PEAK POWER S-BAND KLYSTRON**, A. Auberdic, C. Bearzatto and G. Faillon, *THOMSON-CSF, Boulogne-Billancourt, FRANCE* 656

9:55 a.m.

- 29.3 KLYSTRON UPDATE**, M. Shrader and D. Preist, *Varian EIMAC, San Carlos, CA* 660

- 10:20 a.m.
29.4 AN EXPERIMENTAL TEST STATION FOR MULTISTAGE DEPRESSED COLLECTORS, K. Moy and T. Grant, *Varian Associates, Inc., Palo Alto, CA* 665
- 10:45 a.m.
29.5 LARGE SCALE SIMULATION OF ELECTRON DEVICES (Invited Paper), A. Drobot, *Science Applications, Inc., McLean, VA* 668
- 11:10 a.m.
29.6 COMPUTATIONS OF VSWR AND MODE CONVERSION FOR COMPLEX GYROTRON WINDOW GEOMETRIES, A. Salop and M. Caplan, *Varian Associates, Palo Alto, CA* 672
- 11:35 a.m.
29.7 A NUMERICAL METHOD FOR PREDICTING BRILLOUIN PLOTS OF COUPLED CAVITY CIRCUITS, P. Prince, J. Baird and R. H. Jackson *Litton Systems, Inc., San Carlos, CA* 676

SESSION 30: Integrated Circuits—Bipolar and Buried-Layer MOS Structures 681

Wednesday, December 12, 9:00 a.m.
Pacific Room

Co-Chairmen: I. Lagnado
Y. Okuto

- 9:00 a.m.
INTRODUCTION
- 9:05 a.m.
30.1 A 1.6 GHz LOW POWER SILICON DUAL MODULUS PRESCALER IC, H. Suzuki, T. Akiyama and K. Ueno, *Fujitsu Limited, Kawasaki, JAPAN* 682
- 9:30 a.m.
30.2 AN 80ps ECL CIRCUIT WITH HIGH CURRENT DENSITY TRANSISTOR, T. Tashiro, H. Takemura, T. Kamiya, F. Tokuyoshi, S. Ohi, H. Shiraki, M. Nakamae and T. Nakamura, *NEC Corporation, Kanagawa, JAPAN* 686
- 9:55 a.m.
30.3 A 2 MICRON HIGH PERFORMANCE BIPOLAR 64K ECL STATIC RAM TECHNOLOGY WITH 200 SQUARE MICRONS CONTACTLESS MEMORY CELL, M. Vora, F. Chien, G. Burton, Y. Koh, R. Brown, W. Herndon and R. Heald, *Fairchild Research Center, Palo Alto, CA* 690
- 10:20 a.m.
30.4 PERFORMANCE AND STRUCTURES OF SCALED DOWN BIPOLAR DEVICES MERGED WITH CMOS FETs (Invited Paper), H. Higuchi, G. Kitsukawa, N. Sasaki and K. Ogiue, *Hitachi, Tokyo, JAPAN*; T. Ikeda, Y. Nishio, *Hitachi, Ibaragi, JAPAN* 694
- 10:45 a.m.
30.5 180V ANALOG-COMPATIBLE, HIGH-SPEED LOGIC UTILIZING SEMI-WELL ISOLATION TECHNOLOGY, T. Okabe, M. Kimura and M. Nagata, *Hitachi Ltd., Tokyo, JAPAN*; I. Shimizu and Y. Nagai, *Hitachi Ltd., Gunma, JAPAN* 698
- 11:10 a.m.
30.6 SOI-CMOS 4K SRAM WITH HIGH DOSE OXYGEN IMPLANTED SUBSTRATE, C-E. Chen, T. Blake, L. Hite, S. Malhi, B. Mao and H. Lam, *Texas Instruments, Inc., Dallas, TX* 702
- 11:35 a.m.
30.7 A P-TYPE BURIED LAYER FOR PROTECTION AGAINST SOFT ERRORS IN HIGH DENSITY CMOS STATIC RAMS, H. Momose, T. Wada, I. Kamohara, M. Isobe, J. Matsunaga and H. Nozawa, *Toshiba Corporation, Kawasaki, JAPAN* 706

SESSION 31: Quantum Electronics and Compound Semiconductor Devices—Photodetectors 711

