Thin Films
Room 306 - Session TF+NS-MoA
Focused Beam Processing & Fabrication

Moderator: J.D. Fowlkes, University of Tennessee

2:00pm **TF+NS-MoA1 Beam-Induced Nano-Structuring for Advanced Mask Repair*, T. Liang,*** Intel Corporation **INVITED**

Photomask repair is a process of editing local pattern structures by adding or removing materials in order to restore a defective mask to good lithographic condition and, in many instances, it is an enabling step for yielding a defect-free mask. Beam-induced nano-structuring has been developed for such process with the use of photons, ions and electrons. However, it has become ever more challenging to repair advanced photomasks because of the limited extendability of these technologies to meet the critical defect specifications and tight edge placement. Specifically, the use of aggressive optical proximity correction structures, resolution enhancement techniques, such as phase-shifting, and entirely new types such as EUV reflective masks has placed a great need for stringent lateral and vertical dimensional control. A capable repair process removes the defect with sufficient placement precision while at the same time preserves the optical integrity of the repaired site. This essentially requires also a damage-free process. Mask shops have put ever increasing emphasis and effort in mask repair at the back end of the production line to fix every defect possible in order to restore an otherwise defective mask. This invited talk will present an overview of advanced mask repair and the lithographic requirements, followed by an assessment of four repair technologies by comparing their respective uniqueness and limitations. The discussion of underlying mechanisms for different repair processes will provide an insight to the fundamental capabilities and ways for further improvements. Detailed descriptions will be given for examples representing binary Cr-on-glass, phase-shifting and EUV masks including repair qualification. I will present our recent progress in electron beam mask repair development and discuss future directions in mask repair using nano-structuring technologies to support the aggressive lithography roadmap

2:40pm **TF+NS-MoA3 Electron Beam Induced Processing Techniques for Advanced Lithography Mask Repair*, D.A. Smith,*** University of Tennessee, Knoxville*; J.D. Fowlkes,* University of Tennessee, Knoxville, US*; T. Liang,* Intel Corporation*; P.D. Rack,* University of Tennessee, Knoxville

Producing defect-free photomasks for semiconductor applications is a critical and challenging operation. Enabling nano-processes are being developed for mask repair to meet the defect requirements for advanced 193nm and EUV lithography. To this end, we are investigating electron beam induced deposition (EBID) and etching (EBIE) techniques for mask repair involving material deposition and removal, respectively. The EUV masks are typically composed of multi-layer Mo-Si on a quartz-like substrate, capped with a Ru etch stop layer with an overlaying TaBN absorber layer. For material removal, an etchant vapor such as XeF2 or NF3 is flowed over the mask surface in an SEM in the presence of an electron beam. The electron beam interacts with the etchant gas to produce an electron induced etch effect, allowing material removal at a controlled rate with nano-scale precision. Repair operations involving deposition are typically carried out with a precursor gas such as cyclopentadienylplatinum (IV)-trimethyl (CpPtMe3) which dissociates under an electron beam and adsorbs to the substrate. This presentation will demonstrate the results of a study involving the optimal operating conditions for controlled etching and deposition, including an analysis of the sidewalls, roughness, and spontaneous etching. Monte-Carlo based computer simulations of the material deposition will also be employed to describe the effects of varying system parameters such as operating voltage, gas pressure, current and time.

3:00pm **TF+NS-MoA4 Reduction of Laser-Induced Roughness in a-Si:H Surfaces for Vacuum Compatible Lithography*, R.N. Jacobs,*** US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate, 22060*; E.W. Robinson, A.J. Stoltz, J.H. Dinan,* US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate*; L.G. Salamanca-Riba,* University of Maryland, College Park

A vacuum compatible lithography technique has recently been demonstrated, whereby amorphous hydrogenated silicon (a-Si:H) films are used as a resist. Following plasma deposition of the a-Si:H film, poly-Si patterns are generated on the surface by excimer laser exposure through a projection mask. Development is then carried out by hydrogen plasma etching for which etch selectivities of over 1000:1 have been achieved for a-Si:H and poly-Si regions.@footnote 1@ However the rms roughness induced by excimer laser irradiation can be well over 10 times that of the as-deposited a-Si:H surface. This is problematic because the roughness may be transferred to underlying device layers during subsequent pattern transfer plasma etching. We have developed a step-wise laser irradiation procedure that results in a reduction of surface roughness by an order of magnitude to a level of ~1 nm (rms). This value is approximately equal to the surface roughness in the as-deposited a-Si:H film. The irradiation procedure uses multiple pulses with progressive increases in the energy density, in contrast to single high energy density pulses used previously. Transmission electron microscopy and Fourier transform infrared spectroscopy are used to understand and confirm the mechanism behind this process. Our data suggests that the observed reduction in roughness is due both to smaller grain sizes and to a slow rate of H removal from the film surface. While useful for a-Si:H vacuum-lithography processing, our results also hold significance for other applications of laser processed a-Si:H, even where different film properties may be desired. @FootnoteText@ @footnote 1@R.N. Jacobs, A.J. Stoltz, J.H. Dinan, and L. Salamanca-Riba, J. Vac. Sci. Technol. B, 22 1071 (2004).

