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Using Raman mapping to determine hypervelocity impact peak shock pressures in high purity silicon, germanium, gallium arsenide and peridot targets.

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Abstract

Raman mapping is used to determine shock induced shifts in various materials. The goal is to develop a 'barometer' that can be used to infer the shock history of a material. Preliminary results are presented for Si, Ge, GaAs and olivine.

1. Introduction

Impacts are ubiquitous throughout the Solar System and occur at all scales and at a range of speeds. However, on Earth, the only evidence we have of such events is through direct observation of impact flashes [1 - 3], or by looking at materials that fall onto the Earth as a result of such events (such as meteorites). Knowing the shock history of these meteorites would enable us to infer the impact energy of the event. However, although shocks are known to cause changes to minerals (such as phase changes, melting etc.) there has been (to date) very little work done to quantify such changes.

2. Impact Experiments

To help redress this lack of knowledge, impacts were performed using the two stage light gas gun (LGG) at Kent [4]. In these experiments monodisperse molybdenum spheres with a diameter of 50 microns were fired at speeds between 0.3 km s^{-1} – 4.5 km s^{-1} onto high purity wafers of silicon, germanium and (in one case) gallium-arsenide. Although these materials are not exactly relevant to Solar System impacts, they are extremely useful as they can be obtained with very high purities, known crystal orientations, and have a very clean, very strong Raman spectrum (indeed, silicon is a standard calibrator for Raman spectrometers). When stressed, the position of the distinctive Raman peak of each of these materials shifts in wavenumber due to the deformation of the crystal lattice. The amount of this shift (typically a few wavenumbers) is detectable with a high sensitivity Raman spectrometer, and thus the degree of impact induced stress within the material can be measured. For example, for silicon, the relationship between Raman shift, $\Delta\omega$ (cm^{-1}), and stress, σ (MPa), is $\sigma = -476\ \Delta\omega$ (using the average of the two expressions given in [5] and [6]). Similar expressions exist for pure germanium [7].

Table 1: Details of shock experiments.

Shot ID	Vel. (km s^{-1})	Target(s)
E090114#1	0.362	Si
E191213#1	0.382	Si
S290114#1	0.612	Si, Peridot
G221113#1	1.209	GaAs, Ge
G150114#1	1.569	Si, Peridot
G061113#1	2.090	Si
G131213#2	2.705	Si, Ge
G150114#2	3.030	Si, Peridot
G160114#1	4.170	Si, Peridot

Low speed gun: Although the Kent gun is a two stage LGG, we have recently developed the capability to fire at speeds significantly below 1 km s^{-1} (our lowest speed to date is 362 m s^{-1}). This is achieved by replacing our aluminium burst disk with a Mylar disc with a thickness of 250 µm, or an aluminium foil with a thickness of 50 µm. The launch tube is then pressurised until the burst disk ruptures, which then launches the sabot and projectile. The speed is tuneable by changing the gas that is used to pressurise the tube: N_2 (to get ~380 m s^{-1}), He (to get ~600 m s^{-1}), H_2 (to get ~1000 m s^{-1}). This means that we can fire onto brittle targets (such as silicon) at speeds that do not totally destroy the target. Indeed, our lowest speed shots at 362 m s^{-1} caused minimal damage to the surface of the silicon, merely circular 'bruises' with no visible damage to the surface, Figure 2 (A).

3. Results

After impact, the targets were removed from the target chamber, and then placed in a scanning electron microscope to get high resolution images (and stereo-pair) images of some of the impact craters (Fig. 1). These craters were then mapped using a Horiba *LabRam-HR* Raman spectrometer with a high power (500 mW) 532 nm laser. This spectrometer has a resolution of better than 1 $\mathrm{cm^{-1}}$, using an 1800 lines per mm grating and a 532nm wavelength laser. Using this system, very high resolution (100 × 100 pixel) maps could be obtained of a crater in approximately 10 hours (Figure 2). The maps were then processed, and contour maps produced to show the degree of stressing within the target. Detailed olivine data are also presented in [8].

Conclusions and on-going work

High resolution, high speed Raman mapping of silicon, germanium and gallium-arsenide wafers and gem quality olivine (peridots) that have been shocked by impact with high velocity metal spheres may provide a novel way of determining the peak shock pressure experienced by a material during an impact event. The shock deforms the lattice, and leaves a 'fingerprint' of the event. This lattice deformity causes a change in the Raman signature of the target from which the degree of strain that the lattice has experienced can be deduced. The shot programme has been finished (Table 1), and mapping of the craters, detailed analyses and hydrocode modelling are on-going and will be presented.

