L.11: Carbon decontamination of optical surfaces using RF discharge plasma

The deposition of carbon contamination on the surface of any optics deteriorates its performance (reflectivity of a mirror, diffraction efficiency of a grating etc.). Usually, metal coated reflective optics is used in XUV / soft x-ray spectral region and it is expensive. Metal coated reflective optics such as gratings and off-axis parabolic mirrors are routinely used in ultra-short high intensity laser systems delivering laser peak power in the range of hundreds of terawatts. The deposition may result in increasing the surface roughness that leads to an increase in the background stray light and also reduction in intensity of the diffracted light from the optics in the case of gratings. Although the optics is kept in ultra-high vacuum (UHV) chambers while in use, still some hydrocarbon gases (CH_4, CO, CO_2) present in the surrounding gases get disintegrated by the high intensity laser radiation (x-rays in the case of the beamline optics) over the optical surface. This results in deposition of a carbon layer on the active surface of the optics and contaminates it more rapidly. In the case of optics like grating used in high power laser system (e.g. in pulse stretcher, compressors etc.) the problem due to contamination is more severe as the gratings are used in multi-pass configuration in these systems. The size of optics is also large in such systems due to large beam size of the laser may vary from tens of mm to sub hundred mm. To remove the contamination from such large size optics, cleaning system is required that can clean such large area uniformly.

At Laser Plasma Division, RRCAT, in collaboration with Indus Synchrotron Utilization Division, RRCAT, a capacitive coupled radio-frequency plasma discharge based cleaning system has been set up for removal of carbon contamination from such optics.This system is capable of generating a large size plasma column with nearly uniform particle density that sputters the carbon atoms from the optics surface and cleans the surface uniformly. The setup is installed in an ultra-high vacuum (UHV) chamber with a turbo-molecular pump backed by dry-scroll pump. Before cleaning of any optical component, the chamber is evacuated to 10^{-7} mbar in order to remove the stray hydro-carbons present in the chamber. The RF discharge plasma is created in oxygen gas at low pressure ($\sim 10^{-2}$ mbar) using an RF source operating at 13.56 MHz and can deliver a maximum power up-to 300 W. The RF power is fed to two parallel plate copper electrodes mounted in the chamber. Before cleaning of actual optics, parameters like gas pressure, RF power, irradiation time etc. had to be optimized. It was observed that over-irradiation of the sample leads to removal of gold coating from the sample. To obtain optimum condition for cleaning, different gases (like Ar, O_2, mixture of Ar and O_2 etc.), RF power, and gas pressure were used and it was observed that an RF power of 10 W and a gas pressure of 4×10^{-2} mbar are quite optimum for optics cleaning. The irradiation time was varied according to the level of contamination present on the sample surface, keeping other parameters constant. Under the above conditions, a carbon coating removal rate of ~ *0.6* nm per minute was estimated.

After this optimization, this setup was used for cleaning of actual laser optics like compressor gratings of the high power laser system, off-axis parabolic mirror etc. Fig.L.11.1 shows a compressor grating (size : *120* mm × *70* mm × *20* mm) used in multi-pass (4-pass) configuration in a *10* TW Ti:sapphire laser system. The two black patches on the grating surface show the positions of the laser beam hitting the grating surface. The reflectivity of the contaminated grating measured before cleaning was ~70%, and in four passes, the net reflectivity will get reduced to ~25%. This is very low and reduces the laser energy reaching the experimental chamber substantially. After RF cleaning at optimum parameter (gas : O_2, pressure : 4×10^{-2} mbar, RF power : 10 W, and irradiation time ~30 minutes), the black patches were completely removed from the surface (as seen clearly in Fig. xx.1) and the reflectivity increased to ~95%, which is close to that in a new grating. In four passes, the net reflectivity will be ~81%.

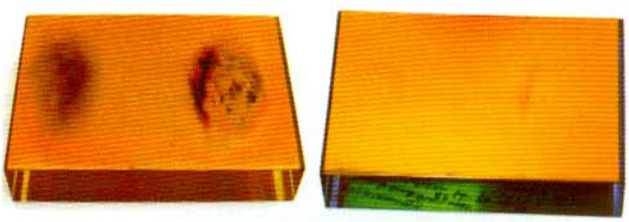

Fig. L.11.1: A pulse compressor grating before and after cleaning by RF discharge plasma

For online monitoring of the carbon removal from the surface of the contaminated optics, optical emission spectroscopy of the RF plasma was carried out. It was observed that the intensity of third positive band (297 nm, 312 nm and Angstrom band (482 nm, 519 nm) of carbon mono-oxide (CO) decreases with increase in irradiation time. In ~30 minutes, the intensity of these lines reduces by a factor of 6, which shows the significant reduction of CO in the plasma. At the same time, the intensity of two intense lines from oxygen (777 nm and 844 nm) was observed to increases with increase in irradiation time. This also confirms the removal of carbon from the sample surface with increasing irradiation time.

This set up has enabled Laser Plasma Division to reuse the discarded costly gratings, thereby making a sizable saving of the project funds.

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