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FILTERS FOR HIGHER ORDER REJECTION IN VUV MONOCHROMATORS

by

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Filters for Higher Order Rejection in VUV Monochromators

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Abstract

To reduce the higher harmonics present in the light from diffraction grating monochromators, thin metal foils have been installed on beamlines 6.1, 6.2 and 1.2. Using photoelectron spectroscopy, these filters have been shown to reduce the second order content on 6.1 and 6.2 to a few per cent between 16 eV and 100 eV. Their measured transmission is lower than predicted because of oxide contamination. Specifications for higher performance filters are given.

Contents

1. Introduction

Although a continuously tunable source of photons is a very desirable feature of synchrotron radiation, it has one main drawback; the contamination of the photon beam by higher order diffracted light. Several elements have absorption edges which lie between 10 eV and 100 eV, a range prone to high second order content in the present surface science VUV monochromators. They can therefore be used as transmission filters to reduce this higher order content. This paper describes the filters installed in the surface science beamlines and compares the calculated transmission with the measured transmission on BL6.1 and BL6.2.

2. Choice of filter

2.1. Calculation of filter efficiency

The transmission, T, of a material at a particular photon energy E can be calculated from

$$T = e^{-\mu_l x} \qquad (1)$$

where x is the thickness of the material and μ_l(cm^{-1}) is the linear absorption coefficient and is dependent on E. Henke et al (reference 1) have compiled sets of data for the mass absorption coefficient, μ(cm^2/gm), between 30 eV and 10000 eV for 94 elements. The relation between μ and μ_l is given by,

$$\mu = \rho\mu_l \qquad (2)$$

where ρ is the mass density of the absorber in cgs units. Also tabulated in reference 1 are the scattering factors, f_1 and f_2. The relation between f_2 and μ is given by the Kramers-Kronig dispersion equation,

$$f_2 = \frac{E\mu A}{2r_0hcN_0} \qquad (3)$$

where A is the atomic weight, r_0 is the classical electron radius, h is Planck's constant, c is the velocity of light and N_0 is Avogadro's number.
The transmission can be calculated using equations (1) to (3) or more conveniently by programmes such as the Optical Constants Grapher package, SF, (reference 2), or a ray tracing programme called SHADOW (reference 3). Both SF and SHADOW contain tabulations of f_1 and f_2 based on Henke's compilation. The programme SF was used for the calculations in this paper.

An estimate of how well the filters reduce second order content of the beam at any photon energy, E, is given by the ratio of the transmission for second and first order light and is called the rejection ratio, RR, here.

$$RR = \frac{T(2E, x)}{T(E, x)} \qquad (4)$$

Figure 1 shows the first order transmission for boron, beryllium, silicon, aluminium and magnesium. For an efficient filter, the first order transmission needs to be high while the rejection ratio should be low. Al, Mg and Si are the most generally useful elements and between them cover the photon energy range 27 to 99 eV.

