

**Laser Ablation of Diamond and Genesis Concentrator Target Material.** A. L. Butterworth<sup>1</sup>, R. J. Chater<sup>2</sup> and I.A. Franchi<sup>1</sup>. <sup>1</sup>Planetary and Space Sciences Research Institute, The Open University, Walton Hall, Milton Keynes, MK7 6AA, UK (a.l.butterworth@open.ac.uk). <sup>2</sup>Department of Materials, Imperial College, London SW7 2BP, U.K

**Introduction:** In this work, ablations of CVD diamond and diamond-like carbon using two wavelengths of UV radiation (266 nm and 213 nm) have been compared. The impetus for these tests is the preparation for the return of the NASA Discovery 5 Mission Genesis.

Genesis was launched on August 8<sup>th</sup> 2001 and will return to Earth in 2004. It will be carrying amongst the precious cargo CVD diamond implanted with solar wind oxygen ions over a depth of 200 nm. The radiation damage to the diamond surface will be such that the UV absorbance is more similar to the high sp<sup>2</sup>/sp<sup>3</sup> diamond-like carbon than pristine sp<sup>3</sup> CVD diamond.

The main aim of Genesis is to measure the oxygen isotopic abundance of the solar wind. In order to achieve this end, our technique will extract the implanted oxygen from the diamond collector for analysis by mass spectrometry [3]. Major challenges in perfecting the technique involve maximizing the O-extraction efficiency and removing surface contamination.

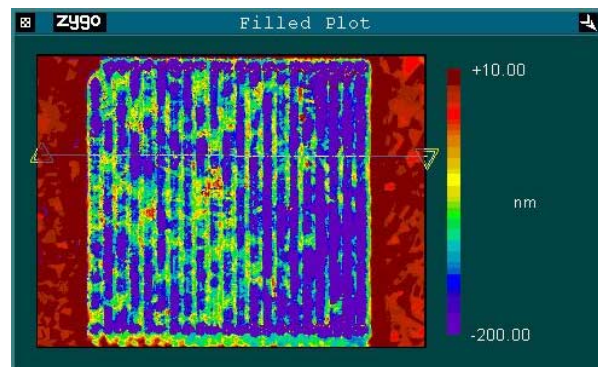
UV absorbance in diamond has been studied extensively, e.g. [1, 2]. The band gap of synthetic CVD diamond (chemical vapor deposition) is 5.47 eV or 227 nm. Laser radiation at shorter wavelength than 227 nm should be required to ablate diamond.

Diamond-like carbon films (DLC) and graphitized diamond have an increasing proportion of sp<sup>2</sup> hybrid bonding present, which affects the optical properties. In this case a lower energy radiation is needed to ablate, for example a quadrupled Nd:YAG,  $\lambda=266$  nm, 4.7 eV has been used successfully [3].

**Method:** We ablated CVD diamond, O-implanted CVD diamond and 2.5- $\mu\text{m}$  thick DLC film on silicon wafer substrate using two different wavelengths of UV radiation. One laser was a quadrupled Nd:YAG,  $\lambda=266$  nm (Spectron Laser Systems). The second laser used was a quintupled Nd:YAG  $\lambda=213$  nm (Merchantek UP213). The radiation energy ranged from 0.1 to 3 mJ/pulse at  $\lambda=266$  nm, and 0.1 to 0.5 mJ/pulse at  $\lambda=213$  nm. In both systems, pulse frequency was 10 Hz and pulse duration was  $\sim 14$  ns.

The ablated surfaces were analyzed using a white light interferometer (Zygo Corporation). 3D imaging of the surfaces allowed pit depths to be measured. A change in reflectivity from the diamond surface to the ablated pits reduces slightly the precision of depth measurements from the maximum 0.1 nm resolution.

**Results:** The relatively high-energy radiation at both wavelengths was successful in ablating O-implanted CVD diamond and DLC film. A 1 mm<sup>2</sup> area was produced by rastering  $\lambda=266$  nm, 3 mJ/pulse, 100  $\mu\text{m}$  spot size at 0.2 mm/s. Figure 1 shows material removed to a depth of 200 nm. The ablation appeared to be uneven, which may be due to focusing of the laser, but also due to the roughness of the diamond surface (RMS = 45 nm measured over several areas of implanted CVD diamond surface)

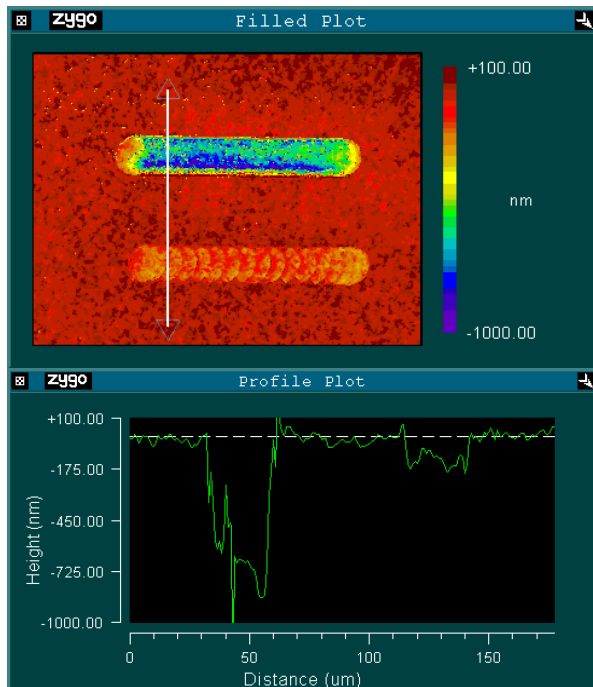


**Figure 1.**  $\lambda=266$  nm ablation of 1mm<sup>2</sup> area by rastering (vertical lines) at 0.2 mm/s

Figure 2 shows the results of an ablation of O-implanted CVD using  $\lambda=213$  nm, 0.3 mJ/pulse and 140  $\mu\text{m}$  spot size. Two lines were formed by rastering at 70  $\mu\text{m/s}$  and 560  $\mu\text{m/s}$ . The vertical profile taken at a cross section shows the different depths achieved. The slow raster excavated 6 times more material than the 4-times higher speed raster.

