

Diblock Copolymers for Diamond Patterning and Applications

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Abstract:

Nitrogen-vacancy (NV⁻) centers have been recently forecasted as possible quantum bits — the fundamental unit of quantum information. Their properties include long spin lifetimes and the ability to store quantum information and transmit it in the form of light [1]. However, interaction with their environment leads to decoherence in the presence of nearby nitrogen spins. The key to enhancing NV⁻ centers is to control their location and reduce their interaction with the environment. Here, we present an innovative method that allows for control over the size and location of diamond nanopillars (DNPs). A hot filament chemical vapor deposition (HFCVD) reactor was used to grow polycrystalline diamond on silicon wafers. The diblock copolymer poly(styrene)-*block*-(2-vinyl pyridine) (PS-*b*-P2VP) was used to create a mask that directs the location and size of the DNPs. Reactive ion etching (RIE) was then used to transfer the patterns from the mask to the underlying substrate. We achieved ~ 10 nm sized diamond nanopillars, which were characterized using atomic force microscopy (AFM) and scanning electron microscopy (SEM).

Introduction:

Nitrogen-vacancy (NV⁻) centers are point defects found in diamond that consist of a nitrogen substitutional atom that is adjacent to a lattice vacancy. These NV⁻ centers have recently emerged as a potential candidate for qubits, the basic information unit for quantum computers. Their unique optical and spin properties makes them attractive for applications in areas such as magnetometry, biomedicine and spintronics [2]. The challenge when working with NV⁻ centers is that they can easily decohere (lose quantum state) when there are other defects close by. In order to enhance the NV⁻ center's properties, interaction with the environment must be reduced by keeping them separate.

A fabrication process employing diblock copolymers (DBCP) was developed to create diamond nanopillars (DNPs) as a way to isolate NV⁻ centers. DBCPs are macromolecules that consist of two polymers covalently linked that self-assemble into various equilibrium ordered nanostructures upon annealing. The DBCP used, poly(styrene)-*block*-(2-vinyl pyridine) (PS-*b*-P2VP) was dissolved in a selective solvent for one block and a precipitant for the other, forming micellar aggregates. These micelles consist of a condensed core of the insoluble block surrounded by a swollen shell of the soluble block in solution phase. The micelles offer advantages for surface modification because they are individual nanoscale entities that can be easily coated over many types of substrates. [3]

The array can be switched between two complementary surface topographies simply by changing the selective solvent used.

Materials and Methods:

Monolayers of PS-*b*-P2VP (91,500-*b*-105,000 g/mol, PDI 1.1) micelles (PS matrix, P2VP core) were created by spin coating a 0.5 wt% solution in toluene at 2000 rpm for 60 seconds on a clean silicon substrate. The substrate was then dipped in methanol, a selective solvent for P2VP, and an inversion of the polymer film forms, P2VP matrix and a PS core.

Reactive-ion etching (RIE) (Plasma-Therm 790) was used to transfer the pattern created by the polymer film into the underlying silicon substrate. The inverted thin film was exposed to a five second oxygen (O₂) etch that removed the PS block, leaving holes in the P2VP matrix layer that reached the underlying silicon substrate. The sample was then further subjected to a sulfur hexafluoride (SF₆) etch (2½ min, 55W, 187.5 mT), which allowed the exposed silicon to be etched, thus creating holes in the substrate.

Poly-crystalline diamond was grown on the etched substrate via a hot filament chemical vapor deposition (HFCVD) process. The silicon substrates were first cleaned with acetone, methanol and toluene and then

seeded by sonicating in a methanol:nanodiamond seed (1:1) solution. The diamond was grown at a filament temperature of 2300°C and a substrate temperature of 750°C with a ratio of hydrogen to methane of 80:1, for three hours.

The diamond surface was then waxed onto a SiC substrate to remove the silicon substrate and expose the DNPs grown inside the substrates' holes. A wet etch solution was used to etch away the silicon substrate completely. The wet etch solution consisted of a hydrofluoric and nitric acid aqueous solution in a 2:2:3 ratio.

Results and Conclusions:

PS-*b*-P2VP was successfully used as a mask to create DNPs with tunable size and distribution. Figure 1 shows an AFM image of the micelles formed (P2VP core) after an O₂ etch to remove the PS matrix. Next, a film of similar characteristics was dipped into a methanol bath, which inverted the core and matrix. After O₂ and SF₆ etches, ~ 15 nm deep holes were obtained on the silicon substrate, as seen in Figure 2. A poly-crystalline diamond layer was grown on the silicon substrate by HFCVD and then transferred to a silicon carbide substrate with a wet etch method. We achieved DNPs with a diameter of approximately 10 nm (Figure 3), which are several orders of magnitude smaller than what can be currently found in literature. Smaller sized DNPs increases the possibility of having just one NV center per pillar. This would avoid any center interactions, making them more stable and therefore more ideal as qubits.

Future work includes adjusting the RIE parameters to obtain taller DNPs and growing a nitrogen-doped layer of diamond on the substrate to create NV centers.

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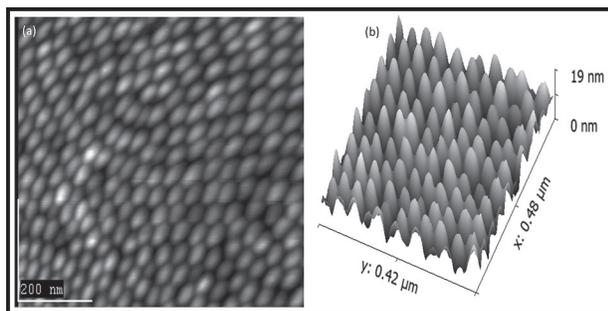


Figure 1: AFM image of (a) PS-*b*-P2VP coated silicon substrate after O₂ etch; (b) corresponding 3D image.

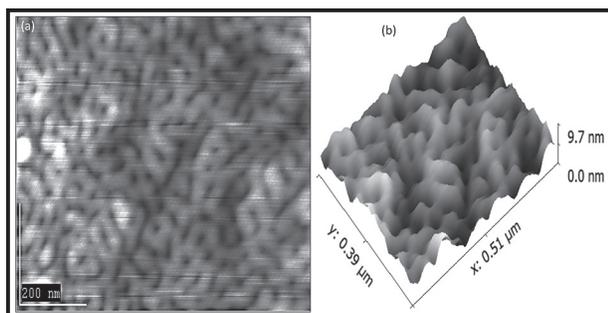


Figure 2: AFM image of (a) PS-*b*-P2VP silicon substrate after O₂ and SF₆ etch; (b) corresponding 3D image.

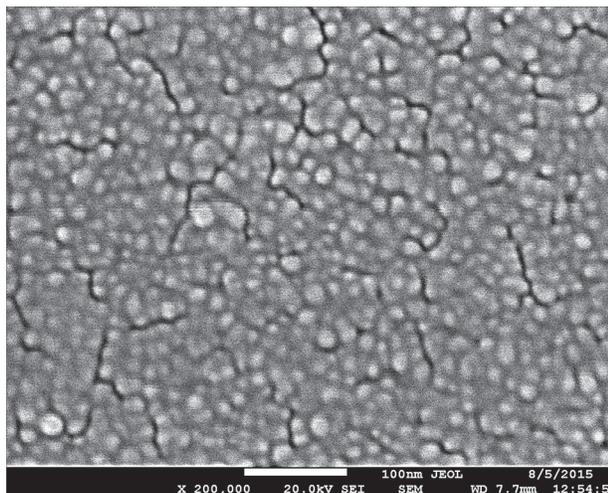


Figure 3: SEM image of diamond nanopillars with an average diameter of 10 nm.