Luminescent nanodiamonds as a material platform for production of single photon emitters

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Abstract. The prospects of using individual nanodiamond particles as a source of single photons were studied for diamonds of various origin. It was shown that the single photon emitters could be produced on a base of “nitrogen-vacancy” centers in detonation nanodiamond synthesized from graphite-hexogen mixture. Studying meteoritic NDs we have found that single photon emitters based on "silicon-vacancy” centers could be realized even in molecular-sized diamond (less than 2 nm). Currently we are developing a new class of diamond materials, nanodiamonds synthesized from organic compounds at high pressure. In particular, we have demonstrated the possibility of synthesis of nanodiamond from its molecular analogue adamantane, controlling the size of crystallites in a wide range by changing synthesis temperature. A minimum size of obtained diamond particles about 3 nm was reached. Crystal structure of such diamonds is the most perfect in comparison with other classes of diamond materials, therefore they are the most promising material platform for production of single photon emitters.

1. Introduction
Single photon emitters (SPEs) are one of the key components in quantum communication technology. For today the most attractive SPEs, which operate at room temperature, are dye molecules, quantum dots, and color centers in wide-bandgap materials (diamond, silicon carbide and others). Owing to a longest photostability and a high quantum yield of luminescence, diamond with different color centers is the best candidate for practical implementation of single-photon devices. This paper presents our results on studying luminescent nanodiamonds of various origin in terms of their applicability to be used as SPE, as well as on searching for smallest diamond crystallite capable to host active luminescent centers.

2. Results and discussion
2.1. Detonation Nanodiamonds (DNDs)
This material demonstrates a high potential for the production of SPE. It is produced at an industrial scale and contains large amount of N impurity, which is required for formation of luminescent “nitrogen-vacancy” (NV) centers. We have studied representative classes of DNDs produced from
different combinations of explosives and having various characteristic sizes of diamond nanoparticles. We have demonstrated, that (1) optically active NV centers are mainly detected in diamond particles larger than 30 nm in size; (2) DNDs synthesized from a mixture of graphite/explosive contain the largest amount of NV centers formed during the synthesis. Through autocorrelation function measurements the greatest number of crystallites containing single NV centers was found in detonation nanodiamonds synthesized from graphite-hexogen mixture [1]. Thus, this class of nanodiamond was concluded to be the best candidate among others to produce SPE based on DND.

2.2. Meteorite Nanodiamonds
Production of SPE was seen elusive for very small diamond nanoparticles because of their limited availability and a lack of fundamental understanding of impurity stability in such nanostructures. We have shown that isolated diamond nanoparticles with size below 2 nm, extracted from stone meteorites, are still capable of housing photoluminescent “silicon-vacancy” (SiV) colour centers [2]. Surprisingly, fluorescence from SiVs was stable (no bleaching) over time, and a few or only one colour centers were found per a diamond crystallite.

2.3. HPHT nanodiamonds
Currently we are developing a new class of diamond materials, nano- and micro-diamonds synthesized from organic compounds at high pressure and high temperature (HPHT technique). In particular, we have demonstrated the possibility of synthesis of nanodiamond from its molecular analogue adamantane, controlling the size of crystallites in a wide range by changing the synthesis temperature. A minimum size of synthesized diamond crystals about 3 nm was reached [3]. The possible presence of single NV centers in individual diamond particles, dispersed on a glass substrate was investigated by scanning confocal microscope and Hanbury-Brown and Twiss interferometer for two samples synthesized from adamantane at pressure of 8-9 GPa and temperatures of 1600 K and 1800 K. The

Fig. 1 Confocal luminescence scan image of “1800 K” sample dispersed on a glass substrate. Bright spots correspond to diamond crystallites containing NV centers.
samples consisted of diamond particles with mean sizes of 30 nm and 500 nm, respectively. No NV centers were detected in “1600 K” sample. It is explained by small sizes of the diamond particles and low level of the sample contamination with nitrogen. From one to five centers was found in individual “1800 K” crystallites, whose volume was three orders of magnitude greater than the volume of “1600 K” crystallites. Figure 1 shows 20x20 μm² luminescence map of “1800 K” sample. Autocorrelation function $g^{(2)}$ measured for luminescent diamond particle containing one NV center is shown in Fig. 2. Presently, controllable production of NV-containing nanodiamonds based on a mixture of adamantane with its derivatives, containing nitrogen, is under development.

3. Conclusion

It was established that nanodiamonds of various origins and sizes (down to ~ 1 nm) can be used for the production of single photon emitters. The most promising for this purpose are HPHT nanodiamonds synthesized from organics. They are produced in thermodynamically stable conditions, which are the most favorable to obtain the perfect diamond structure, and do not contain metal impurities inherent for HPHT synthesis in traditional metallic media.

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