Wednesday, December 12, 9:00 a.m.
Franciscan Room

Co-Chairmen: M. A. Pollack
V. Diadiuk

- 9:00 a.m.
INTRODUCTION
- 9:05 a.m.
31.1 ULTRA-HIGH SPEED PHOTODETECTORS, (Invited Paper), S. Y. Wang, *Hewlett-Packard Laboratories, Palo Alto, CA* 712

- 9:30 a.m.
31.2 FAST InGaAs PHOTOCONDUCTIVE DETECTORS WITH SPEED ENHANCED BY BERYLLIUM ION BOMBARDMENT, P. Downey and R. Martin, *AT&T Bell Laboratories, Holmdel, NJ*; R. Nahory, *Bell Communications Research, Murray Hill, NJ*; O. Lorimor, *AT&T Bell Laboratories, Murray Hill, NJ* 716
- 9:55 a.m.
31.3 ION IMPLANTED LATERAL IN $_{2}\text{Ga}_{.8}\text{As/GaAs}$ STRAINED-LAYER SUPERLATTICE PHOTODETECTOR, G. Bulman, D. Myers, J. Wiczer, L. Dawson, R. Biefeld and T. Zipperian, *Sandia National Laboratories, Albuquerque, NM* 719
- 10:20 a.m.
31.4 NEW PSEUDO-QUANTERNARY GaInAsP SEMICONDUCTORS: A HIGH SPEED "HIGH-LOW" AVALANCHE PHOTODIODE WITH $\text{Ga}_{.47}\text{In}_{.53}\text{As/InP}$ GRADED GAP SUPERLATTICE, F. Capasso, A. Hutchinson and N. Olsson, *AT&T Bell Laboratories, Murray Hill, NJ*; H. Cox and S. Hummel, *Bell Communications Research, Murray Hill, NJ* 723

- 10:45 a.m.
31.5 FULLY OPTICALLY AND ELECTRICALLY INTERFACED, MONOLITHIC 1×12 ARRAY OF $\text{In}_{.53}\text{Ga}_{.47}\text{As/InP}$ p-i-n PHOTODIODES, M. Brown, S. Forrest, P. Hu, D. Kaplan, M. Koza, Y. Ota, J. Potopowicz, C. Seabury and M. Washington, *AT&T Bell Laboratories, Murray Hill, NJ* 727
- 11:10 a.m.
31.6 GaInAs, AlInAs SCHOTTKY BARRIER DIODES AND GaInAs/AlInAs HETEROJUNCTION DIODE AS INTERNAL PHOTOEMISSION DETECTORS, K. Hsieh, *Hughes Research Lab., Malibu, CA*; L. Eastman, *Cornell University, Ithaca, NY* 729
- 11:35 a.m.
31.7 A HIGH SPEED, LOW VOLTAGE SILICON PHOTODIODE WITH BURIED ISOLATION REGION, G. Chang, A. Hartman, M. Robinson, T. Riley and K. Lee, *AT&T Bell Laboratories, Murray Hill, NJ* 733

SESSION 32: Device Technology—Advanced Bipolar Technology 737

Wednesday, December 12, 1:30 p.m.
Continental Ballroom 4,5

Co-Chairmen: J. Aitken
A. Wieder

- 1:30 p.m.
INTRODUCTION
- 1:35 p.m.
32.1 CONDUCTION MECHANISM OF POLYSILICON EMITTERS WITH THIN INTERFACIAL OXIDE LAYERS, H. Schaber, B. Benna, L. Treitinger and A. Wieder, *Siemens AG, Munich, FRG* 738
- 2:00 p.m.
32.2 SIPOS HETEROJUNCTION CONTRACTS TO SILICON, Y. Kwark, R. Swanson and R. Sinton, *Stanford University, Stanford, CA* 742
- 2:25 p.m.
32.3 A SILICON BIPOLAR TRANSISTOR WITH A HYDROGENATED AMORPHOUS EMITTER, M. Ghannam, J. Nijs, R. DeKeersmaecker and R. Mertens, *Katholieke Universiteit Leuven, Heverlee, BELGIUM* 746
- 2:50 p.m.
32.4 SELF-ALIGNED BIPOLAR TRANSISTORS WITH ENHANCED EFFICIENCY POLYSILICON EMITTERS, A. Cuthbertson and P. Ashburn, *Southampton University, Southampton, Hampshire, ENGLAND* 749
- 3:15 p.m.
32.5 NEW SELF-ALIGNED COMPLEMENTARY BIPOLAR TRANSISTORS USING SELECTIVE-OXIDATION MASK, H. Sadamatsu, M. Inoue, A. Matsuzawa, A. Kanda and H. Shimoda, *Matsushita Electric Industrial Co., Ltd., Osaka, JAPAN* 753
- 3:40 p.m.
32.6 MODELLING OF POLYSILICON DOPANT DIFFUSION FOR SHALLOW-JUNCTION BIPOLAR TECHNOLOGY, G. Barbuscia, G. Chin and R. Dutton, *Stanford University, Stanford, CA*; T. Alvarez, *Motorola, Mesa, AZ*; L. Arledge, *Texas Instruments, Dallas, TX* 757