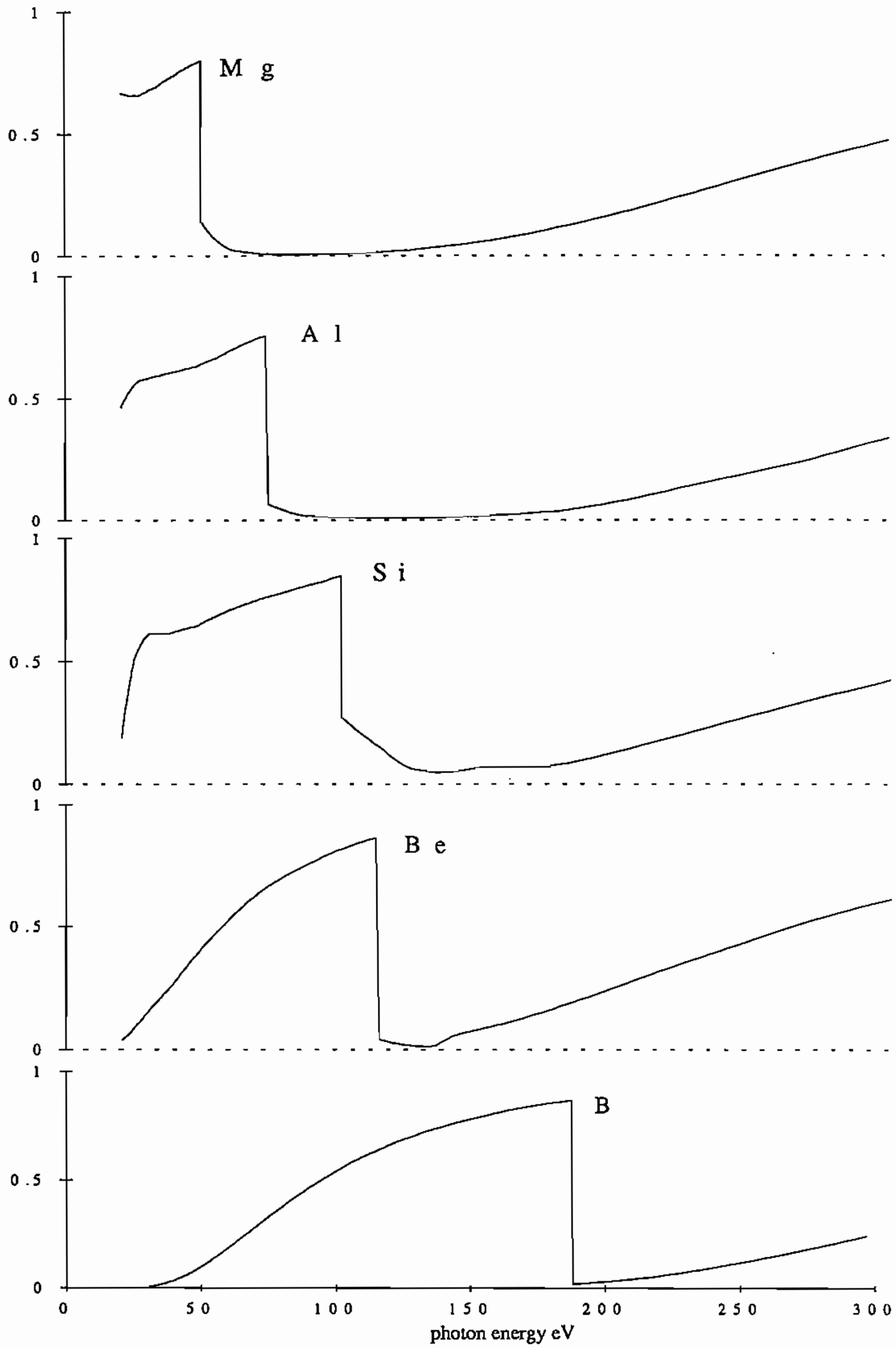

Figure 1. Calculated transmission of 0.2 µm Mg, 0.15 µm Al, 0.12 µm Si, 0.15 µm Be and 0.2 µm B as a function of photon energy

Over the photon energy range 10 to 27 eV there are no filters which have a wide bandpass (as the useful range is proportional to the energy of the absorbtion edge). Elements such as tin, germanium, indium and lead transmit over a limited range and can be useful for specific experiments (see figure 2).

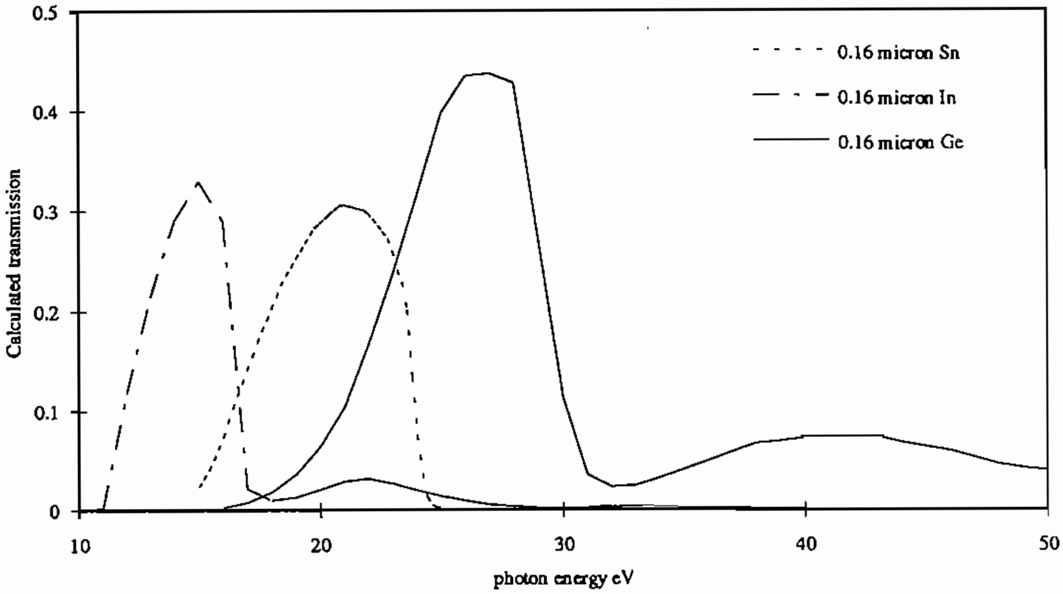

Figure 2. Calculated transmission of Sn, In and Ge.

2.2. Description of filters

A useable filter should transmit about 50% of the first order light, requiring material thicknesses of 0.2 μm or less for the VUV region. Such thin foils need to be supported to survive the operating environment of a typical beamline.

Luxel corporation manufactures filters of the required thickness cemented to a high transparency nickel mesh. As these can survive rocket launches, they were considered robust enough for use on SRS beamlines.

The filters chosen for the initial tests on the surface science beamlines were 0.12 μm Si, 0.15 μm Al, 0.2 μm Mg, and 0.16 μm Sn. They were all 16 mm diameter mounted on standard 82% transmitting nickel mesh in circular frames. Except for the magnesium filter, these were the standard sizes and thicknesses available. The magnesium filter was over- and under-coated with 0.05 μm of Al to reduce the build up of magnesium oxide.

The filters were mounted on linear drives and placed just after the exit slits of the monochromators where the photon beam is relatively small, thus reducing the size (and cost) of the required filter.

3. Filter performance

3.1. Transmission measurements

As a VUV monochromator produces both the desired first order and higher order light, the filter transmission cannot be measured by a simple transmission experiment. The end stations on BL6.1 and BL6.2 are photoemission spectroscopy stations, enabling the higher order content to be measured by setting the monochromator to an energy, E, and taking photoelectron energy spectra for

$$KE = 0 \text{ to } 2*E$$

with and without filters present. The first order transmission, $T_1(E)$, is given by the ratio of the count rates for the peak produced by photons with energy E, CR_1, with a filtered and unfiltered photon beam

$$T_1 = \frac{CR_1(\text{filtered})}{CR_1(\text{unfiltered})} \qquad (5)$$

Similarly, the second order transmission, $T_2(2E)$, is given by the ratio of the filtered and unfiltered count rates, CR_2, for the peak produced by photons with energy 2E. The effect of electron energy analyser transmission and cross-section for production of photoelectrons (different for E and 2E) cancel out. **This is not the case when measuring the exact second order content, and due to the difficulty in measuring these unknowns, the ratios given here for second order content are uncorrected for any of these variables.** The rejection ratio, RR, is then

$$RR = \frac{T_2}{T_1} \qquad (6)$$

On BL6.1, spectra were taken using a cleaned Cu(111) crystal. The electron energy analyser was a VSW 100 mm mean radius hemispherical analyser. Data from BL6.2 were taken using an VG ADES 400 spherical sector analyser and a cleaned Cu(111) crystal.

