Efficiency Optimization of Ge-V Quantum Emitters in Single-Crystal Diamond upon Ion Implantation and HPHT Annealing

*Elena Nieto Hernández, Elisa Redolfi, Claudia Stella, Greta Andrini, Emilio Corte, Selene Sachero, Sviatoslav Ditalia Tchernij, Fabio Picariello, Tobias Herzig, Yuri M. Borzdov, Igor N. Kupriyanov, Alexander Kubanek, Paolo Olivero, Jan Meijer, Paolo Traina, Yuri N. Palyanov, and Jacopo Forneris**

The authors report on the characterization at the single-defect level of germanium-vacancy (GeV) centers in diamond produced upon Ge^{-} ion implantation and different subsequent annealing processes, with a specific focus on the effect of high-pressure-high-temperature (HPHT) processing on their quantum-optical properties. Different post-implantation annealing conditions are explored for the optimal activation of GeV centers, namely, 900 °C 2 h, 1000 °C 10 h, 1500 °C 1 h under high vacuum, and 2000 °C 15 min at 6 GPa pressure. A systematic analysis of the relevant emission properties, including the emission intensity in saturation regime and the excited state radiative lifetime, is performed on the basis of a set of ion-implanted samples, with the scope of identifying the most suitable conditions for the creation of GeV centers with optimal quantum-optical emission properties. The main performance parameter adopted here to describe the excitation efficiency of GeV centers as single-photon emitters is the ratio between the saturation optical excitation power and the emission intensity at saturation. The results show an up to eightfold emission efficiency increase in HPHT-treated samples with respect to conventional annealing in vacuum conditions, suggesting a suitable thermodynamic pathway toward the repeatable fabrication of ultra-bright GeV centers for single-photon generation purposes.

1. Introduction

Color centers in diamond represent an emerging class of solid-state systems for single-photon emission,[1–8] with appealing applications in quantum-enhanced technologies, including quantum information processing and quantum sensing.[9–18] Among them, point-defects related to group-IV impurities have displayed promising properties in terms of high photon emission rate, relatively narrow spectral signatures, and spin-dependent emission properties.[19–26]

The identification of reliable pathways toward their reproducible fabrication is therefore crucial for a widespread adoption of these systems. The most convenient method to date is represented by the fabrication by ion implantation and subsequent high-temperature annealing, which enables in perspective the control on both the position and the number of individual emitters on a diamond chip.[19,27–29] It is therefore

E. Nieto Hernández, E. Redolfi, C. Stella, E. Corte, S. Ditalia Tchernij, P. Olivero, J. Forneris
Department of Physics
University of Torino
Torino 10125, Italy
E-mail: jacopo.forneris@unito.it

E. Nieto Hernández, E. Redolfi, G. Andrini, E. Corte, S. Ditalia Tchernij, P. Olivero, J. Forneris
Istituto Nazionale di Fisica Nucleare (INFN)
sezione di Torino
Torino 10125, Italy

The ORCID identification number(s) for the author(s) of this article can be found under https://doi.org/10.1002/qute.202300010

DOI: 10.1002/qute.202300010

C. Stella, S. Ditalia Tchernij, F. Picariello, P. Olivero, P. Traina, J. Forneris
Istituto Nazionale di Ricerca Metrologica (INRiM)
Torino 10135, Italy

G. Andrini
Department of Electronics and Communications
Politecnico di Torino
Torino 10129, Italy

S. Sachero, A. Kubanek
Institute for Quantum Optics
Universität Ulm
D-89069 Ulm, Germany

T. Herzig, J. Meijer
Applied Quantum Systems, Felix-Bloch Institute for Solid-State Physics
Universität Leipzig
04103 Leipzig, Germany

Y. M. Borzdov, I. N. Kupriyanov, Y. N. Palyanov
V.S. Sobolev Institute of Geology and Mineralogy
Siberian Branch of the Russian Academy of Sciences
Academician Koptyug Ave., 3, Novosibirsk 630090, Russian Federation