Mapping the Local Spatial Charge in Defective Diamond by Means of N-V Sensors—A Self-Diagnostic Concept

J. Forneris,[1,*] S. Ditalia Tchernij,[2,1] P. Traina,[3] E. Moreva,[3] N. Skukan,[4] M. Jakšić,[4] V. Grilj,[4] F. Bosia,[2,1] E. Enrico,[3] G. Amato,[3] I.P. Degiovanni,[3] B. Naydenov,[5] F. Jelezko,[5] M. Genovese,[3,1] and P. Olivero[2,1]

[1]*Istituto Nazionale di Fisica Nucleare (INFN), Sez. Torino, via P. Giuria 1, 10125 Torino, Italy*
[2]*Physics Department and "NIS" Inter-Departmental Centre, Università di Torino, via P. Giuria 1, 10125 Torino, Italy*
[3]*Istituto Nazionale di Ricerca Metrologica (INRiM), Strada delle Cacce 91, 10135 Torino, Italy*
[4]*Ruđer Bošković Institute, Bijenicka 54, P.O. Box 180, 10002 Zagreb, Croatia*
[5]*Institute for Quantum Optics and Center for Integrated Quantum Science and Technology (IQST), Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany*

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Electrically active defects have a significant impact on the performance of electronic devices based on wide-band-gap materials. This issue is ubiquitous in diamond science and technology, since the presence of charge traps in the active regions of different classes of diamond-based devices (detectors, power diodes, transistors) can significantly affect their performance, due to the formation of space charge, memory effects, and the degradation of the electronic response associated with radiation-induced damage. Among the most common defects in diamond, the nitrogen-vacancy (N-V) center possesses unique spin properties that enable high-sensitivity field sensing at the nanoscale. Here, we demonstrate that N-V ensembles can be successfully exploited to perform direct local mapping of the internal electric-field distribution of a graphite-diamond-graphite junction exhibiting electrical properties dominated by trap- and space-charge-related conduction mechanisms. By means of optically detected magnetic resonance measurements, we performed both point-by-point readout and spatial mapping of the electric field in the active region at different bias voltages. In this novel "self-diagnostic" approach, defect complexes represent not only the source of detrimental space-charge effects but also a unique tool for their direct investigation, by providing an insight on the conduction mechanisms that could not be inferred in previous studies on the basis of conventional electrical and optical characterization techniques.

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I. INTRODUCTION

Diamond is an appealing material for the development of innovative devices, such as high-power and fast electronics [1–4], radiation dosimeters [5,6] and detectors [7,8], biosensors [9–11], and, more recently, integrated platforms for quantum technologies [10–15]. For these applications, a major issue to be addressed in the optimization of device performance is represented by the effect of lattice defects with deep levels in the diamond energy gap acting as charge carrier traps. It has been extensively reported that the introduction of carrier traps caused by the interaction with energetic radiation induces electric-field inhomogeneities and polarization or memory effects in the material [16–18]. In previous works, these effects have been widely investigated by the analysis of current-voltage characteristics exhibiting complex non-Ohmic behavior, elucidating several conduction models ranging from space-charge-limited current (SCLC) to Poole-Frenkel (PF) mechanisms [19–22]. Complementarily, ion, electron, x-ray, and visible beam-induced charge microscopies allow the mapping of the charge-transport parameters of diamond at the microscale [18, 23–26]. Although insightful, these techniques cannot provide direct and unambiguous experimental evidence of the local electric-field distribution in the defective material but, rather, need to model it by means of simplified finite-element methods. Among the large variety of lattice defects in diamond, the nitrogen-vacancy complex (N-V center) has emerged as a system characterized by unique spin properties, enabling magnetic-, thermal-, and electric-field sensing with high sensitivity and spatial resolution [27–32]. The very same N-V centers that are created (among other types of defect complexes) by radiation damage [33] can be therefore exploited to locally investigate the internal electric-field distribution

*forneris@to.infn.it

