Nano-imprint makes its mark

By Russ Arensman -- 7/1/2005
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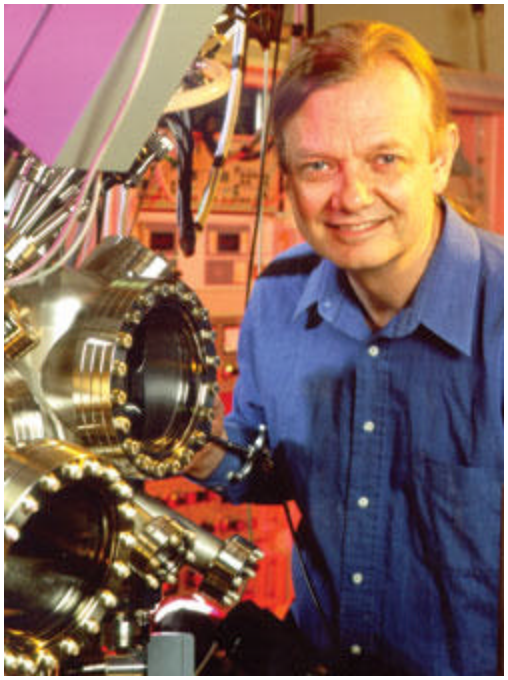


"We think this is an incredibly promising technology. It's the most viable technique for being able to manufacture in the nanoscale realm," says HP researcher Stan Williams.

Although most of the semiconductor industry is still learning to build chips with circuits as narrow as 90 nanometers, **Hewlett-Packard** researcher Stan Williams is using a novel process called nano-imprint lithography (NIL) to make experimental memory chips with tiny electrical pathways less than half that size. "We're now using imprint lithography to routinely make real, operating circuits with a half-pitch [width] of 30 nanometers," says Williams, a senior fellow and director of quantum science research at HP Labs.

Conventional optical lithography tools can't produce features nearly small enough for Williams' chips, which require dozens of tiny parallel wires to be laid out on both sides of a thin layer of electrically switchable material. Instead, HP relies on what's basically a high-tech stamping process. A mold etched with microscopic patterns is pressed into a layer of soft polymer resist material, which is then hardened with ultraviolet light. When the mold is removed, an exact copy of the mold pattern, in reverse, is left behind. Conventional etching and deposition are then used to selectively remove and replace some of the polymer features with a fine grid of metal lines and connections.

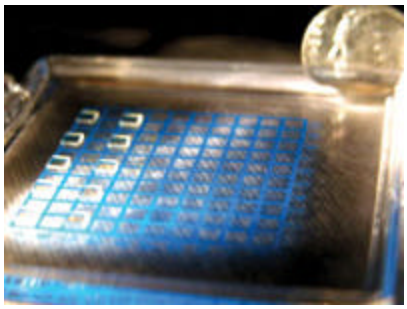
Although HP's prototype chips are years away from finding their way into commercial products, Williams is convinced that imprint technology has the potential to revolutionize the semiconductor industry as well as a host of other fields, from data storage to optical networking to life sciences. "We think this is an incredibly promising technology. It's the most viable technique for being able to manufacture in the nanoscale realm," he says. "There's no other existing technique we could use to make our circuits."

Universities and research labs such as HP's are using imprint lithography to build a plethora of molecular-scale products. And as their experimental results are reported in papers and presentations, imprint lithography is emerging as one of the technology industry's most promising new manufacturing methods. Not only can it produce extremely small features but NIL also offers the potential to greatly simplify many production processes, and at a far lower cost—perhaps as little as one tenth the cost of optical lithography. But first, production-ready tools and manufacturing infrastructure must be developed and potential customers must be convinced that imprints offer both technical and economic advantages over competing technologies.

Gaining momentum

HP is not alone in its enthusiasm for imprint technology. Five other companies—EV Group, Molecular Imprints, Nanonex, Obducat and Suss MicroTec—are selling NIL manufacturing tools, and numerous others are working on other aspects of the technology, including molds, polymer materials and inspection tools. Although the imprint tool industry is still so new that no third-party data exists yet to estimate the total market size, Molecular Imprints and Nanonex each claim to have sold about a dozen machines, with prices ranging from $100,000 to well over $1 million.

Companies are also working to create ecosystems at this early stage. EV recently organized a consortium, dubbed NILcom, enlisting nearly a dozen companies, universities and research institutes in commercializing NIL technology. Helge Luesebrink, director of EV's advanced lithography business unit, estimates that through the end of 2004, about 160 NIL machines had been installed worldwide, mostly at universities and research institutes. He claims that his company accounts for 40, or one fourth, of those systems.



Among the first commercial parts made with imprinting, the optical wave plates on the left side of the grid are used in DVD and CD players.

Molecular Imprints has also assembled its own network of R&D partners, including such prominent names as Motorola, KLA-Tencor, Lam Research, Photronics and Carl Zeiss. Last year Molecular Imprints, which has raised more than $12 million in venture capital, was awarded $36.8 million by the U.S. National Institute of Standards and Technology to demonstrate, along with its partners, the feasibility of using imprint lithography to pattern dense electrical contacts with 65-nm and smaller features.

Another indication of imprint lithography's growing credibility is its inclusion on the International Technology Roadmap for Semiconductors (ITRS), the chip industry's joint planning document that details technologies likely to be used in developing future chip generations. In December 2003, ITRS officials listed both NIL and extreme ultraviolet (EUV) optical lithography as candidates for making 32-nm chips, starting early in the next decade.

Multiple markets

Although commercial chip production is at least several years away for NIL, industry officials expect the technology to be used in other markets much sooner. "There are many markets and applications above and beyond silicon that require this technology," says Norm Schumaker, CEO of Molecular Imprints. Schumaker, a former Bell Labs researcher who helped found two previous semiconductor equipment companies, calls imprint lithography a disruptive technology that will have "enormous ramifications" across multiple industries.

