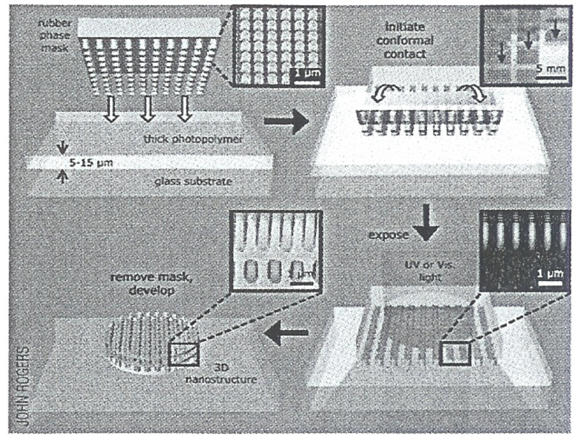
3-D MICROLITHOGRAPHY |

Rubber Phase Mask May Lead to Cheap Method for Building Photonic Crystals



Clockwise from the upper left: A rubber phase mask is placed on a photopolymer, where it sticks due to atomic forces. The system is exposed, the mask removed, and the photoresist developed, leaving a 3-D structure.

Researchers at the University of Illinois (Urbana-Champaign, IL) have come up with a way to make 3-D structures on a nanometer scale with the help of a rubber optical element.

The work at the university's Beckman Institute by professor John Rogers and graduate research assistant Seokwoo Jeon could lead to inexpensive mass production of such 3-D structures.

Existing nanostructure manufacturing techniques, such as photolithography and electron beam lithography, are better suited for creating 2-D features, Rogers says. "Most of them require lasers and are fairly complex in the setup and don't allow a lot of flexibility in the geometry of what you're trying to do," Rogers says.

His process uses a sub-wavelength phase mask made of silicone rubber, with extremely fine relief features patterned into it through traditional photolithography techniques. The mask is placed on a thin film of a standard polymer photoresist. Because the relief features on the mask have dimensions smaller than the wavelength of the light—Rogers uses light around 365 nm—they modulate the phase of the light as it passes. The mask creates an interference pattern, exposing the photoresist in certain areas and leaving it unaffected in others. After exposure, Rogers peels off the phase mask and washes away the unexposed areas with a solvent, leaving behind a 3-D structure.

"Because we're in this contact exposure mode, we don't need the light to have very high coherence," Rogers says. "We can do this complex patterning with a $20 mercury lamp."

The technique can achieve feature sizes as small as 50 nm, he says. The most immediate application may be in building lab-on-a-chip devices for microfluidics. Because such devices use tiny amounts of fluids, laminar flow is the dominant force and two fluids placed in the same channel tend to flow beside each other, rather than mixing. Forcing the fluids to flow through a porous 3-D nanostructure in the channel would introduce turbulence and get them to mix. The technique could also be useful for creating materials that require a high ratio of surface area to volume like catalysts.

Filling a Gap

A little further down the road, and potentially more interesting, Rogers says, is the creation of 3-D photonic bandgap materials, in which the size and placement of nanometer scale structures controls the light traveling through the material. Such materials are seen as ways to create hollow optical fibers or filters for selecting infrared wavelengths to enhance photovoltaic cells.

Rogers says several aspects of the phase mask make it suitable for high-volume manufacturing. It is robust and can be re-used easily. No special equipment is needed to hold it in place—atomic van der Waals forces cause it to stick to the thin film. By deforming the phase mask spatially, researchers can change the periodicity of the relief features and get different effects. The mask can also be used with two-photon absorption using an 800-nm source, creating a different set of geometries.

Younan Xia, professor of chemistry at the University of Washington (Seattle, WA), says the work is a breakthrough in 3-D fabrication and should find widespread use in photonic bandgap crystals. He calls the technique an elegant way to create nanostructures. "People have used the holographic method to generate 3-D periodic structures, but that requires the use of four or more laser beams arranged or aligned in the specific configuration," Xia says. "The use of a phase mask greatly simplifies the procedure and reduces the production cost."

Rogers' lab has developed an algorithm to predict the 3-D structure that a particular mask geometry will produce. Now the lab is working on the harder task, developing a method for designing a mask based on 3-D structure requirements.

—Neil Savage