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EVOLUTION OF MICROSTRUCTURES IN LASER ABLATED PLANAR TARGETS

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Abstract: In this paper we report an experimental study on laser induced ablation and crater formation using a Nd:YAG laser system of 40 picosecond pulse duration with energy up to 50 mJ at 0.53 μm. Crater diameter and depth were measured using optical microscope (OM), and Scanning Electron Microscope (SEM). We introduce 2 new techniques viz. Focused Ion Beam (FIB) and Optical Confocal Microscope (OCM) for the measurement of crater dimensions. Based on our experimental data we discuss the merits of the newer techniques in measuring the dimensions of the microstructures.

Theoretical concept of laser ablation and crater formation:

Physics of laser ablation (Kruer 2001) and crater formation (Momma et al 1996, Borodziuk et al. 2003, Desai et al. 2006) has been studied for a long time. Nevertheless, due to technological advances in the laser development (nanosecond to atto-second and increasing energy) and progressive applications in various fields, laser ablation still offers new challenging topics for research.

When a laser radiation is focused, the electric field (EF) at the focal region is of the order of $27.5 \times (I\ W/cm^2)^{0.5}$ which exceeds the binding energy of the electrons leading to instantaneous plasma formation and target ablation. A variety of features can be observed on target surface like surface modification, hillocks, simple and complex craters etc. which are obviously dependent on laser parameters and material properties. Surface modification is characterized by visual changes like cracks, ripples, spikes etc. observed at low laser energy where the material does not leave the surface but undergoes structural modification.

On the contrary, when the ablated material leaves the target surface causing a permanent depression, well-defined craters are observed. With further increase in the beam energy, complex processes take place like the re-deposition of the ejecta, flat crater floors, craters with rims etc. Based on the characteristics of the crater, they are classified as simple and complex craters. Thus, laser ablation is an interesting process to understand the evolution of crater. In this paper we report an experimental study on the laser induced ablation with an emphasis on crater development.

Experimental measurements:

Experiments were performed using a Nd:YAG laser with energy up to 50 mJ at 0.53 μm wavelength at 1Hz. We have irradiated 2 mm thick aluminum target which is of a standard material commonly used in laboratories as well as industrial interest. Experiments were performed in vacuum at $>10^{-4}$ mbar of atmospheric pressure. Laser radiation was focused normal to the target surface and the laser energy was varied by introducing neutral density filters in the path of the laser beam. A fresh target surface was irradiated each time with known number of consecutive shots, similar to our earlier work, to estimate ablation depth and diameter of the crater (Di Bernardo et al 2003).

Optical microscope coupled with CCD camera was used to measure the crater diameter. Crater images were imaged on the screen with a magnification ×240. We have also adopted 2 newer diagnostics viz. Optical Confocal Microscope (OCM) and Focussed Ion Beam (FIB) to estimate crater depth and diameter. Using OCM we estimate the crater diameter and depth for different laser energy and number of consecutive laser shots. Image magnification was ×800. FIB images were recorded with magnification ×1000 to ×1500.

Optical Confocal Microscope (OCM).

In laser scanning confocal microscopy (LSCM), sample is illuminated point by point and the full image is obtained by scanning the light spot through the field of view. The key feature of confocal optics is the presence of a pinhole diaphragm in front of the detector. Since the light source, the specimen and the detector are simultaneously in focus (confocal), the pinhole allows to reject light from out of focus planes in the sample (Brakenhoff et al 1979). As a consequence, a high contrast image is obtained from a thin section of the sample. Starting from a series of closely spaced sections along the axial direction, it is therefore possible to build a 3-D reconstruction of the imaged structure.

Focused Ion Beams (FIB).

FIB technology finds has drawn several applications related to microelectronics and nano-scale research. It offers the possibility of sectioning the sample while imaging microstructures (Sivel et al., 2004). The FIB / SEM system is a combination of a FIB, an electron beam, and secondary ion and secondary electron detectors. The FIB gallium (Ga^+) ions operated at low beam currents are used for imaging while high beam current, are used for specific sputtering or milling. As the Ga^+ primary ion beam rasters on the sample surface, the signal from the sputtered (secondary) ions or secondary electrons is collected to form an image (Goodhew et al 2001). The imaging resolution of FIB improved in the middle of 1990s to the level where FIB instrument can compete with conventional scanning electron microscopes (Phaneuf 1999). Applications of FIB in various fields is discussed in the ref. (Milani et al., 2004)

Results and discussion:

Fig. 1 shows the top view of the crater image with OCM obtained on an aluminium target of 100µm thickness for 30 consecutive shots with average laser energy ≈20 mJ. Fig. b shows the vertical profile of the crater (of fig. 1a) reconstructed from several Optical Confocal Microscope images. Our results show that we could obtain a depth of 85µm for 30 consecutive laser shots.