- 4:05 p.m.
32.7 2 MICRON MERGED BIPOLAR-CMOS TECHNOLOGY, A. Alvarez, P. Meller and B. Tien, *Motorola Inc., Mesa, AZ* **761**

SESSION 33: Solid State Devices—Lightly-Doped Drain MOSFETs **765**

Wednesday, December 12, 1:30 p.m.
Continental Ballroom 6,7,8,9

Co-Chairmen: J. R. Sokel
 G. Merkel

1:30 p.m.

INTRODUCTION

1:35 p.m.

- 33.1 STATE-OF-THE-ART OF MOS MODELLING**, (Invited Paper), A. Schutz and C. Werner, *SIEMENS Research and Development Center, Munchen, WEST GERMANY* **766**

2:00 p.m.

- 33.2 OPTIMIZATION OF LIGHTLY DOPED DRAIN MOSFETS USING A NEW QUASIBALLISTIC SIMULATION TOOL**, C. Werner, R. Kuhnert and L. Risch, *Siemens AG, Munchen, FRG* **770**

2:25 p.m.

- 33.3 HOT CARRIER DEGRADATION MODES AND OPTIMIZATION OF LDD MOSFETs**, H. Katto, K. Okuyama, S. Meguro, R. Nagai and S. Ikeda, *Hitachi Ltd., Tokyo, JAPAN* **774**

2:50 p.m.

- 33.4 EFFECTS OF FIELD BORON DOSE ON SUBSTRATE CURRENT IN NARROW CHANNEL LDD MOSFETs**, S. Sawada, Y. Matsumoto, S. Shinozaki and O. Ozawa, *Toshiba Corporation, Kawasaki-city, JAPAN* **778**

3:15 p.m.

- 33.5 CHARACTERIZATION OF As-P DOUBLE DIFFUSED DRAIN STRUCTURE**, K. Balasubramanyan, M. Hargrove, M. Lin, D. Hoyniak, J. LaRue, and D. Thomas, *IBM, Essex Junction, VT*; H. Hanafi, *IBM, Yorktown Heights, NY* **782**

3:40 p.m.

- 33.6 MECHANISM OF HOT ELECTRON INDUCED DEGRADATION IN LDD NMOS-FET**, Y. Toyoshima, H. Nihira, M. Wada and K. Kanzaki, *Toshiba Corporation, Kawasaki, JAPAN* **786**

SESSION 34: Device Technology—SOI and 3-D Technologies **791**

Wednesday, December 12, 1:30 p.m.
Imperial Ballroom

Co-Chairmen: D. Bartelink
 S. Malhi

1:30 p.m.

INTRODUCTION

1:35 p.m.

- 34.1 3-D SOI/CMOS** (Invited Paper), M. Nakano, *Fujitsu, Ltd., Kawasaki, JAPAN* **792**

2:00 p.m.

- 34.2 FABRICATION OF HIGH SPEED 1 MICRON FIPOS/CMOS**, K. Anzai, F. Otoi, M. Ohnishi and H. Kitabayashi, *OKI Electric Industry Co., Ltd., Tokyo, JAPAN* **796**

2:25 p.m.

- 34.3 ADVANCES IN OXIDIZED POROUS SILICON FOR SOI**, L. A. Nesbit, *IBM Corporation, Essex Junction, VT* **800**

2:50 p.m.

