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LABORATORY CRATERS TO METEORITE COMPLEX-CRATERS, CAN WE?

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Abstract:

Here we report an experimental study on laser produced craters using our facility at the Univ. of Milano-Bicocca at low laser energy and in PALS, Prague at higher energy to study the possibility of laboratory craters to investigate the planetary events such as meteorite craters. An aluminium foil (100 µm thick) of density 2.7 g /cc, which could model the earths crest (density ~2.67 g/cc), was used as a target. We measured the diameter and depth of the laboratory craters by adopting different techniques viz. Laser Scanning Confocal Microscope (LSCM), Focused Ion Beam (FIB) and Scanning Electron Microscope (SEM) for the accuracy of the measurements.

We obtained two types of craters in the laboratory viz. simple, which are circular, bowl-shaped depressions with depth to diameter ratio ~ 1:5, and intricate structures resembling complex craters produced due to large meteorites impact on earth and other planets. The contours from the laser-ablated craters could represent the natural meteorite craters on the earth and elsewhere on other terrestrial surfaces.

We have also made some Multi 2 dimensional simulations and the preliminary results show the possibility of generating the complex crater structures. Details of the simulations will be published elsewhere.

Keywords: Laser produced simple craters, complex structures and planetary events

1. INTRODUCTION:

Advanced high-power lasers have opened new opportunities with laboratory plasma environments and we discuss one of the laboratory crater applications to meteorite impact. An intense laboratory astrophysical research is emerging with high power lasers [1] and the important point is the possibility of scaling laboratory experiments to enormous astrophysical phenomena [2]. Advanced high-power lasers have opened new opportunities with laboratory plasma. Here we discuss one of the laboratory crater applications to meteorite impact. Laser impact crater study has importance in planetology, astrophysical, industrial, basic physics etc. In fact meteorites are endowed with information about the early history of the solar system. They are left over rocks during the formation of our solar system. They are located between Mars and Jupiter and revolve around the sun. Small pebble like meteors begin to heat up because of the extreme compression of the atmosphere and commonly known as shooting star or falling star. In fact these are regular events but several megatons meteors approaching the earth is a devastating natural catastrophe. It is widely accepted that about 65 million years ago, around 10 Km diameter iron meteorite impact perturbed the global environment so catastrophically that a major biological extinction ensued [3]. There are several detail reports on meteorite craters [4], and also web based programs to calculate impact cratering effects [5]. Several efforts are made to investigate meteorite impacts in the laboratory and by field study to recognize the natural crater mechanism.

Remnants of the large meteorite craters including ejecta not only provide information about the mass, composition and velocity of the meteorite during the impact but also cratering processes on the surfaces of telluric planets (Earth, Moon, Mars, Jupiter etc.). Simple craters are [4] circular, bowl-shaped depressions with depth to diameter ratio[3] ~1:5. On the contrary, complex craters have relatively a low depth to diameter ratio with a central uplift [6] (such as the 40 Km diameter Araguainha, Brazil; ~ 180 Km diameter Chicxulub crater, Mexico; and 18 Km diameter Yuty crater on Mars).

Before commencing the laboratory experiments on meteorite impact using laser radiation, it is important to discuss the merits of the similarities and disparities between laser produced laboratory craters and meteorite craters on our earth. In laboratory experiments the laser beam is focussed at 90° or obliquely on the target surface. The target surface instantaneously heats up to a peak temperature [7] ~ hundreds of eV and generates several Megabars shock pressure [8]. The shock wave propagates in the target and the material is heated, shaken, and jets out from the surface carving a crater larger than the laser spot.

In the case of Meteor impact, meteor burrows at an oblique angle on the earth surface, mostly impact angle [9] is 45°. Assuming the meteor is spherical, it imparts its KE= $(4\pi R_i^3 \rho_i V_i^2/6)$ to the earth surface (ex. Meteor radius=50 meters, ρ= 2500 Kg/M^3, V_i=20 Km/s, KE=60 MT where 1 Megaton = 4.2×10^{15} J). Part of the KE is spent in heating and evaporating the earth's surface. This generates a shock pressure [10] of the order of $P \approx (\rho_{target} \times V^2_{meteorite})$ in the target. Shock pressures 1-10 Mbar are produced for 11-30 Km/s impact velocities [11]. A crater much larger than the meteorite is carved with the ejection of the surface material. Laser produced craters and meteorite impact craters differ in time and space scales by several orders of magnitudes, both events have strong analogies. Although aluminum density (=2.7g/cc) models the 15 Km thick earth-crust density (=2.67 g/cc and average earth density ~ 5.5 g/cc), many factors vary with respect to the properties of earth. Gravity plays a very vital role in natural craters which is insignificant in laboratory craters. Resistance of the atmosphere to a large meteor is negligible and a similar condition can be aptly generated by performing the experiments in vacuum.

