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New Nanoscale Process Created by UCSB Engineers Will Help Computers Run Faster and More Efficiently

(Santa Barbara, Calif.) -- Smaller... Faster... More efficient... These are the qualities that industry needs in electronic devices in order to speed up computers and reduce their energy consumption.

Materials engineers at UC Santa Barbara have made a major contribution to this field by creating a new nanotechnology that will ultimately help make computers smaller, faster, and more efficient. The new process was described in Science Express, the online version of the prestigious journal Science, and will be published in the print edition in the near future.

For the first time, the UCSB engineers have created a way to make square, nanoscale, chemical patterns for use in the manufacture of integrated circuit chips. The method is called block co-polymer (BCP) lithography, and may be used in commercial production as soon as two years from now.
Five leading manufacturers, including Intel and IBM, helped fund the research at UCSB, along with the National Science Foundation and other funders. The university has already applied for patents on the new BCP lithography methods, and it will retain ownership.

A multidisciplinary team led by Craig Hawker, materials professor and director of the Materials Research Laboratory at UCSB, with professors Glenn Fredrickson and Edward J. Kramer, developed the process, which can create features between five and 20 nanometers wide on silicon wafers. (A nanometer is one billionth of a meter, or roughly one-thousandth of the thickness of a human hair.)

Hawker explained that for computers to continue to develop, we need more powerful microprocessors that use less energy. "If you can shrink all these things down," he said "you get both more computing power and higher energy efficiency, in a smaller package."

He said that the industry was up against limits to Moore's law, first described by Gordon Moore, Intel co-founder, in 1965, in which the power of available microprocessors is said to double every 18 months. "The industry is now running into physical limitations," said Hawker. "You can't shrink things down any more with the current photolithography techniques." In photolithography, light is directed onto the surface of a silicon wafer to make patterns which become circuit elements. He explained that the wavelength of light has become the limiting factor for feature size with photolithography.

"Our new blending approach, BCP lithography," said Hawker, "essentially relies on a natural self-assembly process. Just like proteins in the body, these molecules come together and self assemble into a pattern. We use that pattern as our lithographic tool, to make patterns on the silicon wafer."

With this technique, the size of the features is about the same as that of the molecules. They are very small, between five and 20 nanometers. "With this new form of lithography, we can make many more features," said Hawker, "and hence we can pack the transistors and everything else closer together."

When this technique has been tried before, the molecules spontaneously self assembled into hexagonal arrays, which look like bee hives. Since industry uses parallel lines on a square or rectangular grid, however, the hexagonal arrays have only limited application.

"Our research has actually shown that by changing the structure of the molecules, and using two self-assembling procedures at the same time, we're actually able to get square arrays for the first time," said Hawker. "Now you can start to marry the old technology with the new technology for the fabrication of microprocessors."

Hawker said that the new technology was designed to be compatible with current manufacturing techniques, giving it the potential to be a "slip-in" technology. "All the big microprocessor companies like Intel and IBM have invested billions of dollars in their fabrication plants," said Hawker. "They're not going to throw out that technology anytime soon. It is too big of an investment and would not make good business sense. This allows them to introduce a new technology using current tools in the same fabrication plants. So they don't have to make huge up front investments to bring this to manufacturing. That's a key feature."

An analogy that Hawker uses in describing the development of the new methodology of block co-polymers is that of mixing salad dressing. "Think of the block co-polymers as oil and water," said Hawker. "When you make salad dressing you shake up the bottle because the oil and water don't want to be together. They separate into two layers. You shake your salad dressing and you mix everything up into much smaller droplets. What we've done is taken two polymer molecules that hate each other and joined them together. And so they want to separate just like the oil and water in your salad dressing. But because we've molecularly joined them, they can't. And so they arrange themselves into very, very small droplets, or domains, based on the fact that they hate each other. Those are the BCPs."

He noted that an interesting feature of this work is that the engineers combined the repulsive force with another self-assembly force which is slightly attractive.
"What we do is take one BCP (made of two components that hate each other) another BCP (again made of two components that hate each other) and simply mix these together," said Hawker. "When we mix them together, we've designed groups on one chain to be attracted to groups on a different chain, and so they actually start to blend and mix together. It is this combination of all these forces trying to get away from each other, and attract to each other that allows us to make the square arrays. What nature gives you is hexagonal, if you just use a single component system."

The engineers design the BCPs to have specific structures, and they use simulation to define the structures that are needed to prepare. "We design the molecule by understanding what needs to happen during the self-assembly process," said Hawker. "We need one block to be oil-like and one block to be water-like. So that's our first level of sophistication. We then design the molecular weight or the size of the molecule, to give us the desired feature size."
In the next step, the engineers design into the oil block the sticky groups that will form this attractive interaction, and by controlling the number of sticky groups, different levels of phase separation and different structures are created.
Polystyrene is the oil-like block, and one of the water-soluble blocks is polyethylene glycol. Polyethylene glycol is found in shampoos and many consumer products. It's a non-toxic, water-soluble, biocompatible polymer. By putting those together, the polyethylene glycol loves the water and the polystyrene loves the oil, and they hate each other. Polystyrene is found in disposable coffee cups, and according to the engineers is a

fairly cheap commodity material that if designed in the right way, becomes a high value added application.

"The key to this technology is that we put all the information into those molecules," said Hawker. "From a molecular level, we've built all the information into them that will allow them to undergo controlled phase separation. And the key is then just simply blending of two specifically designed materials, and then all we do is spin that down into a thin film on a silicon wafer. And then we heat it, and all the information that is pre-built into the molecule does its thing, and gives us the structure."

BCP lithography has another major attraction, besides feature scale, for industry- it is a really cheap technique. Hawker notes, "All you have to do is heat things up and you get the structures that you desire. This means that BCP layers can be added to multi-layer microprocessor production lines by adding $5,000 ovens instead of multimillion-dollar photolithography equipment."

In addition to Hawker, the paper's authors include: Chuanbing Tang, a postdoctoral fellow at the Materials Research Laboratory; Glenn Fredrickson, professor of chemical engineering and director of the Mitsubishi Chemical Center for Advanced Materials; Erin M. Lennon, a graduate student with Glenn Fredrickson at the time of the work; and Edward J. Kramer, professor of materials and of chemical engineering. (Lennon is now a National Science Foundation Research Training Group postdoctoral scholar at Northwestern University.)

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Profile for Craig Hawker

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