Some areas show an uplift of material, similar to results for  $\lambda=266$  ablations, suggesting a blistering effect. At lower energies (both  $\lambda$ ) the blistering effect was more prominent with vertical profiling showing only positive deviation from the surface mean of implanted CVD.

At the lower energy radiation (0.1 mJ/pulse  $\lambda=213$  nm), spots and rasters visible under the microscope were not detected by interferometry. The results puts an upper limit of 40 nm uplift and ablation on these areas, which is equivalent to the surface roughness.



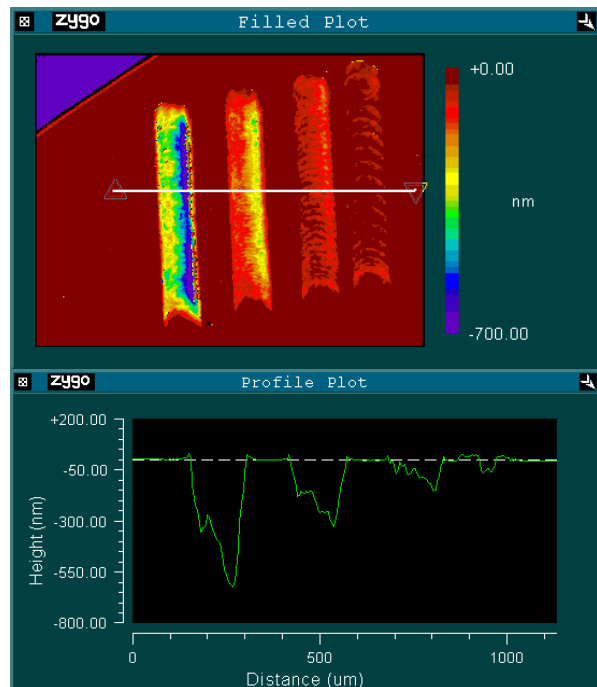
**Figure 2:** Ablation of two areas of O-implanted CVD diamond using 213 nm UV beam, 10 Hz at 0.3 mJ/pulse, 70 and 560  $\mu\text{m/s}$  raster speeds. The lower plot shows the profile along the bold white line.

The roughness of the DLC film surface was less than 10 nm, making these carbon films useful in investigating very shallow ablation techniques.

Figure 3 shows four areas ablated from DLC film at different speeds, but the same 0.25 mJ/pulse. As expected, the slowest raster removed twice the volume of diamond than the next trench completed at twice the speed. The volume was five-times larger than the raster completed at four-times speed. The 8-times speed rastered area showed as much blistering as ablation. With the smoother surface of the DLC film, it was possible to see that the  $\lambda=213$  nm beam was not symmetrical.

The comparison of the two laser systems was most striking with polished CVD diamond.  $\lambda=266$  nm did not ablate CVD diamond, but a 2  $\mu\text{m}$  deep pit was produced with  $\lambda=213$  nm, 0.3 mJ/pulse

**Discussion:** Laser ablation used in the application of extraction of solar-wind oxygen implanted in diamond requires a high level of depth sensitivity. Surface contamination must be removed followed by complete removal of all implanted oxygen. The CVD diamond flown on Genesis is ultrapure with respect to oxygen content, but ablation of too much material should be avoided to minimize contamination of the solar-wind sample. The ablation depth produced by



**Figure 3.** Ablation of four areas on DLC film using 213 UV beam, 0.25 mJ/pulse, spot size 140  $\mu\text{m}$  rastering at 70, 140, 280, 560  $\mu\text{m/s}$ .

varying energy and wavelength of UV radiation is an important result to consider.

Etching of CVD diamond has been performed using excimer lasers (XeCl  $\lambda=308$  nm and KrF  $\lambda=193$  nm at 350mJ/pulse, [4] and KrF  $\lambda=248$  nm, 10mJ 0.5 ps pulses[5]). Diamond absorbs strongly at  $\lambda=213$  nm (Nd:YAG) with only 0.2 mJ/pulse.

Diamond containing significant proportions of  $\text{sp}^2$  bonding requires lower energy (longer  $\lambda$ ) radiation to ablate material. Considering the high thermal conductivity of diamond and the lower proportion of  $\text{sp}^2$  bonding at the base of the implanted CVD layer, it may be beneficial to use a shorter wavelength ablation (lower mJ/pulse needed) to achieve the required depth sensitivity and the essential high yield of implanted oxygen recovery.

**References:** [1]<sup>o</sup> Benedict, L.X., et al. (1998) *Phys. Rev. B.*, **57**, 9385 [2]<sup>o</sup> Barberini, L., S.et al.. (2001) *Nuc. Ins. Meth & Phys Res A.*, **460**, 127-137. [3]<sup>o</sup> Butterworth, A.L., et al. (2000) *LPSCXXX.#1796*. [4]<sup>o</sup> Meaden, G., et al. (1997) *J. Mater. Sci.*, **32**(14), 3801-6. [5]<sup>o</sup> Preuss, S. and M. Stuke. (1995) *App Phys Lett.*, **67**, 338-340.