SYMPOSIUM J
Advanced Materials and Techniques for Nanolithography

November 28 – December 1, 1999

Chairs

Hersong Chen
SEH America, Inc.
MS 65-1-705
Vancouver, WA 98682
360-885-8422

Kenneth E. Gonsalves
IMS and Dept of Chemistry
Univ of Connecticut
Storrs, CT 06269-3136
860-486-6134

Lhadi Merhari
CERAMEC France
Limoges, F-87000 FRANCE
33-555-94005

Paul F. Nealey
Dept of Chem Eng
& Ctr for Nanotechnology
Univ of Wisconsin-Madison
Madison, WI 53706
608-265-8171

Symposium Support
CERAMEC France
City Technology Limited
ComSys GmbH
Conexant Systems, Inc.
SEH America, Inc.
ST Microelectronics France

A joint Proceedings with symposium N will be published as Volume 584 of the Materials Research Society Symposium Proceedings Series.

*Invited paper
TUTORIAL

PTI: ADVANCED RESISTS FOR MICRO-
AND NANOLITHOGRAPHY

Sunday, November 28, 1999
2:00 - 5:00 p.m.
Room 204 (H)

This tutorial will begin with a brief introduction to lithographies in microelectronics and the need for advanced polymer resists. A brief historical outline of resist materials will then be given, with the focus on the following topics:

- The technical requirements that have driven the evolution of resist materials
- The range of resist chemistries that have been used over time
- Key resist advances that have been made in response to new exposure technology/application requirements
- Materials up to and including DNA-nucleic acid resists

A section on modern resists based on chemical amplification will cover:

- Motivations for developing CA resists
- Mechanisms/modes of operation
- Explanatory examples of CA resist chemistries for 248 nm lithography
- Chemistry/properties of materials in use today in the manufacturing setting
- How and why CA resist materials are evolving for near-term future use in 193 nm lithography

The final section on next-generation lithographies will discuss an introductory level of the top candidates for NGL exposure technologies; the unique resist requirements of each of these different NGL technologies; and potential limits of extendibility of resist materials due to factors such as product diffusion, line edge roughness, and thinner films vs. defects and etch resistance.

Instructors:
William D. Hinsberg, IBM Almaden Research Center
Kenneth Gonsalves, University of Connecticut
Liliand Merhar, CERA/IMEC France

SESSION 1: ADVANCES IN PHOTO AND X-RAY LITHOGRAPHIES, ISSUES FOR MOLECULAR SCALE ELECTRONICS

Chair: Kenneth E. Gonsalves and Liliand Merhar
Monday Morning, November 29, 1999
Boston College [M]

8:30 AM *31.1
EXTREME ULTRAVIOLET LITHOGRAPHY AND THE MATERIALS CHALLENGE. Sheila Vaidya, Don Sweeney, Lawrence Livermore National Laboratory, Information Science and Technology Program, Livermore, CA; Nick Stulen, Sandia National Laboratory, EUV, Livermore, CA; David Attwood, Lawrence Berkeley National Laboratory, Center for X-Ray Optics, Berkeley, CA.

Extreme Ultraviolet Lithography (EUVL) has emerged as one of the leading successors to optics for sub 0.1 μm IC fabrication. Its strongest attribute is the potential to scale to a much finer resolution at high throughput. As such, this approach could satisfy the lithography requirements for Si integrated circuits down to fundamental device limits. In the United States, Lawrence Livermore, Sandia, and Lawrence Berkeley Laboratories are participating in an industry funded research effort to evolve EUV technology and build a prototype camera for lithographic exposure. This effort has driven the development of special, ultra-thin optics fabrication and coatings, in mask making, as well as in the use of thin photoresists for 50nm imaging. This talk will review some of the major advances in apheric optics fabrication, the attendant metrology innovations, and the multilayer coating technology, which have enabled the design of a high throughput, all-reflective imaging system with high-quality imaging behavior. Multilayer coated apheric optics have necessitated the evolution of deposition techniques which provide stress control and better than 0.1% thickness uniformity across 8 substrates; the reflective mask imposes additional demands on substrate quality, multilayer interface perfection and mask defect density. These requirements are well on the way to being met through model-based deposition control and advanced diagnostics. In the photoresist arena, conventional DUV materials are showing significant promise with regards to line edge roughness and resolution in bilayer/trilayer configurations. These results will be reviewed and the challenges remaining highlighted.

9:00 AM *31.2

Extreme ultraviolet lithography (EUVL) is one of the leading candidates for synthesizing integrated circuits with critical dimensions of less than 70 nm. EUV reticles are fabricated by depositing multilayer reflective coatings such as Mo/Si on superpolished substrates. The reticles must be nearly defect-free in the sense that there can not be localized structural imperfections in the coating that perturb the reflected radiation field sufficiently to print at the wafer. Consequently it is important to understand and control the evolution of defects nucleated by small particle contaminants in the substrate/multilayer film interface. In order to investigate and quantify the effect of particulates on the film growth, we have deposited low pressure ion beam sputtered Mo/Si multilayer films on substrates with particles of known sizes, ranging from 40 to 80 nm in diameter. We have used atomic force microscopy (AFM) and transmission electron microscopy (TEM) to characterize the defects before and after coating. We compare our experimental results to recent theoretical studies of film growth based on a linear continuum model.

9:15 AM *31.3
SCANDIUM: A BRIGHT HOPE FOR MID EUV OPTICS? David D. Allred, R. Steven Turky, David Bakogh, Spencer Olson, Matthew B. Squires, Douglas Markos, Alex Borshonov, and Jason Flint, Department of Physics and Astronomy, Brigham Young University, Provo, UT.

