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Mirrors as Power Filters

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X-ray mirrors are often positioned as the first optical element in synchrotron radiation beamlines because of their ability to focus, collimate and deviate x-rays and because of their spectral filtering ability. Conventional total reflection mirrors act as low-pass spectral filters, while multilayer interference mirrors act as band-pass spectral filters. This is demonstrated in Figure 1, which shows calculated reflectance profiles for flat platinum total reflection and tungsten/carbon multilayer mirrors positioned in angle to reflect 8 keV x-rays with a minimum of reflected total reflected power. The band-pass reflectance of the multilayer mirror reduces the power reflected down the beamline compared to the low-pass reflectance of the total reflection mirror, assuming a broad-band x-ray source such as a bending magnet or wiggler.[1]

This reduction in integrated power reflected by the multilayer mirror compared to the total reflection mirror has lead to the suggestion[2,3,4,5] that multilayer mirrors might act as power filters to reduce unwanted reflected power which can produce thermal distortions in grating and crystal monochromators which could spoil their high resolution performance. Such power filtering might be especially attractive at the third generation of high-brightness synchrotron radiation facilities currently under construction, where x-ray beams with unprecedented power densities will be produced. Some experimental progress towards using multilayers as power filters in bending magnet beams at existing synchrotron radiation sources has already occurred.[6,7]

We have previously compared the power filtering ability of multilayers and total reflection mirrors in wiggler beams at third generation 1.5 and 7.0 GeV synchrotron radiation sources.[8] This computational study utilized calculated broad-band wiggler source spectra and calculated reflectance spectra to obtain various quantities, including the spectrally integrated power reflected by and absorbed in the two types of mirrors set for operation at a range of photon energies. It was found that multilayer mirrors reduce the unwanted power reflected down the beamline by roughly an order of magnitude, with some variation depending on the value of the desired photon energy compared to the maximum critical energy of the wiggler. Whether this reduction in reflected power is significant depends on the specific application.

In undulator beams the comparison of multilayer versus total reflection mirrors is simplified because the spectral output power of undulators is peaked at a fundamental energy and its higher energy harmonics.[1] Both total reflection and multilayer mirrors can be positioned to reflect a given harmonic and reject higher harmonics. In addition, multilayer mirrors can at least partially reject lower harmonics in the undulator spectrum by positioning the multilayer Bragg peak at a desired higher harmonic. Thus multilayers also have some advantages in power filtering over total reflection mirrors in undulator beams.

The improved power filtering performance of multilayer compared to total reflection mirrors comes at the expense of an increase in absorbed power the

