



# Defects Formed During Ion Beam Modification Of Diamond

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The doping of diamond for semiconductor use by ion implantation causes new problems compared with the well known cases of Si and GaAs. These problems are related to the strongly directional nature of carbon-carbon bonding and to the formation of C=C bonds. This results in the formation of a large variety of specific comparatively stable defects being formed upon ion implantation. The presence of the double bonded defects is expected to have a large influence on the electrical properties of the resultant material. Also as a consequence of these attributes of carbon, there is the problem of the metastability of diamond and the ease of graphite formation during implantation or annealing.

Raman spectroscopy was found to be sensitive to the presence of these specific defects and also to the overall level of damage produced in the sample when diamond was implanted with doses in the range of  $10^{16}$ - $10^{18}$  ions/cm<sup>2</sup> H or He with energies greater than 1 MeV. The main series of experiments discussed herein used  $1 \times 10^{16}$ - $3 \times 10^{17}$  ions/cm<sup>2</sup> of 3.5 MeV He<sup>+</sup>.

Use of a geometry, shown in Figure 1, in which ions were implanted into the edge of a diamond slab allowed the damage to be measured as a function of distance along the ion track by both Channeling Contrast Microscopy (CCM)<sup>1</sup> and Raman spectroscopy.

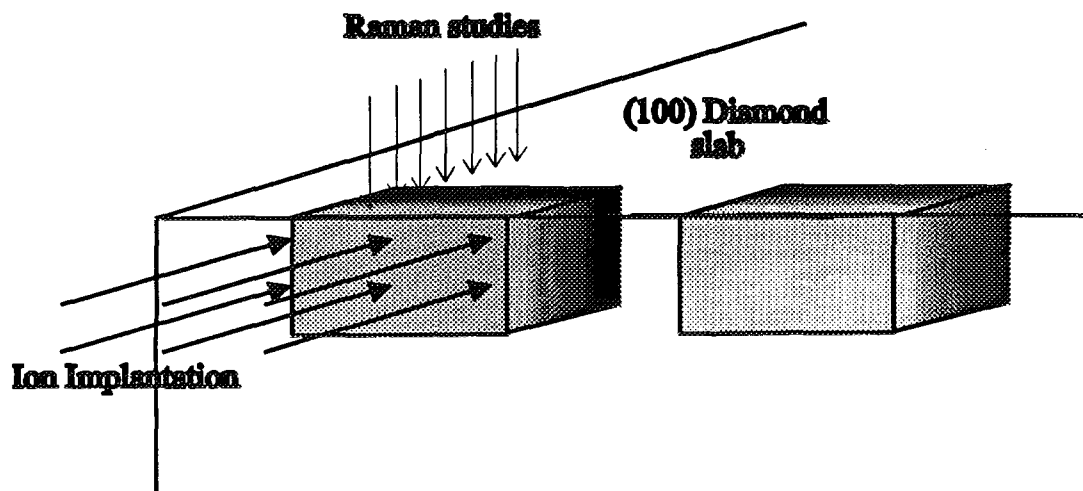


Figure 1. The geometry used for Raman (and CCM) studies relative to the original ion implantation.

Comparison of the data taken at the same distance along the ion track for the range of ion doses used showed that the shift in the diamond line position from that of virgin diamond was linear with ion dose. The shift in the diamond line to lower energy with increased dose is consistent with measurements of diamond under externally applied stress in that a shift to lower energy is observed for tensile stress, and the presence of defects in the lattice produces a tensile strain, evidenced by the swelling of the implanted region. The diamond line position was therefore confirmed to be a sensitive experimental measurement of damage. The shift in the diamond line as a function of distance along the ion path for a given dose was then compared with TRIM predictions. The comparison showed that TRIM overestimates the damage in the region approaching end of range, possibly due to the effects of dynamic annealing.

The specific defects mentioned above are characterised by a number of sharp peaks in the range  $1350\text{--}1700\text{ cm}^{-1}$ , the most important being those at  $\sim 1490\text{ cm}^{-1}$  and  $\sim 1630\text{ cm}^{-1}$ , as shown in Figure 2. The sharpness of the peaks indicates that only a limited number of specific defects are produced, rather than a range of related defects. The peaks have been further shown to be Raman rather than luminescence peaks by looking at the dependence of the spectrum on the exciting wavelength. These defects are produced when diamond is implanted with a range of ions, including H, He, C, P and As. As the same defect peaks are observed for a variety of ions, including C and He, the defects must contain only carbon atoms. The positions of the peaks in the Raman spectrum, at higher energy than the diamond peak, lead to the assignment of these peaks as arising from double bonded defects. Comparison of the dose dependence and annealing behaviour of the defect peaks showed that two main defects are formed, and these are respectively assigned as due to interstitial C atoms (giving rise to the  $1630\text{ cm}^{-1}$  peak) and to an ordered array of vacancies (most of the other peaks). Temperatures of up to  $1000^\circ\text{C}$  are required to anneal these defects.

