Resolution Determination of the XM-1 X-ray Microscope

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INTRODUCTION

The x-ray microscope is an extension of a visible light microscope to the x-ray region. It makes use of the differential absorption of the sample for imaging. The microscope not only provides very high resolution, but also a unique capability to image a thick sample in aqueous environment, which other kinds of high resolution microscopes (like electron microscopes or atomic force microscopes) do not have. X-ray interaction with matter allows the microscope to provide elemental and chemical contrast. All these unique features make this microscope very useful in biology, material science, and other areas[1,2].

At the beamline 6.1.2 of the Advanced Light Source (ALS), we have a soft x-ray microscope XM-1 that operates between 250 eV and 900 eV. Our research is to measure the resolution of the system and understand the factors that affect it[3].

EXPERIMENTS

Several test objects have been made for measuring the resolution of the system. They consist of lines and spaces with different periods and duty cycles. One of them is shown in figure 3. They were fabricated by the same lithography tool as used for the zone plates in the microscope.

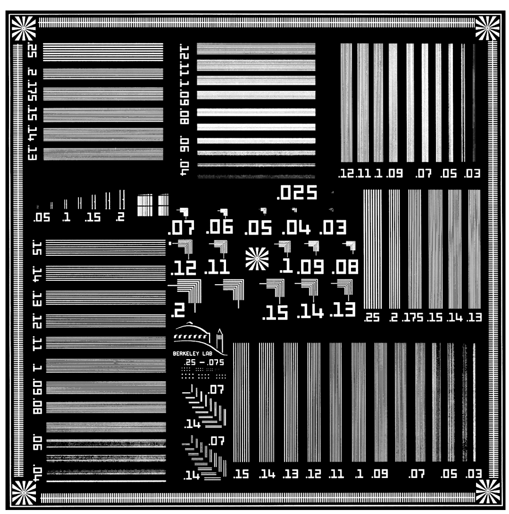

Figure 1. One of the test objects used for resolution measurement. This gold-plated object contains two sets of lines and spaces with linewidths from 30 nm to 250 nm. One set has line-to-space ratio of 1:1, another has the ratio of 1:2. The center of the object has a set of elbows with linewidths as narrow as 25 nm. The dimension of this test object is 120 µm X 120 µm

To determine the resolution limit of the system, test patterns with feature sizes as small as the resolution are needed. The resolution of the microscope is expected to be slightly below the outer zone width of the MZP, depending on the partial coherence of the system. However, the current outer zone width is close to the limit of the fabrication tool. Thus, determination of resolution is not straightforward. Several resists, including Calixarene and HSO, and different fabrication techniques have been experimented for obtaining high quality lines and spaces with small periods[4]. The latest test object, which is one of our best, was made with HSO resist and was plated with nominally 40-nm thick gold.

Figure 2 shows of the images of the lines and spaces taken, along with the corresponding SEM image. Because of the lack of "landmarks" on the object, the x-ray image and SEM image might not be taken from the same location. The x-ray images were taken at wavelength of 2.4 nm with 3100x magnification. The x-ray images have pixel sizes of 8 nm.

The x-ray images clearly shows that the patterns can be resolved by the microscope. The normalized lineout of the 15 nm lines and 45 nm spaces gives us a measured contrast of 54%. Figure 3 shows the experimental contrast as a function of the spatial frequency of the corresponding patterns. The theoretical cutoff of the microscope, which depends on the numerical apertures of the KZP and MZP, is about 17 nm half-period. Along with the assumption that large features would have 100% contrast, the points are fitted with a numerical curve. Lines and spaces with a half-period of 23 nm are predicted to yield 15.3% contrast, which is the Rayleigh criterion.