3:20pm **TF+NS-MoA5 Maskless, Direct-Write Nanolithography using Electron Beam-Induced Deposition*, S.J. Randolph,*** University of Tennessee, Knoxville*; J.D. Fowlkes,* University of Tennessee, Knoxville, US*; P.D. Rack,* University of Tennessee, Knoxville

Several groups have investigated electron beam-induced deposition (EBID) as a nanoscale direct-write fabrication technique. The EBID process is similar to focused ion beam processing; however deleterious damage associated with ion implantation is mitigated when using an electron beam. Our group has been investigating this technique as a tool for rapid nanoscale device prototyping as well as for device and lithography mask repair. More recently, we have investigated EBID as a technique to be coupled with a massively parallel electron beam lithography concept-the so-called Digital Electrostatic E-beam Array Lithography (DEAL) system. The goal is to develop an alternative ultra-thin resist scheme for the DEAL low energy electron beam lithography system. We have developed a single layer and bilayer resist scheme using a tetraethylorthosilicate (TEOS) and tungsten hexafluoride precursors to deposit SiO@sub x@ and tungsten resist layers. In this presentation our experimental procedure and EBID system will described and the DEAL lithography concept briefly reviewed. The fundamental EBID process will be explained, and we will describe the relevant EBID parameters that affect the single and bilayer EBID resist schemes. The effects of secondary, backscattered, and forward scattered electrons on the resolution and exposure requirements will also be explained, and dose requirements for optimum exposure as a function of beam energy will be illustrated. Pattern transfer of sub-100 nm features requires excellent control of etch selectivity and profile control. The effects of RIE parameters such as pressure, power, and chemistry as they are related to etch selectivity and profile will also be presented.

3:40pm **TF+NS-MoA6 Focused Ion Beam Sculpting of Curved Shapes in Metals and Amorphizable Solids*, D.P. Adams,*** *M.J. Vasile,* Sandia National Laboratories

We describe how focused ion beams can be used to sculpt predetermined micron-scale, curved shapes in a variety of initially planar solids. Using a vector-scanned focused Ga ion beam system, we sputter different shapes including hemispheres, paraboloids and sine waves having dimensions from 1-50 microns. Ion sculpting is accomplished by varying pixel dwell time (i.e., dose) within individual boustrophedonic scans. The pixel dwell times determined for a given shape account for the material-specific, angle-dependent sputter yield, Y(theta), the beam current and the ion beam spatial distribution. We highlight new results that show how this sculpting technique can be applied to a large set of materials. Using appropriate sets of dwell times, we sculpt semiconductors (Si, C) amorphized by the high-energy beam, and single crystal metals (Au, W) that remain crystalline with ion exposure. The ion-milled features, in most cases, match the intended shape with milled feature depths repeatedly within 5% of intended values. Finally, we describe techniques that minimize the deleterious effects of redeposition. This includes a method that determines the optimal range of pixel dwell times and research of gas-assisted FIB sculpting techniques.

4:00pm **TF+NS-MoA7 Focused Electron and Ion Beam Processing and Fabrication*, J. Melngailis,*** University of Maryland*; I. Utke,* EMPA, Thun, Switzerland*; P. Hoffmann,* EPFL, Lausanne, Switzerland **INVITED**

Beams of electrons and ions are now fairly routinely focused to dimensions in the nanometer range. Since the beams can be used to directly alter material, they represent direct nanofabrication tools. We will focus here on direct fabrication rather than lithography which is indirect in that it uses the intermediary of resist. In the case of both ions and electrons material addition or removal can be achieved using precursor gases. In addition ions can also alter material by sputtering (milling), by damage, or by implantation. Many material removal and deposition processes employing precursor gases have been developed for numerous practical applications, such as mask repair, circuit restructuring and repair, and sample sectioning. In many cases the minimum dimensions at which these processes can be realized are considerably larger than the beam diameters. The detailed atomic level mechanisms responsible for the precursor gas activation have not been studied in detail in most cases. We will review the state of the art and level of understanding of direct ion and electron beam fabrication and point out some of the unsolved problems. We will present recent results on beam deposited contacts to carbon nanotubes, nanowires and nanofibers.

4:40pm **TF+NS-MoA9 Sub-Micron Features Using a Focused Ion Beam and Novel Resist Structures*, M.H. Ervin,*** U.S. Army Research Laboratory

Typically, sub-micron features are written with an e-beam lithography tool. However, e-beam tools are very expensive and availability is an issue. A method for writing sub-micron features (e.g. short gate-length contacts) using a focused ion beam (FIB) is described. It is not just a matter of milling a pattern into any resist. To avoid sputtering the substrate, the mill has to be incomplete, and the partially milled resist may be cross-linked due to the ion irradiation damage. The cross-linked resist is then resistant to solvent development or plasma ashing. This might make it useful as a negative resist, but for positive resist applications write times would be problematic. Instead, two metal films are deposited on top of the resist. The top layer (e.g. Au) is cut through by the FIB to form the pattern, and the underlying layer (e.g. Ti) is the backstop layer which prevents the FIB Ga ions from penetrating through to the resist. The backstop layer is then selectively wet etched. The etch is allowed to produce an undercutting of the pattern layer features for good lift-off. Similarly, the underlying resist can be plasma ashed to expose the substrate. One has to be careful with the ashing temperature to prevent blistering of the resist/metal layers. Subsequent metallization and lift-off can produce features below a quarter micron. Of course, if the substrate is vulnerable to resist solvents, one could omit the resist entirely if the backstop layer can be used to provide lift-off at the end. Another potential advantage for sensitive substrate materials, is that the substrate is never irradiated with ions or electrons as is the case in e-beam lithography.

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