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Efficient Fabrication of High-Density Ensembles of Color Centers via Ion Implantation on a Hot Diamond Substrate

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Nitrogen-vacancy (NV) centers in diamonds are one of the most promising systems for quantum technologies, including quantum metrology and sensing. A promising strategy for the achievement of high sensitivity to external fields relies on the exploitation of large ensembles of NV centers, whose fabrication by ion implantation is upper limited by the amount of radiation damage introduced in the diamond lattice. In this work an approach is demonstrated to increase the density of NV centers upon the high-fluence implantation of MeV N^{2+} ions on a hot target substrate (>550 °C). The results show that with respect to room-temperature implantation, the high-temperature process increases the vacancy density threshold required for the irreversible conversion of diamond to a graphitic phase, thus enabling to achieve higher density ensembles. Furthermore, the formation efficiency of color centers is investigated on diamond substrates implanted at varying temperatures with MeV N^{2+} and Mg^{+} ions revealing that the formation efficiency of both NV centers and magnesium-vacancy (MgV) centers increases with the implantation temperature.

1. Introduction

Nitrogen-vacancy (NV) centers have been widely studied in the last decade due to their unique opto-physical properties.[1–3] The coupling of their electronic spin to external interacting fields, the optical readout of their spin state based on photoluminescence intensity detection, and the availability of dynamic control protocols enable optically-detected magnetic resonance (ODMR) experiments and make this color center appealing for applications in the fields of quantum computing,[4,5] sensing[6–11] and metrology.[12,13] Several sensing schemes have been proposed, relying on high-density ensembles of NV centers to enable the development of field sensors with unprecedented sensitivity,[14,15] thanks to the maximization of the signal-to-noise-ratio. Additional classes of diamond color centers have also received increasing interest for field sensing because of their narrow zero-phonon line (ZPL) and higher photon emission rate and spin addressability.[16–20] Among them, the magnesium-vacancy (MgV) center,[17,20] has recently been demonstrated to exhibit intriguing properties such as a high emission rate and a short excited state lifetime. Moreover, its field-sensitive spin state has been theoretically predicted to be addressable for operation as a quantum bit for computing and sensing applications.[21] To date, ion implantation followed by high-temperature annealing is the most straightforward method to achieve the localized fabrication of color centers in diamonds. NV centers can be routinely fabricated upon the introduction of nitrogen ions in the crystal lattice with a high degree of control on the volume density from the single-ion level,[22,23] to highly dense ensembles of emitters.[24] However, an upper limit

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