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Fluorine-based color centers in diamond

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We report on the creation and characterization of the luminescence properties of high-purity diamond substrates upon F ion implantation and subsequent thermal annealing. Their room-temperature photoluminescence emission consists of a weak emission line at 558 nm and of intense bands in the 600–750 nm spectral range. Characterization at liquid He temperature reveals the presence of a structured set of lines in the 600–670 nm spectral range. We discuss the dependence of the emission properties of F-related optical centers on different experimental parameters such as the operating temperature and the excitation wavelength. The correlation of the emission intensity with F implantation fluence, and the exclusive observation of the afore-mentioned spectral features in F-implanted and annealed samples provides a strong indication that the observed emission features are related to a stable F-containing defective complex in the diamond lattice.

Diamond has been widely investigated as an appealing material for quantum optics and quantum information processing applications, due to the availability of several classes of optically active defects (usually referred to as “color centers”) that can be suitably engineered in its crystal structure[1–3]. To date, the most prominent type of defect is the so-called negatively-charged nitrogen-vacancy center (NV^-), due to several key features of this system, namely: photo-stability at room temperature, high quantum efficiency and most importantly unique spin properties with great potential for applications in quantum sensing and computing[4–9].

The need for single-photon emitters displaying desirable opto-physical properties (high emission rate, narrow linewidth) has also motivated the discovery and characterization of several classes of optical centers in diamond alternative to the NV complex, based (among others) on group-IV impurities[10] (Si[11,12], Ge[13,14], Sn[15,16], Pb[17,18]) and noble gases (He, Xe[19–21]). In this context, ion implantation represents a powerful and versatile tool to engineer a broad range of different types of color centers, allowing for the fine control of key parameters such as ion species and energy, as well as irradiation fluence to determine the type and density of defect complexes[22,23].

Up to now though, the number of the emitters characterized by a reproducible fabrication process is fairly limited, and a systematic investigation in this field is still to be finalized. Thus, the fabrication of novel luminescent defects with desirable properties upon the implantation of selected ion species still represents a crucial strategy to achieve further advances in the field. Following from a previous report with preliminary results on this system[24], in this work we report on the systematic characterization in photoluminescence (PL) under different optical excitation wavelengths of F-related color centers in diamond created upon ion implantation and subsequent annealing.

Experimental

The characterization of F-related emission here presented was performed on a type-IIa single-crystal diamond sample (*Sample #1*) produced by ElementSix with Chemical Vapor Deposition technique, namely a $2 \times 2 \times 0.5$ mm^3 “electronic grade” substrate having nominal concentrations of both substitutional nitrogen and boron impurities below the 5 ppb level.

The sample was implanted with 50 keV F^- ions at the low-energy accelerator of the University of Leipzig. Several circular regions of ~ 175 µm diameter were irradiated at varying fluences in the 5×10^{10}–5×10^{15} cm^{-2} range by the use of a custom beam collimator. An additional region was implanted with 1.47 MeV F^{2+} ions (1×10^{13} cm^{-2} fluence) at the Laboratory for Ion Beam Interactions of the Ruđer Bošković Institute. The sample

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