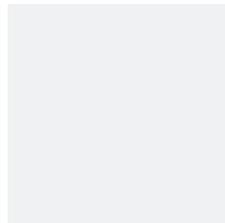


Cathodo-  
luminescence

## Luminescent defects in synthetic CVD diamond films localized by Cathodoluminescence spectroscopy



Application  
Note  
  
Material  
Science  
CL29

Alexandre Tallaire<sup>a</sup>, Vianney Mille<sup>a</sup>, Ophélie Lancry<sup>b</sup> and Didier Hocrelle<sup>c</sup>  
<sup>a</sup>Laboratoire des Sciences des Procédés et des Matériaux, CNRS, 93430 Villetaneuse, France  
<sup>b</sup>HORIBA Scientific, 231 rue de Lille, 59650 Villeneuve d'Ascq, France  
<sup>c</sup>HORIBA Scientific, Avenue de la Vauve, 91120 Palaiseau, France

### Abstract

The characterization of synthetic CVD diamond material by hyperspectral cathodoluminescence spectroscopy and imaging allows the detection and accurate location of the promising NV luminescent point defects for innovative solid-state quantum mechanical systems.

**Keywords:** Cathodoluminescence spectroscopy, imaging, panchromatic image, SEM (Scanning Electron Microscopy), defect, synthetic diamond, semiconductor

Luminescent defects in single crystal diamond are the focus of intense research activities due to a broad range of possible applications in quantum computing, cryptography and magnetometry. Among them, the so called Nitrogen-Vacancy (NV) centre is particularly promising due to exceptionally long spin coherence times at room temperature. The spin state of this defect can also be optically manipulated and read-out which could pave the way to innovative solid-state quantum mechanical systems. In this context, the Plasma Assisted Chemical Vapour Deposition (PA-CVD) technique has emerged as a very efficient way to directly create such defects during epitaxial growth of diamond. However the creation of a given NV density in a high-purity diamond matrix is still very challenging. Besides, most applications require the defects to be spatially localized in the crystal so that they can be easily addressed and manipulated. In this work we performed CVD epitaxial growth on a pattern of micro-pillars etched on a diamond substrate. Cathodoluminescence (CL) analysis revealed that NV centres were successfully localized at the edges of the pillars.

### Fabrication of the diamond micro-pillars

Cylindrical pillars with a diameter of 20  $\mu\text{m}$  and a height of 5  $\mu\text{m}$  were etched on a High Pressure High Temperature (HPHT) synthetic diamond substrate (Fig. 1a).

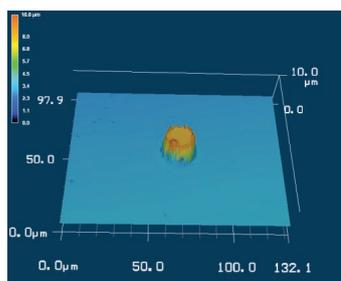


Fig. 1. (a) 3D laser microscope images showing the HPHT diamond pillar after etching

To this end, standard optical lithography techniques and plasma etching in Ar/O<sub>2</sub> were used. PACVD diamond growth was then performed in a H<sub>2</sub>/CH<sub>4</sub> mixture with intentional addition of 0.5 ppm N<sub>2</sub> in a home-made system. Growth conditions were adapted so that growth essentially proceeds laterally from the pillar, in the <110> directions, while almost no growth should occur in the vertical direction. The pillar ended up having a pyramidal shape with clear faceting (Fig. 1b).

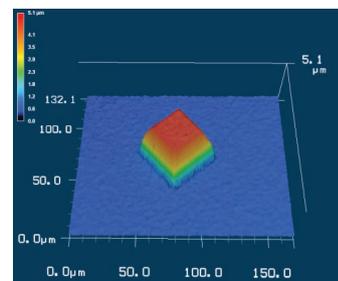


Fig. 1. (b) 3D laser microscope images showing the same pillar after CVD growth

### Cathodoluminescence analysis

Cathodoluminescence analysis was carried out using a HCLUE system mounted on a ZEISS EVO MA 15 Scanning Electron Microscope (SEM) equipment and operated at 10 kV with a current of 2 nA. The light emitted by the sample under the impinging electron beam was collected by a parabolic mirror and sent to a IHR 550 spectrometer for analysis using either a Photomultiplier tube (fast imaging mode) or a CCD camera (hyperspectral mode). The sample was kept at room temperature during analysis.

