Total reflection mirrors for VUV Free Electron Lasers

B. Steeg[a], S. Jacobi[b], R. Sobierajski[a], C. Michaelsen[c], J. Feldhaus[a]

[a]HASYLAB at DESY, Notkestrasse 85, 22603 Hamburg, Germany

[b]GKSS Research Center, Max-Planck-Strasse 1, 21502 Geesthacht, Germany

[c]Incoatec GmbH, Max-Planck-Strasse 2, 21502 Geesthacht, Germany

1. INTRODUCTION

Advances in linear accelerators and undulators have recently boosted the development of short-wavelength free electron lasers (FELs). The FEL at the TESLA Test Facility (TTF) has demonstrated maximum light amplification in the range 80 nm to 120 nm wavelength with an output power in the GW range [1,2]. In the next development stage this FEL will provide intense, sub-picosecond radiation pulses with photon energies up to 200 eV for scientific applications. Very precise, ultra-smooth mirrors and gratings are required to transport, focus and disperse the radiation. Usually suitable thin film coatings on silicon or other subtrates are used in the vacuum ultraviolet (VUV) and x-ray spectral range. Coatings of light elements are preferred because of their superior reflectivity and, consequently, their low absorption at grazing angles of incidence. Carbon appears to be ideal for the TTF FEL since the K absorption edge at 284 eV is well above the photon energy range of the FEL. Therefore carbon coated mirrors have been developed in a joint project by GKSS and DESY.

2. EXPERIMENT

Single-layer amorphous carbon coatings have been produced on planar, well polished silicon substrates by magnetron sputtering [3] at GKSS. In order to optimize the deposition process, the coatings were routinely characterized with unpolarized Cu-Kα radiation using a conventional x-ray reflectometer [4]. The optical characterization of the coatings in the VUV and soft x-ray spectral region was done at HASYLAB/DESY using the soft x-ray reflectometer at beamline G1 [5]. For comparison carbon coatings produced by other deposition methods, i.e. plasma-enhanced chemical vapor deposition (PE-CVD) and pulsed laser deposition (PLD) were also investigated. Annealing experiments have been performed to test thermal stability [6].

The radiation stability of the carbon mirrors was investigated in the FELIS (Free Electron Laser - Interaction with Solids) [7] experiment at the TTF-FEL. The ablation of carbon was analyzed by a time-of-flight (TOF) spectrometer as a function of the radiation power density. All measurements were performed at room temperature under UHV conditions.

3. RESULTS AND DISCUSSION

Fig. 1 shows energy dependent reflectivity spectra of carbon coatings which were produced by three different methods. Characteristic properties of those coatings, such as thickness, roughness and layer density, were determined by fitting angle dependent reflectometry curves for a fixed photon energy [6]. The PE-CVD coating (dashed line) has the lowest reflectivity in the energy region of 50 - 200 eV. The low density of this coating can possibly be explained by the incorporation of hydrogen during the deposition process. The PLD film has high reflectivity and very high density, but also high roughness. The sputtered amorphous carbon coating has the highest reflectivity (95-96%). The density is about 2.2 g/cm^3 and the roughness is much lower than that of the PLD film. For the proposed application a reflectivity as high as possible in combination with high density and low roughness is required. The amorphous carbon coating produced by magnetron sputtering shows the best combination of properties.

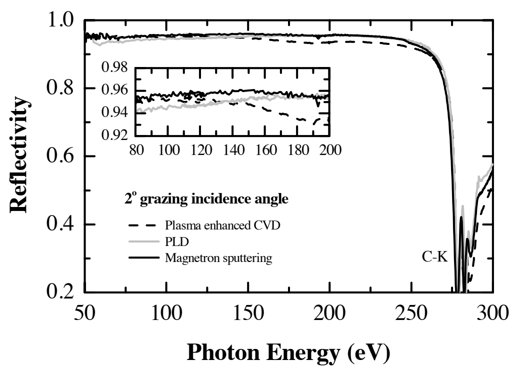

Figure 1. Energy dependent reflectivity spectra of different carbon coatings for a fixed grazing incidence angle of 2°.

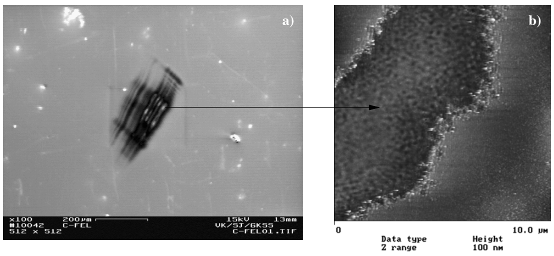

Figure 2. a) SEM image of a carbon mirror irradiated by the TTF-FEL beam (V. Küstner, GKSS). b) SFM topographic image of the irradiated area (F. Felten, TUUH).

Sputtered carbon coatings were investigated in the FELIS experiment at the TTF-FEL. The mirrors were irradiated perpendicular to the surface. The wavelength of the FEL was 98 nm (12.7 eV) with a pulse energy of 40 μJ and a pulse length of 100 fs. From TOF measurements at different FEL pulse energies the damage threshold for a 39 nm carbon film was estimated to 0.06 J/cm^2 [7]. Scanning Electron Microscopy (SEM) studies of irradiated carbon mirrors show clearly the spots where the FEL beam hit the surface (Fig. 2a). A stripe pattern arises from interference of the beam with a wire placed in the light path for beam diagnostics. The irradiated area shows, in most cases, two different regions of damage. One of strong damage is situated in the middle (small bright spots) surrounded by a second region of less damage (dark structure). Two different regions of damage could also be resolved with Scanning Force Microscopy (SFM). On the left of Fig. 2b, the area of strong damage is seen, which looks like melted material. On the right side, the region of less damage is visible.

Up to now it has not been possible to perform experiments with intense, sub-picosecond radiation pulses in the planned working energy range up to 200 eV. This energy range, however, is much less critical because the photoabsorption cross section of carbon is two to three orders of magnitude lower than in the VUV where the current studies have been made. In addition, the mirrors will be used at grazing angles of incidence in the regime of total reflection, reducing the absorbed power density to < 1 mJ/cm^2, i.e. two orders of magnitude below the damage threshold reported above. Therefore we are confident that the mirrors will not be damaged by the FEL radiation.

REFERENCES

1. V. Ayvazyan et al., Phys. Rev. Lett. **88**, 104802 (2002).
2. V. Ayvazyan et al., Eur. Phys. J. D **20** 149-156 (2002).
3. C. Michaelsen et al. Adv. X-ray Anal. **42**, 308 (2000).
4. S. Jacobi et al., in *Optics for Fourth-Generation X-Ray Sources* (San Diego, 2001), Vol. 4500 of *Proceedings of SPIE*, pp. 187 - 192.
5. http://www-hasylab.desy.de/facility/experimental_stations/stations/G1.htm
6. S. Jacobi et al., *Proceedings of SPIE 2002* (to be published).
7. A. Andrejczuk et al. *HASYLAB Annual Report*, pp. 117-120, 2001.