4. **X-Ray Nanolithography (XNL)**

**Sponsors:**
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**Project Staff:**
James M. Daley, Euclid E. Moon, and Professor Henry I. Smith

For several years, we have been developing the tools and methods of x-ray nanolithography (XNL). 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.” In recent years interest in, and support for, x-ray lithography has disappeared in the USA due to decisions in the semiconductor industry and the emergence of imprint lithography as an alternative means of replicating nanopatterned masks at low cost. Research in, and applications of, x-ray lithography continue in Japan.

XNL is a reliable and simple means of replicating patterns with feature sizes down to 20 nm. Typically, the x-ray mask is made with scanning-electron-beam lithography (SEBL), although we often employ a combination of interference lithography, photolithography, SEBL, and XNL to fabricate the mask. Once the mask it fabricated it can be replicated repeatedly. In the NanoStructures Lab (NSL), XNL has been used in the fabrication of a large variety of structures and devices, including: photonic bandgap devices, short-channel MOSFETs, and optical channel-dropping filters.

Our sources for XNL are simple, low-cost electron-bombardment targets. We utilize the L line of copper at $\lambda = 1.32$ nm. The sources are separated from a helium-filled exposure chamber by a 1.5 µm-thick SiNx vacuum window. Figure 1 is a photograph of an alignment and exposure system that is used for both XNL and imprint lithography. This system will enable us to evaluate the comparative merits of the two technologies.

![Figure 1: Photograph of the NSL alignment system set up for use with either XNL or imprint lithography. The system employs interferometric spatial phase imaging, which is capable of 1nm alignment precision.](image)

Although the wavelength used is very short (1.32 nm) compared to the minimum feature sizes of interest (e.g., 20 nm) diffraction in the gap between the mask and the substrate can be detrimental. For example, with a CuL 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 such very small features, we eliminate the gap and use contact between the substrate and the flexible membrane mask; essentially the same as in imprint lithography. This technique has enabled us to replicate features as small as 20 nm in a practical, reproducible way.