Process Development for Writing Sub-100 nm Linewidths using a Scanning Electron Microscope

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Abstract:

Lithography is a process whereby a polymer resist is selectively exposed to some form of radiant energy such as UV light or, in our case, a concentrated beam of electrons, in order to create or transfer patterns. Although photolithography has a higher throughput, electron-beam lithography (EBL) can most reliably produce linewidths under 30 nm. To circumvent the restrictive costs associated with dedicated EBL systems, an existing JEOL 6360-LV scanning electron microscope (SEM) was paired with a RAITH ELPHY lithography system. The goal was to explore the boundaries of this machine and determine the minimum linewidths that could be written with this setup. A diluted solution of 950,000 MW polymethylmethacrylate (PMMA), when spun at 3000 rpm, created a 56 nm thick resist layer on a silicon wafer. An acceleration voltage of 30 kV and a working distance of 10 mm were kept constant while the beam spot size was varied between 10 and 50 (equivalent to a beam current range of 0.19 pA to 500 pA) and the dosage was varied from 90 μAs/cm to 9000 μAs/cm. A minimum linewidth of 100 nm was obtained, and after evaporating a 10 nm layer of chrome onto the sample and performing liftoff, metalized lines were measured to be 120 nm, with the discrepancy being due to chrome buildup along the non-vertical resist sidewalls and non-uniform liftoff.

Introduction:

Electron beam lithography (EBL) is an important technique in microelectronic fabrication because an electron beam's resolving power is not limited by the wavelengths of light. For this reason, EBL is essential in creating nanometer-scale features such as the gates in transistors. EBL, however, is a time-consuming serial process, and EBL systems are extremely expensive. The system utilized for this project was a stand-alone JEOL JSM-6360LV SEM attached to a Scanservice 890 beam blanker and a RAITH ELPHY Quantum nanolithography system. The cost of this system is significantly lower than that of a dedicated e-beam writing system and puts it at cost parity with UV systems, which makes this an attractive solution for university labs.

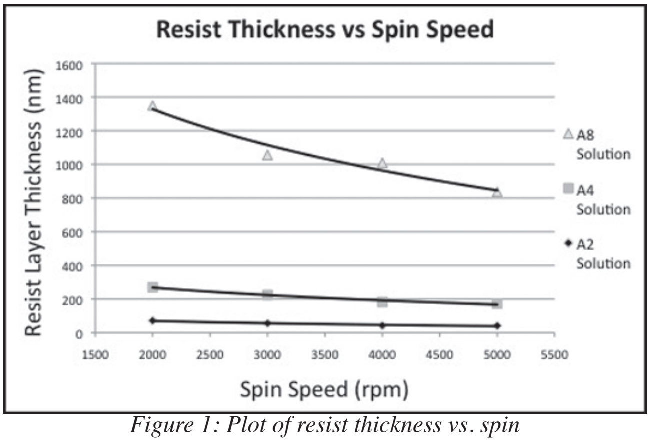

Figure 1: Plot of resist thickness vs. spin speed for A8, A4, and A2 PMMA solutions.

The objective of this work was to characterize this system and determine the minimum linewidth possible using its setup.

Experimental Procedure:

The first step was e-beam resist characterization. The initial resist was a MicroChem 950 polymethylmethacrylate (PMMA) solution with 8% solids in anisole. The resist was diluted to create 4% and 2% solutions and characterized for thickness versus spin speed (Figure 1). The 2% solution yielded 56 nm at 3000rpm and was the standard resist for the project. Silicon wafers were cut into 1 cm^2 pieces using a diamond-tip cutting blade. Samples were then washed using soap and water, followed by methanol and acetone rinses to clear the surface of debris. PMMA resist was spun on and baked on a hot plate at 180ºC for 60 seconds.

After baking, a sample was inserted into the SEM and brought into high focus, then the beam current was set and the sample was exposed with patterns generated by the RAITH ELPHY Quantum software. Testing was systematically performed over a wide range of parameters: SEM spot size (10-50), SEM aperture (20-30 μm), beam current (0.2-500 pA) and line dose (90-9000 pAs/cm). The acceleration voltage was kept constant at 30kV.

