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Luminescence centers in proton irradiated single crystal CVD diamond

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ABSTRACT

Diamond displays a large variety of luminescence centers which define its optical properties and can be either created or modified by irradiation. The main purpose of the present work is to study the radiation hardness of several of such centers in homoepitaxial single-crystal CVD diamond by following the evolution of photoluminescence and ionoluminescence upon 2 MeV proton irradiation. Luminescence decays were observed with values of the fluence at half of the starting luminescence ($F_{1/2}$) of the order of 10^{14} cm^{-2}. The 3H center displayed a non-monotonic behavior, with a growing behavior and a subsequent decay with a rather high $F_{1/2}$ value (in the order of few a 10^{16} cm^{-2}), maintaining at the highest fluences an intensity significantly higher than the blue A-band. A simple model based on a double-exponential trend was defined to fit with satisfactory accuracy the evolution of the 3H center. Several PL centers (namely: 3H, TR12, 491 nm and 494 nm) exhibited clear correlations and anti-correlations in their fluence dependences, which were considered in the attempt to acquire some insight into their possible alternative attributions.

1. Introduction

Artificial and natural diamonds, in either polycrystalline or monocrystalline form, display a vast variety of optical centers [1], most of which display specific sensitivity to radiation-induced structural damage (induced by electrons, ions, etc.). This implies that such centers are related to specific structural defects in the diamond lattice, and thus can be not only quenched, but also created by radiation itself.

The "radiation hardness" is an important parameter characterizing different luminescence centers, both for fundamental research on the dynamics of defects formation in diamond, and for several applications, such as the employment of these centers as scintillators in radiation detectors [2], or for applications in photonics (i.e. single photon emitters) in which radiation-induced damage is employed as a tool to control their formation [3].

Ionoluminescence (IL) is a powerful and direct method that allows the monitoring in real time of the quenching of intrinsic luminescence during irradiation, as well as the investigation of the more complex evolution of luminescence centers created by irradiation itself [2,4,5]. Moreover, IL has the advantage of both inducing structural changes in the material and exciting the related luminescence centers from very specific regions of the sample, since both the nuclear and the electronic energy loss (which are respectively responsible for the two processes) are characterized by well defined profiles which can be readily simulated with Monte Carlo codes, such as SRIM [6].

In this work the evolution of optical centers in CVD single crystal diamond upon 2 MeV proton irradiation was monitored in real time by means of IL as a function of radiation fluence (up to 10^{17} cm^{-2}, corresponding to about $7 \cdot 10^9$ Gy). Moreover, photoluminescence (PL) was performed on regions implanted at increasing fluences, representing a complementary approach in the study of the evolution of luminescent centers upon ion-induced damage.

In order to have more flexibility in the acquisition of extended spectra or in the monitoring of specific emissions, IL was collected using a versatile double apparatus consisting in a CCD detector array allowing the acquisition of spectra in the 200–900 nm spectral range, and in a grating monochromator coupled with a photomultiplier to follow the trend at a specific wavelength with more sensitivity and fastness.

The IL and PL results are presented and discussed in order to obtain new insight in the study of radiation-related luminescent centers in diamond, particularly with regards to the new generation of homoepitaxial CVD monocrystalline samples that has been developed in recent years.

2. Experimental

The samples under analysis are type IIa single crystal diamonds grown with Chemical Vapor Deposition (CVD) technique by Element-Six with size $3.0 \times 3.0 \times 0.5$ mm^3 [7]. The crystals consist of a single {100} growth sector and the concentrations of nitrogen and boron impurities are below 0.1 ppm and 0.05 ppm, respectively.

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