- 34.4 ELECTRICAL CHARACTERIZATION OF OXYGEN IMPLANTED SILICON SUBSTRATES**, D. Foster, A. Butler and P. Bolbot, *Plessey Research (Caswell) Ltd., Caswell, Towcester, Northants, U.K.* **804**

3:15 p.m.

- 34.5 DEVICE PERFORMANCES OF A SUBMICRON SOI TECHNOLOGY**, A. Auberton-Herve, J. Joly, J. Hode, J. Gautier and P. Jeuch, *LETI/Commissariat a l'Energie Atomique, Grenoble, FRANCE* **808**

3:40 p.m.

- 34.6 MERGED CMOS/BIPOLAR TECHNOLOGIES AND MICROWAVE MESFETS UTILIZING ZONE-MELTING-RECRYSTALLIZED SOI FILMS**, B. Tsaur, H. Choi, C. K. Chen, C. L. Chen, R. Mountain and J. Fan, *Massachusetts Institute of Technology, Lexington, MA* **812**

4:05 p.m.

- 34.7 PROMISING NEW FABRICATION PROCESS DEVELOPED FOR STACKED LSIs**, M. Yasumoto, H. Hayama and T. Enomoto, *NEC Corporation, Kawasaki, JAPAN* **816**

SESSION 35: Electron Tubes—Fast Wave Tubes **821**

Wednesday, December 12, 1:30 p.m.
Hilton Plaza

Co-Chairmen: J. M. Baird
 T. Kageyama

1:30 p.m.

INTRODUCTION

1:35 p.m.

- 35.1 SURVEY OF PHYSICS RESEARCH IN MICROWAVE DEVICES** (Invited Paper), G. Bekefi, *Massachusetts Institute of Technology, Cambridge, MA* **822**

2:00 p.m.

- 35.2 A 60 GHz, 200 kW CW GYROTRON WITH HIGH OUTPUT MODE PURITY**, H. Jory, K. Felch, R. Bier, L. Fox, H. Huey, L. Ives, N. Lopez, J. Manca, J. Shively and S. Spang, *Varian Associates, Inc., Palo Alto, CA* **826**

2:25 p.m.

- 35.3 A 100 GHz, 500 kW GYROTRON OSCILLATOR**, W. DeHope, J. Eldridge, P. Ferguson, S. Hart, A. Krycuk, V. Matranga, J. Sandoval, M. Schmitt, J. Tancredi, C. Thorington and M. Wozniak, *Hughes Aircraft Co., Torrance, CA* **830**

2:50 p.m.

- 35.4 DESIGN CONSIDERATIONS FOR A 100 kW CW, 140 GHz GYROTRON OSCILLATOR**, K. Felch, R. Bier, L. Fox, H. Huey, L. Ives, H. Jory and S. Spang, *Varian Associates, Inc., Palo Alto, CA* **834**

3:15 p.m.

- 35.5 PERFORMANCE OF A THREE CAVITY GYROKLYSTRON**, W. Bollen and C. Sedlak, *Mission Research Corp., Alexandria, VA*; A. Ganguly, B. Arfin and R. Parker, *Naval Research Laboratory, Washington, DC* **838**

3:40 p.m.

- 35.6 FOURTH HARMONIC GYROMAGNETRON DEVELOPMENT**, L. Barnett, J. Baird, U. Shrivastava and R. Grow, *University of Utah, Salt Lake City, UT* **842**

4:05 p.m.

- 35.7 PENIOTRON AMPLIFIER RESULTS**, G. Döhler, D. Gallagher, C. Lowrie, R. Moats and F. Scafuri, *Northrop Corporation, Rolling Meadows, IL* **845**

NOTE: The following paper was not available at time of publication.

9:05 a.m.

