Diamond Coated Tips for Scanning Tunneling Microscopy

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Scanning Tunneling Microscopy (STM) has shown promise as an emerging tool for nanotechnologists to enable atomically-precise control over surface modification in the nanometer regime via surface lithography [1] for device fabrication, and atomic-scale surface imaging and microanalysis. However, researchers have reported tip performance issues such as wear, oxidation and damage from electrostatic discharge, among other effects [2]. While polycrystalline tungsten (W) wires have been typically used for tip fabrication via KOH-etching, diamond has long been considered an ideal potential candidate for numerous applications in scanning probe microscopy [3] due to its well-documented hardness, chemical inertness and corrosion resistance, high Young's modulus, low coefficient of friction, and potential for controlled conductivity through selective doping via either Boron or Nitrogen atom insertion in grain boundaries [4]. Numerous methods have been developed for fabricating diamond-based STM probes [5]. However, no standardized practices have been established due to lack of repeatability, scalability and doping requirements. Clearly, there is room for improvement in the design and fabrication of diamond-based STM tips.

In this presentation, we report the development, application, and characterization of diamond coated STM tips and demonstrate their superior functionality in scanning imaging and lithography modes. Polycrystalline tungsten probe tips are prepared using the established method of electrochemical etching terminated at drop-off automated by the Zyvex ZEtcher system, followed by a secondary self-limiting Field-Directed Sputter Sharpening (FDSS) step, which utilizes an unfocused Ar^+ ion beam directed at a positively biased tip [6]. Ultra-nanocrystalline diamond (UNCD) is then directly grown onto the tips without prior seeding in a microwave plasma chemical vapor deposition (MPCVD) process utilizing Bias Enhanced Nucleation (BEN) and Bias Enhanced Growth (BEG) [7]. We have found that by lowering the process temperature and plasma pressure, the extreme point of the tip can be quickly coated with a UNCD film tapering to a point with a radius of curvature <10 nm. While further sharpening of the diamond tip is possible with a lower energy FDSS step, it has been found that with ideal growth conditions no further sharpening is needed, nor is any extra doping step required to achieve tip conductivity. Furthermore, the tip can be used immediately for surface scanning and hydrogen depassivation lithography. UNCD film-based tips exhibit excellent durability, maintaining consistent scanning performance over very large scan areas. Tip morphology and crystallinity have been characterized via STEM, EDAX, and electron diffraction.

[1] Ruess, NanoLetters. **4**, 10 (2004).
[2] Tseng, JVST B **23**, 877(2005).
[3] Grushko, Nanotech. **25**, 025706(2014).
[4] Auciello, "Electrically conductive Nitrogen Doped UNCD Films", US patent #6,793,849 B1 (2004)
[5] Liu, JVST B. **12,**1712 (1994).
[6] Schmucker, Nature Comm. **3,**935 (2012).
[7] Ding/Auciello, J. Vac. Sci. Tech **B17**, 705 (1999).

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Supplemental:

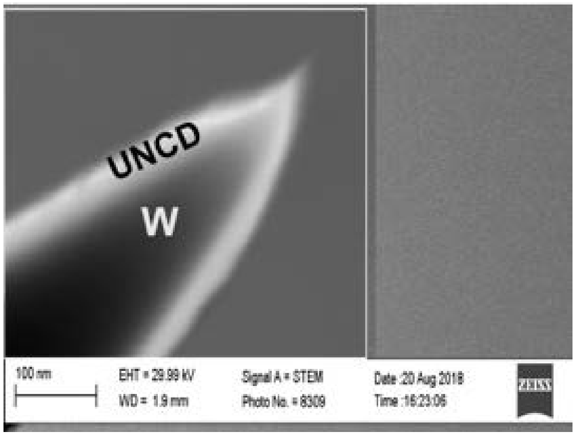

Figure 1: STEM image of UNCD-coated W tip

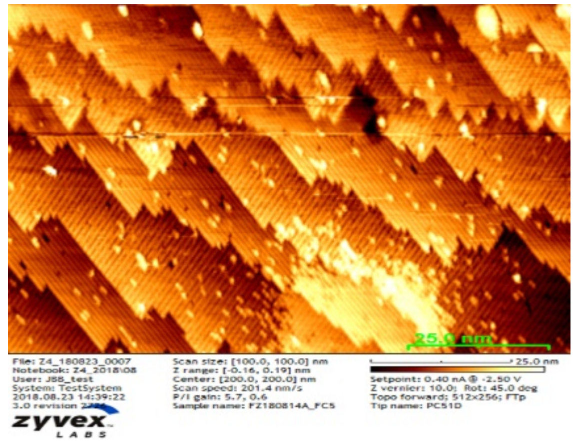

Figure 2: STM image of passivated Si surface taken with UNCD-coated W tip in Fig.1

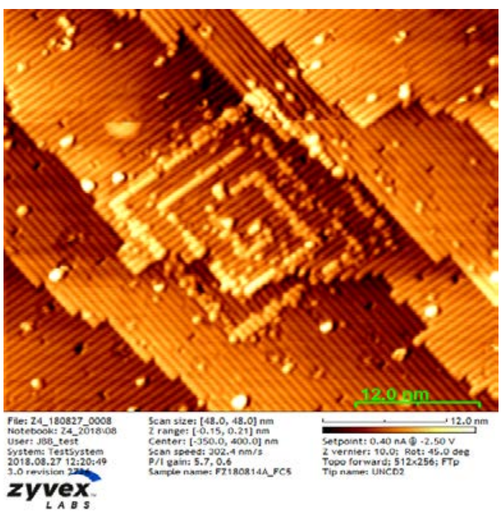

Figure 3: Nanoscale spiral pattern created via hydrogen depassivation lithography on same Si surface in Fig.2, using tip in Fig.1

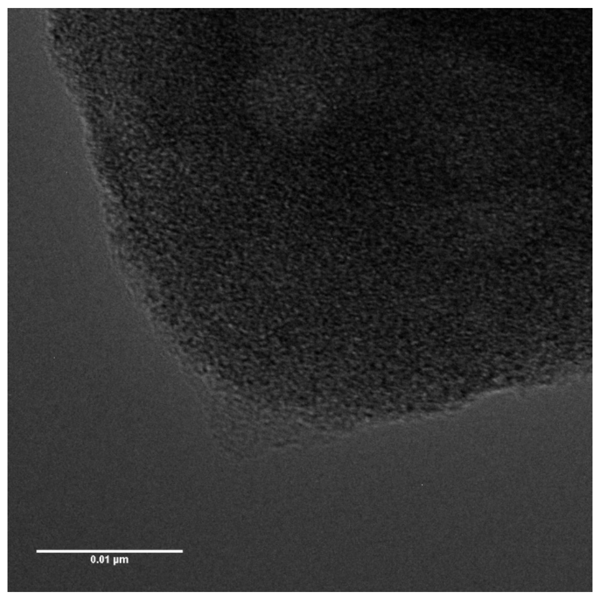

Figure 4: TEM image of UNCD-coated W tip (different from Fig.1). Scale bar is 10 nm.

Note: Results reported in this abstract are considered preliminary. Further work will be conducted prior to the conference date and will be presented accordingly. Anticipated work includes studies of UNCD-coated W STM tip stability as a function of usage and demonstration of nanoscale lithography-based patterning using UNCD-coated W tips, TEM imaging before/after scanning to determine tip stability, field emission characteristics, and further optimization of the UNCD-coated W tip fabrication process.

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