Radiation resistant VUV coatings for Excimer- and Free Electron Lasers

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Fig. 1:
Development of Ultra Low Loss Evaporation Technology for radiation resistant VUV optics.

Interference coatings for the vacuum ultraviolet spectral range (VUV) between 200 nm and 50 nm find several classical and innovative application fields in astronomy, semiconductor industry, synchrotron radiation optics, materials processing and medicine. Components comprise for example antireflective coatings, enhanced aluminum mirrors and broad band reflectors. Research on optical interference coatings, as the key element for resonant light amplification and laseroptics, has currently gained vital interest at VUV wavelengths. Up to the present day, absorption of optical crystals prevents generation of laser harmonics below 180 nm. Classical optical resonators, available from microwave down to UV wavelengths, meet strong material limitation at wavelengths shorter than 200 nm.
The operation of Excimer lasers, as unrivalled VUV sources, gives rise to several challenges for the VUV optical Research and Development. Indeed, for such wavelengths, strong radiation interactions exist. Origin comes from the high VUV photon energy which approaches the band gap of available coating materials. Therefore, radiation interactions can drastically degrade the components properties and thus limit or even kill any application field. Excimer laser optics has to withstand billions of pulses during long term industrial operation.
Obstacles to working in this spectral domain are numerous and must be overpassed. Equal challenges have to be met with Free Electron Lasers (FELs) which represent a next generation of accelerator based light sources, capable in principle of operating at any wavelength from the far infrared to the X-ray region. In the VUV region, FEL oscillators represent excellent light sources for scientific research, as soon as high quality mirrors are developed. Durability for this application requires resonator coatings to survive in a strongly harsh environment caused by the combination of high energy synchrotron radiation and residual gases from the cavity vacuum.
In 2001, new ultra low loss VUV technologies (Fig.1) have been developed at Fraunhofer IOF to optimize the laser radiation resistance of optical thin film elements. Only few known material combinations offer a desirable compromise of optical, absorption and scattering reduced, mechanical and chemical characteristics down to 120 nm. In collaboration with MIT Lexington, marathon irradiation tests (Fig. 2) have demonstrated the robustness of optimized VUV coatings.
Devoted and customized evaporation techniques brought out excellent performances down to 150 nm and even shorter (Fig. 3). In the context of European projects, the first phase of development of a FEL operating in the UV/VUV spectral range on the ELETTRA storage ring, high brightness synchrotron radiation source for the VUV/soft X-ray region, has recently been completed (Fig. 4). The project comprises several European programs involving institutes such as Sincrotrone Trieste, Fraunhofer IOF, CEA/LURE, CLRC-Daresbury Laboratory, the University of Dortmund , ENEA-Frascati, Institut Fresnel. In 2001, 560 mW power at 250 nm was measured at the European FEL project at Elettra with customized Transmission mirrors and lasing at 189.7 nm was obtained with High Reflection oxide mirrors, the shortest wavelength obtained so far with FEL oscillators (Fig. 4). Beyond the technological challenge, the project work at Fraunhofer IOF included the establishment of a reliable analysis technique as well as innovative coating designs.
Therefore, a complete DUV/VUV characterization setup has been developed, allowing photometric angle and polarization resolved reflection and transmission measurement down to 120 nm.

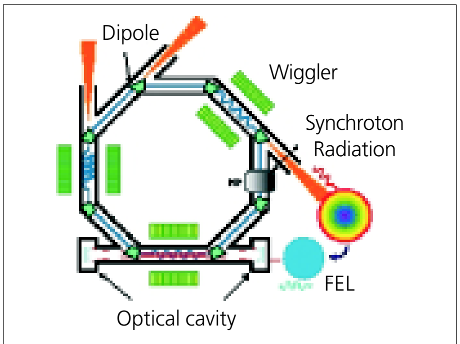

Fig. 5:
Typical set-up of a Storage Ring FEL. Electron bunches confined inside emit Synchrotron Radiation passing through the dipoles and wigglers. FEL optical cavity is shown.

A coupled Excimer laser implemented on the spectrophotometer can be used for in situ sample irradiation and Reflection and Transmission measurements at 157 nm. Accurate evaluations and computing resources enable now the precise determination of the optical constants for relevant VUV materials.

Based on the results obtained, future research activities at Fraunhofer IOF will continue to pave the way for coating applications at VUV wavelengths, including the development of new laser source resonators and the design of VUV specific coating technology.

