www.nature.com/scientificreports

SCIENTIFIC REPORTS

OPEN

# Refractive index variation in a free-standing diamond thin film induced by irradiation with fully transmitted high-energy protons

Received: 9 September 2016
Accepted: 22 February 2017
Published online: 24 March 2017

S. Lagomarsino[1,2], S. Calusi[3], M. Massi[2], N. Gelli[2], S. Sciortino[1,2], F. Taccetti[2], L. Giuntini[1,2], A. Sordini[4], M. Vannoni[4,11], F. Bosia[5,6,7], D. Gatto Monticone[5,6,7], P. Olivero[5,6,7], B. A. Fairchild[8,10], P. Kashyap[8], A. D. C. Alves[8], M. A. Strack[8], S. Prawer[8] & A. D. Greentree[9]

**Ion irradiation is a widely employed tool to fabricate diamond micro- and nano-structures for applications in integrated photonics and quantum optics. In this context, it is essential to accurately assess the effect of ion-induced damage on the variation of the refractive index of the material, both to control the side effects in the fabrication process and possibly finely tune such variations. Several partially contradictory accounts have been provided on the effect of the ion irradiation on the refractive index of single crystal diamond. These discrepancies may be attributable to the fact that in all cases the ions are implanted in the bulk of the material, thus inducing a series of concurrent effects (volume expansion, stress, doping, etc.). Here we report the systematic characterization of the refractive index variations occurring in a 38 µm thin artificial diamond sample upon irradiation with high-energy (3 MeV and 5 MeV) protons. In this configuration the ions are fully transmitted through the sample, while inducing an almost uniform damage profile with depth. Therefore, our findings conclusively identify and accurately quantify the change in the material polarizability as a function of ion beam damage as the primary cause for the modification of its refractive index.**

Diamond is emerging as a promising platform for the development of integrated photonic devices, due to the appealing properties (quantum efficiency and photo-stability, spin-preserving transitions and room temperature operation) of a vast range of defect-related colour centres[1–5], which can be incorporated in the broadly transparent crystal matrix of diamond by ion implantation[6–8]. Different integrated photonic devices were created in diamond to take advantage of the unique properties of the above-mentioned centres by means of different microfabrication strategies, many of which rely on the use of energetic ion beams to both fabricate photonic microstructures[9–13] and fine-tune their refractive index[14, 15]. The structural effects of both MeV ion beam[15] and femto-second laser pulse[16, 17] irradiations have been used to directly write waveguides in bulk diamond. In particular, Focused Ion Beam (FIB) techniques are well-established in the fabrication of optical/photonic nanostructures in diamond[18, 19]. In this context, the accurate control over both intentional and unintentional variations of the refractive index of the material is of paramount importance for the development of photonic devices with the desired functional properties.

The effect of ion-induced structural damage on the refractive index in diamond was observed for the first time in the 60 s[20] and qualitative observations have more recently been reported[21]. However, only in recent years

[1]Department of Physics and Astronomy, University of Firenze, Firenze, Italy. [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Firenze, Firenze, Italy. [3]Department of Experimental and Clinical Biomedical Sciences "Mario Serio", University of Firenze, Firenze, Italy. [4]Istituto Nazionale di Ottica (INO), CNR, Firenze, Italy. [5]Physics Department and NIS Inter-departmental Centre, University of Torino, Torino, Italy. [6]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Torino, Torino, Italy. [7]Consorzio Nazionale Interuniversitario per le Scienze fisiche della Materia (CNISM), Sezione di Torino, Torino, Italy. [8]School of Physics, University of Melbourne, Melbourne, Australia. [9]Australian Research Council Centre of Excellence for Nanoscale BioPhotonics, RMIT University, Melbourne, 3001, Australia. [10]Present address: Royal Melbourne Institute of Technology (RMIT), Melbourne, Australia. [11]Present address: European XFEL GmbH, Hamburg, Germany. Correspondence and requests for materials should be addressed to P.O. (email: paolo.olivero@unito.it)