

Microwave Plasma CVD of Diamond Films for MEMS Applications

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MEMS is a manufacturing strategy that integrates miniature mechanical devices and semiconductor microcircuitry on a silicon chip. Many potential applications for MEMS devices in harsh temperature or corrosive environments are not practically possible because the properties of the material currently used, i.e., silicon, are not suitable. The physical limitations of silicon have been the limitations on the MEMS revolution. Components made of diamond are hard, durable, and practically impervious to heat and chemical attack, which have, in fact, been the major limitations of silicon. In order to enable the application of diamond films for MEMS, it is necessary to fabricate microstructures such as gears, bridges, and cantilever beams. This paper presents a surface micromachining technique similar to the one described by Ramesham with some improvements for fabrication of diamond structures, such as cantilever beams and bridges for MEMS applications [1].

Different pretreatment techniques are used to enhance the nucleation density of diamond on silicon. The size of seeding powder used affects the roughness and nucleation density. In MEMS applications, very smooth and thin films are desired in order to make cantilevers, bridges, etc. The use of 4 nm diamond powder aids in the quick formation of a continuous film since the nano-diamond particles are expected to lower their surface energy by coalescing together under plasma conditions. This, in turn, leads to a smoother diamond film. The nucleation density can be increased almost 600 times if seeding is done with 4 nm diamond powder instead of 0.1 μm diamond powder [2].

Three-inch silicon wafers were used in our experiments. They were first cleaned in a freshly prepared piranha solution ($\text{H}_2\text{SO}_4:\text{H}_2\text{O}_2$) in ratio of 7:3. The complete surface of the 3-inch silicon wafer was oxidized to a thickness of 1-1.2 μm . The oxidized wafer was photolithographically patterned using thick (AZ series) photoresist. The sample was seeded with 4 nm diamond powder, among other techniques, by ultrasonic agitation for 15 minutes in methanol containing diamond powder (4 nm). The seeded wafer (with the photoresist in place) was then introduced in the deposition chamber.

Selective diamond deposition was carried out using a Wavemat, Inc. microwave plasma disc reactor operating at a frequency of 2.45 GHz. It uses a cylindrical cavity tuned to excite TM₀₁₂ mode. The substrate was loaded on a molybdenum stack. Graphite paste was applied to all the interfaces between the substrate and the cooling stage. Initially, hydrogen and argon gases were introduced inside a bell jar located within a microwave cavity and the plasma was excited. The power and pressure were varied in the range of 3000-3600 watts and 50-60 torr, respectively. Methane, argon, and hydrogen flow rates were 6, 200, and, 300 sccm, respectively. The substrate temperature at which depositions were performed was 800°C (+/-10°C). The deposition time was fixed at 3 hours for all our experiments. Diamond was selectively deposited using the process parameters listed above. The photoresist burns off at high temperatures (800°C) in a hydrogen plasma.

After diamond deposition, the silicon dioxide/silicon substrate was coated with photoresist, patterned using a second level mask, and finally, dipped in buffered oxide solution to etch the silicon dioxide in order to yield the diamond microstructures by undercutting.

Good quality diamond films were obtained using the ultrasonic seeding procedure. XRD plots of the diamond films show all the diamond peaks at 44° (111), 75° (220), 91° (311), 119° (400), and 140° (331). The film roughness was also moderate (110 nm), compared to the roughness values obtained using other seeding methods in the course of this research. Initial experiments were done using a process flow in which the photoresist is removed from the substrate after seeding but before the wafer is introduced into the deposition chamber. However, we observed stray diamond growth on SiO₂ in the undesired areas. These are the regions that were protected by photoresist during seeding, and therefore, should not have diamond growth at all.

The undesired diamond growth on silicon dioxide regions, that were not seeded, caused problems in etching of the silicon dioxide in BOE. It prevented the etching, thereby drastically increasing the etch time for complete removal of silicon dioxide. Sometimes the silicon dioxide was etched along the sides, but not sufficiently to release the diamond structure. It may be that the seeds impregnated in the photoresist mask during ultrasonic seeding do not wash off upon stripping thereby causing this spurious diamond growth.

In order to improve the patterning of structures, the substrates were directly introduced into the deposition chamber after ultrasonic seeding without stripping the resist. This resulted in a marked reduction in spurious diamond deposition. The photoresist was removed in a hydrogen plasma in the deposition chamber before the diamond deposition. It must be pointed out here that Ramesham had subjected the seeded substrate to an oxygen plasma in order to avoid stray growth of diamond on unseeded silicon dioxide regions. We tried a different approach by leaving the photoresist on the seeded substrate and performing diamond deposition. The idea behind initiating the

deposition with the photoresist in place is that whatever seeding exists on regions covered by photoresist will be removed, along with the photoresist which burns off at high temperatures (800°C) in a hydrogen plasma.

A second level mask was used to release the cantilever and bridge structures. A diamond cantilever formed by this improved process is shown in the SEM Fig. 1. The silicon dioxide was etched off completely so that the silicon surface is clearly seen in this picture. A magnified image of the overhanging diamond cantilever is shown in Fig. 2, which also shows the shadow of the cantilever.

In summary, selective diamond deposition was carried out on 3-inch silicon substrates at high powers (3500 W) and high pressures (55-60 torr) using a surface micromachining technique to fabricate polycrystalline diamond cantilevers and membranes for MEMS applications. Initial depositions, carried out following stripping of the photoresist used for protecting regions of diamond growth on silicon dioxide, resulted in stray/spurious diamond growth in undesired regions. A change was implemented by allowing the photoresist to remain on the seeded substrate during depositions in order to prevent stray diamond growth. This approach resulted in easier fabrication of diamond microstructures using a buffered oxide etch process. The photoresist burns off at high temperature (800°C) in a hydrogen plasma.

References:

1. Ramesham, R., *Thin Solid Films*, 340(1999)p. 1.
2. Khan, M. A., Naseem, H. A., Haque, M. S., Malshe, A. P., and Brown, W. D., *Thin Solid Films*, 332(1998)p. 93.

Figure 1 – SEM of a diamond cantilever.

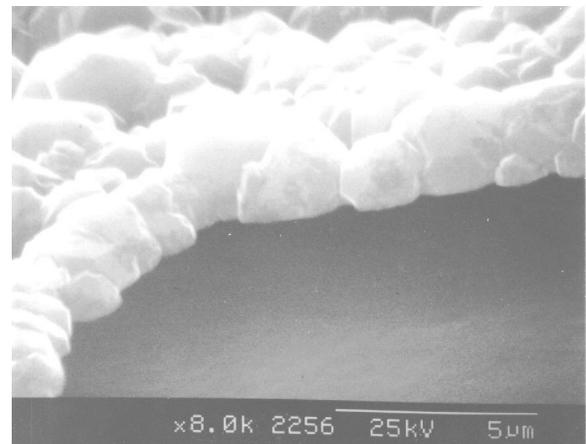


Figure 2 – Magnified view of the diamond cantilever shown in Figure 1.