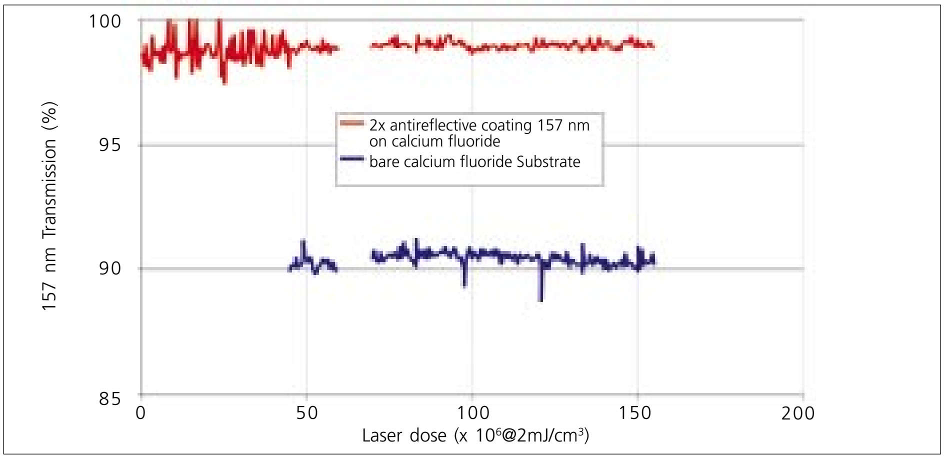

Fig. 2:
Durable VUV coating components
(example: 157 nm MIT Marathon Test): T (157 nm) = 99%, > 300x10^6 pulses @2mJ/cm^2.

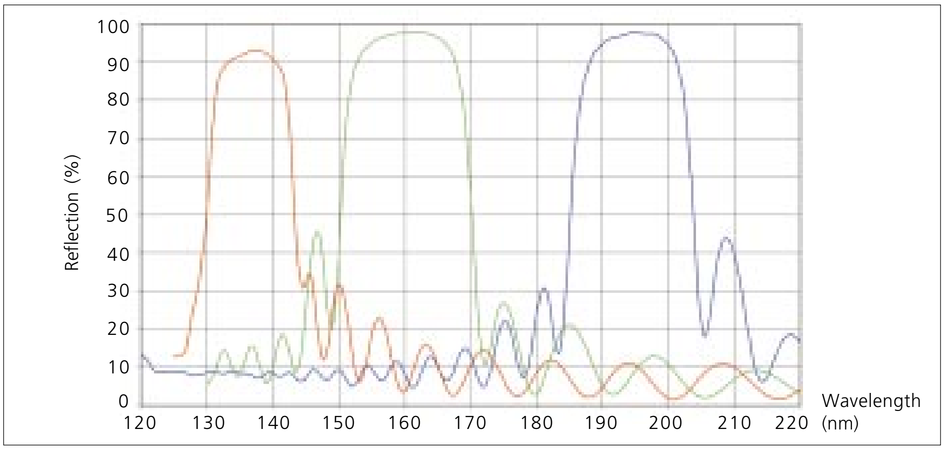

Fig. 3:
High reflective mirrors for the VUV spectral range.

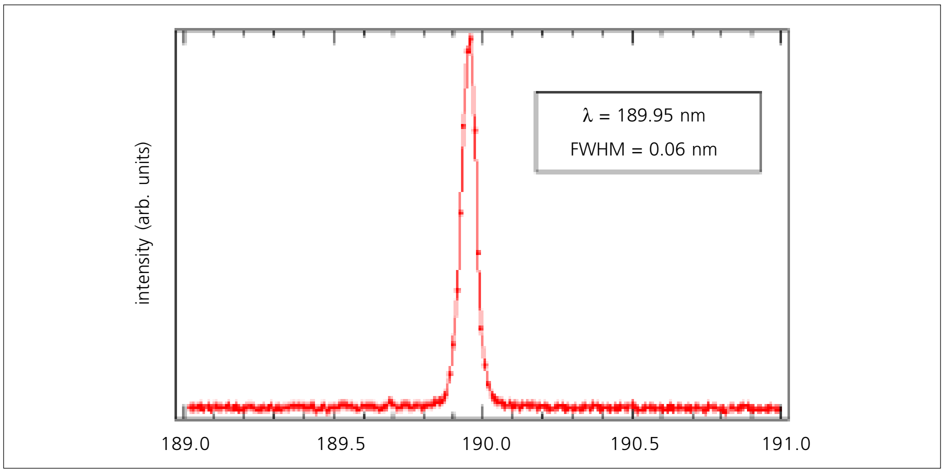

Fig. 4:
"In February 2001, the SRFEL on ELETTRA, Europe's first 'third generation' high brightness synchrotron radiation source for the VUV / Soft X-ray region, succeeded in lasing at 190 nm, representing a new world record for the shortest wavelength of a Free Electron Laser oscillator." Result obtained in the frame of European projects involving LZH (Germany), CEA SPAM and LURE (France) and the European project at ELETTRA.