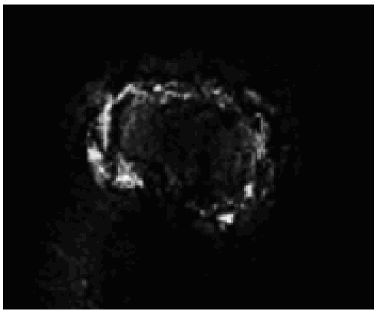
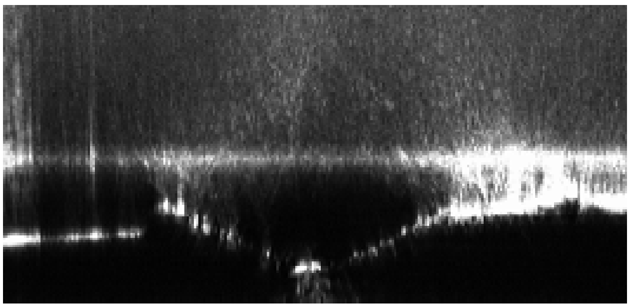


Fig. 1a. Top view of the Crater on aluminium target.



b. Reconstructed crater profile corresponding to the crater in fig.1a. Depth is 85 µm.

Fig.2 shows crater diameter and depth as a function of number of laser shots deposited on the target. Laser shots were accumulated from 1 to 10 at the same place. Fluctuation in the energy is about 5 % from shot to shot.

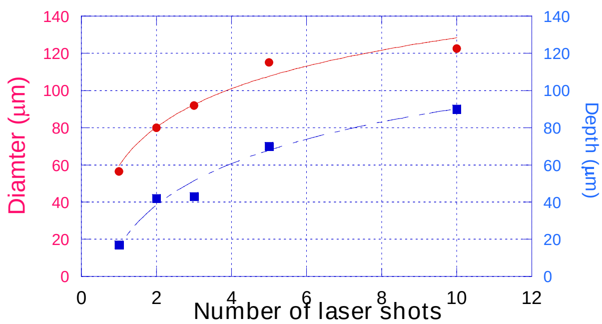


Fig.2. Crater depth and diameter Vs number of laser shots.

Our preliminary results show that the initial diameter of the area (where multiple laser shots are deposited) is very important in deciding the final diameter of the crater with number of laser shots (or energy).

Crater images were recorded using FIB and OCM and are shown in Fig. 3 and 4 respectively. Fig. 3 represent the image with a magnification of ×1500 at a tilt of 52° using 5 KV electron beam. Crater diameter is ~90 µm. Another crater was obtained using 0.44 µm, 450 ps PALS laser system at 3.64 J energy on aluminum target and fig.4 shows the image recorded using OCM with ×800 magnification.

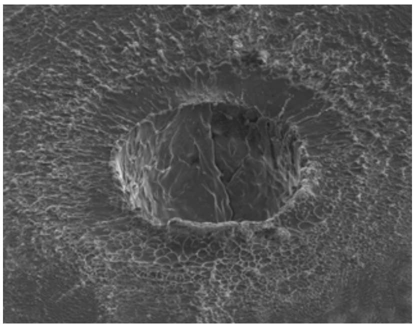


Fig.3. ~90 µm diameter crater on Al-target. M= 1500.

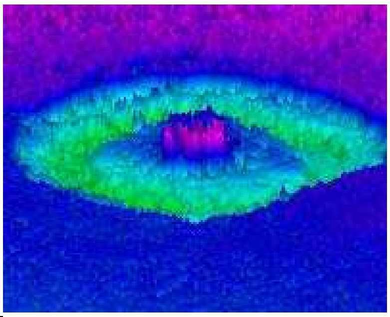


Fig.4. ~350 µm diameter crater on Al-target. M=800.

In conclusion, Optical Confocal Microscopy and Focused Ion Beam technique can be conveniently adopted for the analysis of laser produced craters. Results obtained by both the techniques are reasonably in agreement. Analysis shows the ease of operation of the methods for estimating the crater depth. Possibility of drawing additional information on the crater with the proposed newer techniques is being investigated.

References:

Brakenhoff G. J., et al., Journal of Microscopy, 117: 219-232, (1979).
Desai T, Batani D et al., Radiation effets and Defects, 160, 595-600 (2005)
Di Bernardo A. *et al.*, Laser Part. Beams 21(1) 59–64 (2003).
Kruer W.L., *The Physics of Laser Plasma Interactions* (West View Press, 2001).
Momma C. *et al.*, Optics Commun. 129(1) 34 (1996).
Borodziuk S. *et al.*, Czechoslovak J. Phys. 53 (2003).
Goodhew, P.J. et al., Electron Microscopy and Analyses. Tylor and Francis, UK. (2001)
Milani, M., et al, Eur. Phys. J.-Appl. Phys. 26, 123 (2004).
Phaneuf, M.W. Micron 30, 277-288. (1999).
Sivel, V.G.M., et al., J. Microsc.-Oxford 214, 237 (2004).