- 28.1 X-RAY LITHOGRAPHY FOR HIGH RESOLUTION** (Invited Paper), A. Heuberger, *Fraunhofer-Institut für Mikrostrukturtechnik, Berlin, FRG*

SIPOS HETEROJUNCTION CONTACTS TO SILICON

Young H. Kwark, Ron Sinton, Richard M. Swanson

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Stanford, CA. 94305 (415)497-0503

Abstract: Using SIPOS films (SiO_x , $x < 2$) as an emitter contact has been previously shown to reduce the emitter saturation current, J_{oe} , by at least a factor of fifty when compared to a conventional emitter structure with a metallic contact. Previous attempts to explain this J_{oe} reduction have focused on the bulk properties of the SIPOS films. Experimental results of this study which attained J_{oe} values of $2 \times 10^{-14} \text{ A/cm}^2$, suggest that an interfacial layer between the SIPOS and underlying silicon may play an important, if not dominant, role with the implication that the high oxygen concentrations previously used may not be essential for J_{oe} reduction. This would permit the use of lower oxygen content SIPOS films whose lower bulk resistivities would allow utilization of these films in structures such as scaled VLSI bipolar devices and high concentration point contact solar cells where series resistance is detrimental to device performance.

Introduction: Deliberate introduction of controlled amounts of an oxygen bearing species such as nitrous oxide into the deposition ambient normally used for chemical vapor deposition of polysilicon produces SIPOS, a class of silicon oxides which exhibits a wide range of physical properties (1). It is possible to tailor film characteristics such as the refractive index, by altering the oxygen partial pressure in the deposition ambient. The addition of a dopant species converts these films from semi-insulating to a form that can be made sufficiently conductive after annealing to make them interesting for electronic applications (2). Incorporation of these films into the emitter structure of an NPN bipolar transistor had been found to reduce the emitter saturation current fifty fold (3); this translates into potential improvements of energy conversion efficiency for solar cells and enhanced high frequency performance of bipolar structures.

Matsushita (3) hypothesized that large amounts of oxygen in his SIPOS films produce a bandgap larger than for monocrystalline silicon. In N-type SIPOS emitter contacts the lining up of the equilibrium Fermi levels results in a barrier in the valence band which blocks hole transport and accounts for the reduction in J_{oe} . Simplified density of states calculations using small clusters of SiO_x lend qualitative support to this scenario; namely the gap in the density

of states increases in a continuous manner as the oxygen content in SiO_x is increased (4). However, it is important to note that these clusters were constructed assuming a uniform and random distribution of oxygen throughout the film. While this may apply to films prepared at low temperatures (e.g. evaporation or sputtering), the CVD deposited SIPOS films used in these devices require a high temperature anneal in order to activate the dopant. A phase precipitation which results in a fine dispersion of silicon microcrystallites embedded in an oxygen rich matrix appears to be the result of such anneals (5). Such a heterogeneous structure would indicate that a model based on an effective bandgap and diffusion length may be oversimplified.

Experimental Results: Bipolar test structures and measurement techniques were refined to allow measurement of the emitter saturation current at these low levels; a sample Gummel plot showing the area related component from which J_{oe} , the emitter saturation current, was extracted is shown in Fig. 1. Devices with differing area/perimeter ratios were used in conjunction with the definition

$$I_{base} = \text{Area} * J_{area} + \text{Perimeter} * J_{peri}$$

to effect this separation. By utilizing various SIPOS emitter contact configurations, these measurements, after correcting to 300°K, allowed determination of which film parameters were relevant in determining the hole blocking action of the films.

The first set of experiments investigated the effect of varying the oxygen content on J_{oe} . These films were deposited in a hot wall APCVD reactor using nitrogen as the carrier gas. Varying γ , the ratio of nitrous oxide to silane in the deposition ambient, from $\gamma = 0$ (which should produce POLY) to $\gamma = 1.5$ (which should produce films comparable to ref. (3)) should display a monotonically decreasing J_{oe} as hole transport is increasingly impeded by the increasing bandgap in the bulk SIPOS. In fact for devices annealed at 900°C/13 min, there is very little dependence on γ as seen in Fig. 2, although increasing the anneal temperature to 1000°C adversely affected J_{oe} . That the $\gamma=0$ films produced such good results was surprising since POLY films of comparable thickness should yield a J_{oe} an order of magnitude larger. In fact it was discovered that these $\gamma = 0$ films

incorporated significant (several atomic %) amounts of oxygen as indicated from electron microprobe and the fact that they etched, albeit slowly, in buffered HF. This insensitivity to bulk film properties implies that other mechanisms, in this case the formation of an interfacial oxide layer as a result of the annealing process (Fig. 3), may be primarily responsible for the reduced hole currents. This conclusion suggests that the mechanism of hole suppression is akin to that for polysilicon SIS contacts, and that the distinguishing feature of SIPOS may be its built-in source of oxygen which aids in the formation and/or maintenance of this interfacial layer.

