Deep subsurface, nanosecond laser induced modification of Si: phase transformation and solidification induced morphology

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The study of deep subsurface laser induced modifications is an active area of research. To date, a majority of the work has been concerned with insulators due to the wide parameter space available for laser processing. Investigations in semiconductors, such as Si, has been limited, despite being of obvious interest both for technological and material science purposes. This current work examines modifications in Si created with nanosecond regime pulse lengths. The resulting modifications are of ~1 m diameter and 10's of m height. They have technological applications as part of an alternative wafer dicing technique that can improve device yields. The emphasis here is on the characterisation of the modification by electron microscopy. This is challenging due to the difficulty in creating transmission electron microscopy (TEM) samples from modifications 10's or 100's of microns below the sample surface. Infrared microscopy guided tripod polishing combined with focussed ion beam milling is the approach used in this work.

TEM of these modifications, fig. 1, reveals a complex morphology of crystalline defects, voids, amorphous material and high density crystal phases. These features can largely be explained by a process involving laser induced melting, followed by rapid epitaxial. This process is complicated by the interplay between the interfacial free energy and interface kinetic coefficients along different crystal orientations, which results in different morphology depending upon the local thermal gradients. Furthermore, thermal gradient dependant transitions in solidification behaviour from crystallisation, to amorphisation occur, the result of which is shown in fig. 1a.

Variations in density are also of significance in explaining the resultant morphology. Initially, the high density of liquid Si, relative to ordinary diamond cubic Si, induces void formation. During solidification, these voids partially but incompletely refill. An example is shown in fig. 1b. Because of the entirely subsurface nature of these modifications, the displaced material must be accommodated by high density regions elsewhere in the sample. Simple compressive stress is clearly one such mechanism, although this also has its own influence on the solidification process. A second component is the formation of crystal phases with an elevated density, relative to ordinary diamond cubic Si. These phases have long been known in high pressure physics, but their manifestation in this work opens new, non-pressure related pathways to reach these exotic phases.

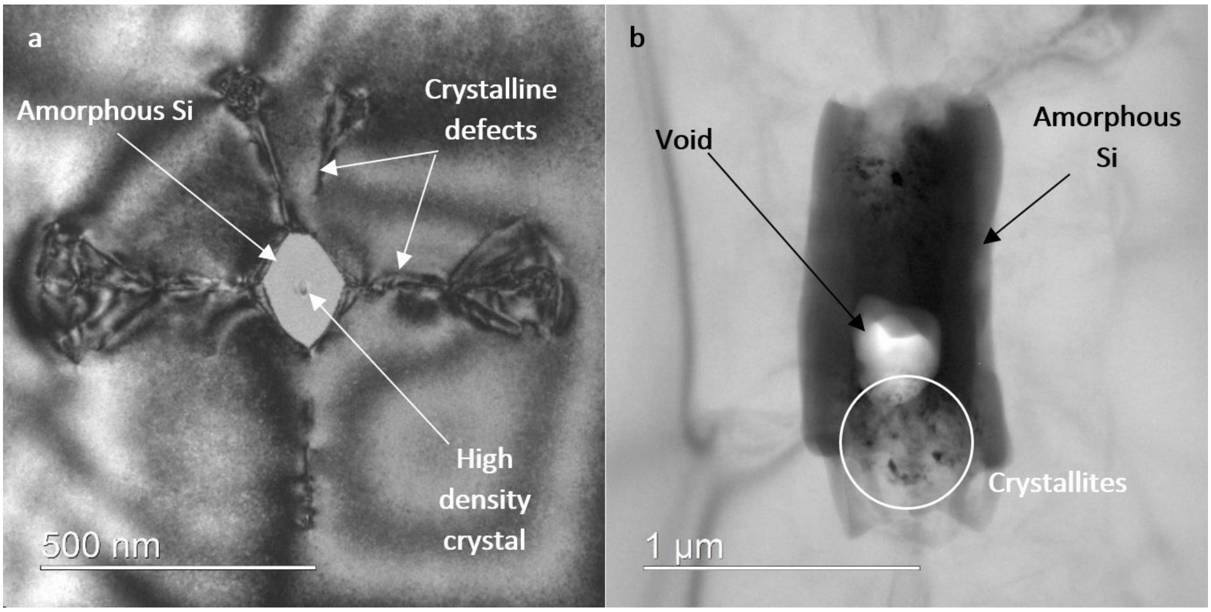

Figure 1. TEM images of sections of the laser induced modifications. An example of a short axis cross-section (a) recorded in BF reveals lines of crystalline defects extending from an amorphous region. The amorphous region encapsulates a crystallite of PT high density Si. A long axis cross-section (b) recorded in BF with the sample tilted to poorly diffracting conditions reveals a remanent void surrounded by amorphous Si and crystallites.