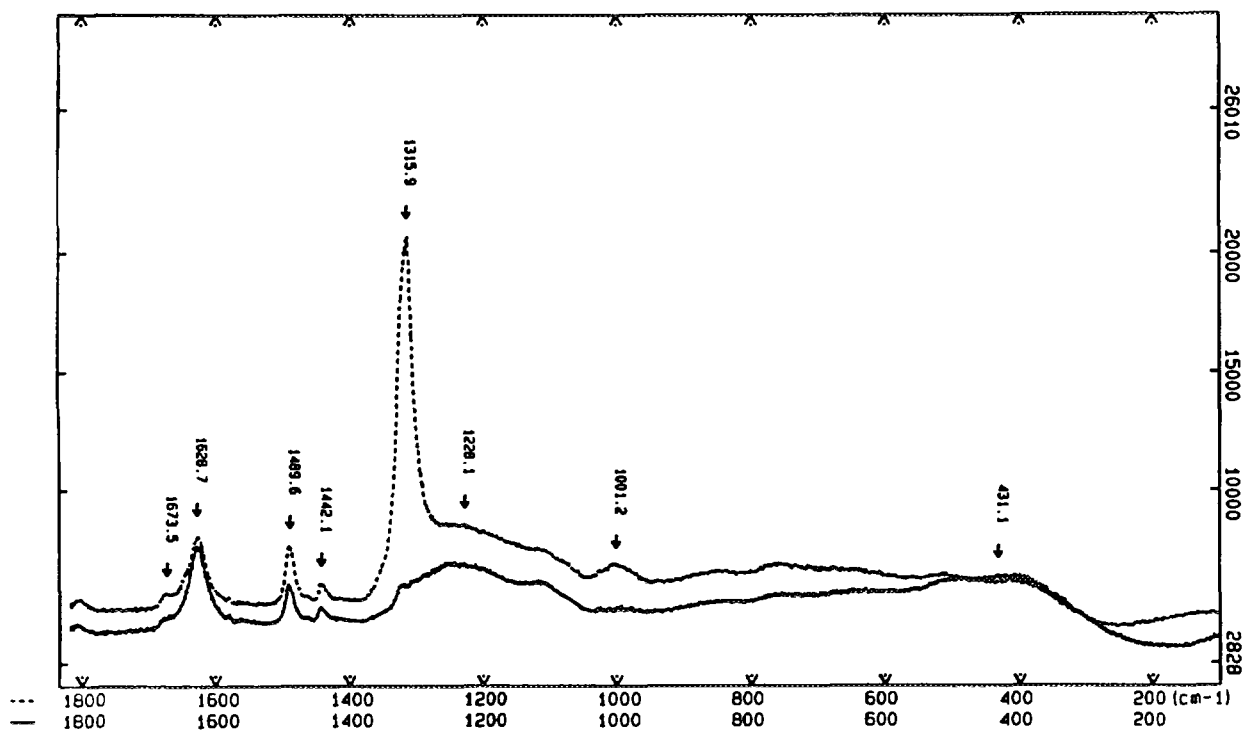


Figure 2. The Raman spectra for parallel and perpendicular polarisations of aligned (100) diamond implanted with  $1 \times 10^{17}$  ions/cm<sup>2</sup> 3.5 MeV He. The spectra were recorded near the beginning of the ion track. The perpendicular spectrum includes a strong diamond peak at  $1317\text{ cm}^{-1}$ . For unimplanted diamond this peak is observed at  $1332\text{ cm}^{-1}$ .

A further point of interest in the Raman spectrum is the presence of the broad peak to the low energy side of the diamond line. This is assigned as due to the presence of diamond like carbon (DLC, "amorphous diamond"), although it is very unlike the spectrum of chemically produced DLC, which is dominated by resonance enhanced peaks from  $sp^2$  clusters.

#### REFERENCES

1. Dooley, S.P, Jamieson, D.N, Nugent, K. W. and Prawer, S. "Transverse Microanalysis of High Energy Ion Implants" AINSE 1995