2. EXPERIMENTS:

Two sets of experiments were performed. First set at the Univ. of Milano-Bicocca using Nd:Yag laser delivering about 50 mJ optical energy in 40 ps (FWHM) duration. Laser wavelength was up converted to 532 nm using second harmonic crystal. Laser radiation was focused normal to the target surface and spot diameter was ~50-100 μm on the aluminum target of 100 μm thickness placed in an evacuated plasma chamber. Laser intensity on the target was varied in the range 5×10^{12} - 5×10^{13} W/cm^2 by varying the spot diameter. Crater diameter and depth were studies for single laser shot.

Second set of the experiments were performed using the Prague Astrix Iodine gas Laser System at 0.44 μm wavelength (3ω of Iodine laser) in 450 ps (FWHM). Aluminum targets of 100 μm thickness were glued on the metal ring at the periphery and placed in the vacuum chamber. Laser radiation was focused normal to the target surface and spot diameter was ~350 μm. A Phase Zone Plate ¯PZP [12] was used to smoothen the laser beam to produce a flat-top intensity distribution in the focal spot. Laser energy was varied up to 15 J corresponding to an intensity range (8×10^{12} - 3×10^{13} W/cm^2). Since all the hydrodynamic processes take place on the time scales much larger than laser pulse duration, laser energy deposited on the target is responsible for all the developments taking place instantaneously in time at a given point source (because crater formation takes place on a much larger spatial and temporal scale lengths). Therefore the process of crater formation will be insensitive to the precise interaction time.

3. RESULTS AND DISCUSSION:

Experimental craters depth and diameter were estimated using Laser Scanning Confocal Microscope (LSCM) with magnification ×800. LSCM images were analyzed in reflection mode by Leica TCS SP2 confocal microscope coupled to DMIRE2 inverted microscope and results were compared with SEM and both the techniques show good agreement. We use Leica LCS software for 3-D reconstruction of crater topography. By rotating 3-D images we obtained the detailed internal morphology. Crater depths were estimated along XZ and YZ axis which agree with the values obtained from 3D images.

In the first set of experiment we obtained several bowl and hemispherical craters. They are simple craters with depth to diameter ratio ~ 1:5. One of such craters is shown in fig. 1. This shows the top view of the crater surface in XY plane. Fig. 2 shows the internal profile of the crater showing the depth of the crater along XZ and YZ axis.

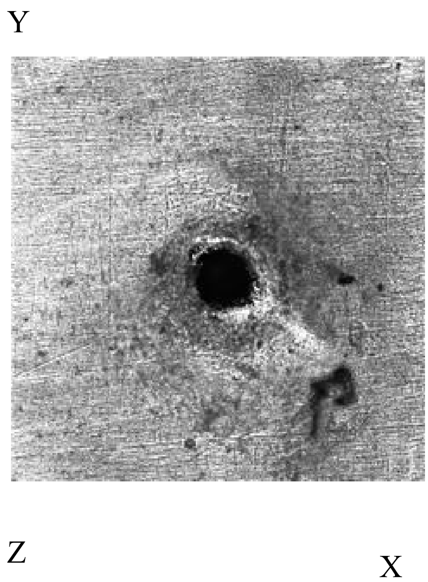

Fig. 1.

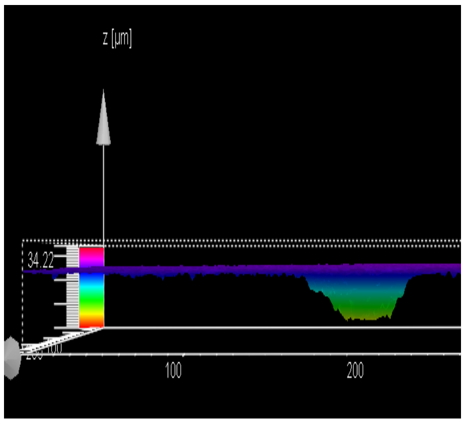

Fig. 2.

Fig.1. Top view of the simple crater diameter on Al- target is ~ 55µm. Laser energy = 50 mJ.
Fig.2. Internal contours of the crater showing crater depth along XZ and YZ axis.