Below about 120 nm, there are no acceptable optical materials for lens or single surface mirrors which could be readily used for advanced lithography. The next band where there are well researched multilayer mirrors (Mo/Si and Mo/Be) with high reflectance is from 11-14 nm. Normal incidence reflectances of above 70% have been reported. We would like to highlight the possibility of another band from 30-40 nm where highly reflective mirrors may be possible. A Russian group recently calculated that multilayer mirrors with high reflectivity (R > 70%) for this range could be fabricated using scandium and silicon. They fabricated a Si/Sc mirror whose reflectance reached 50% at 37 nm. We will report on materials science aspects of our work with scandium and other chemically active, but optically attractive, elements for multilayers for this range. We will address using the natural tarnish which forms on the mirror as an integral part of achieving the mirror’s optical response, the use of hexagonal structures, and the design and characterization of periodic mirrors which perform several optical functions, including blocking some EUV wavelengths and acting as broadband reflector. Achieving reflectances above 50% could revolutionize optics in this range and provide a useful alternative to 11-14 nm for projection lithography. This may be important since compact sources of EUV light in the 30-40 nm range are more developed than for 11-14 nm. The material challenges include the strong effort that first row elements (especially C and O) have on altering the reflectances in this range, and the relatively high reactivity and diffusivity of many of the best optical materials in this range.


9:30 AM *31.4
LITHOGRAPHIC MATERIALS TECHNOLOGIES, 180 NM IMAGING AND BEYOND. Elsa Behnamian, Omikram Nalbandian, Francis H. Houthian, Bell Laboratories, Lucent Technologies, Murray Hill, NJ; Allen H. Gabor, Mark O. Neisser, Marjoe J. Bowden, Arch Chemicals, Inc., East Providence, RI.

Advances in micro lithographic resist materials have been a key enabler of the unyielded productivity gains in the microelectronics industry and are continuing to push the ultimate limits of optical lithography. The challenges posed by the introduction of new optical technologies that use smaller wavelengths have been successfully met by the materials community through the design of chemically amplified resist technologies and 130 nm resist materials based on aliphatic polymers and dissolution inhibitors. With continued advances in resist materials, exposure systems and resolution...
enhancement and mask technologies, optical lithography will be capable of patterning sub-one-tenth micron design rule devices in future. This technique will fit the lithography and mask technologies that have been successfully met in the development of 193 nm
lithographic materials technologies and begin to examine future
directions.

10:30 AM #11.5
IMAGE FORMATION IN HIGH-ENERGY LITHOGRAPHY: FRACTALS AND MATERIAL PROPERTIES. E. Gering, Electrical and Computer Engineering Department University of Wisconsin-Madison, Madison, WI.

The continuing decrease in device dimensions leads to the development of new patterning techniques. While there are several possible approaches, the most likely volume production techniques will be based on electron and electron projection schemes. In all cases, these lithography use particle of energy high enough to cause

etching of the target substrate. Possibilities include erosion of mask materials by electron or xenon halogen or erosion of the mask electron when the atom returns to the ground state. Thus energy redistribution plays a vital role in exposing the photosensitive material. Interestingly enough, no detailed model explaining satisfactorily the process exists. Since line edge roughness (LER), i.e., resist linewidth fluctuations become more relevant as the dimension of the features decreases, it is becoming necessary to understand in detail the origin of these fluctuations. Most activity to date has concentrated on developing average values, and even Monte Carlo methods are based on

continuum models for the energy loss. This models cannot predict detailed processes at the molecular level that are likely to be at the root of roughness and other scattering effects. In addition, the concept of LER itself is not explained, and in particular the meaning of "roughness." In order to quantify the LER more accurately, we have studied a quantification in terms of fractal analysis, and explored the confrontation between top roughness (TR, much easier to measure) and LER, concluding that the two are

essentially the same. In this talk we will review the status of research on LER, and discuss its origin using both experimental results in Extreme Ultraviolet and X-ray Lithography, and show how the roughness is dependent not only on the physical process leading to image formation but also on the type of chemical reactions involved in the image storage, and in its development.

11:00 AM #11.6
SOFT X-RAYS FOR DEEP SUB-100 NM LITHOGRAPHY, WITH AND WITHOUT MASKS. Henry J. Smith, Massachusetts Institute of Technology, Cambridge, MA.

The development of micro- and nanofabrication, their applications, and their dependent industries has progressed to a point where a bifurcation of technology development is occurring. On the one hand, the Semiconductor industry, (at least in the USA), has decided to develop EUV and SCALPEL to meet its future needs. Even if the semiconductor industry is successful in this (which is by no means certain!), such technologies will be useful in many other segments of the industry and research that will employ nanolithography. As examples, MEMS, integrated optics, biological research, magnetic information storage, quantum-effect research, lithography on curved surfaces, and multiple applications not yet envisioned will not employ the lithography tools of the semiconductor industry, either because they are too expensive, insufficiently flexible, or lacking in accuracy and spatial-phase coherence. Of course, direct-write electron-beam lithography can meet any of these non-semiconductor-industry needs, but in other cases a technique of high throughput or broader process-intensity is necessary. Our experience at MIT in applying low-cost proximity x-ray lithography to a wide variety of applications leads us to conclude that this technique can provide the alternative path of a bifurcation. A new version of x-ray lithography, zone-plate x-ray lithography (ZPL), does not require a mask, and has the potential to reach the limits of the lithographic process with a minimum projection process. In this talk we will show results of deep-sub-100 nm lithography, and review the fundamental reasons why a lithography based on photons in the range 1 to 5 nm (i.e., x-rays) can provide: low capital costs, 20 nm resolution, high throughput, and sufficient flexibility to meet the needs of a variety of current and future industries.

11:30 AM #11.7
MOLECULAR SCALE ELECTRONICS, CRITICAL NANOGRAPHY ISSUES OF SYNTHESIS AND ADDRESSING. James M. Tour, Rice University, Department of Chemistry and Center for Nanoscale Science and Technology, Houston, TX.