In order to establish unambiguous results for a relatively oxygen free film, POLY films doped insitu in an RF heated cold wall APCVD reactor using a hydrogen carrier were used in the next set of emitter contacts; these films did not etch in BHF. Fig. 4 displays the resulting J_{oe} as a function of annealing temperature for emitter B which had a Gaussian (3×10^{19} surface concentration, 1 micron depth into 5×10^{16} background) emitter diffused prior to the POLY deposition and emitter C which relied solely on outdiffusion from the doped POLY to form the base-emitter junction. For both structures, devices were prepared with and without a chemically grown oxide (chemox) by dipping half of the wafer which underwent a full RCA clean in dilute HF. The value for emitter B with a conventional aluminum contact is shown for reference. Addition of POLY without the chemox does not greatly impact J_{oe} as would be expected since the heavily doped POLY acts essentially as an extension of the monocrystalline emitter. Addition of the chemox greatly decreases the J_{oe} as has been previously reported (6). "Prediffused" emitter B displays a baseline J_{oe} of 5×10^{-14} A/cm² due to recombination in the bulk of the emitter. To this is added a component due to outdiffusion from the heavily doped POLY which becomes increasingly significant for annealing temperatures above 900°C. This is apparent if one notes that the increase in J_{oe} for emitter B can be accounted for by the J_{oe} of emitter C at the same temperature. At 1000°C, this outdiffusion is severe enough to dominate the J_{oe} which accounted for the lack of difference between emitters B and C.

In Fig. 5, J_{oe} for a $\gamma = 0$ SIPOS film (which recall has several at% oxygen) without the chemox is shown. The behavior above 850°C strongly resembles the POLY case with chemox. Addition of the chemox to the SIPOS contact structure does not greatly affect the lowest values of J_{oe} attained. However, the increase in J_{oe} at higher temperatures is not as severe as for the devices in Fig. 4 and 5. Furthermore, devices annealed at 850°C, while displaying the same J_{oe} as the SIPOS devices without the chemox, also suffered from greatly increased series resistance.

Discussion: Emitter saturation currents of $1 - 2 \times 10^{-14}$ A/cm² have been attained for POLY with chemox and for both SIPOS contact structures. That there was little difference in J_{oe} between the SIPOS contacted emitters with and without the chemox would indicate that the interface between SIPOS and monocrystalline silicon is similar in

both cases. Postulating the formation of a thin tunnelable interfacial oxide as a consequence of the high temperature annealing step is consistent with the observed similarities in J_{oe} . The smaller increase in J_{oe} for the SIPOS device with chemox can be explained by assuming that the chemox simply adds an additional thickness to the oxide layer resulting from the anneal step. This would act as a more robust diffusion barrier and would limit the extent of outdiffusion of dopants from the SIPOS thus reducing bulk recombination in the monocrystalline emitter region. This is also consistent with the increased series resistance which would arise from a thicker interfacial layer. The possibility remains that a thin thermal oxide is growing during the thermal equilibration phase prior to deposition of the SIPOS films; although standard precautions were taken to minimize the presence of oxygen and water vapor in the deposition ambient, the apparatus currently available can not be used to rule out this possibility.

A key figure of merit which has not been discussed is the specific resistivity of the emitter contact structure. For the SIPOS films mentioned in ref. (3), a specific contact resistivity of 1×10^{-3} ohm-cm² would result for a 1000 angstrom thick film. This is far too high to permit use in scaled bipolar or in high concentration point contact solar cells. If the hole barrier mechanism operative in SIPOS contacts is indeed associated with the formation of interfacial layers, then there is no apriori need for such high oxygen concentrations in the bulk of the films with their attendant high resistivity. The focus, in this case, would shift to the kinetics of the annealing process and to the morphology of the near interface region, much as is the case with POLY SIS structures. For the $\gamma = 0$ SIPOS contacts, an upper limit to the specific resistivity can be set at 1×10^{-4} ohm-cm² from device Gummel plots; although the actual value is quite likely to be far below this, the presence of other parasitic resistances does not allow a more refined determination from the device data. The ability to directly measure the voltage drop at the interface is being incorporated into the next mask set.