Figure 3 shows sample photoelectron spectra taken using the plane grating monochromator on beamline 6.1 at a photon energy of 60 eV. With an Al filter, the number of 120 eV photons was reduced to less than 1% of the incident beam while the number of 60 eV photons was only reduced by 50%.

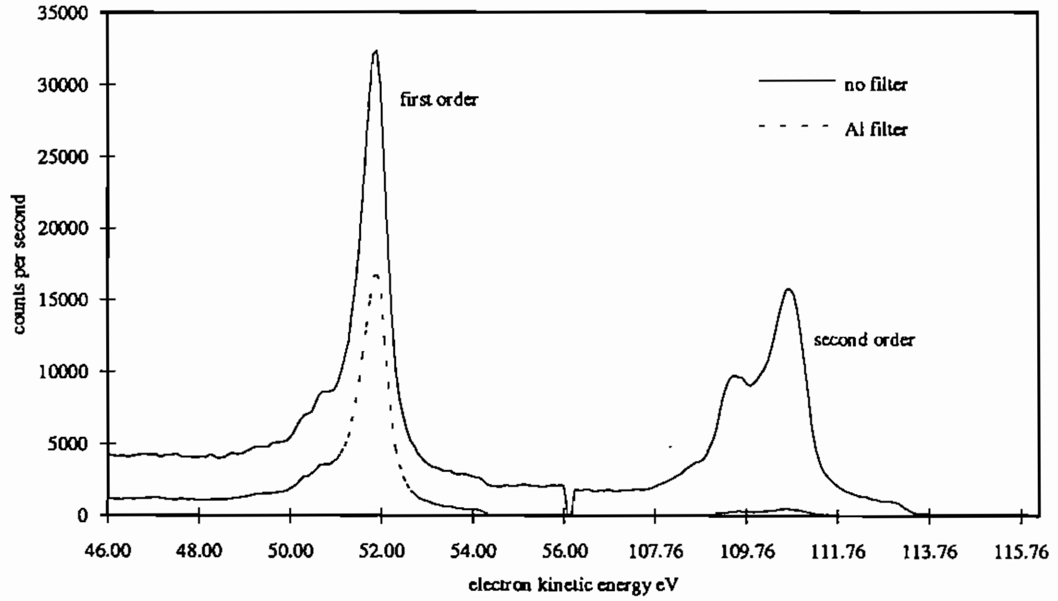

Figure 3. Photoelectron spectra taken with a 100mm hemispherical analyser on 6.1 at a photon energy of 60eV. The second order content at this energy is about 50%; this is reduced to 1% by an aluminium filter.

The following figures show the calculated and measured transmission and rejection ratio for the filters installed on 6.1 and 6.2. Similar filters have been installed on 1.2 but have not yet been characterised.

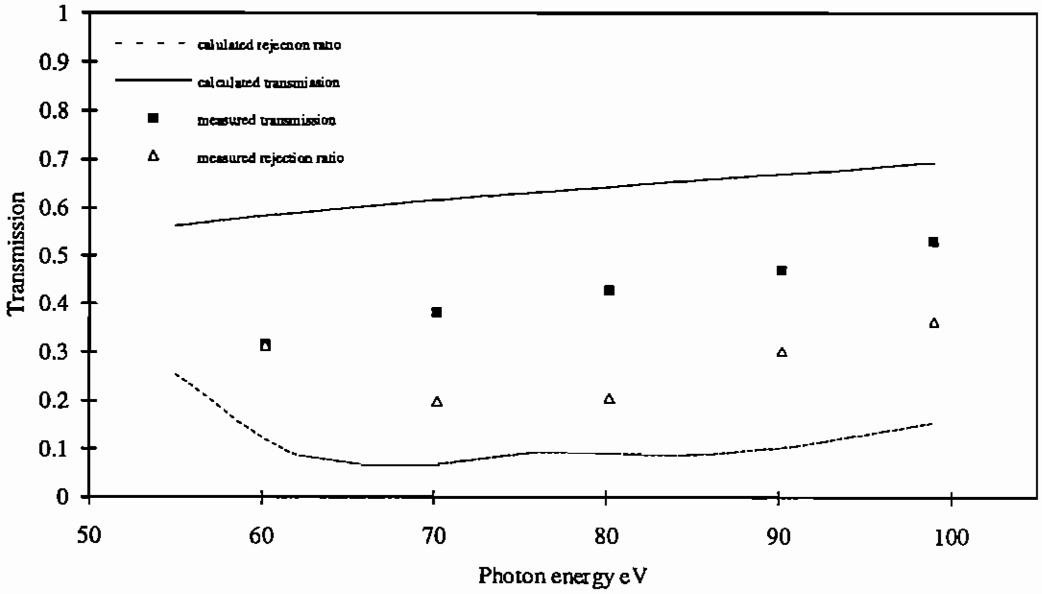

Figure 4. Transmission and rejection ratio for a 0.12 micron thick Si filter.

