Rapid characterization of threading dislocations in diamond via coincident cathodoluminescence and electron channeling contrast imaging

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Diamond is an attractive wide bandgap semiconductor with application as a host for useful point defects such as the N-V center for solid-state quantum technologies, as well as in diodes and transistors for power electronics and radiation detectors[1]. Synthetic diamond substrates and epitaxial films are commonly grown by chemical vapor deposition (CVD), which often results in crystalline defects like dislocations. To achieve reliable growth of single-crystal diamond wafers and devices, the relationship between CVD process parameters, device design, and the resulting defects (i.e. a processing feedback loop) must be established. While transmission electron microscopy, x-ray topography, and etch-pit formation methods remain gold standards in defect characterization in diamonds[2,3,4], the laborious, destructive, and costly nature of these techniques sacrifice the efficiency of the feedback loop. In this work, we demonstrate dislocation characterization on a single crystal diamond using electron channeling contrast imaging (ECCI) in a scanning electron microscope (SEM) and highlight the applicability of this technique widely used in other semiconductors also to diamond.

As it is challenging to obtain sufficient backscattered electron (BSE) signal from diamond given its low atomic number[5], we optimize microscope conditions to best overcome this challenge. In doing so, we can consistently observe features in BSE images with ECCI contrast in a test structure of single crystal (001)-oriented CVD diamond sample with a 2.5 μm homoepitaxial boron doped layer. These features indicate threading dislocations as confirmed by the reversal of their contrast as we move from one edge of the channeling band to the other[6]. Furthermore, we explore the A-band blue luminescence properties of the sample using cathodoluminescence (CL) imaging of the same micron-wide observational regions. In line with literature[4], we find that all observed luminescence connects to dislocations identified by ECCI, whereas the converse was not always true. CL spectra recorded from individual dislocations also revealed a 430 nm broad peak. Our results highlight the complementary nature of ECCI and CL imaging in diamond where dislocations can be luminescent but also caution against the sole use of CL in high defect density samples as this could lead to an underestimation of the defect density. Hypotheses for non-emitting dislocations will be discussed in the current system. In summary, the statistical study of extended defects in diamond with the convenience of the SEM provides a pathway for an efficient and reliable characterization feedback loop for

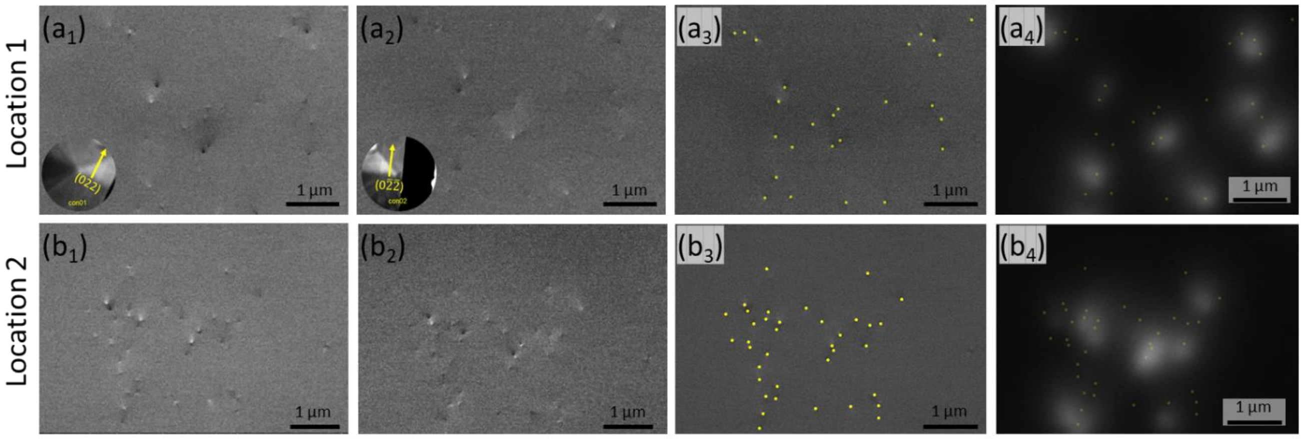

Fig. 1 –ECCI and CL images of two different regions in a single crystal (001)-oriented CVD diamond sample. (a$_1$, b$_1$) were imaged near the (022) channeling band edge whereas (a$_2$, b$_2$) were near $(0\bar{2}\bar{2})$. The bright/dark spots indicative of threading dislocations are marked with yellow dots in (a$_3$, b$_3$), which are also overlaid in CL images of the same area in (a$_4$, b$_4$). Note that observed luminescence connects to dislocations identified by ECCI, and not all dislocations are luminescent.

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