References:

- (1) D. Dong, E. Irene, et al "Preparation and Some Properties of CVD Si-rich SiO₂ and Si₃N₄ Films", J. Electrochemical Soc. 125(5), May 1978, p819
- (2) H. Yamoto, N. Oh-uchi, et al "New Technology by the Use of Doped SIPOS Films", ECS Abstracts, #168, 1979
- (3) T. Matsushita, "A Silicon Heterojunction Transistor," Appl. Phys. Lett., vol 35(7), p 549, 1979
- (4) A. Bennet, L. Roth "Calculation of the Optical Properties of Amorphous SiO₂ Materials" Phys. Rev. B 4(8), Oct. 15, 1971, p 2686
- (5) M. Hamasaki, "Crystallographic Study of SIPOS Doped with Oxygen Atoms," J. Appl. Phys. 49(7), p 3987, 1978
- (6) B. Soerowirdjo, P. Ashburn, et al "The Influence of Surface Treatments on the Electrical Characteristics of Polysilicon Emitter Bipolar Transistors" Tech. Digest IEDM, 1982, p 668

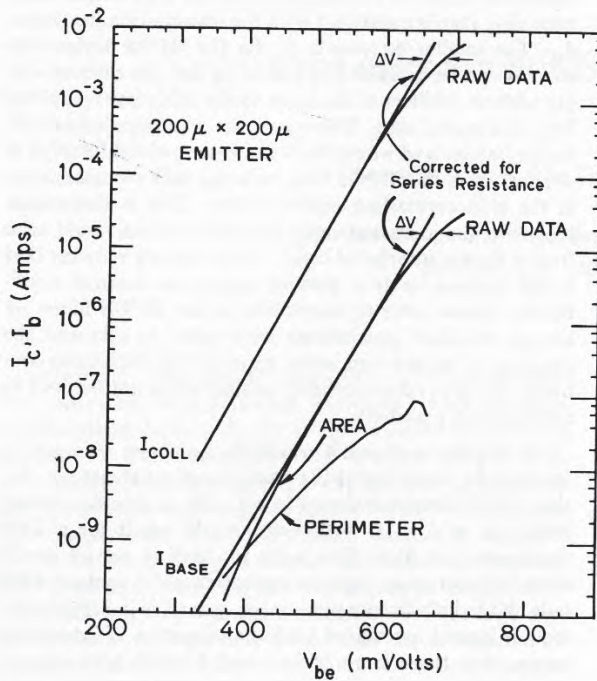


Fig. 1: Gummel plot of test bipolar structure showing area and perimeter related components.

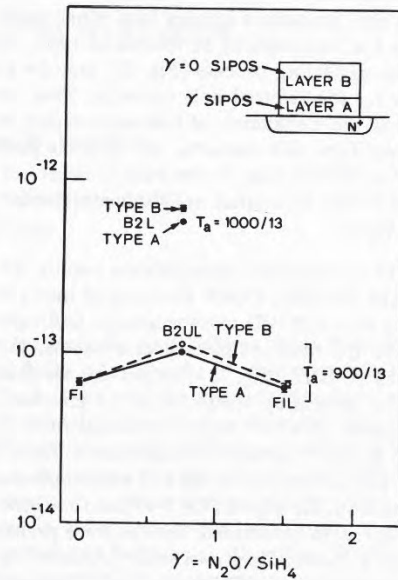


Fig.2: γ is the ratio of nitrous oxide to silane in the SIPOS deposition ambient, T_a is the anneal temperature (followed by a slash and anneal time in minutes). Layer B is a 2000 angstrom capping layer; layer A is the "active layer" ranging from 1000 to 1600 angstroms.

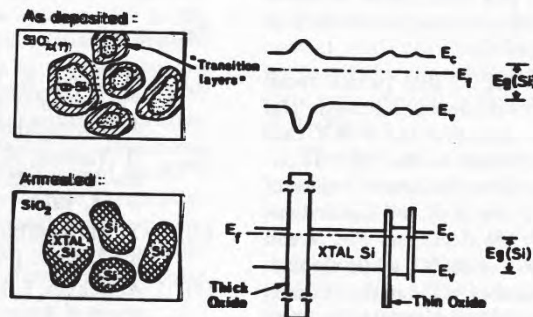


Fig. 3: (A) postulated structure of as-deposited SIPOS (B) and after annealing; the "oxide-like" regions become more SiO_2 -like, accompanied by crystallization of the silicon crystallites.

