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Analysis of Impact Craters using Optical Coherence Tomography.

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Introduction: Micrometeoroids and orbital debris (MMOD) in the near Earth environment are of significant interest for two reasons; the potential damage that they can cause to space assets and other anthropogenic objects, and in the case of extra-terrestrial particles – for the information they can provide on early solar system or parent body composition and processes.

Many space borne detectors utilize exposed surfaces and characterise MMOD from the analyses of impact craters between the surface and MMOD particles. The morphology of a crater can be used to calculate the flux, size, speed and trajectories of MMOD particles. Hence, innovative techniques for accurate crater analyses are important.

Previous flux estimates of the naturally occurring micrometeoroid particles put the flux arriving at the Earth at 40,000 tons per annum [1], with 90% of this burning up in the Earth's atmosphere prior to any surface bound evaluation on the surviving micrometeorites being able to be carried out [2].

There are thought to be trillions of objects larger than 100 µm in the near Earth environment [3]. Whilst the larger (>10 cm) of these particles are able to be remotely observed [4], we are only able to gain numerical information on the abundances of smaller particles via their impact rate on space exposed surfaces, *in situ* or returned.

Unfortunately, it is time consuming to perform an accurate count of the small size craters, as such measurements often rely on the ground based analysis of the surfaces via detailed Scanning Electron Microscope (SEM) maps of the surface and as such smaller features are often ignored in favour of a lower resolution, shorter time length scan.

OCT: Optical coherence tomography (OCT) is a non-contact optical imaging technique employing low-coherence interferometry to produce three-dimensional representations of translucent media with micron-sized resolution [5]. With opaque structures, OCT is capable of performing profilometry (surface-based) measurements, with a 5x5mm lateral scan being typically achieved in a few seconds, whilst simultaneously gaining depth profiles.

We are able to preview the area being imaged with a lower density scan, which can yield many cross-sectional views simultaneously, aiding in the identification of features – this is possible due to the Master-Slave OCT technique developed by the Applied Optics Group at the University of Kent group [6,7].

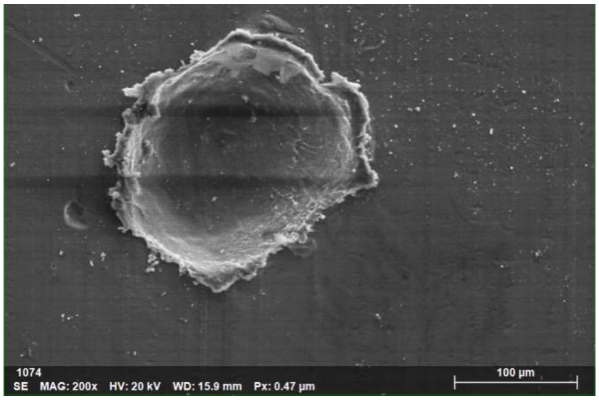

Figure 1: Example SEM secondary electron image of a crater formed following the impact of an ice particle at 1.5 kms^{-1}.

While SEM imaging provides accurate measurements of crater widths, it is difficult to achieve accurate depth measurements without using additional stereo software. As such, OCT can provide a less complex method for crater analysis with a shorter time scale. Here we present our work on the use OCT to analyse impact samples.

Impact Samples: The impact samples analysed were produced using the two-stage light gas gun (LGG) at University of Kent. The LGG is capable of firing a range of projectiles of sizes less than 4 mm in excess of 7 kms^{-1} [8].

In order to test the capability of OCT to analyse impact sites, thin aluminium foils were impacted at approximately 1.5 km/s with ice particles at a range of sizes. The resulting impact craters ranged in diameter between 2 µm and 400 µm. These craters were initially analysed using an SEM, as shown in Figure 1. The analysis was then repeated using the OCT system (Figures 2).

In addition to foil samples, analysis was also carried out on an aerogel sample, which had been impacted at 0.64 kms^{-1} by a three millimetre brilliant cut olivine (Fosterite 92) projectile fired by the LGG, following its passage through atmosphere at normal conditions [9].

Results: To date, we have been able to analyse impacts on aluminium foils for a range of projectile sizes. Our method enables both the depth profile and crater diameter to be measured. We are also able to produce 3D representations for further analysis of the crater morphology, as shown in figure 2.

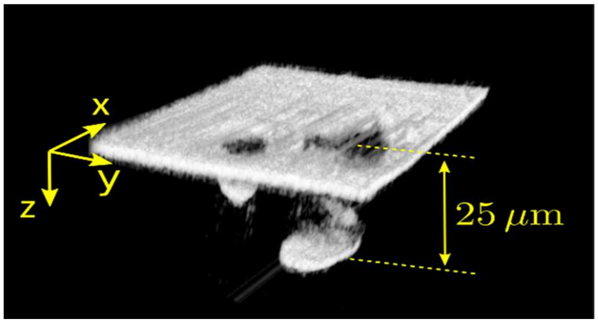

Figure 2: Showing two impact craters on x thick aluminium foil. The largest crater has a depth of 25μm and the smallest 15μm.

Imaging the surface of the foil took a few seconds (with around a minute to process and display a high density scan) , covering a 0.5x0.5mm^2 area. This scan was able to capture morphological details about the surface at a resolution of $\lesssim 10\mu m$. From these scans we are able to obtain a crater size distributions for a small area, along with crater morphology details including depth, interior shape, limited wall angle details and axis lengths. Scanning area is able to be increased via the use of mechanical stages and image montages, however for these preliminary scans this was not used.

Following analysis of the thin foil, we moved onto the analysis of the aerogel sample. The projectile was still embedded within the block approx. 1cm from the surface. Analyse prior to removal gives detailed map of the embedded projectile prior to its exposure to destructive processes or environments. Additionally, this allowed for the fracture patterns around the projectile to be mapped *in situ* giving a directly corresponding direction of travel for fragments which may otherwise collapse away from the main body during removal from the aerogel block.

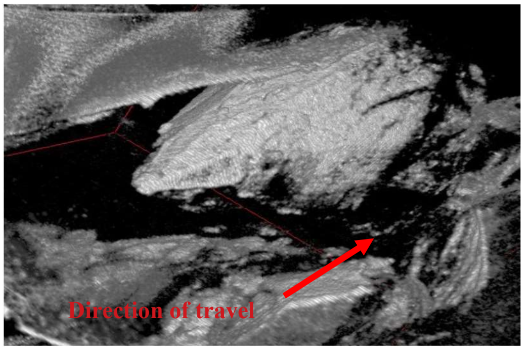

Figure 3: The tip of the 3mm olivine projectile imaged whilst embedded in the aerogel block.

.**Future Work:** In the near future we plan to add a motorised precision stage to the system to increase the scan range. This will allow us to expand our scanning area allowing large samples to be analysed in a single run via the use of montaged images. We also aim to improve the system resolution.

Whilst both of our initial tests have been carried out on commonly used, impacted material, we aim to demonstrate the feasibility of the technique of a number of other common external materials including solar arrays and radiator panelling

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