Efficiency measurements of the Extreme ultraviolet Opacity Rocket's broadband multilayer-coated diffraction gratings

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INTRODUCTION

Among the numerous unsolved problems in astrophysics is the identity of extreme ultraviolet (EUV) opacity sources in the atmospheres of hot stars with high surface gravity. This is due in large part to a lack of EUV data with sufficient spectral resolution to enable positive identifications of the species which absorb the EUV surface emission of the stars. Previous attempts at detecting individual absorption features unambiguously either have been limited by instrumental resolution[1,2,3] (*eg. The Extreme Ultraviolet Explorer; EUVE*) or by lack of signal in time limited rocket experiments[4]. However, a new suborbital experiment, the Extreme ultraviolet Opacity Rocket (EOR), has been designed and flown with an optical system which overcomes the problematic efficiency and resolution obstacles. EOR accomplishes this by using two adjacent diffraction gratings in single bounce Wadsworth mounts. The gratings are spherically curved, holographically ruled, ion-etched, and broadband multilayer coated (MLC) to substantially increase the normal incidence EUV reflectivity. This design achieves both higher effective area and resolution over a bandpass of 220-340 Å without resorting to prohibitively expensive grazing incidence components. See Table 1 for a list of relevant grating parameters.

In order to examine the EUV opacity source's constituents and to demonstrate the applicability of normal incidence broadband MLC designs to space astronomy, EOR observed G191-B2B, a hot white dwarf star, during a sounding rocket flight at 10:00:00 GMT 27 September 1999. The subsequent evaluation of both the instrumental flight performance and the analysis of flight spectra require ground-based measurements of the MLC gratings' efficiencies. These measurements were made with ALS beamline 6.3.2 and are presented in this abstract.

GRATING PARAMETER	VALUE
Surface dimensions	4×5 in
Radius of curvature	1384 mm
Groove density	3460 grooves/mm
Blaze angle	3.1 degrees
Multilayers	ZrC and Si in 158 Å periods
Incident angle	5.56 degrees

Table 1. Relevant parameters describing the EOR flight optics.

THE EXPERIMENT

Since the EOR spectrograph images inside first order (m=-1) diffracted light off of two gratings, the grating efficiencies (E_{grat}) and groove efficiencies (E_{groove}) of those optics at m=-1 over the instrumental bandpass are of greatest interest. Here E_{grat} is defined as the ratio of the outgoing m=-1 intensity to the direct beam intensity and E_{groove} is defined such that

$$E_{grat} \equiv E_{groove}\, R_{MLC}, \qquad (1)$$

where R_{MLC} is the reflectivity of the MLC. Efficiency results are presented in Figure 1.

To reach the results in Figure 1, the efficiencies of four optics were measured in this experiment: The two flight optics and two flat witness samples, each of which was coated at the same time as one of the flight optics. All of the optics' efficiencies were measured at multiple points on their surfaces to test the uniformity of those surfaces.

First, the witness samples' specular reflectivities (R_{MLC}) were measured to assess the quality of the MLC's. Peak reflectivities were 0.22 and 0.24 near 286 and 285 Å, dropped to 0.06 and 0.07 at 250 Å and dropped to 0.19 and 0.21 at 300 Å, respectively. Based on short wavelength emission line measurements of the periodicity of the layers (see Haisch *et al.*[5] for details on this type of analysis) these reflectivities match model predictions[6].

Next, the gratings' efficiencies (E_{grat}) were measured at m=-1 (β≈0 degrees from normal) and "groove efficiencies" were calculated according to (1). "Groove efficiency" is put in quotes here because it is not a true measurement of the groove efficiency: Degradation of the coatings' performances due to the underlying surface and due to the varying incident and diffracted optical path lengths through each MLC layer cannot be decoupled from true diffractive efficiencies with this data set. However, this does not preclude the "groove efficiency's" usefulness in assessing the gratings' performance and quotes will be omitted hereafter.

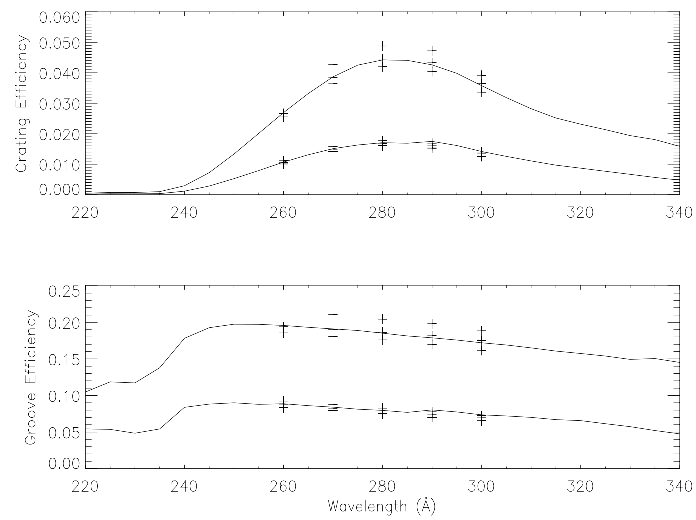

Figure 1. Grating efficiency measurements (*top*) and groove efficiency measurements (*bottom*) of the two EOR MLC gratings in m=-1. The upper curve in each plot represents measurements of one grating, and the lower curve in each plot represents measurements of the other grating. Crosses represent measurements made at different surface locations of each grating, and are associated with the grating to whose efficiency curve they are the closest.

DISCUSSION

Grating efficiency and groove efficiency results are shown in Figure 1 for both gratings. Because the 6.3.2 beam intensity weakens towards the longer wavelengths in EOR's bandpass, grating efficiency measurement errors increase from approximately ±0.002 to ±0.010 and groove efficiency measurement errors increase from approximately ±0.01 to ±0.02.

The first obvious result is the difference between the two gratings' efficiencies and between their groove efficiencies. One grating's efficiency exceeds the other's by more than a factor of two at its peak value. Since the corresponding witness samples to each grating have reflectivities which are within 0.02 of each other (<10% difference), the differences must be in the gratings themselves. These differences might originate in the quality of the gratings' rulings but also could result from differences in the quality of their surface preparations prior to coating. Decoupling these defects from each other or from any other potential defects cannot be done with this data set alone.

The individual points which are clustered around the plotted curves in Figure 1 represent measurements made at different locations on the gratings' surfaces and at five wavelength values per location. The distribution of the individual points around the central curve appears to be real because for each position on the gratings' surface, the grating efficiencies and groove efficienies at all five wavelengths vary consistently relative to the grating efficiencies and groove efficiencies which the central curve represents. This non-uniformity across the surface of the optic is consistent with blaze angle variability that was observed during atomic force microscope (AFM) measurements prior to coating. Furthermore, the variability is unlikely to have resulted from non-uniformities in the coatings across the surface because no such reflectivity variation is observed over the surfaces of the witness samples. The measured witness sample reflectivities are within 0.01 of each other (<5% difference.)

Although the MLC response dominates the shape of the grating efficiency curves, the groove efficiency curves resemble a more traditional blaze function. Groove efficiency curves of both gratings peak near 250 Å, corresponding to a blaze angle of 3.1 degrees, 0.3 degrees steeper than nominal. Unfortunately, there is not enough data to compare the peaks of the groove efficiency curves at different locations on the gratings' surfaces and determine if, in fact, the efficiency variability is due to blaze angle variations.

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