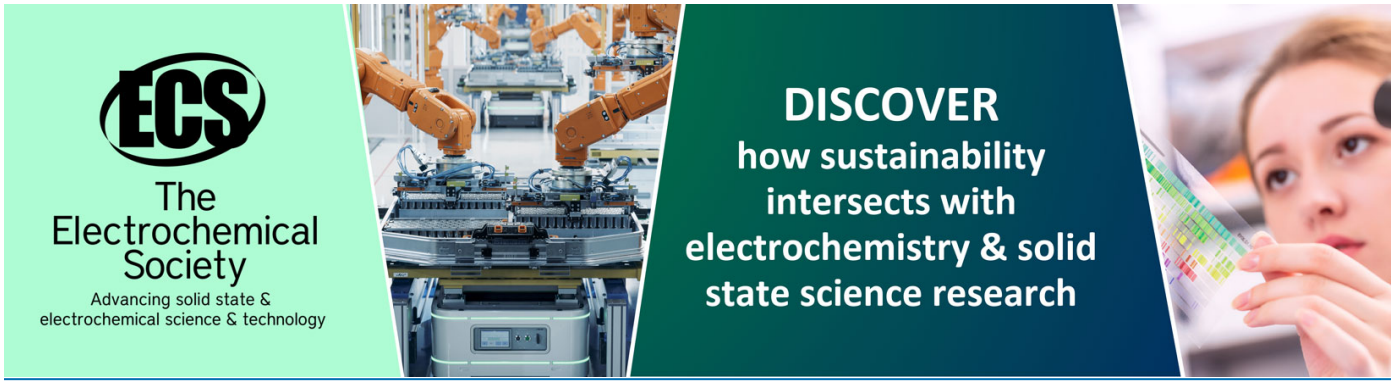
On-chip controlled placement of nanodiamonds with a nitrogen-vacancy color centers (NV)



On-chip controlled placement of nanodiamonds with a nitrogen-vacancy color centers (NV)

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Abstract. Here we studied the fabrication technique of a kilopixel array of nanodiamonds with a nitrogen-vacancy color centers (NV) on top of the chip and measured the second-order correlation function deep, clearly demonstrated the presence of single-photon sources. The controlled position of nanodiamonds, determined from the measurement of second-order correlation fiction, was realize, as well as the yield of optimized technique equals 12.5% is shown.

1. Introduction

The theoretical and experimental studies of quantum mechanics have moved to the use of various physical systems for use in metrology, quantum cryptography, quantum communication, and teleportation, quantum computer science, and others. For the practical implementation of quantum technology, single photon sources are of interest, since photons are ideal carriers of information. In addition, such sources are promising for integration with quantum photonic integrated circuits (QPICs) [1] for the implementation of fully functional nanophotonic devices. QPICs combine several advantages over table-top components and devices, including small size, high performance, no need of alignment, high temperature stability as well as the possibility of integration with electronic circuits on the same platform. Along with single-photon detectors [2] and integrated photonic components [3], a fast and effective single-photon source (SPS) for the implementation of such circuits is required [4]. A promising candidate for an integrated SPS is a nanodiamond with a nitrogen-vacancy (NV) color center.

To improve the performance of NV-centers as a single-photon source and gaining the ability to scale, one should be able to place them in a controlled manner. Here we experimentally study method to deterministically position nanodiamond basing on lift-off process.

2. Device design and fabrication.

To create an array of nanodiamonds, we used a glass substrate and a reactive magnetron sputtering method, to deposit a 60 nm TiN layer on top. The choice of titanium nitride was determined because of its good adhesion to nanodiamonds as well as the possibility of creating a nano-antenna from it in the future work.

For controlled placement of nanodiamonds we applied a layer of polymethyl methacrylate 100 nm thick and baked at 150 °C for 2 minutes on a hot plate. Using the electron-beam lithography system, we created an array of 33 by 33 holes with a diameter of 170 nm. For a successful placement in the holes in the resist, previously, we varied the diameter of the holes and thickness of the resist. The ratio of the thickness of the resist to the height of the holes should have been no less than 1 to 1.5.

If the resist is too thick, for example with a ratio of 1 to 1, after it removing nanodiamonds removes also. If the resist is too thin, then it will not be able to remove the unnecessary diamonds. For the resist development, we pierced the chip in a mash of isopropanol and water (8: 1) for 20 seconds.

At the next step, we put a drop of nanodiamonds solution and incubated it for 30 minutes. To avoid unnecessary particles, we first removed a drop of the solution with a pipette and sent a stream of isopropanol on the sample. Finally, for removing polymethyl methacrylate (PMMA), we sent a stream of acetone heated at 55 °C on the chip, washed the chip in isopropanol and drying in a stream of N_2. The main steps of the fabrication process are shown in Figure 1.

