Preparation of Ultrasmooth Diamond Surfaces for Fabrication of Membranes

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1. Introduction

Single-crystal diamond (SCD) in particular in form of thin membranes with incorporated color centers, such as for example nitrogen-vacancy (NV) centers or silicon-vacancy (SiV) centers, has gained an ever-increasing interest over the years as a highly promising platform for photonic integrated devices or for envisioned applications in quantum information technologies (QITs). To achieve the desired long optical and spin coherence times for QIT applications, such membranes need to be free from lattice defects, paramagnetic impurities, and charge traps. This requires an initial removal of the damaged surface layers from the cut and polished starting material. Additionally, further processing of diamond by e.g., dry etching for fabrication of photonic structures, can lead to higher roughening of the surface due to a micro-masking effect from particles, originating from the polishing procedure. In our work we address the importance of the SCD surface preparation to overcome the above mentioned challenges, which affect the structuring process and critically influence the final quality of the membrane or structured photonic devices as well as their performance.

2. Surface preparation

Initially the importance of the cleaning processes before the actual structuring and during the etching to remove efficiently particles, otherwise causing micro-masking and hence further roughening of the surface, will be highlighted. Repeated cleaning cycles of piranha acid and O_2 plasma treatment are necessary to reduce drastically the number of particles from the SCD surface. As a next step with the help of a planarization procedure, consisting of a combination of different Ar/Cl_2 plasma recipes with low etch rates and utilizing the Ar/Cl_2 chemistry, surface defects e.g., “nano-grooves” from polishing are minimized and smooth surfaces are acquired. Since the polishing damage can extend significantly into the bulk SCD from hundreds of nanometers up to micrometers under the surface, additionally a strain relief etch should be applied to remove up to 10 µm of the damaged material. For this procedure a cyclic $Ar/Cl_2 + O_2$ recipe is utilized. Here the Ar/Cl_2 steps contribute not only to the further smoothening of the surface but mainly to remove diamond particles that originate from the polishing process or are sputtered during etching, which could cause micro-masking. The planarization and strain relief etching procedures reduce the surface roughness of SCD down to 0.2-0.3 nm (Figure 1).

3. Applications

After the preparation of the surface, defect-minimized and planarized SCD membranes or photonic nanostructures can be fabricated. The ultrasmooth surface is advantageous e.g., for bonding of high-quality SCD membranes via van der Waals forces on plane cavity mirrors for optical characterization in a fiber-based Fabry–Pérot microcavity system and their enhanced finesse or for the performance of photonic crystals structured in membranes.

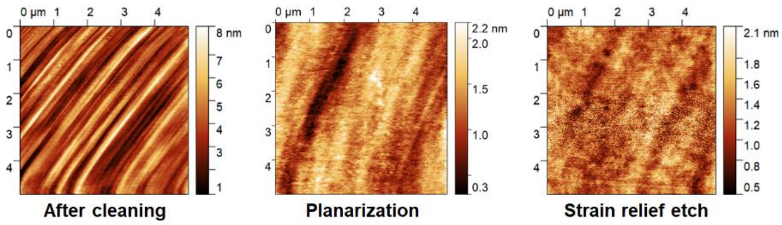

Figure 1. AFM measurements of a SCD sample after distinct etching procedures: (left) initial surface after cleaning ($R_q = 1.3 \pm 0.1$ nm), (middle) after planarization (etch depth ~ 700 nm) with drastically reduced surface roughness ($R_q = 0.33 \pm 0.04$ nm), (right) after strain relief etch (removal of ~ 10 µm) with even lessened sharpness of the polishing grooves ($R_q = 0.26 \pm 0.03$ nm).