Formation of Nitrogen vacancy center ensembles in Diamond Nanowires

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Abstract: We have demonstrated incorporation of a thin layer of nitrogen-vacancy (NV) center ensembles at the surface of diamond nanowires. The signature of NV ensembles was confirmed by photoluminescence spectroscopy and electron spin resonance measurements.
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1. Introduction

Nitrogen-vacancy (NV) centers in diamond have attracted significant attention in optics community due to their potential for quantum memory and magnetometry applications [1]. NV ensembles, in particular, have been proved to be strong candidates for low noise high precision magnetic sensing and magnetic marking applications. With the growing applications of NVs as magnetic sensors for neuro-science and cellular biology [2,3], and nanoscale magnetic resonance imaging [4], there is a need for making and functionalizing NV ensembles in nanostructured surfaces. Nanowires in particular offer significantly higher surface to volume ratio than bulk substrates. In earlier works, diamond nanowires were demonstrated as single photon emitters [5]. In this letter, we demonstrate development of NV ensembles on an array of diamond nanowires that can be utilized for nanoscale magnetic sensing.

2. Experimentals

Single crystalline electronic grade diamond substrates, products of Element 6, were used for fabrication of diamond nanowires. Fig. 1(a) and (b) summarizes the fabrication process for diamond nanowire along with nitrogen ions implanted at the surface of nanowires. A rapid thermal anneal at different temperatures was used to anneal the vacancy defects and form Nitrogen-vacancy centers. The measurement setup of Fig. 1(c) was used to measure photoluminescence spectrum, optically detected electron spin resonance (ESR), and Rabi nutation signal of the NV ensemble centers formed at the surface of diamond nanowires. Fig. 1(d) shows a SEM image of a sidewall implanted diamond nanowire arrays. The diameter and height of the nanowires were estimated as 200 nm and 2 μm, respectively.

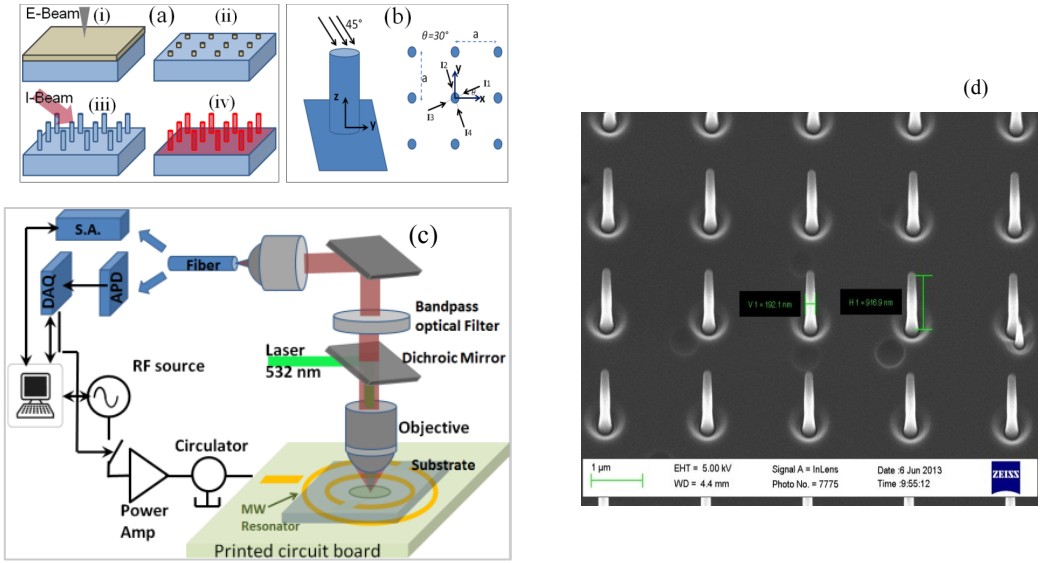

Fig. 1: a) Fabrication process for the diamond nanowire, (b) schematics of nitrogen implantation for NV formation, (c) Experimental setup for PL, ESR, and Rabi measurements (d) SEM image of the fabricated diamond nanowires with ensemble nitrogen vacancies (d) SEM image of the fabricated diamond nanowires with ensemble nitrogen vacancies.

Fig.2 (a) shows PL spectrum of 3 sets of diamond nanowire samples that were annealed at 650 ^{o}C, 750 ^{o}C, and 1000 °C, respectively. The samples annealed at 650 ^{o}C and 750 °C both show a strong photoluminescence in the 740 to 760 nm wavelength window pointing out to a large density of lattice vacancies formed in the ion implantation process [10-11]. The photoluminescence signature of the lattice vacancies disappears when the samples go through a 1 min rapid thermal anneal at 1000 °C in a nitrogen ambient indicating that the majority of the vacancy defects get recovered after this short but high temperature process. Fig. 2(b) is an ESR spectrum obtained on a diamond nanowire made by the process of Fig. 1(a) and annealed at 1000 °C. The ESR signature with a minimum photoluminescence around 2.87 GHz and a full width half minimum of 12.6 MHz confirm the formation of negatively charged nitrogen vacancy centers in diamond nanowires. Fig. 2(c) is a Rabi nutation signal obtained from the sample at about 100 mW microwave power excitation. The Rabi nutation frequency was measured to be 2.86 MHz.

PL and ESR spectra as well as the Rabi nutation measurements all confirm the formation of NV centers at the surface of the nanowires. Nanowires of diamond might be advantageous over bulk diamond due to a larger surface to volume ratio, flexibility in placement of the nanowires adjacent or inside a sample, and large photon collection efficiency. This work reported a process for making NV center ensembles on the surface of diamond nanowires. Two dimensional PL and ESR contrast mapping revealed a high level of uniformity on PL and spin resonance properties of the NV ensembles formed on the surface of nanowires.

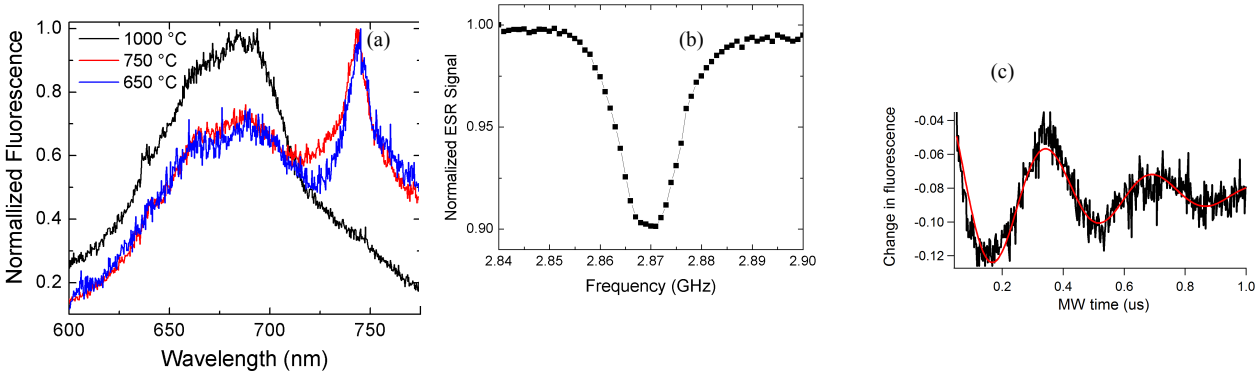

Fig. 2: (a) PL spectrum of the diamond nanowires annealed at different temperatures (b) Optically detected electron spin resonance response of NV ensemble in diamond nanowires. (c) Rabi nutation response of the NV ensembles made on the surface of diamond nanowires.

3. References

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