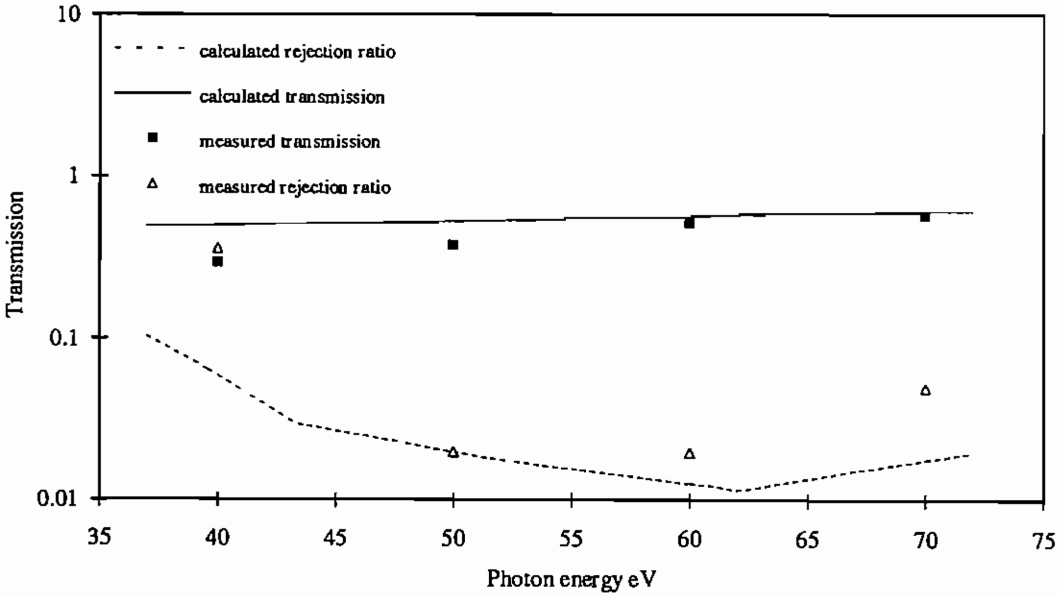

Figure 5. Transmission and rejection ratio for a 0.15 micron thick Al filter.

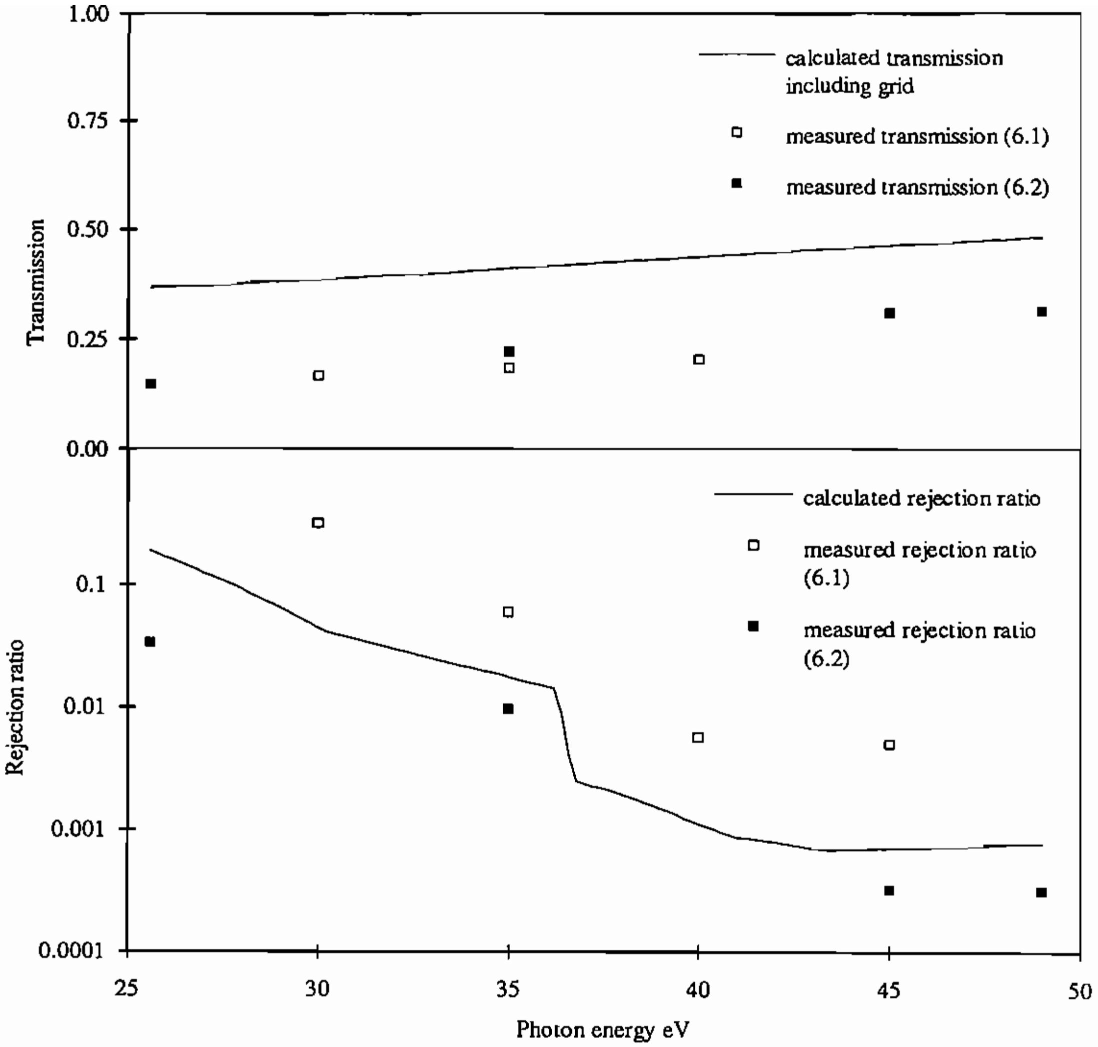

Figure 6. Transmission and rejection ratio for a filter of 0.2 micron Mg over- and under-coated with 0.05 microns Al.