Synthetic organic routes to precisely defined conjugated macromolecular scale wires will be described as solution and solid phase approaches. The molecular scale wires are based on poly(phenylene ethynylene)s and poly(thiophene ethynylene)s and they possess thiol, selenol, and tellurium end groups to function as molecular scale alligator clip fingers. Ordering of these molecular scale wires on gold surfaces has been studied by ellipsometry, XPS, and grating angle IR. Experimental approaches will be described for isolating some of these single molecules in alkane thiolate self-assembled monolayers and addressing them with an STM probe. Single molecule conductivity has been measured using a mechanically controllable break junction. These experiments demonstrate single molecule conductivity and they are a prelude to the testing of single molecular scale devices. Several molecular based resonance tunneling diodes (RBDs) have been demonstrated. Some of the molecular scale structures that have been synthesized are wires with tunnel barriers, wires with quantum wells, three terminal systems that could act as molecular switches, four terminal systems that could be logic devices, and wires based on DNA/fullerene hybrids. Scenarios will be outlined wherein a single molecule could function as a logic device rather than the traditional use of multiple transistors. The devices have been modeled using density functional theory. Potential routes to molecular based CPUs will be outlined. The applications of these devices to future electronic uses as the information-carrying packets. The enormous potential and obstacles of molecular scale electronic architectures will be discussed.

SESSION 32: ADVANCED RESISTS AND CHARACTERIZATION

Chairs: Kenneth E. Gänsler and Paul F. Nealey
Monday Afternoon, November 29, 1999
Boston College (M)

1:45 PM #32.1
RESIST MATERIALS AND NANOLITHOGRAPHY. Elizabeth A. Dobisz, Naval Research Laboratory, Electronics Science and Technology Division, Washington DC.

The work focuses on lithographic processes and materials for sub-50 nm lithography. The discussion will give a critical examination of the use of polymeric resists for nanolithography. This will be followed by a discussion of alternative resists, such as self-assembled monolayers (SAMs). Polymers have radii of gyration 


below 5.0 nm, depending upon molecular weight, configuration, and solvent environment. The developer solvent can penetrate the remaining resist structure causing swelling. Developer induced resist compromise swelling of the resist, pattern integrity, and the overall mechanical stability of the pattern.

Furthermore, the current state-of-the-art chemically amplified resists (CARs) are composed of multiple-components that can diffuse. Patterns are defined by e-beam lithography or SFM lithography, which have a probe sizes less than 10 nm. Atomic force microscopy and scanning electron microscope images provide complementary information on pattern formation. The results are compared to calculated image profiles. With carefully controlled process conditions, 40 nm lines and 40 nm period gratings can be produced in some polymer resists. 20-25 nm lines can be produced in a CAR. Small molecule SAM resists have been proposed to circumvent the macromolecular resist issues and for applications requiring the nanometrical precision. A review of work at the Naval Research Laboratory on a metal bonding SAM resists is given.

2:15 PM #32.2
FACTORS CONTROLLING PATTERN FORMATION IN POLYMERIC RESISTS AT NANOSCALE DIMENSIONS. W. Hinzebush, F. Houle, G. Wolfra, M. Sanchez, M. Morrison, J. Hoffm, Hiroshi Ito, Carri N, C.E. Larson, P.J. Brock and G. Krey, IBM Research Division, Almaden Research Center, San Jose, CA.

At minimum feature dimensions below 100 nm, the required dimensional tolerances for pattern formation in integrated circuit fabrication approach the length scales of the molecular components and processes typically found in a polymeric resist film. Photocid diffusion and line-edge roughness are two key factors that influence dimensional control and determine the ultimate utility of chemically amplified photoresists to the fabrication of nanoscale devices. In this paper, newly developed experimental methods for quantifying these characteristics will be described and recent results will be summarized.

2:45 PM #32.3
DIFFUSION OF PHOTOCID GENERATORS IN THIN POLYMERIC FILMS. Tongzhuang Liu, Marie Angekoppals, IBM T. J. Watson Research Center, Yorktown Heights, NY; Narayan Sundarajan, Ginn Weibel, Christopher O. Ober, Department of Materials Science and Engineering, Cornell University, Ithaca, NY.

Fundamental understanding of the diffusion of small molecules, such as photoacid generators (PAGs), photo-generated acids, base additives and solvents, is critical to the rational design of high performance resist materials. In this work, direct measurements of the diffusion of
two fluorinated PAGs in thin polymer films were conducted with Rutherford Backscattering Spectrometry (RBS) and Secondary Ion Mass Spectrometry (SIMS). Deposition of the PAGs from thin films of poly(methyl methacrylate) or a silicon-containing methacrylate copolymer under the thermally cross-linked Novolak films on a silicon substrate has been investigated as a function of the Novolak cross-linking temperature. Both RBS and SIMS results show that deposition of the PAGs containing polymer films on top of the cross-linked Novolak film by spin coating results in an interphase with enriched PAG. Subsequent annealing of the film stack causes expansion and diffusion of the PAG in the underlying Novolak film when Novolak is cross-linked at lower temperatures. On the other hand, there is no detectable diffusion of the PAG in the Novolak when it is cross-linked at high temperature. The effects of the PAG molecular size, the microstructure of the cross-linked Novolak films on the PAG diffusion will be discussed. The effects of the PAG diffusion on lithographic performance of a bilayer resist will also be presented.

3:30 PM #12.4 RESIST MATERIALS PROVIDING SMALL LINE-EDGE ROUGHNESS: Hisao Nakanoh, Toru Yamaguchi and Kenji Kuribara, NTT Basic Research Laboratories, Kanagawa, JAPAN

In sub-100 nm lithography, accuracy of linewidth as well as resolution becomes important factors. This is because the amount of linewidth fluctuation cannot be disregarded as the linewidth decreases. The evaluation of the linewidth fluctuation has been reported as line-edge roughness (LER) by many researchers. However, so far there has been little discussion on the cause of, or effective way to improve the LER, by examining the properties of resist materials. In this paper, we report on the cause of LER in nanolithographic resists and also on material design for reducing LER. Polymer aggregates, which are generally confined in resist films, cause LER. When the aggregates exist in the resist film, development rate becomes uneven. This is because the aggregates are not dissolved but extracted in the developer. The aggregates remain at the pattern sidewall result in LER. Therefore, preventing the aggregate extraction leads to resist patterning free from LER. There are two approaches to reducing the influence of the aggregate extraction on LER. One is a technique of reducing the aggregate size. The other is suppressing the extraction itself. The former can be achieved by using a small aggregate size. A typical example is hydrogen silyloxy groups. The effectiveness of this resist in reducing LER has been confirmed by improving the properties of single electron transistors. The latter is obtained by reducing the difference in the development rate between the aggregates and the surroundings. We have achieved a resist with a small difference in the development rate by cross-linking the aggregates.

