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Controlled variation of the refractive index in ion-damaged diamond

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ABSTRACT

A fine control of the variation of the refractive index as a function of structural damage is essential in the fabrication of diamond-based optical and photonic devices. We report here about the variation of the real part of the refractive index at $\lambda = 632.8$ nm in high-quality single-crystal diamond damaged with 2 and 3 MeV protons at low-medium fluences (10^{13}–10^{17} ions cm^{-2}). After implanting the samples in 125×125 μm^2 areas with a raster scanning ion microbeam, the variation of optical thickness of the implanted regions was measured with laser interferometric microscopy. The results were analyzed with a model based on the specific damage profile. The technique allows the direct fabrication of optical structures in bulk diamond based on the localized variation of the refractive index, which will be explored in future works.

1. Introduction

Since many years diamond has been considered the ultimate material in many optical applications. Diamond optical devices are ideal in extreme physical conditions where low optical absorption is required together with efficient heat dissipation and structural resistance (i.e. laser fan-out and diffractive elements, RF power optics, high-vacuum windows, optical micro-electromechanical systems, etc) [1–8]. More recently, diamond attracted wide interest as a prominent candidate for the implementation of quantum information processing schemes with the employment of defect-based single color centers as single photon emitters or quantum bit storage elements [9–11]. In 2009 it was proposed that the local alteration of the refractive index can be employed in the fabrication of diamond-based photonic devices, such as photonic crystals and high-Q microcavities [12].

The variation of refractive index of single-crystal diamond as a function of structural defect density has been investigated in a surprisingly limited number of works [13–16] and no systematic data have been reported on the variation of the refractive index in diamond in the low-damage-density regime. Our paper represents a systematic study of the variation of the real part of the refractive index of single diamond at $\lambda = 632.8$ nm as a function of MeV-ion-induced structural damage. This specific wavelength is very close to the NV^- emission, which is of extreme interest in the emerging field of diamond-based quantum optics and photonics [9–11].

2. Experimental

This study was carried out on two $3.0 \times 3.0 \times 0.5$ mm^3 samples of type IIa single-crystal diamonds grown with Chemical Vapour Deposition (CVD) technique by ElementSix [17]. The crystals consist of a single {100} growth sector, with concentrations of nitrogen and boron impurities below 0.1 ppm and 0.05 ppm, respectively. The crystals are cut along the <100> axes and the two opposite faces of the samples are optically polished.

The samples were implanted at the external scanning microbeam facility of the LABEC laboratory in Firenze [18]. The beam was focused on the polished side of the samples to a spot of ~10 μm and ~20 μm, for 3 and 2 MeV protons, respectively.

The ion current varied between 0.2 nA and 1.5 nA. For each implantation, the ion beam was raster scanned over a square area of $\sim 125 \times 125$ μm^2, in order to deliver a homogeneous fluence in the central region; the samples were implanted at fluences ranging from $\sim 10^{13}$ cm^{-2} to $\sim 10^{17}$ cm^{-2}. The beam charge was measured in real time by monitoring the X-ray yield from the beam exit window [18], resulting in ~3% accuracy in the determination of the implanted charge. The actual size of the implanted area was subsequently evaluated for each implantation as the area in which the measured optical path difference (OPD) lies above the half-maximum value. The sizes dispersion (about 1.5%) was assumed to be equal to the uncertainty in

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