SOFT X-RAY TRANSMISSION GRATINGS*

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Soft x-ray transmission gratings

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A technique has been developed for producing transmission diffraction gratings suitable for use in the soft x-ray region. Thin self-supporting films of a transparent material are overlaid with several thousand opaque metallic strips per mm. Gratings with 2100, 2400, and 5600 l/mm have been produced and tested. Representative spectra over the wavelength range from 17.2 to 40.0 nm are given for a grating consisting of a 120-nm-thick Al support layer overlaid with 2400, 34-nm-thick, Ag strips/mm. The absolute transmittance is ~13% at 30 nm, and the efficiency in the first order is ~16%. The observed resolution of ~2Å is acceptable for many of the potential applications. These gratings have several advantages over the two presently available alternatives in the soft x-ray region (i.e., reflection gratings used at grazing incidence and free-standing metallic wire transmission gratings). Fabrication is relatively quick, simple, and cheap. The support layer can also serve as a filter and help conduct excessive heat away. Higher line densities and hence higher resolutions are possible, and when used at normal incidence the spectra are aberration free. Suitable materials, component thicknesses, and line densities can be chosen to produce a grating of optimum characteristics for a particular application.

Introduction

In the soft x-ray region, reflection gratings must be used at grazing incidence because of the low normal incidence reflectance of all materials at these wavelengths. Grazing incidence geometries are cumbersome, efficiencies are relatively low, and astigmatic imaging properties are a problem. On the other hand a transmission grating can be used at normal incidence, resulting in a very simple geometry with reasonable transmittance, efficiencies, resolution, and stigmatic imaging properties.

Interferometrically formed, electrodeposited, free-standing gold transmission gratings supported by a randomized auxiliary gold grid system^{1,2} have been produced by a complex process. Later, gratings produced by the same techniques have been developed with a regular support structure^{3,4} with a resultant reduction in scattering compared with gratings supported by a randomized structure. The highest line density reported is 1000 l/mm, the limiting factor being the mechanical rigidity of the free-standing gold strips.

We have recently developed a new method for the production of transmission gratings suitable for use in the soft x-ray region. In this paper, we present some representative spectra obtained using one of our gratings, and compare and contrast these gratings and their use with other gratings available for use in the soft x-ray region.

Grating production

Our method for producing holographic transmission gratings for use in the soft x-ray region has been described previously.^{5,6} Photoresist is spin-coated onto a glass substrate and then exposed to the interference pattern created by two coherent point sources. The sinusoidal relief pattern which is formed after development is coated at normal incidence with a suitably transparent material by vacuum evaporation. An opaque metal is then added obliquely (i.e., to one side of the sinusoidal profile) to provide the necessary wavefront amplitude modulation. Gratings are then removed from the substrate by dissolving the underlying photoresist.

So far we have fabricated gratings with support layers of carbon or aluminum, chosen to be transparent to the wavelength region of interest and metallic strips of silver, copper, or gold chosen to be opaque over the same wavelength region. Line densities of these gratings are 2100 and 2400 l/mm. A grating with 5600 l/mm has also been produced by passing the interfering beams through a prism optically coupled to the surface of the photoresist, increasing the line density by a factor of the index of refraction of the prism.

Test results

Our transmission gratings were tested in the system illustrated in Fig. 1. Radiation from a condensed spark source is limited by a slit before striking the grating at an angle of incidence, ϕ . The diffracted spectra are then recorded as a function of the angle of diffraction, θ , by a channel electron multiplier. Figures 2 and 3 show the first order spectra over the wavelength range from 17.2 to 40.0 nm for $\phi=0^\circ$ and $\phi=50^\circ$, respectively. The grating consisted of a 120-nm-thick Al support layer overlaid with 2400, 34-nm-thick, Ag strips/mm. The size of the entrance slit was 70 μm and the size of the exit slit was 150 μm . The absolute transmittance for this grating is $\sim 13\%$ compared with a theoretical 35% at 30 nm. This latter figure is calculated on the assumption that the "transparent" regions and opaque strips are of equal sizes and then allowing for the known absorption in the Al "transparent" regions.⁷ The efficiency in the first order was found to be 16% of the 0 order, whereas an ideal, half-open, symmetric transmission grating has a theoretical efficiency in the first order of 40% of the 0 order.² The observed resolution is $\sim 3.5\text{\AA}$ at normal incidence (see Fig. 2) and $\sim 2\text{\AA}$ at a 50° angle of incidence (see Fig. 3). In the present case, the $2\text{\AA}$ resolution is not limited by the grating but by the single slit diffraction pattern of the entrance slit and by the non-focussing entrance and exit slit geometry used in the experiment. Using the grating at a 50° angle of incidence spreads the spectrum out over a larger angular range but, in the example shown, does not alter the efficiency significantly, as might be expected if the fabrication techniques had produced a "blaze" on the grating.

Figure 1. Soft x-ray transmission monochromator.

For comparison with the spectra produced using our holographic transmission grating, Fig. 4 shows the spectrum for the same condensed spark source dispersed by a 2.2 m grazing-incidence monochromator employing an aluminum reflection grating with 300 l/mm. In this case the size of the entrance slit was 100 μ m and that of the exit slit was 250 μ m.

Figure 4. First order spectrum of condensed spark source produced by a 2.2 meter grazing incidence monochromator.

Figures 2 and 3 are typical of the spectra obtained with 2400 l/mm gratings. The grating with 5600 l/mm gave spectra which were similar except that the efficiency was lower.

Discussion

A comparison of the spectra obtained using the holographic transmission monochromator with that obtained using the grazing incidence reflection monochromator shows that, as expected, the positions of the structures in the spectra agree. The intensities of individual spectral lines depend on many factors including the pressure of the gas in the source discharge tube, the blaze on the grating, and, for the transmission grating, the absorption characteristics of the "transparent" support layer. The resolution observed in the recorded spectra also depends on many factors, including the width of the entrance slit, the rate of scanning, and the characteristics of the grating. Generally the resolving power improves as the grating line density increases. Since, in our holographic gratings, the support layer is continuous and thick enough to be self-supporting, the mechanical rigidity of the metal strips is not the limiting factor in the line density which can be achieved. For practical purposes, at the moment, we are limited to gratings which can be produced with the 457.9 nm emission line from an Argon ion CW laser. The highest line density which we have produced with this laser source is 5600 l/mm. Thus it is seen that these new holographically produced gratings should be capable of higher resolutions than other gratings used in the soft x-ray region. The demonstrated resolution of ~ 2 Å is acceptable for many of the potential applications for these gratings; their unique advantages offsetting the higher resolutions presently attainable with a grazing-incidence reflection monochromator.

The gratings are light-weight transmission gratings which can be used in a simple monochromator geometry with stigmatic imaging properties. The support layer can be used as a filter, transmitting a chosen wavelength range while absorbing other wavelengths. In this connection, it can be used to sort out the interfering multiple orders encountered in existing spectrometers used at synchrotron radiation storage rings. In addition, these gratings could be used in new, simple, designs of soft x-ray spectrometers, and as the monochromatic window for space telescopes. The support layer can also serve to help conduct heat away from the grating, thus lengthening the useful life of a grating used with high intensity, short wavelength sources, such as synchrotron radiation.

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