Nano-Calligraphy: Precisely tuning the feature spacing in scanning-probe lithography

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We report a direct-write scanning probe-based technique relying on custom-nanoscale probes with single and double tip geometries for the patterning of closely-spaced structures with tunable nanoscale linewidth. We show that the produced linewidths are not limited by the sizes of the individual probe tips and as such our technique can significantly enhance patterning resolution in conventional scanning-probe lithography (SPL). By modifying the tip structure of a standard Atomic Force Microscope (AFM) probe, our Nano-Calligraphy Scanning Probe Lithography (nc-SPL) method allows us to produce patterns of variable linewidth based on the writing angle with sub 30nm resolution.

SPL has become increasingly popular among research groups where the overhead of lithographic tools for less complex processes but with high resolution requirements can be prohibitive. Of the various scanning-probe instruments, the AFM has proven to be particularly enabling, and is gaining momentum as a patterning tool. However, the low achievable throughput as well as difficulties in patterning multi length-scale structures have hindered the widespread adoption of AFM-based lithography.

In our approach, we redesign the conventional AFM probe by fabricating probes using a focused ion beam to have two tips. We use these probes to then directly remove material from a substrate. Since the geometry of the tip can no longer be approximated as a point, the path followed by the probe does not directly correspond to the lithography produced on the substrate. However, this can be accurately simulated in advance and the angular dependence of the lithographic operation can be well modeled. We are then able to define functional architectures with sub-30nm features as well as micron-scale patterns in a single continuous lithographic path. Further, we demonstrate that the achievable resolution is not limited by the sharpness of the probe as with conventional SPL. Rather, patterns which are orders of magnitude smaller than the fabricated tips can be readily produced. Finally, we show that this technique can be utilized for lithography through a variety of pattern transfer techniques—even for unconventional calligraphic patterns—and demonstrate integration with other fabrication layers showing that our technique is robust and reliable.

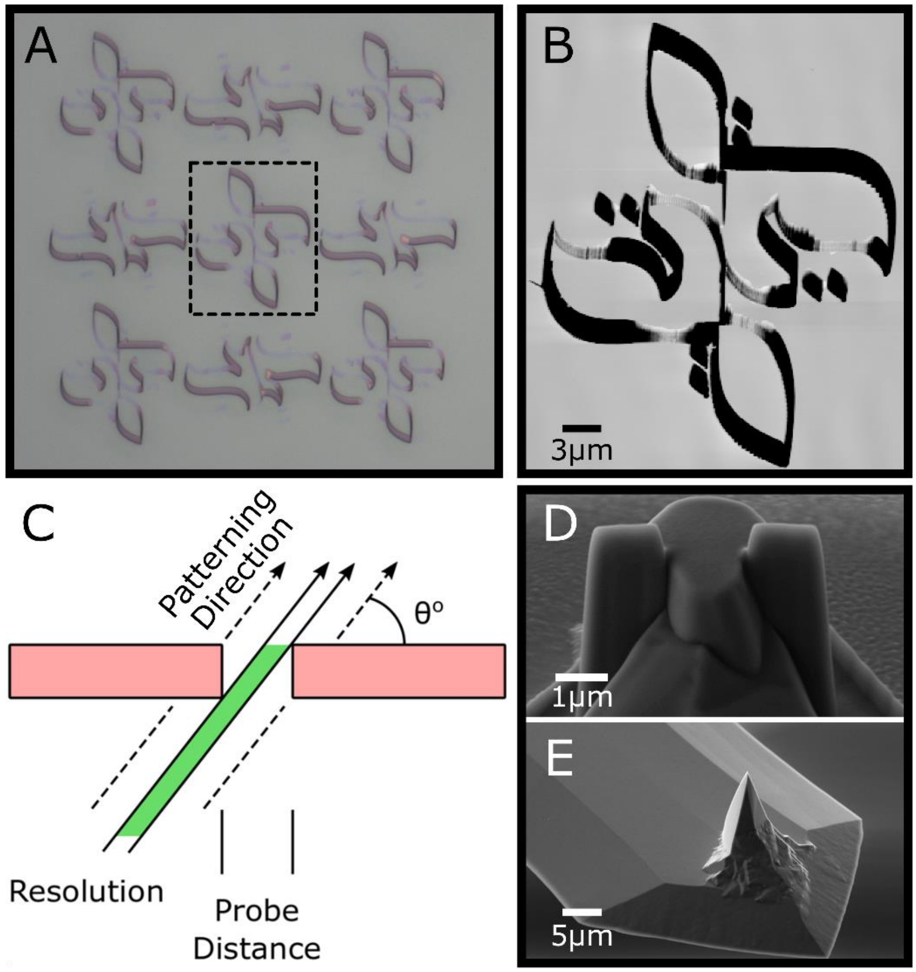

Figure 1: Nano-calligraphy Scanning Probe Lithography (nc-SPL): a) optical micrograph and b) tapping mode atomic force micrograph of calligraphic patterns written using an asymmetric tip in photoresist and subsequently transferred to SiN via reactive ion etching. The artwork was provided by famous calligrapher and type artist, Majid Alyousef. c) Schematic illustrating the dependence of linewidth to patterning angle. d-e) Scanning electron micrographs of e) a conventional AFM probe and d) sculpted AFM probe to produce double tip geometry, allowing the ability to pattern variable linewidths.