Instantaneous generation of single-photons from NV centers in diamond upon electrical excitation

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Abstract

We rigorously study the temporal dynamics of single-photon emission from NV center in diamond under electrical excitation. Using self-consistent optoelectronic simulations of the single-photon emitting diamond diode, we show that NV center can almost immediately respond to a short rectangular electric pulse with a delay of less than 50 ns.

Optical sources that deliver single photons on demand are essential for emerging quantum information technologies. Color centers in diamond, being excited either electrically or optically, can be robust sources of single photons at room temperature. Electrical excitation of these emitters would be more preferable in terms of energy efficiency, integrability, and scalability. However, in spite of continuous research in this direction, the potential of color center as electrically driven single-photon sources (SPSs) is still an open question.

Here, we present for the first time a rigorous study of the dynamics of single-photon emission of electrically-pumped nitrogen-vacancy (NV) centers in diamond. Our dynamics studies comprise both the quantum correlation among emitted photons (Fig. 1a) and response to an ultrashort electric pulse (Fig. 1b), since both of these characteristics are vital for the development of on-demand SPSs. While in the case of optical excitation, the color center can be equally represented by an isolated single-electron system, the process of single-photon electroluminescence unavoidable involves the interaction of the color center with the crystal by means of the electron and hole captures and releases [1–3]. We find that both of these processes are slower than the relaxation of the excited state of the NV center, and thus their impact on the dynamics of single-photon emission is higher. Surprisingly, the slower electron capture determines only the single-photon emission rate in the steady-state, while the characteristic time of the second-order autocorrelation function is mostly determined by the faster hole capture process (Fig. 1a). We also find that since the electroluminescence of the NV center from the negatively-charged state is prohibited [1,2], the response of the pulsed SPS based on the NV center is also determined only by the relatively fast hole capture process. The reason for this is that the NV center is in the NV^- charge state in the i-region of the diamond p-i-n single-photon emitting diode. Therefore, the NV center first captures a hole and only after that it emits a photon [1,2]. Our self-consistent numerical simulations show that the single-photon emitting diamond diode can respond to an ultra-short rectangular electric pulse with a delay of less than 50 ns, which is comparable to radiative lifetime of the NV center. Such a short response time gives the possibility to instantaneously generate single-photon pulses on demand regardless of the pulse repetition rate.

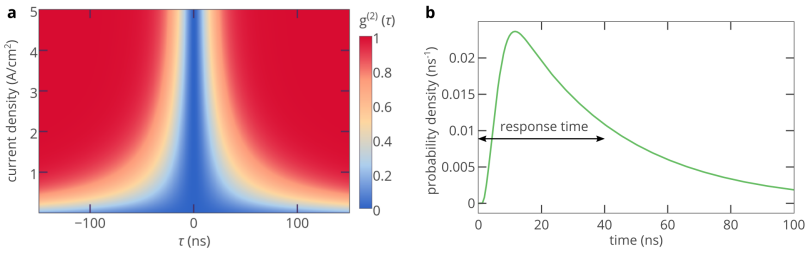

Figure 1: (a) Evolution of the $g^{(2)}$ function with the current through the diode. (b) Simulated probability of the first photon emission under pulsed excitation, the pulse duration is 13 ns.

[1] D. Yu. Fedyanin and M. Agio, *Ultrabright single-photon source on diamond with electrical pumping at room and high temperatures*, New J. Phys. **18**, 073012 (2016).

[2] I. A. Khramtsov, M. Agio, and D. Yu. Fedyanin, *Dynamics of Single-Photon Emission from Electrically Pumped Color Centers*, Phys. Rev. Applied **8**, 024031 (2017).

[3] I. A. Khramtsov and D. Yu. Fedyanin, *Superinjection in diamond homojunction P-I-N diodes*, Semicond. Sci. Technol. **34** 03LT03 (2019).