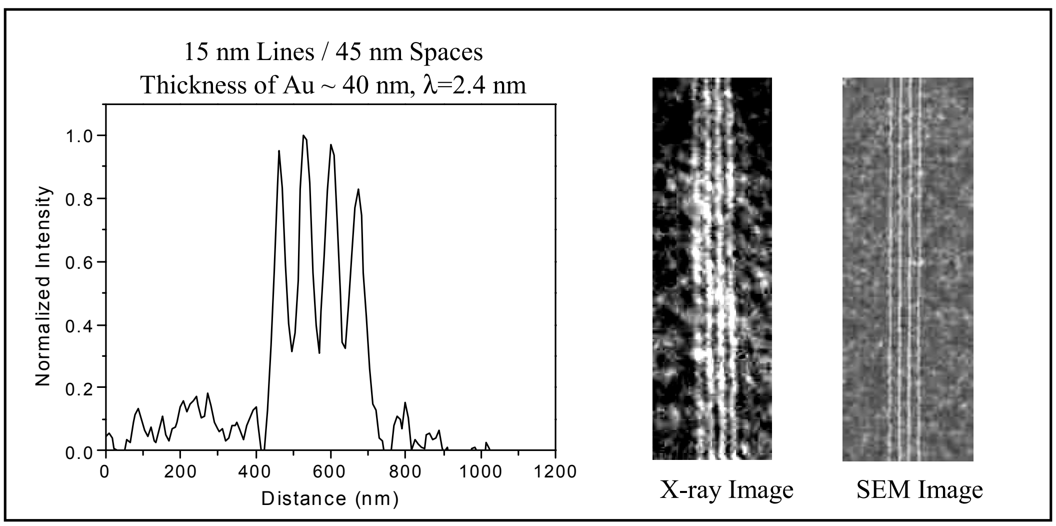

Figure 2. X-ray and SEM images of lines and spaces with period of 60 nm. The SEM and X-ray images may not be taken at the same location. Both have the pixel size of 8 nm.

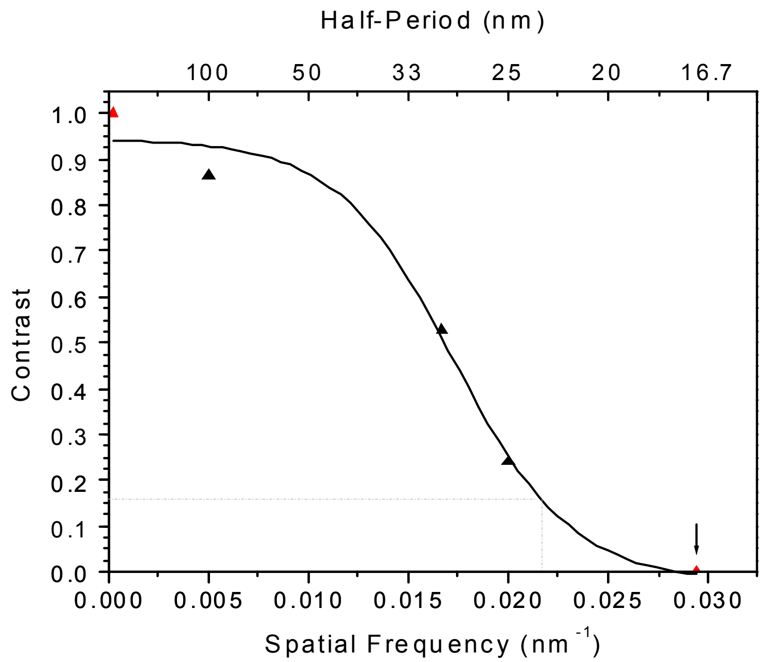

Figure 3. Experimental contrast of different periods. Also shown is the calculated cutoff (half-period of 17 nm) of the microscope. The solid line is a least squares fit to the experimental data, the cutoff, and an assumed value of unity at zero spatial frequency. The Rayleigh criterion of 15.3% contrast corresponds to a half-period of 23 nm.

REFERENCES

1. W. Meyer-Ilse, G. Denbeaux, L. Johnson, W. Bates, A. Lucero, and E. H. Anderson, "The High Resolution X-ray Microscope, XM-1," *X-Ray Microscopy*, Edited by W. Meyer-Ilse, T. Warwick and D. Attwood, AIP, New York, 1999, p. 129-134.
2. A. L. Pearson, W. Chao, G. Denbeaux, T. Eimuller, P. Fischer, L. Johnson, M. Koehler, C. Larabell, M. Le Gros, D. Yager, and D. Attwood, "XM-1, the high-resolution soft x-ray microscope at the Advanced Light Source," *Soft X-Ray and EUV Imaging Systems*, Edited by W. M. Kaiser and R. H. Stulen, SPIE 4146, p. 54-59
3. W. Chao, E. Anderson, G. Denbeaux, B. Harteneck, M. Le Gros, A. L. Pearson, D. Olynick, D. Attwood, "High Resolution Soft X-ray Microscopy," *Soft X-Ray and EUV Imaging Systems*, Edited by W. M. Kaiser and R. H. Stulen, AIP, SPIE 4146, p. 171-715.
4. E. H. Anderson, D. L. Olynick, B. Harteneck, E. Veklerov, G. Denbeaux, W. Chao, A. Lucero, L. Johnson, and D. Attwood Jr., "Nanofabrication and Diffractive Optics For High-Resolution X-Ray Applications," J.Vac. Sci Techn. B **18**(6), 2970-2975 (2000)

This work is supported by the Department of Energy's Office of Basic Energy Sciences, DARPA, and the Air Force Office of Scientific Research.

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