Second set of the experiment was performed at PALS at higher energy up to 15 J. We obtained some simple craters and some complex structured craters. Fig. represents the image of the complex structured crater. This shows top view of the crater in XY plane and the internal profile of the crater is shown by continuous line along XZ and YZ axis at the periphery of fig.3. In this case laser energy on the target was ~ 3.64J corresponding to intensity ~8×10^{12} W/cm^2 and a shock pressure ~3 Mbar. The reconstructed 3D image (fig. 4) shows the crater diameter ~490 μm and maximum crater depth ~ 60 μm from the original target surface. Central uplift is ~ 38 μm above the original target surface with diameter ~ 70 μm in the plane of the original surface.

Laboratory complex craters involve several dynamic processes and their analysis is really complicated. There could be several processes acting simultaneously during the crater formation including the growth of instabilities on the molten material (at the base of the crater), role of shock pressure, uplift structure etc.. Further experimental study, detailed calculations on heat transport, diffusion, shock propagation etc. are needed to understand the laboratory craters.

Appearance of a strong central peak in our experiments shows the possibility of using laser produced craters to try to simulate and understand the formation of complex structured craters in the laboratory.

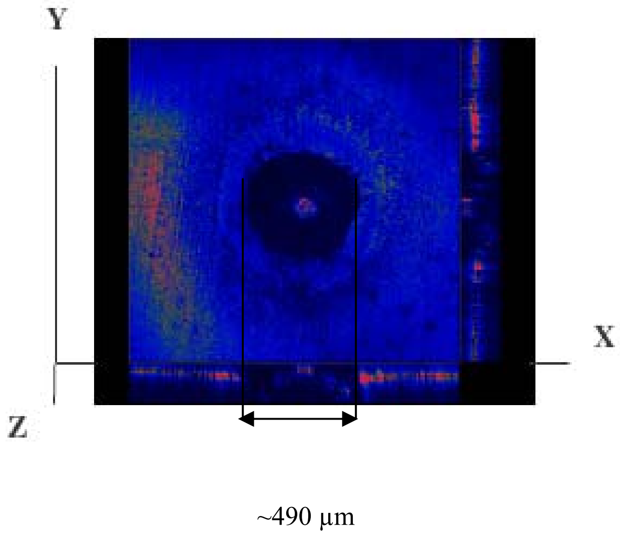

Fig.3. Top view of the complex crater diameter on Al- target is ~ 490 μm. Laser energy = 3.14 J. Internal contours of the crater are shown by continuous line along XZ and YZ axis in the crater region.

4. SIMULATIONS.

In order to verify whether experimentally obtained inner surface contours of the crater is theoretically reproducible, we performed 2D simulations using radiation-hydrodynamic code MULTI [12]. This code uses the SESAME equation of state and the simple average Planck and Roseland opacities. The simulation program works in cylindrical symmetry around the beam axis (z, r coordinates). We have run the simulations with the following parameters for the laser pulse; Gaussian time profile with FWHM = 350 ps, laser wavelength=0.438 μm, super-Gaussian radial profile characterized by an inner flat region with diameter 2R = 300 μm and by a total FWHM = 400 μm (the border tail is Gaussian). Aluminum foil of 100 μm thickness was used as a target.

Keeping these parameters constant, we have performed the simulations for different laser energies. Results show central uplifts for all the laser energies of different magnitude.

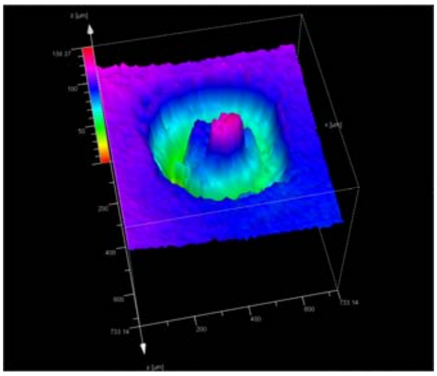

Fig.4. Reconstructed 3D image of the crater with distinct central-uplift. Maximum crater depth is ~ 60 μm from the original target surface. Central uplift is ~ 38 μm above the original target surface. Uplift diameter ~ 70 μm in the plane of the original target surface.

In this work we are reporting our preliminary results. Further theoretical analysis and simulation may explore the physics of simple craters and complex craters leading to the processes of astronomical importance. Further, this study is important for geologists, palaeontologists, plasma physicists, laser physicists, besides understanding the fundamental physics of cratering.

5. CONCLUSIONS:

High power laser interaction with the targets produce bowl shaped craters which are similar in shape and contour to meteorite produced craters. Diameter to depth ratio of the laboratory craters is reasonably similar to those of natural meteorite craters, implying an universal crater mechanism. Further, laboratory complex structured craters offer an interesting scheme to explore the large scale complex meteorite cratering mechanism.

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