References

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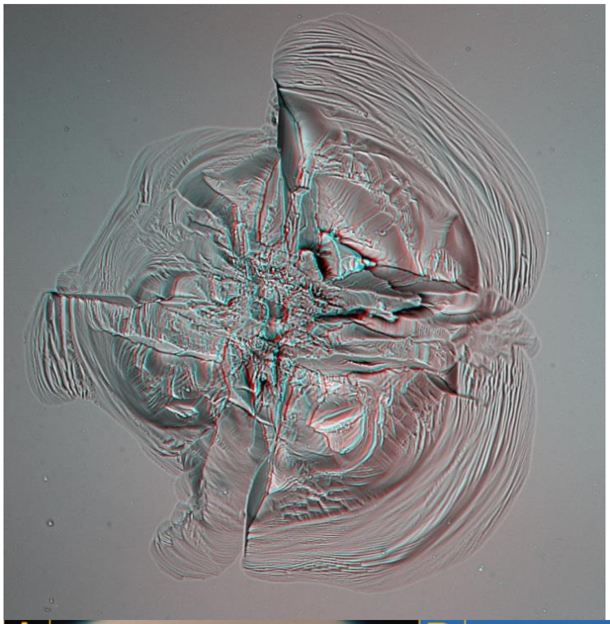

Figure 1 (left): 10 kV secondary electron anaglyph (red: left, cyan: right) SEM image of an impact crater on a [100] oriented silicon wafer impacted with a 50 µm diameter molybdenum sphere at 2.08 km $\mathrm{s^{-1}}$. The crater is 60 µm in diameter.

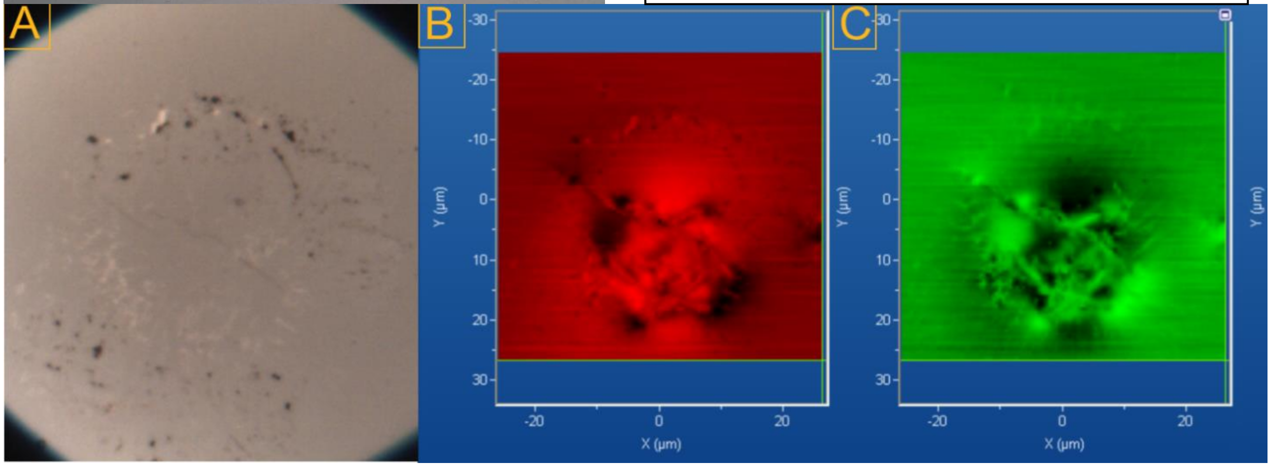

Figure 2 (below): **(A)** Optical image of a low speed (0.362 km $\mathrm{s^{-1}}$) 'bruise' on the surface of a silicon wafer. **(B)** Compression map showing the negative shift of the characteristic 520.6 $\mathrm{cm^{-1}}$ Si line. **(C)** Tension map showing the positive shift of the 520.6 $\mathrm{cm^{-1}}$ Si line. Higher intensity equates to greater shift, and thus higher tension or compression. The max. shift here is approx. ±4 $\mathrm{cm^{-1}}$, equivalent to a stress of ±1.9 GPa.