Nanofountain Probes for the Delivery of Molecular Inks

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Abstract:
Nanofountain probes (NFPs) are atomic force microscopy (AFM) probes designed for direct-write delivery of liquid molecular “inks” with sub-100 nm resolution. Liquid inks stored in an on-chip reservoir are fed through integrated microchannels to apertured dispensing tips by capillary action. This allows continuous delivery either to a substrate for direct-write nanopatterning, or to a cell for in vitro injection. Recently a fourth generation of nanofountain probe with enhanced geometry was fabricated. Fluid flow models quantified how the probe dimensions affect directly the NFP patterning resolution. These results were implemented to the fabrication which will enable a sub-100 nm patterning resolution and reproducibility necessary for a viable large-scale nanomanufacturing.

Summary of Research:
The nanofountain probe (NFP [1-3]) functions as a highly miniaturized fountain pen that can be used to deliver a variety of materials with precision in the 50 nm to 1 μm range. As in a conventional fountain pen, the liquid material to be delivered (the “ink”) is contained in a reservoir and flows through a channel to an apertured dispensing tip (Figure 1). Past demonstrations of direct-write nanopatterning include proteins [4] and DNA [5] in buffer solution, gold nanoparticles in aqueous suspension [6], thiols [1,3], and drug-coated nanodiamonds [7]. Piezoelectric positional control of the NFP by an AFM enables ultra-precise prescription of pattern geometry. The accuracy of the NFP combined with the broad range of molecular delivery capabilities enable studies at a truly single cell level through two modes of delivery: direct write nanopatterning, and direct in vitro injection (Figure 2).

Figure 1: Schematic of the nanofountain probe. Liquid ink is stored in an on-chip reservoir and fed through enclosed microchannels to apertured writing tips by capillarity (inset, scale bar: 2 μm) [7].

Figure 2: Schematic of the two modes of delivery for the NFP. (left) For direct-writing nanopatterning, the tip is brought into contact with the substrate where an ink meniscus forms (right) for in vitro cellular injection, the tip is introduced to the cell membrane [7].
A fourth generation of NFP with enhanced features was fabricated jointly at Cornell NanoScale Science and Technology Facility, NY, and at the Center for Nanoscale Materials at Argonne National Laboratory, IL (Figure 3). A primary objective of this fourth generation fabrication was to incorporate the probe geometry optimized by fluid flow models [4]. A second aim is to better control the overall homogeneity of the probe geometry for a higher throughput yield in the nanopatterning. Fabrication issues typically encountered in previous generation limited greatly the control of the patterning [1]. The new generation addresses these problems through changes in the process flow.

Arrays of sharp silicon tips were created using silicon on insulator by wet anisotropic etching. Low stress silicon nitrides were consecutively deposited by low-pressure chemical vapor (LPCVD) to create the cantilevers with embedded microfluidics ending at the silicon probe. The apertured tip was then defined by etching selectively the outer nitride layer by inductively coupled etching (ICP) (Figure 4). The high-density ion plasma etching enabled a better control of the core shell-tip length definition, a critical feature for the patterning resolution. The inner microchannels were released by hydrofluoric acid-based wet etching. Channels were then sealed by depositing a silicon oxide by plasma enhanced chemical vapor deposition (PECVD). The PECVD parameters including gases and temperature were tuned to alleviate the stresses in the multilayer and prevent the cantilevers from bending after release of the chip by deep reactive ion etching (DRIE). The resulting sharper NFPs are expected to produce patterns with higher resolution and spatial control. They will be applied to building carbon nanotube-based NEMS by patterning catalyst for subsequent CNT growth and in vitro single cell nanoinjection.

References: