Nuclear Inst. and Methods in Physics Research B 435 (2018) 318–322

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Quantum-optical characterization of single-photon emitters created by MeV proton irradiation of HPHT diamond nanocrystals

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ARTICLE INFO

Keywords:
Diamond
Nano-diamond
NV center
Single-photon source
Radiation damage
Ion irradiation

ABSTRACT

Deterministic single-photon sources are a fundamental tool for several emerging applications in quantum sensing and quantum metrology. In these fields, the exploitation of individual quantum systems could significantly improve the current measuring capabilities and define a new generation of standard measure units. In addition, the availability of nanoscale-sized single-photon emitters is also of considerable interest, as it enables a further integration with external structures or biological samples.

In this work, we investigate the role of MeV proton irradiation in the production of single-photon emitters based on the nitrogen-vacancy complex (NV center) in nanodiamonds (NDs). Powders of nitrogen-containing type Ib diamond nanocrystals with a median size distribution of 80 nm were irradiated with 2 MeV protons at $5 \times 10^{13}\,cm^{-2}$ fluence with the purpose of creating vacancies and thus promote the formation of NV centers upon a subsequent thermal annealing. Following a suitable chemical processing, the ND powders were characterized in their opto-physical properties by means of a single-photon-sensitive confocal photoluminescence microscopy setup equipped with a "Hanbury Brown & Twiss" interferometer, enabling the measurement of the second-order autocorrelation function characterizing the PL emission. A comparison with two reference batches of unirradiated NDs powder, which only underwent the chemical, and the chemical and thermal treatment, respectively, enabled to assess the role of ion implantation in the production of single-photon sources.

1. Introduction

Single-photon sources (SPSs) play a key-role in the development of emerging quantum technologies [1,2]. In particular, diamond is an appealing material for SPSs fabrication, as its large energy band gap can host a wide range of optically active centers with appealing emission properties [3,4]. The negatively charged nitrogen-vacancy complex (NV^{-}) is arguably the most widely studied color center in diamond, due to its unique photo-physical properties (quantum efficiency, spin-sensitive transitions, high spin coherence time, etc.) at room temperature [5,6]. Even if an ideal SPS (i.e. an "on-demand" and efficient emitter of indistinguishable single photons at an arbitrarily fast repetition rate) is far from being realized due to several technological constraints, a vast effort from the scientific community is currently dedicated to the improvement in the performance of real sources [7], as well as to their integration in photonic devices [8–10] and to the development of reliable fabrication processes [11–12]. In this paper we report on the fabrication by MeV ion irradiation and subsequent quantum-optical characterization of SPSs based on single NV centers embedded in individual nanodiamonds (NDs). The availability of nanoscale-sized SPS systems is especially appealing for biological research and imaging [13–15], as well as high-sensitivity electromagnetic field sensors [16,17] and quantum key distribution applications [18]. The irradiation protocol was implemented on a batch of NDs powder characterized by a small fraction of particles containing native NV centers. At the same time, the investigated NDs were characterized by a moderately high concentration of native substitutional N, being classified as "type Ib" according standard nomenclature in diamond science. The SPSs creation was therefore achieved upon the introduction of lattice vacancies through radiation damage and a subsequent annealing, with the purpose of promoting the formation of nitrogen-vacancy complexes [19–21]. The typical emission properties of NV-based SPSs in NDs is then presented and discussed. Finally, as the thermal annealing process in itself was reported to result in the formation of NV centers even in

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https://doi.org/10.1016/j.nimb.2018.02.031
Received 14 July 2017; Received in revised form 26 February 2018; Accepted 26 February 2018
Available online 08 March 2018
0168-583X/