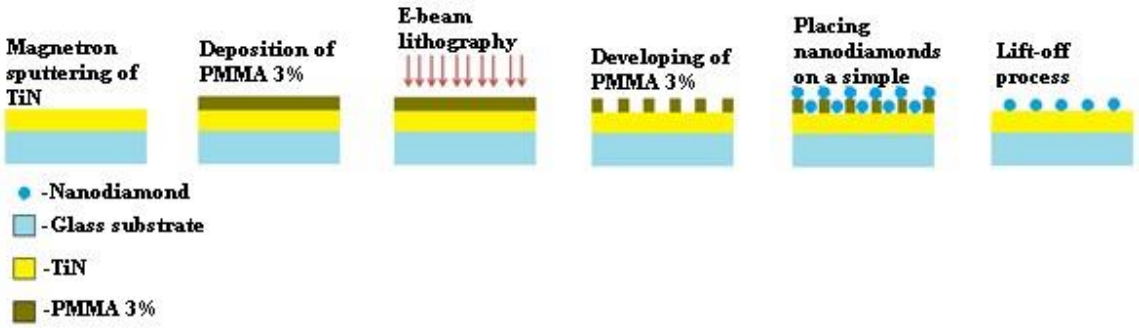

Figure 1 Schematic view of the fabrication process, including (from left to right): magnetron sputtering of TiN film, spin coating of PMMA 3%, e-beam lithography, developing of PMMA, placing nanodiamonds on the chip as well as a lift-off process.

We had a problem of spalling nanodiamonds in large agglomerates, which prevented the decomposition of holes in 1-3 particles. In order to avoid this, we crushed the solution with nanodiamonds in an ultrasonic bath for 3 hours at frequency of sound oscillations of 40 kHz, every hour we took out a test tube and shaken it for five minutes in a centrifuge.

The optical micrograph of one of the fabricated array of nanodiamonds is shown in Figure 2(a).

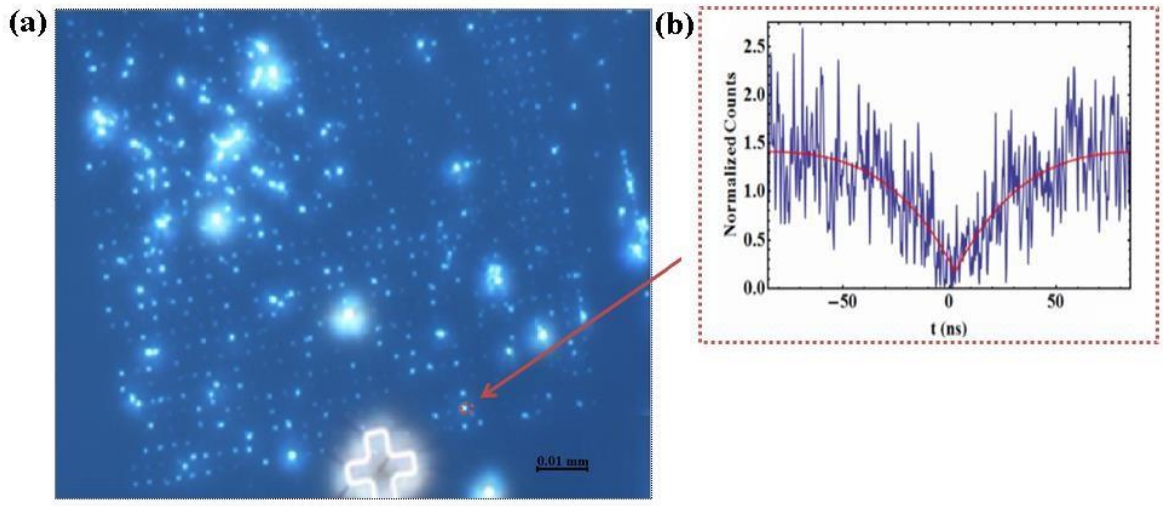

Figure 2(a,b). (a) The optical image of nanodiamond array; **(b)** Second-order correlation function $g^{(2)}(\tau)$ demonstrates the strong deep and represented the nanodiamond with single NV center on top of the chip.

