Optically Addressable Magnesium-Vacancy Color Centers in Diamond

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**E. Nieto Hernández[3,1,4*], E. Corte[3,1,4], G. Andrini[2,1,4], V. Pugliese[3,1,4], Â. Costa[5], G. Magchiels[5], J. Moens[5], S. Malven Tunhuma[5], R. Villareal[5], L.M.C. Pereira[5], A. Vantomme[5], J. Guilherme Correia[6], E. Bernardi[4], P. Traina[4], I.P. Degiovanni[4], E. Moreva[4], M. Genovese[4], S. Ditalia Tchernij[3,1,4], P. Olivero[3,1,4], U. Wahl[6] and J. Forneris[3,1,4]**

*[1]Istituto Nazionale di Fisica Nucleare, sezione di Torino, Via P. Giuria 1, 10125, Torino, Italy*

*[2] Department of Electronics and Communications, Politecnico di Torino, 10129 Turin, Italy*

*[3] Department of Physics, University of Torino, Via P. Giuria 1, Torino, 10125, Italy*

*[4] Istituto Nazionale Di Ricerca Metrologica (INRiM), 10135 Turin, Italy*

*[5]Department of Physics and Astronomy, Quantum Solid State Physics, KU Leuven, 3001 Leuven, Belgium*

*[6]Centro de Ciências e Tecnologias Nucleares, Instituto Superior Técnico,Universidade de Lisboa, 2695-066 Bobadela LRS, Portugal*

We report on a systematic optical and structural investigation of the MgV color center in diamond. The results show unique tunable properties of the center making it appealing for its utilization in quantum information processing.

## 1. Introduction

Color centers in diamond are promising platforms for the development of photonic quantum technologies. These optically active lattice defects can be engineered upon controlled introduction of impurities in the diamond using ion implantation [1], allowing the control on their position within the substrate. Apart from the widely investigated NV center, which offers distinctive opto-physical and spin-related properties at room temperature, additional single-photon emitters with enticing attributes are emerging, including group-IV related centers and other impurity related defects [2].

In particular, a recently explored color center fabricated upon Mg ion implantation and subsequent annealing [2] exhibits appealing features such as a sharp emission line, low phonon coupling , high emission intensity and low radiative lifetime. Additionally, a numerical ab initio study [3] predicted a large and tunable spin-dependent ground state of the Mg-related defect, thus proposing it as an interesting tool for quantum information processing purposes.

In this work a systematic investigation on the MgV color center in diamond is presented [4]. This work provides a systematic extension of the preliminary findings available in the scientific literature and provides further context with respect to the proposed theoretical model. The analysis covers the structural properties of the center, based on a study of its lattice position by means of emission channeling technique as well as its optical emission properties, studied upon photoluminescence (PL) analysis both at the ensemble and single-photon emitter level as a function of the excitation wavelength and the operating temperature.

## 2. Results

### *2.1. Structural properties of Mg related defects in diamond.*

In order to determine the lattice position of the Mg within the diamond that forms the emitting center and its formation efficiency, the electron emission channeling (EC) technique was employed. This EC method consists of the use of a radioactive probe atoms, in this case $^{27}$Mg, implanted in the materialand the subsequent angle-resolved detection of the $\beta^-$ emitted particles that are guided by the crystal via channeling. The preferential lattice sites are identified by comparing the experimental data with theoretical patterns calculated for specific positions of the emitter atoms in the lattice. The results revealed that a high fraction of Mg atoms ( ~35%) are located in sites that are compatible with the split-vacancy configuration. The structural configuration is compatible with the suggested structure of the MgV center [3]; furthermore, the high fraction of split-vacancy sites suggests an efficient structural formation of the defect.

### 2.2. *Optical properties of MgV centers.*

The optical characterization of the MgV centers was performed on a 100 keV Mg implanted "electronic grade" diamond. The regions characterized were implanted at a fluence of 5 x $10^{12}$ $cm^{-2}$ and subsequently annealed at high temperatures (1200 °C) in order to activate the centers.

A room temperature study of the MgV emission spectra was performed at the ensemble level, (**Figure 1a**), confirming the occurrence of a zero-phonon line at 557.6 nm, along with a set of less intense phonon replicas at higher wavelengths. A further temperature-dependent PL characterization in the 5-300 K range (**Figure 1b**) revealed two new spectral features were pointed out. An intense peak at 608.3 nm, accompanied by a set of phonon replicas, exhibits increasing emission intensity at decreasing temperatures and becomes comparable to that of the MgV ZPL at T=5 K. Moreover, a second peculiar feature observed was a spectral red-shift of the MgV ZPL at decreasing temperatures (**Figure 1c**). Both these features can be justified on the basis of the predicted model for the energy diagrams of the MgV center [3] and could offer unconventional paths towards the development of field and temperature sensors based on the MgV complex in diamond.

Additionally, the excitation efficiency of the center was studied under several excitation wavelengths in PL regime. The most effective excitation wavelength was revealed to be at ~520 nm, corresponding to Raman-resonant excitation conditions. This observation offers, in perspective, an efficient tool to maximize the emission intensity and to address optically and coherently individual emitters using cost-effective laser diodes. Finally, a study at single emitter level was performed, indicating high emission rates at saturation (~1 Mcps at 1 mW excitation power) and short radiative lifetime (2.8 ns) both at room- and cryogenic temperature.

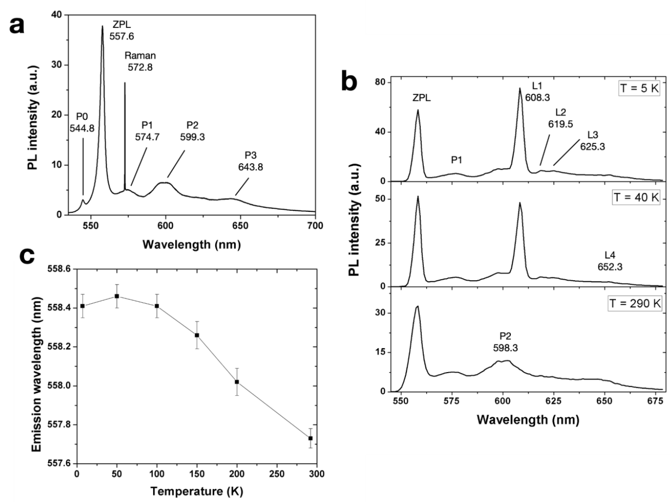


**Figure 1. a)** Room temperature spectrum of the MgV center under 532 nm laser excitation. **b)** Evolution of the spectrum of the MgV center at decreasing temperature. **c)** Temperature dependence of the ZPL position of the MgV center [4].

## 3. Conclusions

The systematic experimental results presented in this work reveal a Mg-related defect compatible with a split-vacancy structural configuration. The MgV center exhibits an efficient structural formation upon ion implantation combined with intense PL emission and peculiar temperature-dependent spectral features. These results offer an appealing perspective of the practical applications of the MgV center as a bright building block for quantum sensing and quantum information processing.

## 4. References


[1]Schröder, T. et al. Quantum nanophotonics in diamond. J. Opt. Soc. Am. B 2016, 33, B65.
[2] Lühmann, T. et al. Screening and engineering of colour centres in diamond. J. Phys. D: Appl. Phys. 2018, 51, 483002
[3] Pershin. A et al. Highly tunable magneto-optical response from magnesium-vacancy color centers in diamond. npj Quantum Inf. 2021, 7, 99.
[4] Corte.E et al. Magneesium-Vacancy Optical Centers in Diamond. ACS Photonics 2023, 10, 1, 101–110