After exposure, the samples were developed in a 1:3 methyl isobutyl ketone (MIBK) to isopropyl alcohol (IPA) solution for 90 seconds. The linewidths were measured using atomic force microscopy (AFM), after which, a 10 nm layer of chromium was evaporated onto the sample. After liftoff with *N*-methylpyrrolidone (NMP), linewidths were measured using SEM.

Results and Conclusions:

Given that acceleration voltage was kept constant, the experiment confirmed that the most important parameter affecting line resolution was dosage, or quantifiable amount of energy received during exposure. The best results were achieved with an acceleration voltage of 30 kV, a spot size of 20, a beam current of 0.5 pA, and a dosage of 1800 pAs/cm. A minimum linewidth of approximately 100 nm in PMMA was observed by AFM, however after metallization and liftoff, SEM imaging revealed linewidths of just over 120 nm (Figure 2). This discrepancy is a result of non-vertical sidewalls (Figure 3). The chromium evaporated into the V-shaped trench formed a contiguous layer, which tore unevenly during lift-off, resulting in larger, jagged lines (Figure 4).

The second issue resulted from the fact that linewidths measured at the top of the trench were larger than at the bottom. Since AFM and SEM techniques image from the top down, the resulting measurements were greater than the actual lines' widths.

In the future, to improve liftoff and create smaller metalized lines, a bi-layer resist technique could be used with an overhanging layer of PMMA on top of a co-polymer resist.

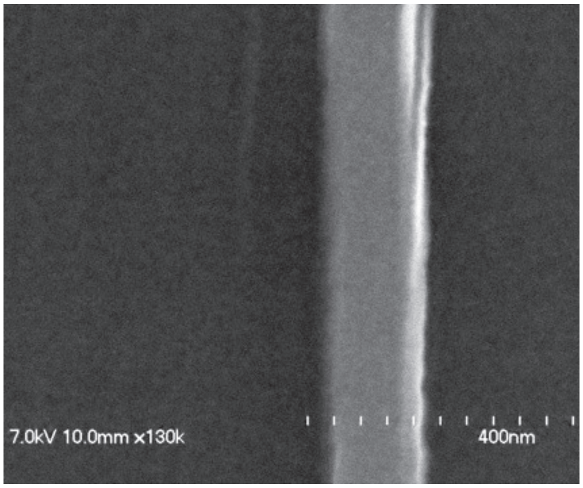

Figure 2: SEM image of an approximately 130 nm wide metalized structure.

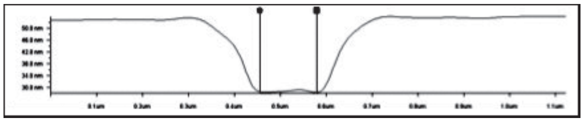

Figure 3: A X-Z line plot of an AFM-imaged cross-section of a 125 nm wide line fully exposed in resist. Note the sloped plot line.

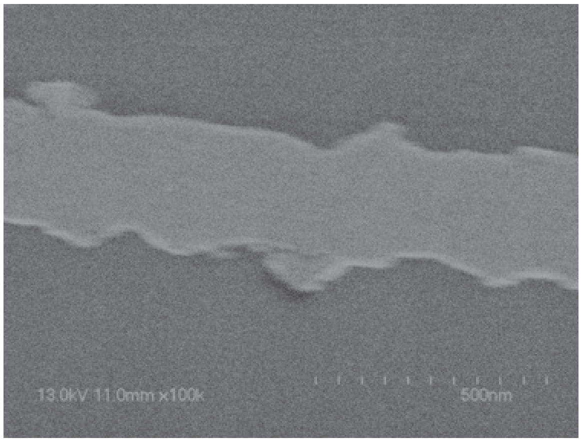

Figure 4: SEM image of a line left jagged by unclean liftoff.

Acknowledgments:

Dr. Gary L. Harris, Principal Investigator; Mr. James A. Griffin, Mentor; Ms. Adaku Ochia, Graduate Student; National Science Foundation; National Nanotechnology Infrastructure Network Research Experience for Undergraduates (NNIN REU) Program; Howard Nanoscale Science and Engineering Facility (HNF) Staff.

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