## 5.1 Neutron Radiation Induced Structural Changes Affecting Optical Performance of Dielectric Mirrors — K. J. Leonard and L. L. Snead *(Oak Ridge National Laboratory)*

### OBJECTIVE

The purpose of the irradiated dielectric mirror examinations is to establish the radiation and thermal limits of these materials and to identify the causes of degradation in optical performance. This research can further be applied towards understanding the radiation behavior of multi-layered devices such as electronic components for sensor and diagnostic applications.

### SUMMARY

Dielectric mirrors consisting of alternating layers of $HfO_2/SiO_2$ and $Al_2O_3/SiO_2$ on sapphire substrates were irradiated at 175°C to damage levels up to 0.1 dpa. No significant changes were measured in the optical properties after irradiation, but absolute reflectivity values in the $HfO_2/SiO_2$ mirrors degraded during post-irradiation thermal anneals up to 400°C. Microstructural examination is being completed to examine the cause. A second round of irradiations to 1 and 4 dpa are being initiated to determine the upper irradiation and thermal limits.

### PROGRESS

Multilayered thin-film dielectric mirrors can significantly improve transmission of reflected electromagnetic energy, greater than 99% as compared to metallic mirrors such as aluminum (80-90%) or silver and gold (<40%) in the UV range. Therefore their use as focusing mirrors for inertial confinement systems as well as incorporation into plasma diagnostic systems for magnetic confinement systems has been considered. However, little is known about their longevity and sensitivity to displacement radiation, or the mechanisms for optical degradation that take place in the material.

In earlier work [1], we reported on the optical performance of dielectric mirrors following neutron irradiation at 175°C to damage levels of 0.001, 0.01 and 0.1 dpa along with subsequent annealing treatments of the irradiated samples at 300 and 400°C for 1.5 hours. The mirrors, designed for optimum reflectivity at a wavelength of 248 nm consisting of $HfO_2/SiO_2$ and $Al_2O_3/SiO_2$ bi-layer coatings on sapphire substrates, survived irradiation without delamination or cracking and showed only minor shifting in peak reflectivity with irradiation. Subsequent annealing of the irradiated samples resulted in a loss of reflectivity in the $HfO_2/SiO_2$, while the $Al_2O_3/SiO_2$ mirror type remained unaffected. No change in reflectivity was observed in the unirradiated materials annealed up to 400°C. Those results indicated an impressive (more than an order of magnitude higher) irradiation resistance as compared to the literature data and suggested a wider applicability of dielectric mirror in fusion systems.

The radiation and thermal-induced changes in the microstructure of the dielectric mirrors examined by X-ray diffraction and transmission electron microscopy (TEM) is being completed. While increased Si concentration in the $Al_2O_3$ film layers has been measured with increasing irradiation dose and in post irradiation thermal anneals, the individual film layers remain amorphous and show no indication of compound formation,

suggesting stability of the $Al_2O_3/SiO_2$ mirror to higher irradiation dose and thermal levels. The $HfO_2$ layers in the $HfO_2/SiO_2$ mirrors show changes in crystallinity with irradiation dose, starting from monoclinic structured crystallites in an amorphous film layer for the unirradiated mirrors to fully crystalline films in the 0.1 dpa material consisting of monoclinic and either tetragonal or cubic crystallites. In both mirror types, the $SiO_2$ layers remain amorphous. Though changes in crystallinity are observed in the $HfO_2/SiO_2$ mirror with increasing dose, no loss in reflectivity is observed to 0.1 dpa. The microstructural cause for the degradation of the mirrors during post-irradiation annealing is currently being examined.

In addition to the concluding microstructural examinations of the mirrors irradiated to 0.1 dpa, work has initiated on irradiations to 1 and 4 dpa at HFIR. The completion date of the irradiations is expected to be late July 2012, with post-irradiation examination to begin following a one month cooling and capsule disassembly. Optical examinations will include changes in relative spectral reflectance versus wavelength and absolute reflectance at 248 nm for the $HfO_2/SiO_2$ and $Al_2O_3/SiO_2$ mirrors in the as-irradiated and post-irradiated annealed conditions. Transmission electron microscopy and X-ray diffraction will again be used to evaluate the microstructural effects contributing to the optical property changes and mirror stability.

The optimum performance of diagnostic materials under severe radiation environments is critical to safe functioning of fusion reactors. Understanding the mechanisms for degradation that impose limitations to the operating range of a given material or component is key to both improving reliability and designing more radiation tolerant systems. The dielectric mirror research work will aid in determining the upper radiation and thermal limits for use in laser control of inertial confinement fusion systems as well as diagnostic systems for both fusion reactor types. Furthermore, examining the radiation induced structural changes in the films will be beneficial for the development of other thin-film based electronic components and sensors used fusion applications.

1. L. L. Snead, K. J. Leonard, G. E. Jellison Jr., M. Sawan and T. Lehecka, “Irradiation effects on dielectric mirrors for fusion power reactor application,” *Fusion Sci. and Technol*. **56**, 2 (2009) 1069-1077.