TECHNICAL NOTE

Transmission grating filtering of 52–140-nm radiation

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Filtering extreme UV radiation by gold freestanding transmission gratings was studied experimentally in the 52–140-nm wavelength range. Computer simulations are in good agreement with experimental results. © 1997 Optical Society of America

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Separation of intense extreme-ultraviolet (EUV) background radiation from particle fluxes, especially from neutral particle fluxes, is required in many space and laboratory applications.[1–4] It has been suggested that diffraction filters[1] simultaneously provide efficient suppression of the incident EUV radiation and high transmission for incoming particles. Diffraction filtering is based on the photon's ability to pass easily through a straight channel pore (slit) in a filter only if the channel diameter (slit width) is much larger than the photon wavelength.[1]

Among various possible filtering structures, freestanding transmission gratings[5] look exceptionally promising for application as diffraction filters.[1] The first studies[2–4] of transmission grating filtering and polarization properties in the EUV were performed at only a few wavelengths and sometimes with inadequate photon-flux intensities. We report here the results of an extensive study of grating filtering properties in the 52–140-nm wavelength range.

A freestanding transmission grating[5] consists of a set of parallel gold bars separated by gaps (Fig. 1) and supported by an extra large-mesh grid (not shown). The transmission gratings are manufactured at the Massachusetts Institute of Technology by a sequence of technological steps including holographic lithography, ion and reactive-ion etching, and electroplating[5]; the gratings are available from X-Opt Inc., Gainesville, Fla. Two freestanding transmission gratings, FS-206 and FS-207, which were fabricated in the same batch, are studied here. The experimentally determined grating filtering characteristics are similar. The gratings have the following geometric characteristics: period, $p = 200$ nm; distance between the metal bars, $d = 62$ nm (geometric transparency, $g = d/p = 0.31$); and thickness, $h = 494$ nm (Fig. 1). The grating area is 5×11 mm. The transmission of an additional large-mesh grid is 0.44. The overall grating geometric transparency, i.e., its transparency for particle fluxes, is ≈ 0.14.

The grating filtering properties were measured at two different facilities. Measurements in the 52–107-nm wavelength range were performed with monochromatic radiation produced by a dc glow discharge source followed by a 0.5-m Seya–Namioka EUV monochromator.[2] Various working gases in the dc glow discharge source allowed measurements at bright helium (52.2-, 53.7-, and 58.4-nm), neon (73.6-nm), and argon (92.0-, 104.8-, and 106.7-nm) spectral lines. Bright monochromatic light is important for this study, because one has to determine light attenuation up to 5–6 orders of magnitude. Use of neon and argon spectral lines allowed significant improvement in the accuracy of measurement for $\lambda > 60$ nm compared with previously reported results.[2,4]

Grating filtering properties in the 113–140-nm wavelength range were measured at the Synchrotron Ultraviolet Radiation Facility (SURF II) at NIST, Gaithersburg, Md. A high-throughput 2-m normal-incidence monochromator (Beam Line 4 at SURF II) was used as a source of monochromatic radiation.[6] A vacuum chamber with a setup for studying grating characteristics was separated from the SURF II vacuum system by a MgF_2 window. The window transmission cutoff established the lower limit of the studied spectral range at 113 nm and eliminated problems associated with multiple-order diffraction

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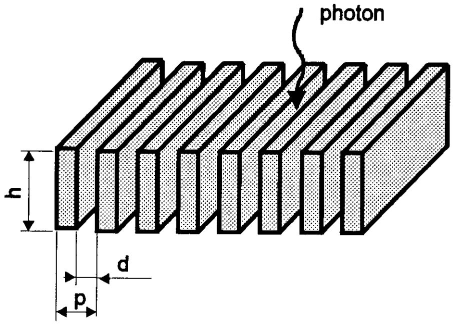

Fig. 1. Schematic view of a freestanding transmission grating. (The supporting large-mesh grid is not shown.)

as well. A precipitous drop in the detection efficiency of a photon-counting detector (open-channel electron multiplier) determined the upper wavelength limit at 140 nm.

Grating transmission measurements are significantly complicated by strong dependence on the incident light polarization. One can introduce the grating transmission $T_P(\lambda)$ for transmission of light polarized parallel to the transmission grating metal bars and the grating transmission $T_S(\lambda)$ for transmission of light polarized perpendicular to the grating metal bars.[2,4] The T_P-to-T_S ratio may be as high as >1000 at some wavelengths.[2,4] The light produced by a glow-discharge source is unpolarized, but it becomes partially polarized after reflecting from the diffraction (reflection) grating in the Seya–Namioka monochromator. Synchrotron light sources provide highly polarized radiation, but the radiation at the monochromator exit would be partially polarized because of finite angles of acceptance into the monochromator system. Therefore, for transmission grating measurements, incident light must always be considered as partially polarized with unknown polarization.

The experimental approach to measuring grating filtering properties with partially polarized radiation is based on the independent measurement of grating transmission at two grating orientations, which are mutually perpendicular and normal to the incident photon beam.[2,4] (All measurements were performed for the zeroth-order diffraction of transmitted radiation only.) From such measurements one can determine[2,4] the sum of grating transmissions, $T_{\mathrm{SUM}}(\lambda) = T_P(\lambda) + T_S(\lambda)$. This is an important parameter of interest because the transmission of the incident unpolarized light T_0 by a single grating would be $T_0(\lambda) = T_{\mathrm{SUM}}(\lambda)/2$.

