

**Scanning Probe Nanostructure Direct-Write:
Serial and Parallel Patterning via High Field Chemistry**
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Future generations of semiconductor heterostructures will require precise materials integration. One method of achieving precise materials integration is through the use of scanning probes. Scanning probes have emerged as attractive tools for nanofabrication in light of their ability to locally deliver desired stimuli or chemicals to a small area of a sample surface. Scanning probe direct write can be used to control the size, shape, and chemical composition of a nanostructure. Techniques such as scanning tunneling microscope-assisted chemical vapor deposition have been shown to add metallic and semiconductor features to a surface; however, low throughput and high vacuum conditions have limited this technique to the laboratory. Atomic force microscope based techniques, such as dip pen nanolithography and high-field carbon direct write, have demonstrated greater throughput at ambient conditions.

We have developed an approach to semiconductor nanostructure direct-write using tip of an atomic force microscope (AFM) to control the size, shape, and composition of semiconductor nanostructures.¹⁻³ In our scheme, the biased probe of an AFM reacts diphenylgermane or diphenylsilane to direct-write carbon free (as investigated with SIMS, x-ray PEEM) Si and Ge nano and heterostructures (Fig.1). In this technique, electrons tunnel from the tip into the precursor molecules, which initiates a chemical reaction that fragments the molecules.² The desired material is deposited on the substrate, while the carbon and hydrogen leave as benzene in the reaction volume.

Low-cost, high throughput of semiconductor heterostructures also remains a challenge. To this end, parallel patterning using the high field direct write technique has been demonstrated using a flexible stamp approach. By substituting the AFM probe with conductive, microstructured stamps, the high field chemical reaction can be scaled up from one reaction site at the tip-sample gap to a user-defined large array of reaction sites. Using this technique, Ge and Si nanopatterning has been achieved (Fig. 2).³ Initial efforts on expanding parallel printing to low cost mass manufacture by adapting this process to a 5" mask aligner will be presented. Our current focus is on adapting this technique to photovoltaic applications, with an eye toward electronic and optical applications in the future. This high-field stamping approach could offer a low-cost, high throughput alternative for depositing materials from the vast library of CVD precursors.

References

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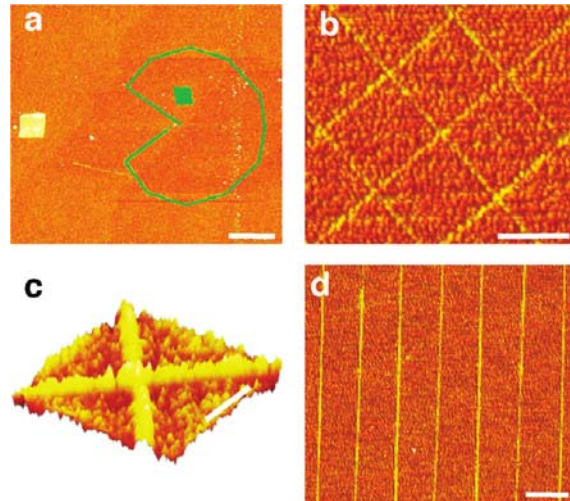


Fig. 1. Tapping mode topographic AFM images of the following: (a) False-colored Ge (green) and Si heterostructure PacMan.. (b) Ge and Si crossbars (c) Detailed view of a crossbar node from the previous image. (d) SiGe lines. Height scale from dark brown to bright yellow 10 nm (a), 5 nm (b-d). Scale bar = 500 nm (a), 500 nm (b), 300 nm (c), 1 μ m (d). Panels b and d were enhanced with 45° virtual illumination.

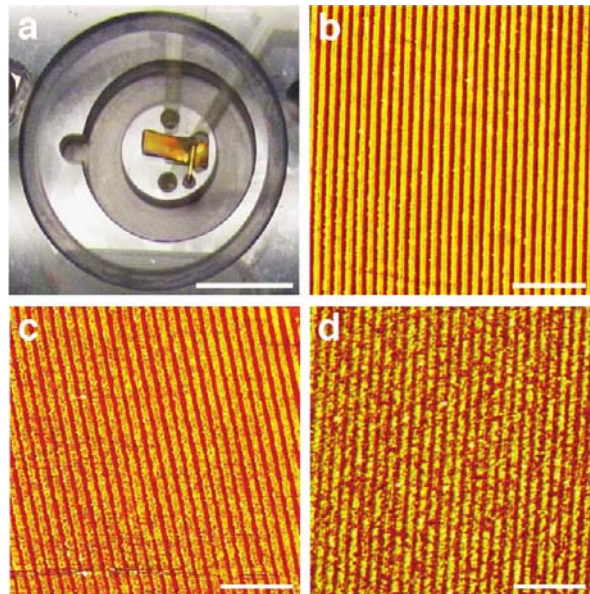


Figure 2. Gold-coated PDMS stamp mounted in an AFM quartz liquid cell (a). Tapping mode AFM images of stamp master (b). Si structures fabricated on the Si substrate with +31 V (sample) pulse for 2 min (c). Ge structures fabricated on the silicon substrate with a +31 V (sample) pulse for 2 min (d). Scale bar = 1 cm (a), 10 μ m (b-d). Height scale from dark brown to bright yellow = 200 nm (b), 20 nm (c,d).