The SEM image of Fig. 2a shows the morphology of the pyramidal diamond pillar. The panchromatic CL image (Fig. 2b) reveals the hybrid HPHT-CVD diamond structure where the central part corresponds to the initial cylindrical pillar, and the lateral part the CVD-grown material.

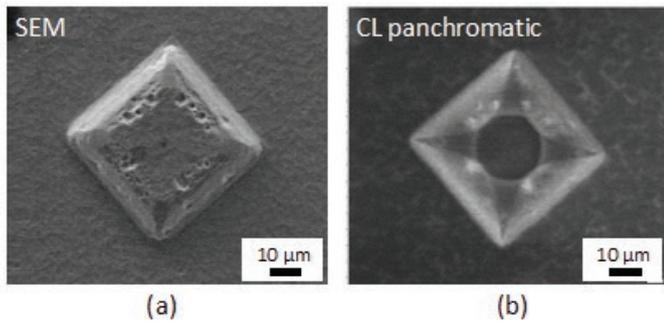


Fig. 2. (a) SE image of the hybrid HPHT/CVD pyramid, (b) panchromatic CL image

A spectral mapping of the pillar (Fig. 3a) was carried out in order to resolve the spatial distribution of the NV defects. The red emission spectrum (Fig. 3b) corresponds to the emission spectrum of the NV centres in their neutral state (NV<sup>0</sup>): both the Zero Phonon Line (ZPL) at 575 nm and the phonon side-bands of NV<sup>0</sup> are observed. The blue colour area is indicative of a region with no luminescence at 575 nm. The hyperspectral CL image confirms that the bright luminescence observed in the panchromatic CL image mostly originates from NV defects. The star-shape pattern corresponds to their non-uniform incorporation in the different growth sectors.

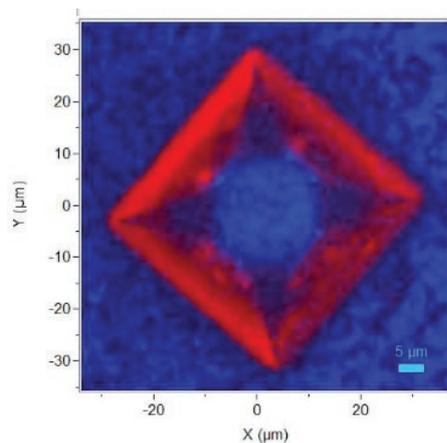


Fig. 3. (a) Classical Least Square (CLS) fitting using multivariate analysis allowing the identification of the substrate and CVD layer region from their emission spectrum

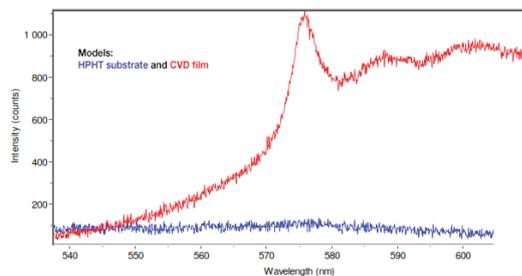


Fig. 3. (b) Luminescence spectra corresponding to the central HPHT substrate region (blue) and to the lateral CVD film region (red). Bright emission from NV centres at 575 nm is detected.

## Conclusion

Nitrogen-Vacancy centres were successfully spatially localized at the edges of a pyramidal structure made of CVD diamond. Conditions were chosen so that growth only occurred in the lateral direction with almost no vertical growth. NV centres were preferentially incorporated in the lateral sides of the CVD-grown diamond. The fabrication of diamond microstructures and arrays is believed to pave the way to innovative solid-state quantum mechanical systems making use of the exceptional properties of NV luminescent defects. In that sense cathodoluminescence is a useful tool allowing identifying and localizing such defects and their environment.

## Acknowledgements

This work is part of the European Community's Seventh Framework Programme (FP7/20072013) under Grant Agreement no 611143 (DIADEMS project). The CL set-up was partially funded by C'Nano Ile de France.

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