Fabrication of Periodic Nanopillar Structures on Polycrystalline Diamond by Reactive Ion Etching

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Diamond has attracted considerable interest as a thermal management material due to its exceptionally high thermal conductivity, along with excellent mechanical strength, chemical stability, and electrical insulation [1, 2]. These properties make diamond suitable for reducing localized thermal accumulation in high-power and high-density electronic devices [3]. However, planar diamond films alone offer limited heat dissipation performance, highlighting the importance of surface structural design. Heat dissipation efficiency depends not only on intrinsic thermal conductivity but also on surface morphology and effective surface area for heat exchange. Accordingly, patterning nanostructures on diamond surfaces provides a promising route to enhance thermal exchange within a limited area. Recent progress in chemical vapor deposition (CVD) has enabled scalable growth of polycrystalline and single-crystalline diamond with improved control over defects and morphology [3]. Furthermore, there is growing interest in creating nanostructures in diamond because as nanoscale features modify and enhance mechanical, thermal and optical properties of diamond [4, 5].

In this work, we propose a plasma-based pattern transfer strategy for forming vertically structured nanopillars on polycrystalline diamond films. Periodic nanopillar patterns are defined by interference lithography (IL) using an anti-reflection coating (ARC) and a positive photoresist, and transferred into a SiO_2 hard mask, as shown in Figure 1. This hard mask is used during oxygen-based plasma etching of the diamond surface using inductively coupled plasma (ICP) reactive ion etching (RIE). Oxygen plasmas combined with additional gases are employed, and key process parameters, including power, pressure, and substrate bias, are considered to control etching behavior and pillar formation. As shown in Figure 2, SEM analysis is used to examine diamond morphology and anisotropic etching behavior. Preliminary etch rate comparisons between diamond and SiO_2 under O_2 RIE are performed to evaluate etch selectivity.

Polycrystalline diamond poses additional challenges for RIE due to grain boundaries, surface roughness, the formation of grass, while remaining attractive for scalable and large-area fabrication. We will discuss process optimization strategies and pillar formation behavior with an emphasis on structural stability, uniformity, and surface characteristics, and explores the potential of diamond nanopillar structures for thermal and optical surface engineering.

References

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Figures:

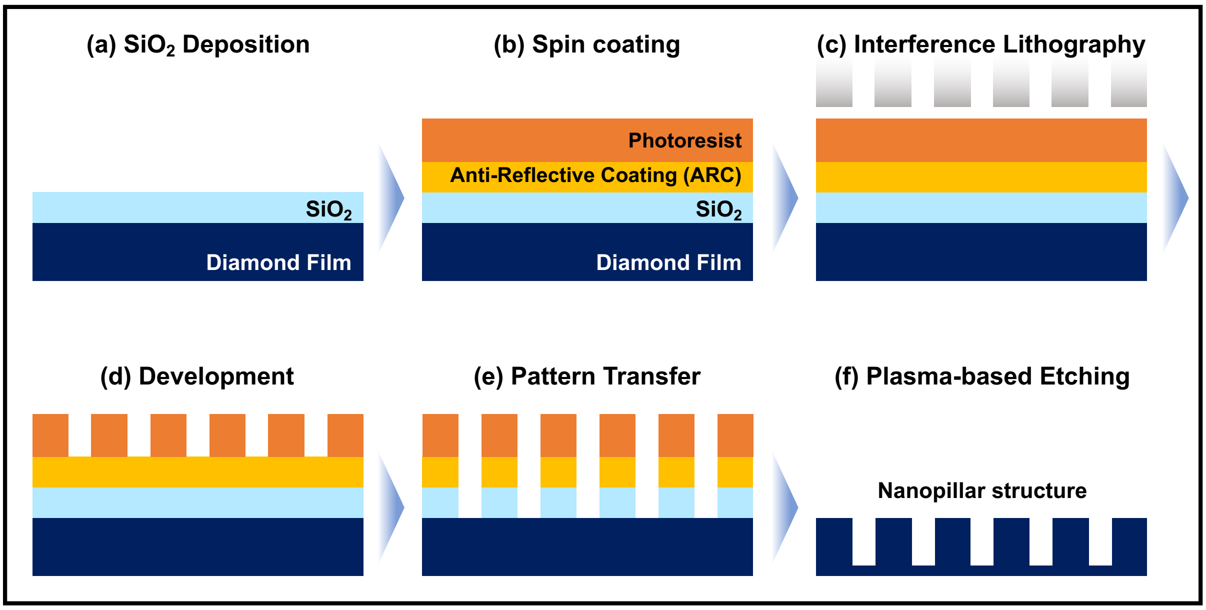

Figure 1. Schematic illustration of the fabrication process for nanostructured diamond surfaces. (a) Deposition of a SiO_2 layer on the diamond film. (b) Spin-coating of an ARC and a positive photoresist. (c) IL exposure of the photoresist. (d) Development of the photoresist to define periodic patterns. (e) Pattern transfer from the photoresist into the SiO_2 hard mask. (f) Plasma-based etching of the diamond film to form nanostructured surface patterns.

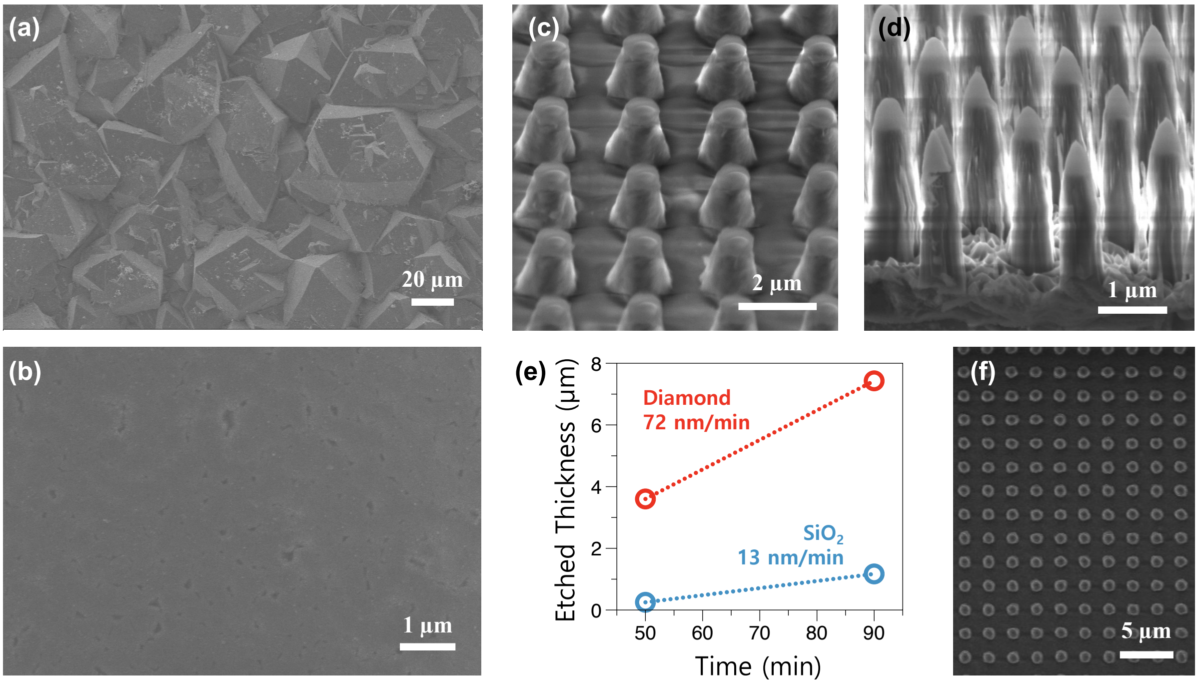

Figure 2. (a) Front- and (b) back-side SEM images of the polycrystalline diamond film. SEM image of (c) the photoresist exposure pattern and (d) the etched nanopillar pattern and SiO_2 hard mask on top. (e) Preliminary etch rate comparison between diamond and SiO_2 under oxygen-based RIE conditions. (f) Top-view SEM image of the photoresist pattern after IL and development.