Digital camera makers, he says, could use imprinting to build higher-quality microlenses with optical "prescriptions" tailored for specific image sensors. NIL tools also could make filters and photonic band-gap structures to enable brighter projection TVs and light-emitting diodes. "Using imprint technology is by far the most cost-effective way of doing these structures," he says.

Disk drive makers are eyeing NIL to create patterned media, in which tiny magnetic dots would replace the uniform layers of magnetic recording materials on today's disks. Disk maker Komag recently licensed imprint technology from EV, with plans to codevelop and sell patterned media it hopes will extend hard drive recording capacities beyond 160 gigabytes per disk. EV's Luesebrink says the storage industry may begin high-volume NIL manufacturing as soon as 2007.

The biomedical industry is another promising market. Schumaker says universities are using imprint lithography to create uniquely textured surfaces where cells either don't grow or grow only in particular directions. Luesebrink says Waseda University and a Japanese medical equipment company are developing a cell-sorting device that uses imprinted components to quickly analyze fluids and identify specific target cells.

The best demonstration of imprint lithography's viability thus far may well be NanoOpto, a private four-year-old New Jersey company that actually has put the technology into commercial production. NanoOpto—which like tool maker Nanonex was founded by Princeton University professor Stephen Chou—recently began using its own homegrown NIL tools to make a variety of optical components, including wave plates for modifying optical signals in DVD and CD players. NanoOpto CEO Barry Weinbaum won't disclose who's buying the parts but says, "We're shipping real products based on this technology to very real customers."

NanoOpto imprints 4-inch wafers in a class-10 clean room (less than 10 particles per cubic foot), followed by semiconductor processing in a less costly class-100 environment, which allows 10 times more airborne particles. Weinbaum says the imprinting process is producing "very healthy yields" of working parts. "Our pattern-transfer process literally takes seconds," he says.

Semiconductor skepticism

Despite such progress, the $5 billion optical lithography industry appears reluctant to embrace a drastically different technology, especially while investing heavily in the increasingly difficult task of extending optical technology to ever smaller dimensions. Market leaders ASML, Nikon and Canon have not disclosed any interest in NIL technology. But some believe that activity is going on behind the scenes. "I do believe optical lithography companies are all working on it," says EV's Luesebrink. "If you go to conferences, you see them. They are all circling and homing in and trying to get a taste of what it's like."

"There are many markets and applications above and beyond silicon that requires this technology."—Norm Schumaker, CEO, Molecular Imprints

Imprint lithography also remains controversial among semiconductor makers, which are understandably cautious about taking risks on an immature technology. "No one is more conservative than a semiconductor fab manager," says Molecular Imprints' Schumaker. "They can't gamble with a $3 billion facility."

Bernie Roman, manager of advanced lithography development for Freescale Semiconductor, says fabricating high-density chips with imprint technology poses "real challenges" and adds, "We do not believe that it is the best solution." VLSI Research analyst Risto Puhakka, when asked how soon he thinks NIL could be ready for use in chip making, replies, "I would say it's a ways off, or maybe never."

Why? Puhakka says a fundamental concern stems from the need for contact between NIL molds and the materials being fabricated. "Something touches the wafer, which is a big no-no in the industry," he says. "That makes every lithography guy shiver." Contact printing was widely used by the industry 30 years ago but was phased out in favor of optical patterning techniques that produced better results.

Other deterrents include the difficulty of obtaining high-quality molds (also called templates) and the need for better tools to precisely align multiple layers of circuits. Of those, the molds are the more challenging issue. "No one has really stepped up to be a commercial producer of molds," says HP's Williams, who relies on molds built by Lawrence Berkeley National Laboratory. It's a classic "chicken and egg" problem, he says, in which a lack of templates slows technology development and potential template makers are reluctant to invest in the technology until the market is bigger.

Franklin Kalk, chief technical officer of Toppan Photomasks, says his company makes a limited number of NIL templates but outsources the painstaking process of inspecting them for defects. "We're not investing tens of millions of dollars in a new electron-beam inspection tool," he says. "It's too early to do that."

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—Walt Trybula, Sematech

Kalk would like to see better, less costly electron-beam tools for making molds. Although it's possible to make NIL molds with features as small as 10 nanometers, Kalk says the current tools are expensive and slow, taking a week or more to etch the features of a complex mold. "That's not a good cost-of-ownership model," he says, adding, "Today's tools just can't do it."

Defects are another key concern, because dust particles or bits of polymer stuck in a mold can be duplicated in every subsequent imprint. "The main issue with NIL is whether the defect density is low enough to be accepted by the industry," says Nanonex's Chou. Allaying defect concerns will require extensive testing in semiconductor production environments, he says.

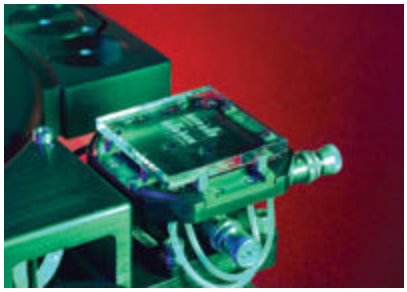
Signs of progress

Walt Trybula, a senior fellow at the chip research consortium Sematech, sees encouraging signs of progress in the industry's ability to build high-quality molds, align chip layers and control defects. "We're making some headway," he says. Research suggests, for instance, that rather than carrying over from imprint to imprint, dust and other contaminants are likely to stick in the material being imprinted. "It appears that if you have a contaminated template, it will rapidly self-clean," he says.

Economics may be NIL's biggest attraction, says Trybula. