Fabrication of Diamond Microwires for Quantum Information Processing Applications

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Abstract:

The nitrogen-vacancy (NV) center in diamond has recently emerged as one of the potential candidates for quantum information processing applications due to its good coherence properties. However, interaction with the environment leads to decoherence — loss of quantum state. It has been reported that nanowire structures reduce interaction with the environment and increase coherence time. The purpose of this project was twofold: (1) grow and characterize diamond on silicon wafers, and (2) fabricate diamond microwires and nanowires using photolithography and electron-beam lithography. A hot filament chemical vapor deposition (HFCVD) system was used to grow nanocrystalline diamond on silicon wafers. Lift-off resists (LOR) 10B from MicroChem Corp. and Microposit S1818 from Shipley were used for a bilayer photoresist process followed by chrome (Cr) evaporation and liftoff process. An etch-back process was also studied to generate Cr patterns. Reactive-ion etching was used to etch diamond with an oxygen plasma with an etch rate of ~ 15 nm/min. We achieved ~ 3 μm sized diamond cylinders, which were characterized using scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Introduction:

Quantum information processing (QIP) is promised to solve certain computational problems by drastically improving acquisition, transmission, and processing of information. Although quantum computers have their advantages, they have limitations: they must be isolated from their environment at low temperatures and the slightest interaction leads to decoherence — loss of quantum state [1].

The nitrogen-vacancy (NV) center in diamond has been proposed as potential candidate for qubit, a basic information unit for quantum computers, for its good coherence properties. The NV-center is formed by two-point defect in the diamond crystal lattice by replacing two carbon atoms with a nitrogen atom and a neighboring vacancy. Because of the particular orientation of electrons, their total spin can be manipulated and easily measured at room temperature [2]. However, when an NV-center interacts with the environment, it loses its coherence easily. Hence, it is important to enhance the coherence duration of the NV-center by reducing its interaction with the environment.

It has been reported that the interaction with the environment is reduced dramatically in diamond nanowires compared to bulk structure [3]. This was shown by comparing their collection efficiency of emitted photon. Having more efficient collection of emitted photon, nanowire structures reduce the interaction with the environment and increase the coherence time. Therefore, it is important to develop fabrication processes for diamond nanowires. In this work a method of diamond growth was studied and approaches to create micron-sized and nano-sized diamond wires were explored by using photolithography, electron-beam lithography process, and reactive-ion etching.

Methods:

We grew poly-crystalline diamond on silicon substrate via a HFCVD process, which flows current through filaments to increase their temperature in low pressure. The HFCVD system is from Blue Wave Semiconductors. At temperatures above ~ 1800°C, the hydrogen dissociates and interacts with hydrocarbon gas and forms free radicals which are essential for diamond growth. All silicon substrates were cleaned with trichloroethylene, acetone, and methanol, and sonicated in a 1:1 (nanodiamond seed:methanol) solution. We grew at 2300°C. with a ratio of hydrogen to methane of 60:1 or 80:1. The growth rate was approximately 0.25 μm per hour.

Photolithography was employed in this work. The fabrication processes are shown in Figure 1. A bilayer photoresist process was used for photolithography. Lift-off resists (LOR) 10B from MicroChem Corp and Microposit S1818 from Shipley were used to define etch patterns using a Karl Suss mask aligner. Next, a 150 nm Cr evaporation was performed followed by lift-off with acetone and Microposit Remover 1165 from Shipley that was heated at 90°C for 5 min.

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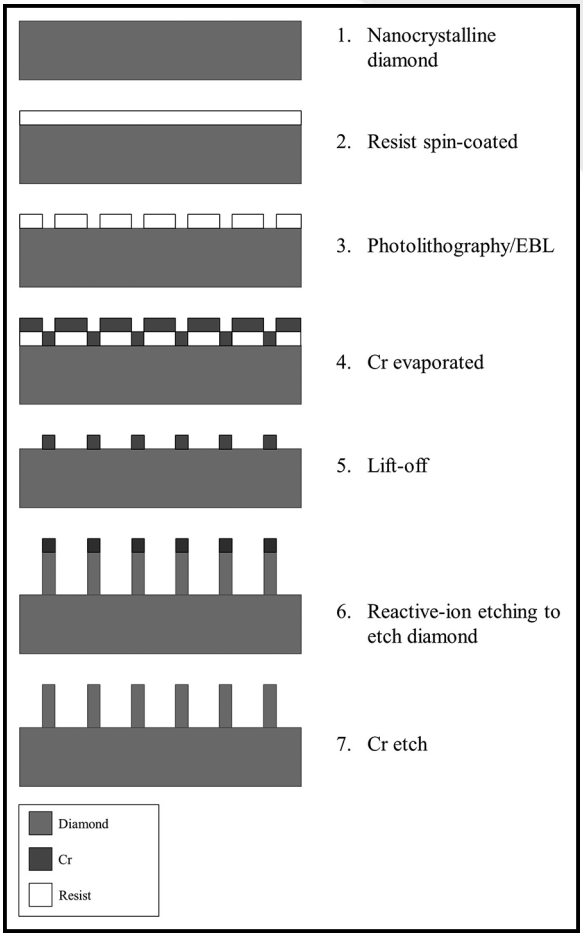

Figure 1: Fabrication process schematic.

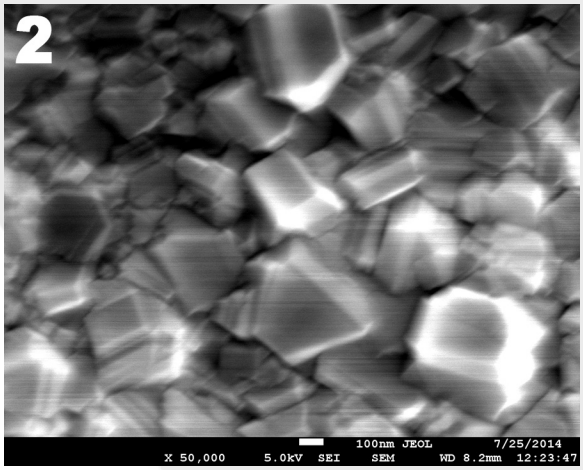

Figure 2, top: SEM image of grown nanocrystalline diamond.

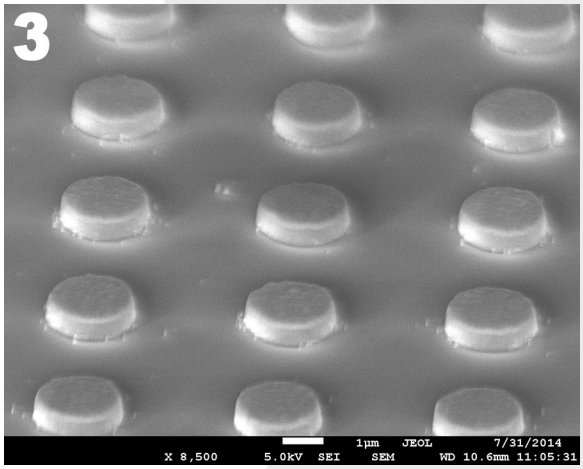

Figure 3, bottom: SEM image of fabricated ~ 3 µm sized diamond pillars.

Oxygen plasma cleaning was done to de-scum resist residue for effective lithography. Since oxygen plasma etches diamond, we also employed an etch-back process. In the etch-back process, the same lithography condition was used except Cr was deposited before resists.

A reactive-ion etching (RIE) system (Plasma-Therm 790) was used to etch the diamond and Cr. The etch recipe used for diamond etching consisted of an oxygen flow rate of 19.57 sccm, power of 100W and a chamber pressure of 10 mTorr. The etch recipe used for Cr etching consisted of an oxygen flow rate of 15 sccm and a flow rate of 35 sccm for chlorine, power of 50W, and a chamber pressure of 50 mTorr.

Results and Conclusions:

Nanocrystalline diamond was successfully grown as seen in the SEM image in Figure 2, which was characterized by SEM, AFM, and Raman spectroscopy. Micron-sized diamond pillars were successfully fabricated and were characterized by SEM and AFM. An SEM image of fabricated wires is shown in Figure 3. Reactive-ion etching was effective in etching diamond and Cr.

Future work includes fabricating nanowires with gold nanoparticles and electron-beam lithography using similar process. We hope to eventually dope nanocrystalline diamond with nitrogen to create NV-center embedded diamond pillars.

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