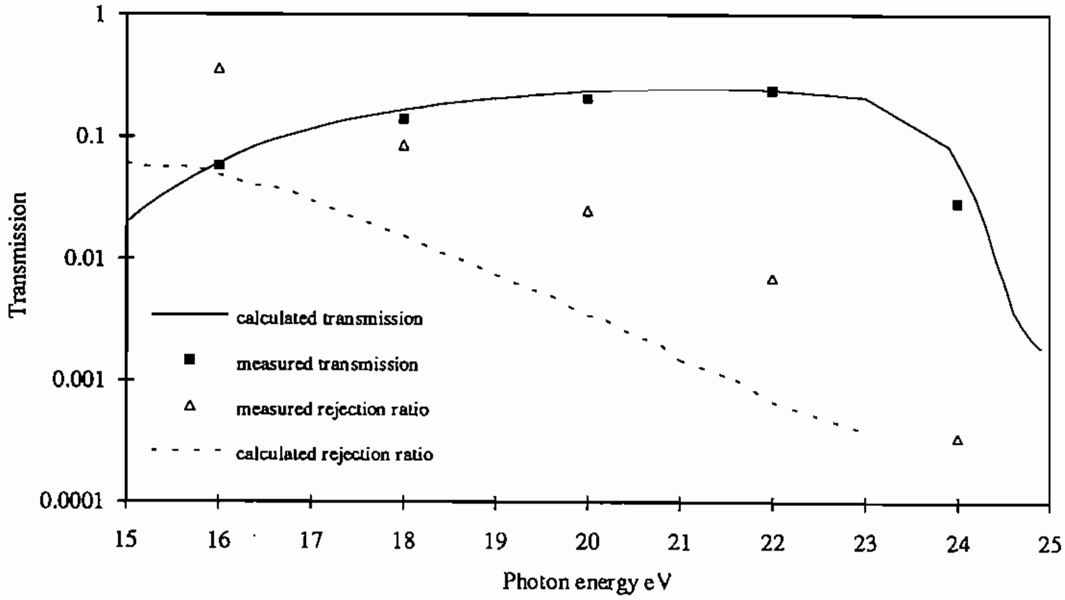

Figure 7. Transmission and rejection ratio for a 0.16 micron thick Sn filter

3.2. Oxide contamination

It is evident from the preceding figures that the measured transmission is significantly below that predicted; the most likely cause is the presence of an oxide layer on the filters. From the difference between the calculated and measured values for the aluminium filter, and assuming there to be no other factor affecting the transmission the thickness of the aluminium oxide layer has been estimated to be 0.008 microns. (This assumes the stociometry of the oxide layer to be Al_2O_3, and the density to be 3.8 gm cm^{-3}). Figure 8 compares the measured transmission to the calculated transmission for the Al filter with this thickness of oxide layer.

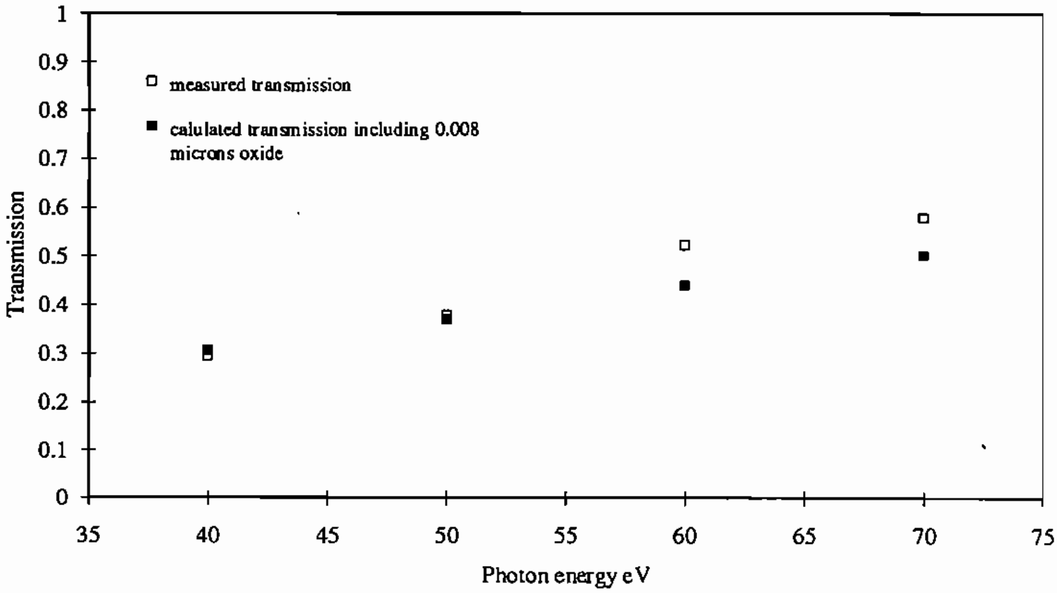

Figure 8. Comparison of measured and calculated transmission for Al filter.

The transmission of the composite magnesium/aluminium filters was then recalculated including this thickness of aluminium oxide layer and compared to the measurements on 6.1 and 6.2 (figure 9). The filter is still not transmitting as much as this predicts, but the oxide thickness may vary from filter to filter and the underlying magnesium layer will also have an oxide coating.