The experimentally measured grating transmission T_{SUM} is shown (plusses) in Fig. 2 for the 52–140-nm wavelength range. Transmission of the incident radiation decreases almost 3 orders of magnitude with the wavelength increasing from 52 to 140 nm, from $T_{\mathrm{SUM}} \approx 1.5 \times 10^{-2}$ down to 1.95×10^{-5}. The measurement accuracy is better than $\pm 5\%$ as determined by the counting statistics and stability of the incident light beam. The excellent match of the experimental data points obtained at the laboratory monochromator ($\lambda < 110$ nm) and at SURF II ($\lambda > 110$ nm) in very different conditions validates the experimental procedure.

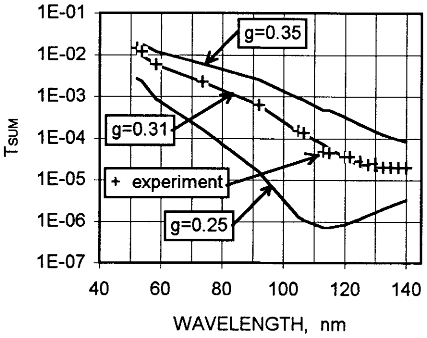

Fig. 2. Spectral dependence of the transmission, $T_{\mathrm{SUM}} = T_P + T_S$. The experimental points are shown by plusses. Calculated dependences are shown for grating geometric transparencies, g = 0.25, 0.31, and 0.35.

A comprehensive theoretical model and a computer code simulating transmission grating optical properties were developed by Anderson.[7] A discussion of the model and computer code is beyond the scope of this note and can be found elsewhere.[2,7] A verified theoretical model of the radiation transmission through gratings is highly desirable for predicting of grating filtering properties in various applications without expensive trial-and-error fabrication and time-consuming extensive testing. Verification of Anderson's model and code is an important task of the current study.

The simulation of grating properties requires knowledge of grating geometric characteristics. The grating thickness ($h = 494$ nm in our case) and period ($p = 200$ nm) are fixed reliably by the fabrication technology; the gap width d is more difficult to control and it may vary. For example, a scanning electron microscope can show the structure of the grating surface but cannot reveal possible slit-width variations inside the transmission grating. Therefore one can assume that the grating period p and thickness h are known. By varying the gap width d, or geometric transparency g, one can fit theoretical model predictions with the experimentally observed grating transmission T_{SUM}. Grating transmission T_{SUM} was calculated at the wavelengths where the measurements were available. The best fit of calculated and experimentally measured transmission spectral dependencies is achieved for $g = 0.31$ (Fig. 2); a set of gold optical constants of Lynch and Hunter[8] was used. Here and below all calculated points are connected by lines to guide the eye.

The transmission curves $T_{\mathrm{SUM}}(\lambda)$ calculated for $g =$ 0.31 and 0.25 demonstrate (Fig. 2) that even small changes in grating geometric transparency g result in a significant change in grating transmission, both in the absolute transmission value and in the curve slope. An excellent match of the theoretically predicted and experimentally obtained data across a

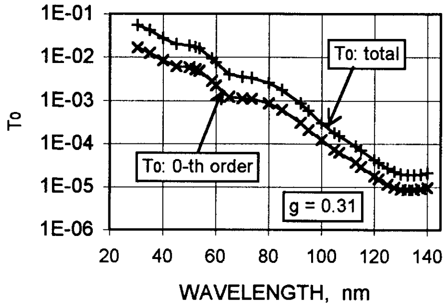

Fig. 3. Calculated spectral dependence of the transmission T_0 for the zeroth-order diffraction and total transmitted radiation, $g = 0.31$.

wide spectral range serves as a definitive verification of Anderson's model and code,[7] at least for a description of the total grating transmission.

The theoretical model predicts[2] that nonzero diffraction orders would contain a large portion (50–80%) of the total transmitted radiation. (The experimental verification of this prediction is currently being performed.) Calculated expected spectral dependencies of grating transmission for unpolarized light ($T_0 = T_{\mathrm{SUM}}/2$) for the zeroth-order diffraction and for the total transmitted radiation, i.e., a sum over all diffraction orders, are shown in Fig. 3 for the 30–140-nm wavelength range. (The calculations were extended beyond the experimentally studied spectral range down to 30.4 nm to include this important for the space applications line.) The total radiation intensity transmitted by the gratings is a factor of ~2–3 greater than the intensity of the zeroth-order diffraction.

The radiation transmission by a grating filter is maximum for normally incident radiation ($\theta = 0$), and it decreases with an increase in angle θ between the direction of radiation incidence and normal to the grating. The spectral dependence of this transmission decrease strongly depends on whether the incident radiation is parallel or perpendicular to the grating bars. As an example we consider the calculated transmission decrease at $\theta = 45°$ incident angle for $\lambda = 584$ and 1216 Å. For incident radiation parallel to the grating bars, the grating transmission decreases by factors of 2.3 and 29 for 584 and 1216 Å, respectively. For incident radiation perpendicular to the grating bars, the grating transmission decreases by factors of 30.7 and 2.8 for 584 and 1216 Å, respectively.

The experimental results presented show that transmission gratings serve as efficient filters in the EUV/UV range. Computer simulations are in good agreement with experimentally determined grating transmission.

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