



Electrical control of deep NV centers in diamond by means of sub-superficial graphitic micro-electrodes



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ABSTRACT

The control of the charge state of nitrogen-vacancy (NV) centers in diamond is of primary importance for the stabilization of their quantum-optical properties, in applications ranging from quantum sensing to quantum computing. In this work buried current-injecting graphitic micro-electrodes were fabricated in bulk diamond by means of a 6 MeV C^{3+} scanning micro-beam. The electrodes were exploited to control the variation in the relative population of the negative (NV^-) and neutral (NV^0) charge states of a sub-superficial NV centers ensemble located in the inter-electrode gap region. Photoluminescence spectra exhibited an electrically-induced increase up to 40% in the NV^- population at the expense of the NV^0 charge state, with a linear dependence from the injected current at applied biases smaller than 350 V, and was interpreted as the result of electron trapping at NV sites. An abrupt current increase at ~ 350 V bias resulted in a strong electroluminescence from the NV^0 centers, in addition to two spectrally sharp emission lines at 563.5 nm and 580 nm, not visible under optical excitation and attributed to self-interstitial defects. These results disclose new possibilities in the electrical control of the charge state of NV centers located in the diamond bulk, which are characterized by longer spin coherence times.

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1. Introduction

The nitrogen-vacancy complex in diamond (NV center) emerged in the last decade as a prominent solid-state quantum system operating at room temperature, and has been exploited for innovative applications in quantum computing and quantum sensing [1–6]. Most of these applications heavily rely on the initialization, manipulation and readout of the spin state of the negatively charged (NV^-) state of the defect. However, the NV center is affected by uncontrolled charge state instabilities [7], thus preventing a coherent spin manipulation of the NV^- state before it accidentally converts to the NV^0 state [8].

In recent years, several works addressed the control of the charge state of the NV center by different approaches. The chemical

stabilization of NV^-/NV^0 charge state was investigated in shallow centers and nanodiamonds, by means of oxygen [9–11], fluorine [12] and hydrogen [13] surface termination. The NV charge state stability has been investigated as a function of laser power and wavelength excitation [7,14,15]. Furthermore, the electrical control was adopted to stabilize the negative charge state of shallow NV centers in a hydrogen-terminated sample [16,17], and to deterministically switch NV^- centers to the neutral charge state through hole injection in p-i-n devices [18,19].

The charge state control of the NV^- center by means of electrical pulse sequences is particularly appealing, since it would enable the development of integrated spintronic devices [18]. Despite the recent progresses, the current studies were mainly limited to surface (i.e. <14 nm) defects [16,17] or to the stabilization of the NV^0 charge state [18,19], with the exception of the negative charge state stabilization in p-i-n devices in a sandwich configuration [20]. On the other hand, the possibility of controlling deep NV^- centers in diamond using flexible electrode geometries would find useful applications in quantum metrology and quantum information

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