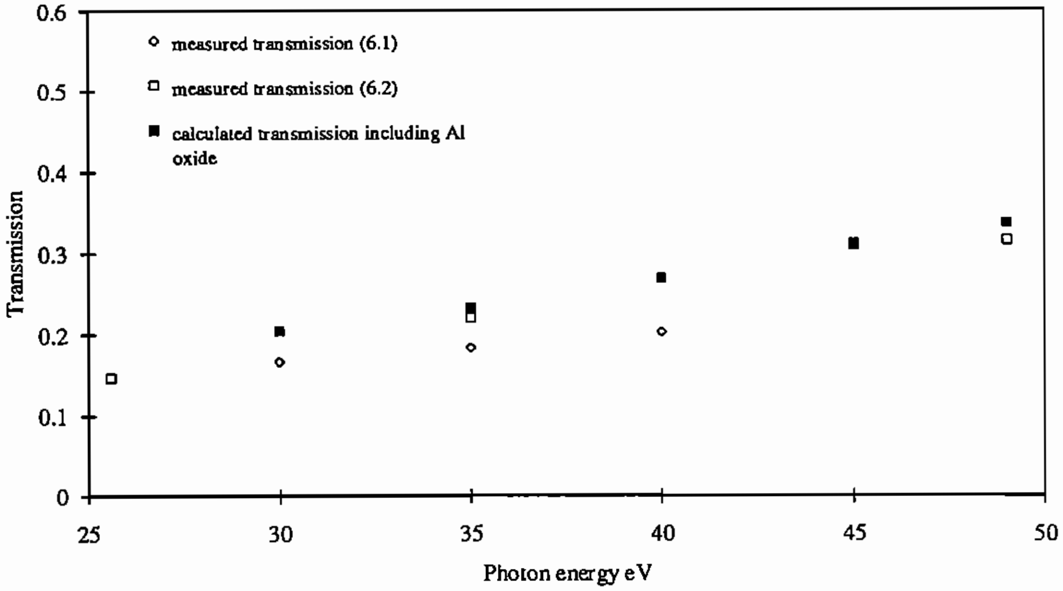

Figure 9. Comparison of the measured and calulated transmission for the Mg filter including 0.008 micron Al_2O_3 layer.

Other factors which could affect the transmission are variations in filter thickness, the presence of any other surface/bulk contaminant, the presence of pinholes or other physical damage. However, simple tests show these to be negligible. The filters are supplied after checks for pinholes and damage. No variation was seen in the transmission when the filters were translated across the beam, indicating a uniform thickness. No 'foreign' edges which could arise from contaminants were observed in any of the filter scans.

In contrast, the problem of oxide layer growth on Luxel aluminium filters has been studied by Powell et al (reference 4). They show the oxide layer to vary from about 18 angstroms at the time of manufacture, to 150 angstroms for older samples. The value derived here of 80 angstroms lies between these thicknesses, indicating that the oxide layer could increase further. The filter transmission will be periodically remeasured to monitor the oxide growth. Care will also be taken to avoid exposing these foils to air unnecessarily.

3.3. Performance as a second order filter on 6.1 and 6.2

Figures 10, 11 and 12 show the uncorrected second order content with and without filters. The results on 6.1 show the present filters to successfully reduce the proportion of second order in the beam to less than 2% (uncorrected) over the useful range of the monochromator.

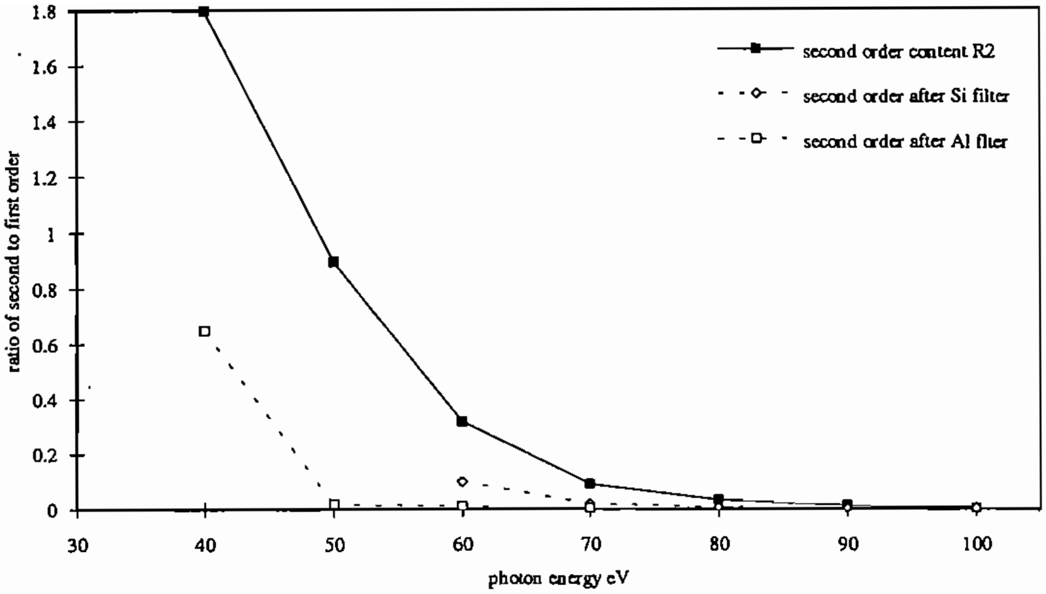

Figure 10. Second order content for the grazing incidence monochromator on 6.1 operating in range 2 with a lamellar grating. The data are not corrected for electron energy analyser transmission or photoemission cross-section.