3. Experimental setup and results

The presence of nanodiamonds with NV centers was detected using a confocal microscope technique [5]. The excitation of an NV center for measurement of the second-order correlation functions $g^{(2)}(\tau)$ was performed by 532 nm continuous wave laser (Coherent; Compass 315M–100). Beam scanning across the sample was realized using Galvano mirrors (Cambridge Technology; 6215H). The fluorescent radiation from NV centers was collected with a wide aperture (NA = 1.49) oil immersion lens (Nikon; CFI Apo TIRF 100X Oil) and separated from the excitation radiation by the dichroic mirror (Semrock; LPD01–633RU-25), notch filter (Semrock; NF03–532E25) and longpass filter (Semrock; LP02–633RU-25). A single-photon avalanche photodiode, SPAD (PerkinElmer; SPCM–AQRH–14–FC) was used as a detector of the NV center single-photon emission [5]. The installation works were made according to the following algorithm. The laser radiation is focused on the substrate surface in a spot about half the wavelength in diameter with a nanodiamond and excites an optical transition in the NV center. The radiation from the NV center is collected by means of an objective and an intermediate layer of immersion oil. The NV center radiation is separated from the reflected green laser light by a filter and detected by a Brown-Twiss interferometer, which includes a 50:50 beam splitter with two channels and avalanche photodiodes.

Digital signal processing and calculation of the autocorrelation function $g^{(2)}(\tau)$ are performed using a digital oscilloscope and software. Second-order correlation functions $g^{(2)}(\tau)$ was obtained for different points of the nanodiamond array. The measured dependence of $g^{(2)}(\tau)$ for one of the nanodiamond, demonstrated the presence of single NV center, is shown in Figure 2(b). Approximately in every eighth point of the array was a single-photon source, demonstrating the achieved yield of the studied method.

Further work will be devoted to the integration of NV centers with nanoantennas from TiN film. In Figure 3 shown a schematic image of such the array, as well as a single nanoantenna with specified dimensions. Titanium nitride is highlighted in blue, as well as alignment crosses are shown in yellow.

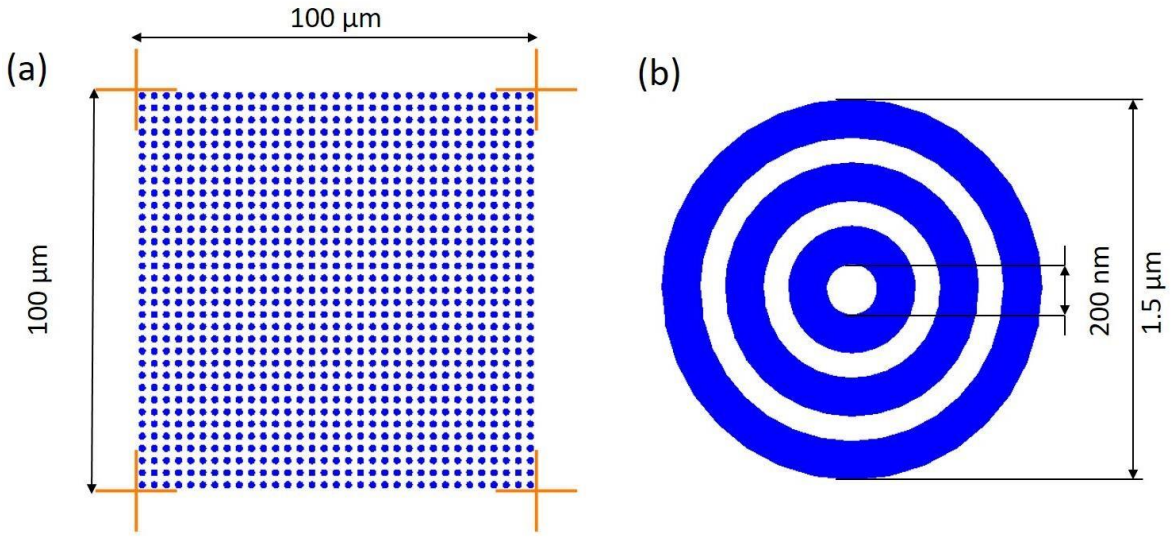

Figure 3 (a, b). (a) Schematic view of the kilopixel array of TiN annular nanoantennas; **(b)** Schematic view of the single annular nanoantenna for NV color center in a nanodiamond placed in the center.

4. Conclusion

In conclusion, we fabricated on-chip array of nanodiamonds using e-beam lithography and liftoff technique, measured the second order correlation function for a large number of single-photon emitters and achieved the yield of 12.5%. The further work will be concentrated on increasing the yield of this method as well as on increasing the speed of spontaneous emission by approaching NVcenters with hyperbolic metamaterials (HMM) and increasing the efficiency of collecting radiation from the NV-center, by placing the nanodiamond at the center of the annular nanoantenna [4-6].

5. Acknowledgments

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