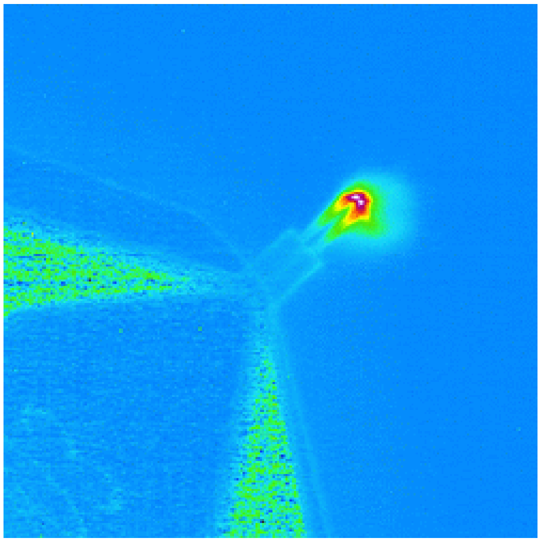
Improved Method for Nanometer-Scale Patterns Writing

August 30 2004



Researchers from the Georgia Institute of Technology and the Naval Research Laboratory (NRL) have developed an improved method for **directly writing nanometer-scale patterns onto a variety of surfaces.** The new writing method, dubbed "thermal dip pen nanolithography," represents **an important extension for dip pen** nanolithography **(DPN)**, an increasingly popular technique that uses atomic force microscopy (AFM) probes as pens to produce nanometer-scale patterns.

Image: Infrared microscope image shows a cantilever during heating. The colors correspond to temperature, the hottest reaching approximately 200 *degrees Celsius. The microcantilevers are engineered such that the temperature increases only near the free end.*

In conventional DPN, a probe tip is coated with a liquid ink, which then flows onto the surface to make patterns wherever the tip makes contact. Dozens of research groups worldwide are working on DPN applications, but the technique – which uses the AFM tips to both sense surface patterns and write new patterns – has been limited by an inability to turn the ink flow on and off. Existing dip pens apply ink as long as they remain in contact with a surface.

The thermal DPN (tDPN) method described by the Georgia Tech and NRL scientists solves that problem by using easily-melted solid inks and special AFM probes with built-in heaters that allow writing to be turned on and off at will. The tDPN technique could be used to produce features too small to be formed with light-based lithography, and as a nanoscale soldering iron for repairing circuitry on semiconductor chips. The technique could also provide a new tool for studying basic nanotechnology phenomena.

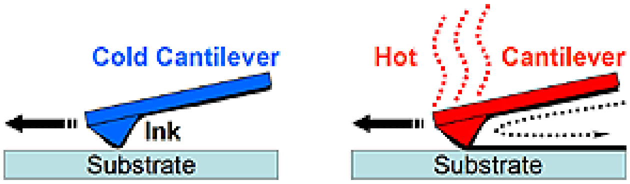
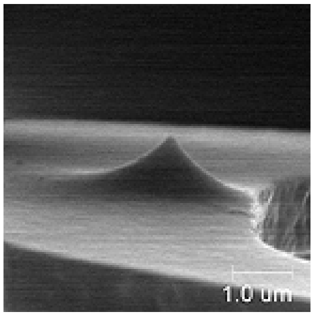


Diagram shows difference between traditional dip pen nanolithography using liquid ink (left) and thermal dip pen nanolithography using ink materials that melt (right).

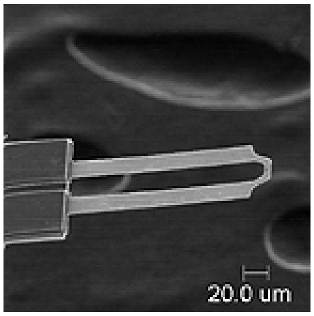
"This technique extends DPN into new sets of materials and provides a higher degree of control," said Lloyd J. Whitman, head of the Surface Nanoscience and Sensor Technology Section at NRL in Washington, D.C. "We also believe this technique will extend DPN into new environments, such as the vacuum environments that would be more compatible with conventional semiconductor device fabrication."

The tDPN technique is described in the August 30 issue of the journal Applied Physics Letters. The research was sponsored by the National Science Foundation (NSF), Office of Naval Research (ONR) and Air Force Office of Scientific Research (AFOSR).

"We've created a heated AFM tip that gives us control over the deposition and deposition rate during writing," said William King, an assistant professor in Georgia Tech's School of Mechanical Engineering. "We can turn the cantilever heating on and off, so for the first time we can write in some places and not write in others."



Microcantilever heaters fabricated by the research group of William King at Georgia Tech. The microcantilevers are made of crystalline silicon, and have been engineered with atomic impurities that allow electricity to flow through them. The cantilevers he



Combining thousands of individually-controlled AFM pens into arrays could allow writing of complex semiconductor patterns. King says the thermal dip pen technique could produce features as small as ten nanometers, well beyond the limits of conventional semiconductor patterning processes that depend on light projected through a lithographic mask.

The researchers have so far produced lines about 95 nanometers wide and are optimizing their process to make smaller features.

“This development could allow the semiconductor industry to reach its goals as specified in the technology road map,” King said. “It could also significantly reduce development costs for the semiconductor industry by allowing rapid prototyping and cost-effective manufacturing of small numbers of devices.”

Conventional dip pen nanolithography cannot be used in a vacuum because liquid inks would simply evaporate. But the solid materials used in the thermal process bond to surfaces, allowing them to be used in vacuum environments that are part of conventional semiconductor manufacturing. The thermal materials also provide sharper features because they don’t spread out like liquid inks.

In their paper, the researchers describe using octadecylphosphonic acid (OPA), which melts at about 100 degrees Celsius, as their ink.

Since submission of the paper, the tDPN technique has been used to apply other materials, including solders and polymers. Using organic materials, the researchers hope to produce a working semiconductor device by the end of 2004.

The ability to sense surface features and put down new patterns with the same AFM tip could be useful in repairing errors in the tiny patterns on circuits or masks used in semiconductor manufacture.

“You might want to use the AFM like a phonograph stylus to feel the bumps on the surface, but if you couldn’t turn the ink off, you’d be leaving a trace of ink as you moved the tip across the surface,” noted Paul Sheehan, a research chemist at NRL. “But with the ability to turn the ink on and off, you can feel the surface without depositing material, and then turn the heat on and put material down only where you want it.”

Beyond nanoelectronics, the technique could also be used to create bioanalytical arrays for simultaneously testing large numbers of genes, pharmaceuticals or proteins.

The researchers began their work using AFM cantilevers provided by IBM’s Zurich Research Lab. King and graduate student Tanya Wright now fabricate their own cantilevers, becoming only the third group in the world to do so.

Beyond the practical applications, the researchers hope their thermal dip pen process will lead to fundamental discoveries.

“This technology is broadly applicable to all kinds of nanotechnology, anywhere you want to make small structures ranging from electronic devices to arrays of sensing elements," said Whitman. "The nanotechnology community is interested in having a wide variety of tools to make nanoscale structures for all kinds of functions. We think this technology could play a role in making them, studying them and possibly repairing them."

The research may also help answer questions about how heat transfer differs at the nanometer size scale.

"There are significant questions about how you define temperature at this size scale," King noted. "If you want to do engineering design work around this process, you cannot use standard heat transfer equations. This technology is helping us to understand the science of nanoscale heat flow."

Source: Georgia Institute of Technology

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