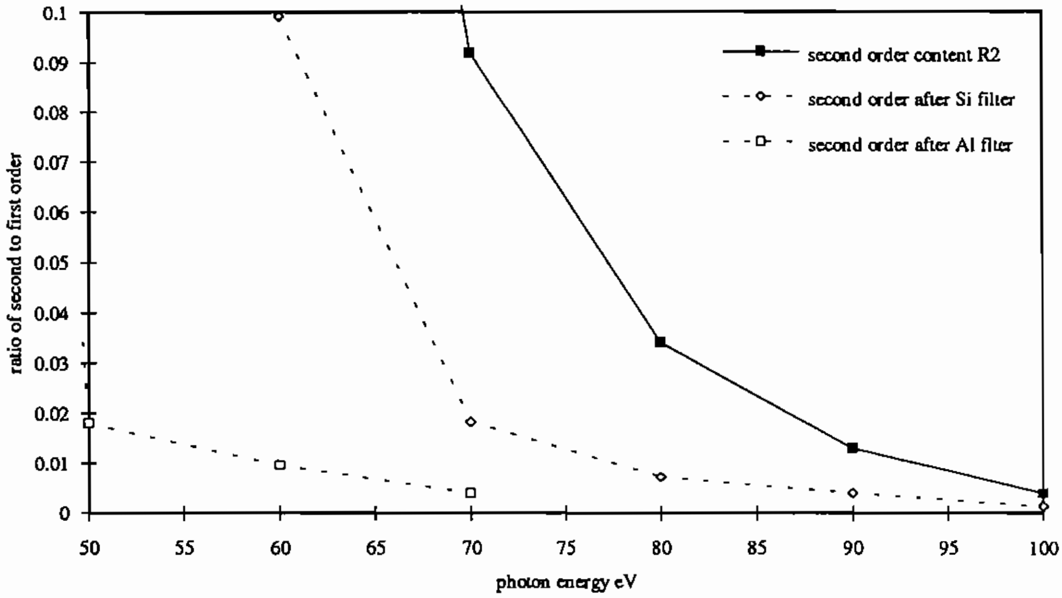

Figure 11. Second order content for the grazing incidence monochromator on 6.1 operating in range 2 with a lamellar grating. The data are not corrected for electron energy analyser transmission or photoemission cross-section.

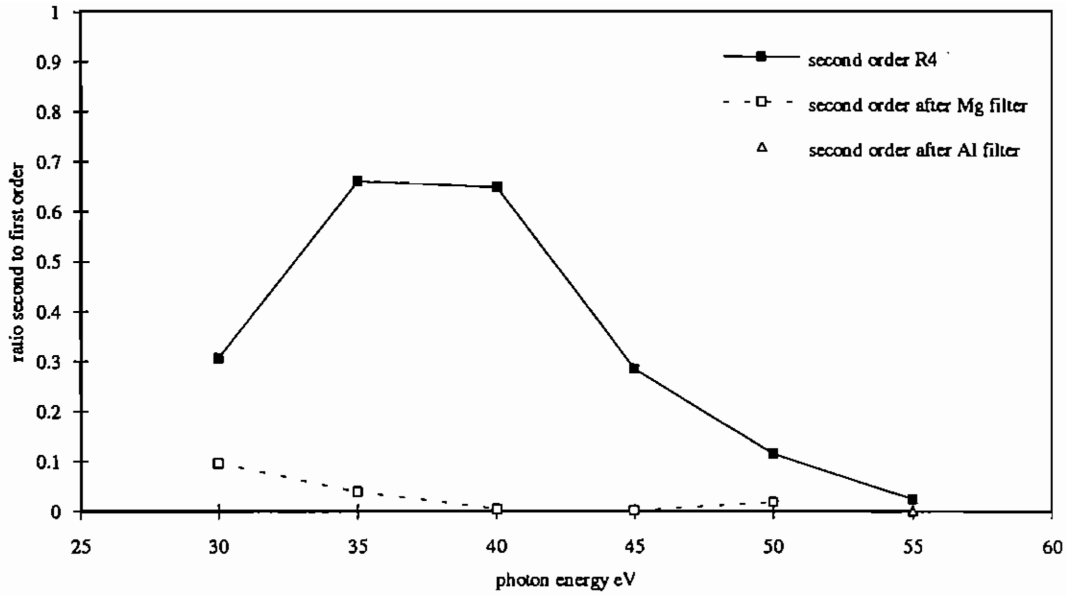

Figure 12. Second order content for the grazing incidence monochromator on 6.1 operating in range 4 with a lamellar grating. The data are not corrected for electron energy analyser transmission or photoemission cross-section.

Figure 13 shows similar results for 6.2. It is clear that the Sn filter reduces the second order content between 16 and 22 eV, a photon energy region where results have been adversely affected by higher orders in the past. However for the Mg filter this graph does not show its usefulness so clearly as there is a second order diffraction efficiency minimum for the low energy grating across its useful range (25 eV to 49 eV). This filter will be most useful for the higher energy grating .