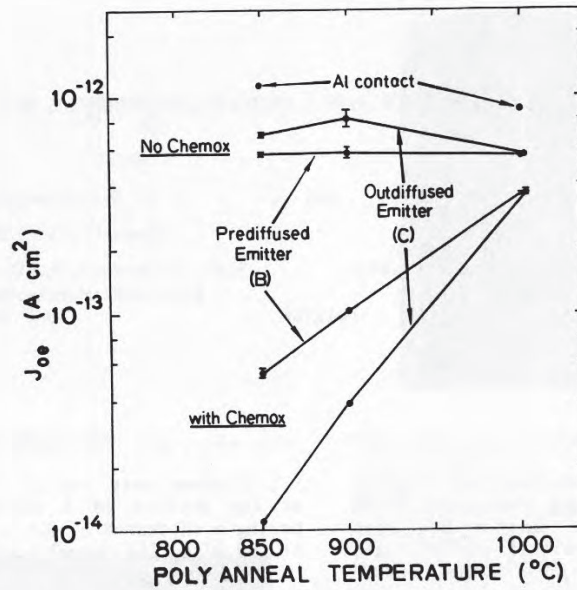


Fig. 4: emitter saturation current for POLY contacts with and without a chemically grown interfacial layer vs. anneal temperature. Thicknesses range from 3000-3600 angstroms. Note the large difference when the interfacial oxide is missing.

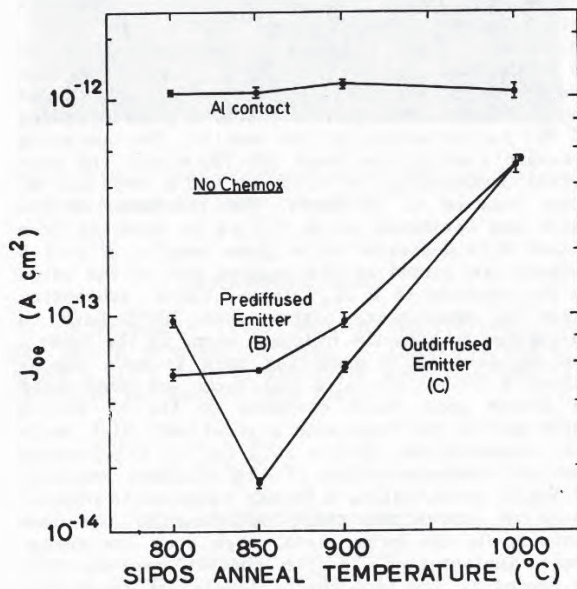


Fig. 5: emitter saturation current vs. anneal temperature for SIPOS contacts without a chemically grown interfacial oxide. The $\gamma = 0$ SIPOS layer is 3300 angstroms thick.

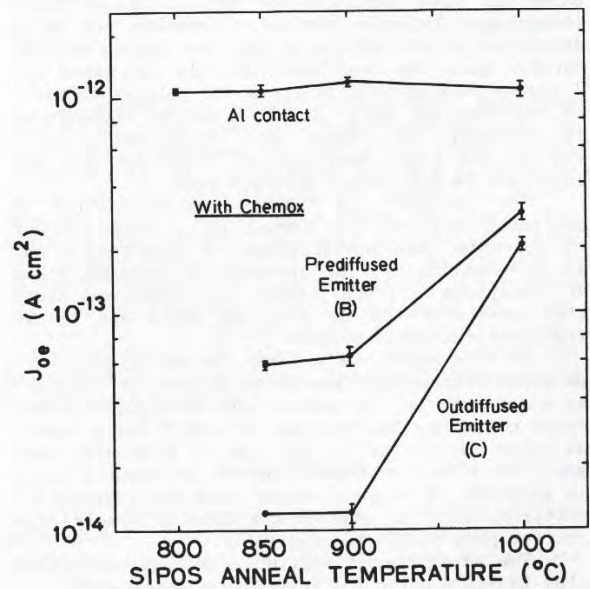


Fig. 6: emitter saturation current vs. anneal temperature for SIPOS contacts with a chemically grown interfacial oxide. The $\gamma = 0$ SIPOS layer is 3300 angstroms thick.