4:00 PM 12.5 OPTICAL CHARACTERIZATION AND PROCESS CONTROL OF TOP SURFACE IMAGING RESIST: Ying-Ying Loo, KLA-Tencor Corporation, Film and Surface Technology Division, Milpitas, CA; Craig Stauffer, GENESIS, Suntex, Chra, CA; Carlos Ygortum, Dinh Chu and Chive Heynekien, KLA-Tencor Corporation.

The use of selectively silylated resists to facilitate top surface imaging (TSI) offers the potential for nanoscale lithography by using both deep ultra violet (DUV) illumination and electron beam techniques. In this process, an exposed resist pattern is transferred to a wafer using a silicon dioxide mask. The silicon dioxide mask is then removed using a selective etch and the metal layers are then etched. The optical properties of the silylated resists are then characterized using a scanning electron microscope (SEM) or a confocal laser scanning microscope (CLSM). The effects of silylation on the optical properties of the silylated resists will be presented. Optical metrology of the thickness of the silylated resists will be correlated with SEM cross-sectional analysis, and process uniformity will be quantified using 454-site wafer maps.

4:15 PM 12.6 A NEW PRITIZED UV SPECTROSCOPIC ELIPSOMETER TO CHARACTERIZE 157NM NANOLITHOGRAPHIC MATERIALS: Pierre Boher, Jean Philippe Piel, Patrick Evrard and Jean Louis Stehle, SOPRA S.A., Bois Colombes, FRANCE

Spectroscopic ellipsometry has long been recognized as the technique of choice to characterize thin films and multilayers. Since 1983, SOPRA has developed the first commercial spectroscopic ellipsometers for research and development. Since this date, the wavelength range has been extended from 193 nm to 157 nm. Significant improvements of the S100 results have been made. For instance, the infrared up to 18 μm. For 193 nm micro lithography, deep UV treatment has been developed and sold more recently. Instrumentation for the next generation of UV lithography at 157 nm requires special optical setup since oxygen and water are extremely absorbing below 190 nm. The new system works in a purged glove box to reduce the oxygen and water contamination in the part per billion range. The optical setup includes a preamorphocromator in the polarization arm to avoid resist photobleaching. The beam size on the sample is around 3 mm, and the wavelength resolution better than 0.5 at 157 nm. The system works in rotating analyzer configuration to minimize the parasitic polarizations. A compensator can be used to enhance contrast on layers deposited on transparent substrates. Ellipsometric and photometric measurement versus wavelength and angle can be performed. The proposed paper will present in detail the new system with some first experimental results in the field of nanolithography.

4:30 PM 12.7 SYSTEMATIC STUDIES OF FULLERENE DERIVATIVE ELECTRON BEAM RESISTS: T. A. Robinson, R.E. Palmer, NanoScape Physics Research Laboratory, School of Physics and Astronomy, The University of Birmingham, Birmingham, UNITED KINGDOM; T. Tsuda, T. Okada, Research Laboratory for Light atom, National Institute for Advanced Interdisciplinary Research, Tsukuba, JAPAN; E.J. Shelley, D. Philp, J.A. Preesh, School of Chemistry, The University of Birmingham, Birmingham, UNITED KINGDOM.

We report systematic studies of the response of C60 derivatives to electron beam irradiation. Films of thirteen different mono-, tri- and tetra-substituted fluorocarbon C60 derivatives were produced by spin coating on hydrogen terminated silicon substrates. Exposure of the films to a 20 kV electron beam substantially altered the absorption rate of the derivative films in organic solvents such as monochlorobenzene. All of the derivatives exhibited negative tone resist behaviour with sensitivities between ~8.5 (10^-4) and ~4 (10^-3) C/cm^2, much higher than that of C60. Features with widths of ~20 nm were produced using these compounds, and the etch ratios of the compounds were found to be more than twice those of a standard novolak based resist (SA1001).

4:45 PM 12.8 EXTENDING THE POSSIBILITIES OF NEAR-FIELD SCANNING OPTICAL MICROSCOPY FOR SIMULTANEOUS TOPOGRAPHICAL AND CHEMICAL FORCE IMAGING: Naomi Nagy, M. Cynthia Goh, University of Toronto, Department of Chemistry, Toronto, ON, CANADA.

Near-field scanning optical microscopy (NSOM) is an innovative new form of surface microscopy which can be used to obtain both topographical and spectroscopic information about a surface. The most important component of this instrument is the scanning probe which is used as both a topographical probe and an optical probe for spectroscopic measurements. In this presentation, we discuss the principles and applications of NSOM. The probe consists of a bent, tapered silicon dioxide optical fiber. We have determined the range of effective chemical detection of several different chemicals using a NSOM fiber probe. We have performed characterization of the optical probes using surfaces prepared by techniques such as resistance printing. Phase and optical images of these surfaces are obtained using both standard atomic force microscopy tips and the optical fiber probe. The optical fiber probe was capable of distinguishing between different chemical regions on the patterned surface. Methods for chemical modification of the optical probe and its sensitivity as a masklayer to image chemically different regions, in both a controlled atmosphere and under liquid will be discussed, as well as the potential for using NSOM to perform simultaneous topographic, spectroscopic and chemical force imaging.

