Benchtop photolithography tool offers a low-cost route to nanomanufacturing

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Solid-state photolithography is an inexpensive and compact tool that can be built from off-the-shelf parts, operated on the benchtop, and could potentially have a large impact on nanomanufacturing.

Nanoscale technology has transformed the electronics industry by miniaturizing desktop computers to sizes that can fit in the palm of our hands. The primary, enabling driver behind this advance is the ability to define patterns at the micro- and nanometer scales. The current workhorse tool that does so is the mask aligner, which is bulky in size and weight (~2m³ and 360kg) and limited in area for single-step patterning to ~0.4m². In addition, a significant amount of infrastructure is needed for operation, such as high-voltage power supplies, gas cooling lines, and cleanroom facilities. The average cost of this tool is on the order of several hundred thousand dollars, which can be a barrier for many labs and businesses in the research and development of nanotechnology applications. If easier access to scale and prototype micro- and nanostructures were available, industries from biotechnology to green energy would benefit.

Much effort has been devoted to reducing the cost and scaling the output of traditional nanopatterning techniques that are serial by design, such as electron-beam lithography (EBL) and focused ion beam (FIB) milling. Recent approaches have primarily included printing and molding methods, where a patterned transfer element (e.g., a stamp or mold) transfers its pattern onto a desired substrate or material. However, this patterning element must first be fabricated, usually by EBL or photolithography using the mask aligner.

We have invented a tool—solid-state photolithography (SSP)—that can overcome the limitations of EBL and FIB as well as produce high-quality nanopatterns without the overhead of conventional mask aligners. SSP is inexpensive (as little as $30), compact (~0.003m³ and <1kg), and can be built from commercially available parts.

SSP is a portable photolithography system powered by AA batteries. Its light source is an array of UV LEDs (see Figure 1). The array-based design of the solid-state light source alleviates the need for the sophisticated exposure optics as well as the mercury vapor lamp used in mask aligners. Also, in principle, the LED array can be scaled to arbitrarily large areas simply by including more LEDs. The LED light source consumes a fraction of the electrical power (<1%) and has a lifetime 50–100 times longer than the mercury lamps. Combined, these factors reduce both the cost and environmental impact of nanomanufacturing. In our work, we built and tested two systems: a 200-LED system that can be used with industry-standard 4-inch wafers ($400 total cost); and a smaller system that can be used with 2-inch test wafers ($30 total cost).

Continued on next page
Figure 2. Scanning electron microscope image of nanoscale patterns. Patterns similar to these may be used to increase the efficiency of solar cells.

The 200-LED SSP system was designed using gallium nitride-based LEDs of wavelength 405nm, purchased at RadioShack. This UV wavelength was selected because of its compatibility with available g-line photoresists. To test the versatility of this system, we used two different types of masks: a traditional chromium/quartz photomask (contact masks used with mask aligners); and unconventional elastomeric masks made from poly(dimethylsiloxane) (PDMS). Using the contact photomasks, we produced submicron patterns in photoresist with vertical sidewalls. The high fidelity of these patterns ensures that they can be easily transferred into functional materials such as metals or semiconductors. Using PDMS 'phase-shifting' masks, we generated subwavelength (<200nm) features with subwavelength spacing over 4-inch wafers (see Figure 2).

In addition, we designed another SSP system that could operate at shorter wavelengths for use with other types of photoresists. This system employed UV LEDs that emit at 365nm, which is ideal for i-line photoresists. To show the ease with which a UV flashlight could be used to prototype simple devices, we patterned negative-tone resists with SU-8, a widely used epoxy for making masters for microfluidic channels. Using laserjet-printed transparency masks, we produced Y-shaped channels in SU-8 whose widths were around 100μm. We then molded PDMS against the SU-8 master to create the devices. Microfluidic networks have promise for lab-on-a-chip applications.

Our work shows that a simple tool such as solid-state photolithography can create a wide range of patterns from a diverse set of masks. Moreover, SSP can easily be integrated with industry-standard photoresist materials to generate high-quality nanoscale patterns. In the future we hope to use the process to create UV LED arrays on curved substrates. This possibility could offer new opportunities for integrating photolithography in roll-to-roll processing. By reducing the unit cost of patterns as well as infrastructure requirements, SSP broadens the availability of micro- and nanostructures that are critical in areas from nanophotonics to microelectrical and mechanical systems. In short, SSP has the potential to deliver high-quality nanomanufacturing to every lab and small business.

This work was supported by the National Science Foundation (NSF) under CMMI-0826219. We made use of the Northwestern University Atomic and Nanoscale Characterization Experimental Center facilities, which are supported by NSF Materials Research Science and Engineering Center, NSF Nanoscale Science and Engineering Center, and the Keck Foundation. M.D.H. was supported by the Department of Defense through the National Defense Science and Engineering Graduate Fellowship Program. M.D.H. gratefully acknowledges support from the Ryan Fellowship and the Northwestern University International Institute for Nanotechnology.

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References