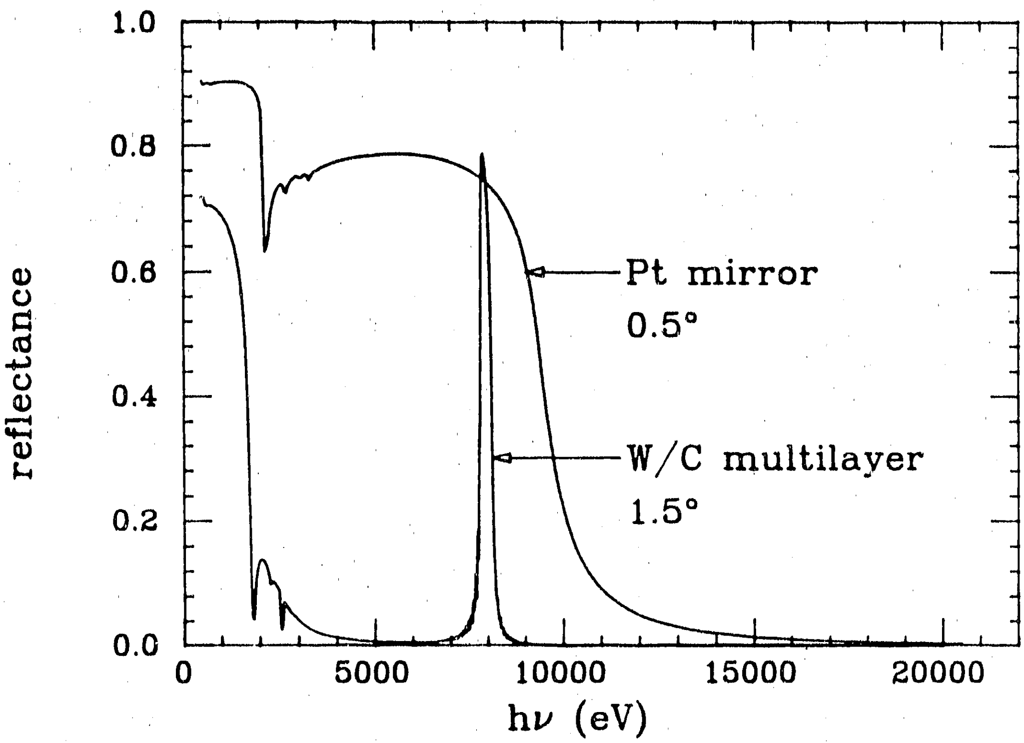

Figure 1. Calculated reflectance profiles for a Pt total reflection mirror and a W/C multilayer mirror with incidence angles of 0.5 and 1.5 degrees, respectively. Each mirror is set to reflect roughly 8 keV x-rays with a minimum of reflected power at other energies.

multilayer mirror. This is because multilayer mirrors operate at higher angles of incidence than total reflection mirrors for a given photon energy and because more of the incident beam is absorbed in multilayer mirrors. In the wiggler study,[8] the power absorbed in the multilayer mirror ranges from 1.25 to 4 times that absorbed in the total reflection mirror. Similar or greater increases in the absorbed power are expected for a multilayer mirror in an undulator beam.

Before one can determine whether the increased power filtering of multilayer mirrors warrants their implementation in the upcoming generation of high-brightness synchrotron radiation sources, the ability of multilayer mirrors to function adequately in the intense beams at these sources must be established. There are two sets of concerns in this regard. One has to do with the stability of the metastable multilayer coating itself under intense x-radiation exposure. Early experiments show that uncooled multilayers in intense white wiggler beams can reach temperatures high enough to destroy the layered microstructure essential to the operation of these mirrors.[9] Further experiments show that even actively cooled multilayers can undergo minor structural rearrangements from exposure to intense beams, though suggest that multilayer materials and processing can be optimized to minimize such changes in cooled multilayers.[10]

A more fundamental concern is the ability of both total reflection mirrors and multilayer mirrors to retain their desired figure under the intense x-ray absorption which produces at least moderate thermal gradients. These gradients distort the mirror surface, and can spoil the high brightness characteristics of the beams if distortions become too large. Active cooling schemes are needed to extract the heat from absorbed radiation to preserve the desired figure, and have been the subject of much recent and current investigation.[11] Theoretical and experimental studies show that mirror cooling designs have been developed for the low energy (e.g. 1.5 GeV electron energy) third generation synchrotron radiation facilities which are expected to preserve the beam quality on total reflection.[12] Therefore multilayer-coated mirrors, with their slightly increased absorbed power, should be feasible at these facilities. The higher power densities in the high energy (e.g. 6-7 GeV electron energy) third generation sources require more elaborate cooling designs for total reflection mirrors before implementation of multilayer mirrors for power filtering. Issues of absorption induced distortion within the multilayer coating itself may also be of importance, and have not yet been investigated.

In addition to power filtering capability and absorbed power considerations, there are many other considerations concerning the relative merit of multilayer versus total reflection mirrors. Total reflection mirrors are typically set at a fixed angle, allowing tuning of photon energy in the total reflectance region to be accomplished with a monochromator in a beam of fixed angular deviation. Since multilayers are band-pass mirrors, tuning photon energy beyond the multilayer band-pass will require tuning the angle of incidence of the mirror. If a single deflection mirror system is used, the entire beamline and experiment must then track the reflected beam. A double reflecting multilayer mirror system can maintain the beam at constant height and angular deviation, but with the increased complexity of both tilt and translation of the second mirror.[13] Because multilayer mirrors operate at a higher angle of incidence, they can be several times shorter than total reflection mirrors. Indeed multilayer mirrors may be the only practical mirrors for hard x-rays with energies in excess of roughly 25-30 kev, as the increasing length makes total reflection mirrors increasingly difficult and costly to fabricate. Relatively little attention has been devoted to the study of multilayer performance at these high x-ray energies.[14] If multilayers are to be applied to figured mirrors, attention must be paid to the effects of possible multilayer period variation over the curved surface and the possible chromatic aberrations such variations may introduce.

In summary, multilayer mirrors offer advantages in power filtering compared to total reflection mirrors in both wiggler and undulator beams at third generation synchrotron radiation sources currently under construction. These advantages come at the expense of increased absorbed power in the mirror itself, and of added complexity of beamline optical design. Further experimental work is required to ascertain whether multilayer mirrors can fulfill their potential as power filters while not degrading the high-brightness beam quality in these sources.

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