SESSION 3: ADVANCES IN ELECTRON BEAM, ION BEAM AND SOFT LITHOGRAPHIES

Chairs: Elizabeth A. Dobisz and Ladhvi Mehta
Tuesday Morning, November 30, 1999 Boston College (M)

8:30 AM 13.1 SCALPELP-PROJECTION ELECTRON BEAM LITHOGRAPHY.
One of the leading candidates for next generation lithography is SCALPEL (Scattering with Angular Limitation Projection Electron-beam Lithography). SCALPEL is a reduction imaging projection electron-beam lithography technique which uses 100 keV electrons to produce images by scattering contrast. The use of electron circulations diffraction limits the performance of optical lithography. We have a comprehensive program to develop SCALPEL as a lithography technology. Our efforts are in the areas of mask technology, resist, and process and tool development. In our paper, we have developed masks using a small-field 100 nm diameter format. Both mask blank fabrication and mask patterning activities have been transferred to commercial vendors for this format. We are developing a full-field mask technology based on a 200 nm diameter format which will be transferred to commercial vendors in the near future. Our activities in resist and processing for SCALPEL have been heavily focused on using resist platforms developed for chemically amplified resists (CAR) in DUV lithography and near-field lithography. It has been demonstrated that SCALPEL technology on our Proof-of-Lithography (POL) exposure tool and have reported on it in the past. We are now designing a high throughput exposure tool which implements beam scanning and beam blending to simultaneously achieve high throughput and meet critical dimension (CD) control requirements for the 100 nm generation. Our throughput models show that we will be able to expose 24,000 wafers per hour with this design and that with modest evolution, it will be able to maintain the throughput through at least the 50 nm generation. This design will be the basis for commercial introduction of SCALPEL technology. In this paper, we will describe our SCALPEL POL tool and discuss its introduction as a disruptive technology. This work was supported in part by DARPA and SEMATECH. SCALPEL is a registered trademark of Lucent Technologies.


The ability to fabricate structures on the sub-10 nm length scale is a long-sought-after goal. While a great deal of emphasis has been placed on such fabrication techniques as scanning probe microscopy and self-assembly, to date, there is no accepted universal approach that can be done in a new system. Electron-beam lithography and lithography and electrodeposition. Insights into the mechanisms, structures, and applications of these techniques will be discussed, as well as some current history of the technology.

9:30 AM *13.3 SUB-10 NM LITHOGRAPHY VIA ELECTRON-BEAM LITHOGRAPHY AND ELECTRODEPOSITION. Minghao W. Wu, Lydia L. Sohn, Princeton University, Dept. of Physics, Princeton, NJ.

The ability to fabricate structures on the sub-10 nm length scale is a long-sought-after goal. While a great deal of emphasis has been placed on such fabrication techniques as scanning probe microscopy and self-assembly, to date, there is no accepted universal approach that can be done in a new system. Electron-beam lithography and lithography and electrodeposition. Insights into the mechanisms, structures, and applications of these techniques will be discussed, as well as some current history of the technology.


Use of a Radio Frequency Inductively Coupled (RF-ICP) Ion Source to Etch Sub 0.1 Micron Structures is Demonstrated. Small Diameter Bond Ions, Using a Combination of Inert Argon and Reactive Oxygen Plasmas, Were Used to Produce Structures With Features Below 100 Nanometers On Aluminum Films. Structures With Nearly Vertical Sidewalls and Free of Trenching and Redeposition Effects Were Successfully Fabricated.

11:15 AM *13.5 FABRICATION OF SUB-10 nm STRUCTURES USING SOFT LITHOGRAPHY. George M. Whitesides, Harvard University, Dept. of Chemistry and Chemical Biology, Cambridge, MA.

This talk will discuss recent work in soft lithography and related techniques. Topics of particular current interest include techniques that generate sub-100 nm features with controlled generation of defects or near-field optical methods, and techniques that are based on microelectrochemistry.
The ability to pack molecules via self-assembly methods into dense, nano-thickness films on semiconductor surfaces offers opportunities to use these films for ultrahigh resolution lithographic patterning. Previous work has shown that self-assembled monolayers can act as both positive and negative contrast electron beam resists. This talk will cover current work on various aspects including methods for improving the line-edge density of the films on a variety of substrates, e.g., Si, GaAs and InP, and on understanding the mechanisms of defect formation during the etching process.

2:00 PM 14.2
ANISOTROPIC ORGANIC/INORGANIC RESISTS: A NOVEL CONCEPT FOR ELECTRON PROXIMITY EFFECT REDUCTION
Libin Meng, CJA MIC R&D, Linogens, FRANCE; Kenneth E. Goodson, Institute for Materials Science and Dept of Chemistry, University of Connecticut, Storrs, CT.

Electron projection lithography is considered to be one of the best candidates for 180 nm production circuits. One of the major problems that hinders its development is not related to machine fabrication issues but to electron proximity effects, which stem from fundamental electron-polymer interactions. During the last two decades, efforts to reduce the electron proximity effects have essentially focused on the optimization of the resist exposure by means of dose modulation correction programs. We propose a novel approach where the structure will be determined by the controlled dose of the electron beam. The novelty of this approach is to internally restrain the electron scattering. This novel approach does not require the use of high-voltage electron beams nor the processing of large amount of data, which is a significant economic advantage. Some concepts for the synthesis of these anisotropic resists will be discussed.

2:15 PM 14.3
NEW HIGH-RESOLUTION LIQUID CRYSTAL ELECTRON BEAM RESISTS
A.P.G. Robinson, R.E. Palmer, Nanocleve Physics Research Laboratory, School of Physics and Astronomy, The University of Birmingham, Birmingham, UNITED KINGDOM; T. Tsai, T. Kirakosyan, Jet Propulsion Laboratory, California Institute for Advanced Research, Tsukuba, JAPAN; MT. Allen, J.A. Price and K.D. M. Harris, School of Chemistry, The University of Birmingham, Birmingham, UNITED KINGDOM.