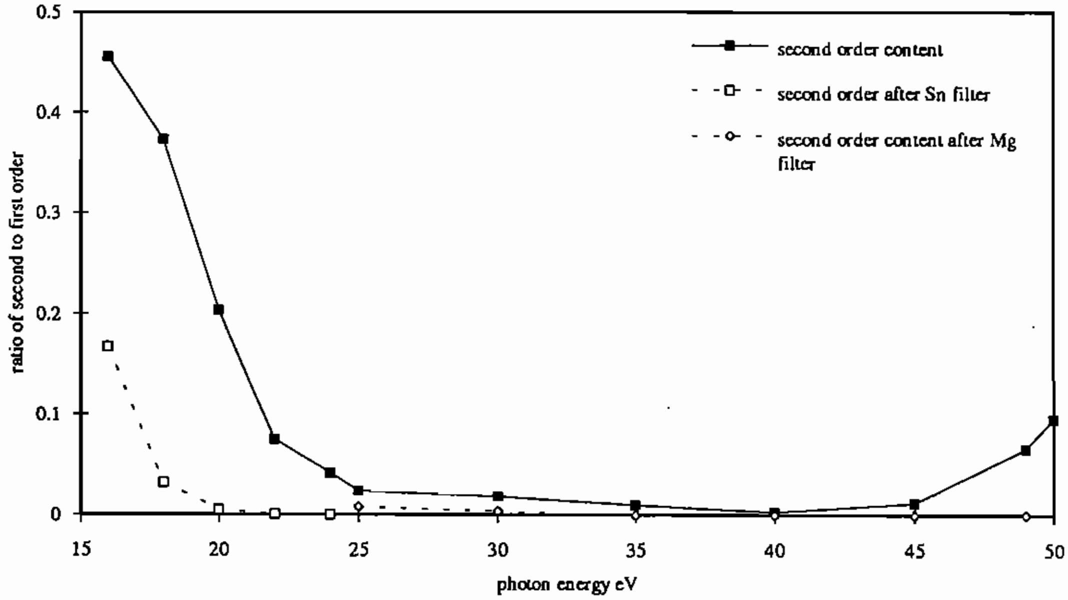

Figure 12. Second order content for the toroidal grating monochromator on 6.2, using the low energy grating. The data are not corrected for electron energy analyser transmission or photoemission cross-section.

4. Future developments

The filters described above have been shown to be useful in providing photon beams with second order contamination levels of only a few percent. Now that more knowledge has been gained about the oxide thickness on the chosen materials, it is possible to choose the required thickness more accurately. In particular, the magnesium filter could be overcoated and undercoated with only 0.02 microns aluminium and not 0.05, thus increasing the transmission.

Any new filters will be as thin as possible and mounted on rotary drives. The rejection ratio in most cases needs only to be around 10%, but if a higher rejection is required rotating the filter to change the angle of incidence of the photon beam will increase the effective thickness of the foil.

The calculated filter performances for more appropriate Sn, Ge, Mg and Al filters are shown in figure 13. All the filters are thinner than those assessed here, in particular the aluminium coating on the magnesium filter has been reduced to 0.02 µm on both sides. The calculations include an estimate of 0.008 µm thickness of aluminium oxide on the Al and Mg foils. These will be purchased and tested as soon as possible.

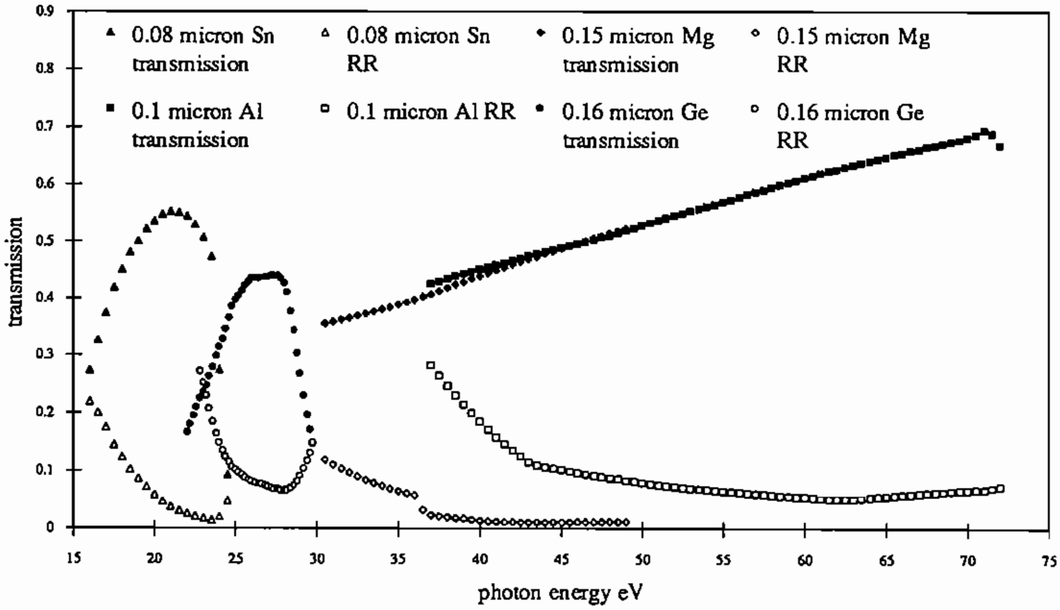

Figure 13. Calculated transmission and rejection ratio for improved filters.

It is interesting to note that the performance of the composite Mg/Al filter is better than that of Al or Mg alone over the range 35 eV to 50 eV.

5. References

1. B.L.Henke, P.Lee, T.J.Tanaka, R.M.Shimabukuro and B.K.Fujikawa, At. Data and Nucl. Data Tables **27**, 1 (1982)

2 Optical Constants Grapher by Mark Thomas, Centre for X-ray Optics, Lawrence Berkeley Laboratory.
This runs on an IBM AT

3. C.Welnak et. al, Rev.Sci.Inst, **63** 865 (1992)

4. F.R.Powell, P.W.Vedder, J.F.Lingblom and S.F Powell, Optical Engineering, **26**, 614 (1990)