

# Electron Paramagnetic Resonance Imaging (EPRI) of defects in diamond.

M.E. Newton<sup>1</sup> and G.A. Watt<sup>2\*</sup>

<sup>1</sup>*Department of Physics, University of Warwick, Coventry CV4 7AL.*

<sup>2</sup>*Department of Physics, Clarendon Laboratory, Parks Road Oxford, OX1 3PU.*

Electron Paramagnetic Resonance Imaging (EPRI) is a powerful technique capable of providing information regarding the spatial localization of free radicals, oxygen and nitric oxide etc in the fields of biology and medicine. EPRI has also found application in materials science, where for example, it has been used to study the distribution of radiation damage induced paramagnetic species. Despite the capabilities of EPRI one serious technical limitation (for both continuous wave and pulsed techniques) is the relatively long time required for image acquisition, and efforts continue to develop fast EPRI techniques.

In this work, we report on studies investigating the usefulness of EPRI for investigating the distribution of paramagnetic defects in polycrystalline diamond. Large polycrystalline diamond films (e.g. up to 4 mm thick and 100 mm diameter) can be grown via chemical vapour deposition (CVD). The applications of this material are diverse and exploit the unique properties of diamond (e.g. optical, mechanical, thermal, radiation hardness etc). Microstructural and morphological properties are inherited from the film growth process. Hence, control of the evolution of these structural characteristics is an important goal of the CVD diamond growth processes. The crystallites in polycrystalline CVD diamond films predominately exhibit  $\langle 111 \rangle$  and  $\langle 100 \rangle$  facets. Which of these facets dominate the structure depends on the ratio of their relative growth velocity which is dependent on many different growth parameters. The rate of incorporation of impurities such as nitrogen depends markedly on the type of growth surface, and thus changes in incorporation of nitrogen as film grows thicker could indicate morphological changes. Conventional 1D EPRI has been used to investigate the changes in nitrogen incorporation [e.g. D.F. Talbot-Ponsonby, M.E. Newton and J.M. Baker, *J Appl. Phys.* 82 (3): 1201-1204 (1997)], and some of these results will be presented. In order to speed up image acquisition hardware and software to enable rapid passage EPRI were developed. Rapid passage EPRI makes use of the typically long relaxation times of EPR centres in diamond, and enables image acquisition with comparable signal to noise ratio approximately 100 quicker than conventional slow passage imaging. Using  $\partial B/\partial z$  gradients up to  $300 \text{ Gcm}^{-1}$  1D images of the variation of incorporation of nitrogen (parallel to the growth direction) were obtained with a spatial resolution of  $10 \mu\text{m}$ , and it was confirmed that the distributions obtained from slow passage and rapid passage experiments were identical. The critical experimental details and the implications of the results will be discussed.

In addition to the paramagnetic single substitutional nitrogen defect, another common defect in polycrystalline CVD diamond is the H1 centre which consists of an unpaired electron coupled to a hydrogen atom approximately 0.2 nm away. This defect is probably formed by a hydrogen atom entering a stretched C-C bond at a grain boundary (or in inter-granular material), allowing the carbons to relax back, one bonding to the hydrogen and the other with an unpaired electron predominately localized in its dangling bond. 1D spectral-spatial EPRI (parallel to the growth direction) has been used to investigate the incorporation of both H1 and single substitutional nitrogen in polycrystalline CVD diamond films, and these results will be discussed. Furthermore, 2D EPRI has been used to correlate the H1 defect with the incorporation of non-diamond material/low quality polycrystalline diamond CVD.

## Acknowledgements

This work was supported by the Engineering and Physical Sciences Research Council, and we thank Element Six Ltd and Professor Jim Butler (Naval Research Laboratory, USA) for the provision of samples.

\*Current address: HR Wallingford Ltd, Howbery Park, Wallingford, Oxfordshire, OX10 8BA, UK.