We report the development of a new family of electron beam resists based on liquid crystalline polysubstituted derivatives of triphenylene. These resists show excellent performance in terms of both high resolution and high durability to plasma etching. Films of these resists have been produced in a controlled manner via room temperature spin-coating on hydrogen terminated silicon substrates. The dissolution behaviour of the resists in various organic solvents was investigated by exposure to a 30 kV electron beam. For instance the solubility of the derivative hexapentyltriphenylene, in polar solvents, was substantially increased by electron doses greater than ~10^10 C/cm^2 (positive tone behaviour). Doses greater than ~2.5 x 10^10 C/cm^2 produced negative tone non-polar solvents. Other derivatives also demonstrated a reduction in their dissolution rate for doses between ~1 x 10^10 and ~7 x 10^10 C/cm^2. The derivative sensitivity was found to be roughly proportional to the molecular mass. Negative tone patterns were found to have an etch durability ~70 % greater than that of a conventional novolac based negative tone resist (SAL601). The performance of these new resists has been demonstrated by the definition of line and space patterns with a resolution of ~14 nm, while structures with an aspect ratio of ~50 to 1 were etched into the silicon substrate.

2:30 PM 14.4
POLYMER-INORGANIC NANOCOMPOSITES: HIGH CONTRAST AND HIGH SENSITIVITY RESISTS FOR NANO-ETCHING
Kenneth Gonzales, Henry Li, Hengeng Wu, Institute of Materials Science and Dept of Chemistry, University of Connecticut, Storrs, CT; Libin Meng, CJA Mic R&D, Linogens, FRANCE.

Novel resist systems for X-ray lithography (XRL), specifically optimized in terms of contrast enhancement are described. Based on terpolymers of methyl methacrylate (MMA), tert-butylacrylate (TBA), polyhedral oligomeric silsesquioxanes (POSS) synthesized by solution polymerization, these systems were optimized by a combinatorial approach. It is shown that the molar ratio of MMA/POSS=85/14.3 leads to maximum contrast (32 k) without sacrificing the sensitivity (1350 mJ/cm^2) which remains comparable to that of standard PMMA. Such major contrast enhancement shows that the above organic/inorganic nanocomposites are promising candidates for sub-180 nm lithography.

2:45 PM 14.5
CARBON DIOXIDE - DIOLATED BLOCK COPOLYMER THIOPHATES FOR NANOSTRUCTURED MATERIALS
Gareth D. Brown, James J. Winklin, Un. of Massachusetts, Dept. of Chemical Engineering, Amherst, MA.

The fabrication of nanoscale devices will require the assembly of metal or semiconductor devices of precise size, shape and connectivity into periodic arrays with k-line (k-space) order. One route to providing such morphological control is the use of nanoscale techniques that are inherently two-dimensional. One method that can provide this level of control is the use of periodic features on an ordered substrate, such as a grid, to impose alignment over macroscopic length scales. Block copolymers meet these criteria, but to date their use as practical 3D templates has been impeded by mass-transfer resistance and transport over bulk scale features. In this paper, we demonstrate that CO2-dilated copolymers are viable reaction media and thus versatile templates for the preparation of periodic nanocomposites. Specifically, organic-inorganic composites (metal precursors) are dispersed in carbon dioxide-expanded block polystyrene-block-polysiloxane (poly(acrylic acid) or polystyrene-block-polystyrene (vinylpyridine) copolymers). Upon exposure to the acid (or pyridine) block selectively binds the metal precursor and the excess is removed from the polystyrene phase by subsequent CO2 extraction. Reduction of the bond organic-inorganic with hydrogen or hydrogen sulfide within spherical domains of an asymmetric copolymer, for example, yields the desired metal or semiconductor clusters (10 nm), which remain positioned on the copolymer lattice. The key to the process is sorption of low weight fraction of carbon dioxide, which significantly enhances reagent diffusivity without destroying the copolymer morphology. The composites are characterised by transmission electron microscopy and x-ray scattering and electron diffraction.

3:30 PM 13.4
FULLY-INTERNOCOMPOUNDING RESIN SYSTEM FOR NANO-MICROGRAPHY
Tetsuya Ishii, Toshiki Tomura, NTT, Basic Research Labs, Atsugi, JAPAN, Hiroshi Nozawa, NTT, Photonics Labs, Atsugi, JAPAN.

A nanocomposite resist system that incorporates sub-nm fullerene molecules (C60 and/or C70) into a conventional resist material as a nanometer range resist is proposed. Fullerene has chemical and physical resistant characters and its incorporation reinforces the original resist film, leading to substantial improvements in resist performance; etching resistance, pattern contrast, mechanical strength, and thermal resistance. We have confirmed improved resist performance in a system composed of a positive-type electron beam resist, ZEP520, and C60 or C70 mixture. Film thinning by enhanced etching resistance is particularly advantageous for template pattern fabrication because a thinner film generally improves resolution. This has been demonstrated through the fabrication of a 30 nm gate HEMT, in which the dimension is clearly delineated in a 200 nm film, but not in a 250 nm film. The sensitivity of nanocomposite resist readily changes with the fullerene content due to the interaction between the fullerene and the resist matrix, and this characteristic may be applied to construct a fullerene-incorporated bilayer resist system for the lift-off process. A bilayer comprising a fullerene-incorporated ZEP top layer and a pure ZEP bottom layer provides an ideal overlapping pattern and makes metal lift-off easy. Using such a bilayer, we have successfully fabricated an array of dot patterns with nanometer dimensions for a quantum box structure and a nanoimprinting mold. Presently, applications of ZEP nanocomposites and composites made of fullerene and other than ZEP resist will be limited by the poor solubility of fullerene. However, the solubility of fullerene can be greatly enhanced by introducing some solubility-promoting functional group to a fullerene molecule. Solubility enhancement by fullerene derivatives is examined for a higher degree of fullerene incorporation and better sensitivity characteristics in future nanocomposite resist systems.

4:00 PM 13.7
LINKING OF ATOMIC AND CONTINUUM SIMULATIONS FOR NANOFABRICATION
Klaus Jensen, Seth Rodgers, Raj Venktesharam, Massachusetts Institute of Technology, Department of Chemical Engineering, Cambridge, MA.

