X-ray Nanolithography

Personnel

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Sponsorship

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For several years, we have been developing the tools and methods of X-ray nanolithography. We have explored the theoretical and practical limitations, and endeavored to make its various components (e.g. mask-making, resists, electroplating, sources, alignment, etc.) reliable and "user-friendly." Because of the critical importance of X-ray mask technology, we discuss this in a separate section.

X-ray NanoLithography (XNL) is a reliable and simple means of replicating patterns with feature sizes down to about 20 nm. Typically, the X-ray mask is made with Scanning-Electron-Beam Lithography (SEBL), although we very often employ a combination of interference lithography, photolithography, SEBL, and XNL to fabricate the mask. Once the mask it fabricated it can be replicated an unlimited number of times. The simplicity and process latitude of XNL make it ideally suited for nanostructures research. In fact, at the present time, XNL is the only technique available for replicating sub-100 nm patterns of arbitrary geometry.

In the NanoStructures Lab (NSL), X-ray lithography is used in the fabrication of a large variety of structures and devices, including: photonic bandgap devices, short-channel MOSFETs, channel-dropping filters, distributed-feedback lasers, and Magnetic-Random-Access-Memory (MRAM)devices.

Our sources for X-ray nanolithography are simple, low-cost electron-bombardment targets. We utilize the L line of copper at λ= 1.32 nm. The sources are separated by a 1.5 µm-thick SiN_X vacuum window from a helium-filled exposure chamber.

We have submitted a proposal to DARPA for the purchase of a laser-plasma source from JMAR, Inc. Their source operates at a wavelength of 1.1 nm which is very close to the wavelength we currently use. Figure 8 is an example of some lithography done with the JMAR source using an MIT mask. Acquisition of a JMAR laser-plasma source should enable us to reduce our exposure times from hours to minutes.

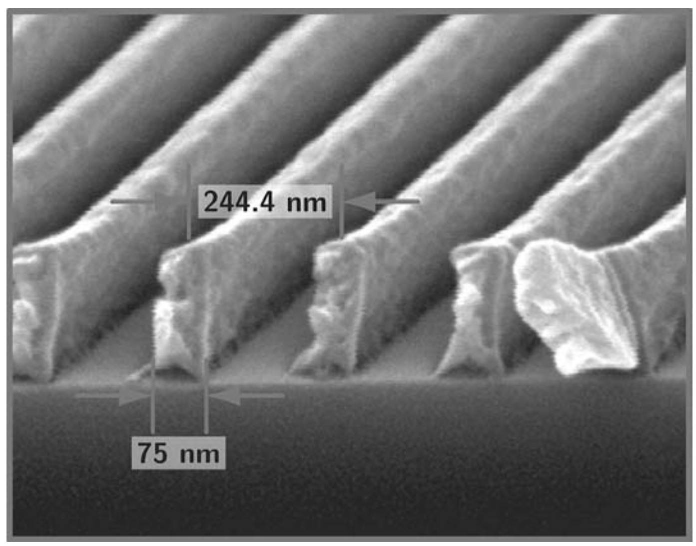

Fig. 8: Example of X-ray lithography done with the JMAR laser plasma X-ray source.

In earlier research, we showed that for wavelengths longer than 0.8 nm, the important limit on resolution is diffraction in the gap between mask and substrate. With a Cu_L source, a 50 nm feature must be exposed at a mask-to-substrate gap of less than about 4 µm in order to maintain good process latitude. A 25 nm feature would require a gap of 1 µm. For very small features, we eliminate the gap and use contact between the substrate and the flexible membrane mask. This technique has enabled us to replicate features as small as 20 nm in a practical, reproducible way. Figure 9 shows scanning electron micrographs of device patterns with feature sizes less than 40 nm.

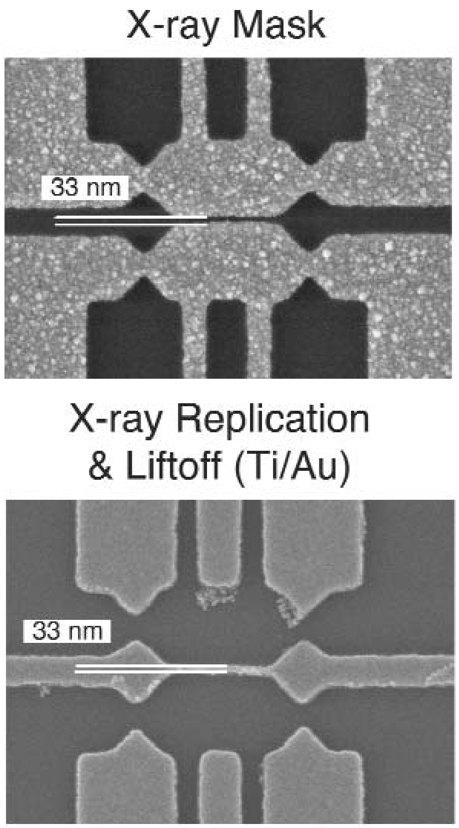

Fig. 9: Scanning electron micrographs of device patterns with feature sizes less than 40 nm achieved by X-ray nanolithography followed by liftoff. The X-ray mask is shown on top and the lifted-off pattern is on the bottom.

Another approach to achieving extremely fine linewidths is to use a much shorter wavelength, around 0.5 nm. At this wavelength the high-atomic-number materials such as gold, tungsten and tantalum, and their alloys, have X-ray attenuation comparable to that at a wavelength of 1 nm. The shorter wavelength enables one to use a larger gap between mask and substrate for the same resolution. The penalty one pays is that the attenuation of resist is significantly reduced, necessitating the doping of the resists with materials such as chlorine or bromine. Another issue is the energetic photoelectrons emanating from the substrate. Their deleterious effect can be eliminated by using a tri-layer resist, with the bottom buffer layer absorbing the energetic photoelectrons. We are collaborating with F. Cerrina at U. Wisconsin and T. Kitayama of Mitsubishi in the development of this shorter wavelength approach.