The coupling of molecular level simulations with traditional continuum phenomena descriptions is increasingly important in predicting vapor phase growth of structures because of the need to understand the relationship between processing and device performance. This development is further driven by the continual reduction in device dimensions into the nanometer regime, the rapid development of nanotechnology, and the introduction of new materials into electronic device fabrication. The development of predictive, efficient models that bridge across multiple length and time scales raises new challenges in terms of simulation strategies, numerical algorithms, and experimental validation. These are exemplified through applications of quantum chemistry, molecular dynamics (MD), kinetic Monte Carlo (MC), and macroscopic finite element simulations. Process examples
are drawn from chemical and physical vapor deposition of metals and semiconductors. Specifically, experimental observations and quantum chemistry predictions indicate that atomic scale surface reactions in MD and MC simulations to provide new understanding of microstructure evolution. By flux balances and level set methods, the results of these computations are subsequently incorporated into self-consistent molecular and reactor scale models. Comparisons with experimental data are given at each length scale along with a discussion of the type of data needed to validate multiscale models.

4:30 PM 14.8
A NEW HIGH PERFORMANCE Ca RESIST FOR E-BEAM LITHOGRAPHY. Yunsong Zhang, Wu-Sheng Huang, Wayne Morgan, Robert Long, Chris Robinson, IBM Microelectronics, Hopewell Junction, NY. We have developed a new high performance e-beam resist that can be used for 0.18-micron planarization and patterning. This resist is based on a new chemistry that allows for higher resolution and sensitivity than previously reported resist formulations. The resist is currently being used in production environments, and we are in the process of optimizing its performance for use in future deep submicron technologies.

4:45 PM 14.9
LOCAL ETCHING OF n-C:H FILMS BY NANOJET. Andrey Redkin, Alexandre Fioshko, Gennady Mikhailov, Dept. of Nanoelectronics, Institute of Microelectronics Technology, Chernogolovka, RUSSIA.

The prospective material for nanoelectronics is amorphous hydrogenated carbon (a-C:H), possessing many attractive properties for potential application as a resist. We developed a nanoelectronics-compatible technique using direct local etching of the amorphous hydrogenated carbon (a-C:H) films using a low energy ion beam. The process is performed using the cold plasma etching. The etching process is reproducibly controllable under constant ambient conditions. The etching rate was directly proportional to the number of carbon atoms in the a-C:H films.

SESSION 15: NONCONVENTIONAL LITHOGRAPHIC TECHNIQUES AND ADVANCES IN DEVICE NANOFACTORIZATION
Chair: Hyoung Chen and John Melngailis
Wednesday, December 1, 1999
Boston College [M]

8:30 AM #15.1
NANOSTRUCTURE FABRICATION USING ELECTRON BEAM M. Shinji Mouri, Himeji Institute of Technology, Himeji, JAPAN.

Nanofabrication developed by using electron beam (EB) is described. Ten-nm structures of organic positive and negative resist patterns have been achieved by using a commercially available EB lithography system with energy of 30.50 keV. The self-developing properties of an AlP3-doped LiF organic resist have been studied for sub-10 nm lithography. By optimizing the organic resist film quality, 5 nm linewidth patterns with 50 nm periodicity were fabricated under a 31 keV EB. Moreover, EB-induced deposition is described as an interesting method for nanofabrication. A novel approach for nanolithography using de Broglie waves has been developed. Line and dot patterns with 100 nm periodicity were exposed on a PMMA resist by EB holography with a thermal field-emitter gun and an electron biprism. This technique allows us to produce nanoscale periodic patterns simultaneously. Furthermore, the possibility of nanofabrication by atomic beam holography has been demonstrated by using a laser-tribe technique and a computer-generated hologram made by EB lithography.
SAM resist which was first exposed with UV light and, then, nanopatterned by AFM. The total throughput of the scanning probe lithography is improved by combining photolithographic and AFM-drawing. [1] H. Sugimura and N. Nakagiri, Appl. Phys. A 66, S427 (1998).

10:30 a.m. | 15.5 | GATE TECHNOLOGY ISSUES FOR SILICON MOS NANOTRANSISTORS D. M. Tennant, Bell Laboratories, Lucent Technologies, Holmdel, NJ; G. L. Timp, L. E. Ochoa, M. Green, T. Scrosati, A. Koszewski, F. Klemens, R. Klein, D. A. Muller, V. Kim, Bell Laboratories, Lucent Technologies, Murray Hill, NJ; and W. Timp, University of Illinois, Champaign-Urbana, IL.

We report on progress and gate technology issues in scaling both NMOS and PMOS conventional planar transistors to a physical gate length of 30 nm and an expected effective channel length of 10 nm. For this work, device fabrication employs direct write e-beam lithography to form a single, uniformly level layer structure capable of exploring the practical limits of gate processing. Other processing features include ultrathin gate dielectric formation (~0.6 nm); highly selective transformer coupled plasma (TCP) etching; and low energy ion implantation. We demonstrate lithographically defined resist features as narrow as 28 nm that were obtained with NEB 31, a negative tone chemically amplified resist. Electron energy loss spectroscopy is used to analyze the interface of the gate dielectric region and to understand the limits of scaling of silicon dioxide. Scanning capacitance microscopy is shown to be useful in determining the effective channel lengths and source drain junction depths on cross-sectioned devices to calibrate process simulation programs and thereby optimize the transistor design. We present DC electrical results obtained for high-performance NMOS and PMOS nanotransistors made using this process. Based on measured performance, simulations are presented which predict sub-threshold current for the NMOS transistor with gate length down to 25 nm. These calculations can be used to infer limits on large-scale integration and also to estimate process latitude for CD control and edge roughness in the gate formation sequence of CMOS technology beyond 40 nm.

11:00 a.m. | 15.6 | FABRICATION OF ISOLATED NANO PARTICLE CIRCUITS VIA LENSLESS OPTICAL TWISTING: G. C. Spalding, M. O. Deering, Illinois Wesleyan Univ, Dept of Physics, Bloomington, IL.

We propose a novel method for trapping a nanoparticle-scale particle into a stable structure useful for a variety of interesting electrical measurements. The particle can be dielectric or metallic, magnetic or non-magnetic. Our methodology was developed, in part, to ensure the absence of extraneous nanoparticles in the region of the device under test; it also has the further benefit of providing a feedback mechanism which indicates when a nanoparticle has been successfully trapped. In particular, we propose irradiating a substrate containing a tiny etch-p hole. On the transmission side of the substrate, the diffraction or evanescent fields should contain large enough gradients to localize a nanoparticle to the region of the hole.

11:15 a.m. | 15.7 | THE NOVEL TECHNIQUE OF NANO-METER SIZE FABRICATION BY USING CONVENTIONAL PHOTOGRAPHY: Shingi Hashioka and Hideki Matsumura, JAIST, Ishikawa, Japan.

The development of novel technique is required for realizing nano-scale devices. Fabrication of nanometer patterns using tips of scanning tunnel microscopy has been reported. However, it cannot be an industrially acceptable technique. Thus, if the conventional lithographic techniques such as photolithography can be applied to fabricate such nanometer-size structures with a few tens nm, it would be useful. In this research a novel nano-technology is proposed. A contact pattern mask with nanometer-size slits is fabricated by the combination of conventional photo-lithography with anodic oxidation method. The proposed fabrication processes are as follows. 1) The GeO₂ is deposited on the Si[111] substrate and Ti is deposited on the GeO₂ layer. Co₃O₄ is used as an interlayer to protect the substrate. 2) The photoresist is coated on it and a half part of it is exposed by light and patterned. After patterning, a half part of photoresist is removed and another half part of Ti appeared is etched by reactive ion etching. 3) The edge of Ti is smoother the silicon is anodized laterally to convert into TiO₂. The thickness of TiO₂ obtained by anodic oxidation is controlled in the range of several tens of nanometer by changing the anodic voltage. 4) The Ti layer is again deposited over the whole surface, and the Ti over the resist is removed by a lift-off technology. 5) The TiO₂ is etched, and thus metal nanometer slit pattern-mask on the GeO₂ layer is obtained. 6) The Co₃O₄ layer is etched, and thus nanometer slit pattern-mask is obtained. The minimum width of each slit can be made as 30 nm. As an application of this slit mask, trenches with nm size can be fabricated on the Si substrate by etching Si through the slit. This result indicates that the nanometer slit mask can be useful for the fabrication of the nano-scale device such as a single electron transistor and metal/insulator tunneling transistor.

11:30 a.m. | 15.8 | LOCALIZED CHARGE STORAGE IN Co₃O₄/Si[111] BY ELECTROSTATIC FORCE MICROSCOPY: J.T. Jones, P.M. Bridger, O.J. Marsh, T.C. McGill, California Institute of Technology, Pasadena, CA.

In this report, the local patterning of charge into Co₃O₄/Si structures by scanning probe microscopy is examined. An electrostatic force microscope (EFM) has been used to write and image localized dots of charge on to double barrier Co₃O₄/Si/Co₃O₄/Si[111] structures. By applying a large tip bias Vₜip = 6.10 V and reducing the tip to sample separation to 3.5 nm, arrays of charge dots 60-200 nm FWHM of both positive and negative charge have been written. The total stored charge is found to be Q = ± (20-200) e per charge dot. These dots of charge are shown to be stable over periods of time greater than 24 hrs, with an initial charge decay time constant of γ = 9.5 hrs followed by a period of much slower decay with γ > 24 hrs. Charge decay time constants are found to be dependent on the thickness of the lower Co₃O₄ tunneling barrier. The dependence of dot size and total stored charge on various writing parameters such as tip bias, tip to sample separation, and write time is examined.

11:45 a.m. | 15.9 | 3PM BASED LITHOGRAPHY FOR NANO-METER SCALE ELECTRODES FABRICATION: Andrea Notargiacomo, Politecnico di Bicocca, Milano, Italy; Fabio Giovanini, Un'Inf.M, Dip. di Fisica "E. Amaldi", Universita di Roma TRE, Roma, Italy; Elena Cianci, Osservatorio Astronomico di Roma, Monteporzio Catone, Italy; Vittorio Boglietti, Istituto di Elettronica dello Stato Solido (I.E.S.S.), CNR, Roma, Italy; Francesco Evangelisti, Istituto di Elettronica dello Stato Solido I.E.S.S., CNR, and Un'Inf.M, Dip. di Fisica "E. Amaldi", Universita di Roma TRE, Roma, Italy.

SPM assisted nanolithography is a very attractive technique in terms of low-cost, patterning resolution and positioning accuracy. Our approach makes use of a commercial AFM and silicon probes to build directly simple nanostructures, such as metal electrode pairs, for application in novel quantum devices. As a first attempt we performed a direct material removal from metal stripes thus producing gaps in the nanometer range. The technique is strongly limited by the short life-time of the probes, whose wearing determines also a worsening of the fabricated gaps. To overcome these limits, which mainly stem from the hard interaction between the probe and the sample, an alternative technique was considered. A multilayer sample preparation, already proposed to pattern a flat silicon surface [1], was suitably adapted to induce nanometer size modifications on pre-existing metal structures. The first step involved metal stripes and sacrificial layer preparation, including a soft polymer film deposition that was optimized to achieve conformal growth and smooth surface. These features are necessary to prevent the probe wearing and to locate exactly the region of the sample where the modifications are desired. Then the AFM probe was used to obtain a pattern by selectively removing a very thin metal layer deposited on top of the polymer. As the final step, by means of dry and wet etching processes, a pattern transfer was performed onto the underlying metal structures, obtaining nanometer size gaps. In conclusion, we have optimized the patterning technique showing high probe life-time and optimal positioning accuracy, both ensured by a suitable choice of the nature and thickness of the sacrificial layers used. Sub-100 nm patterning was successfully performed with high reproducibility leading to metal nanoelectrode pairs.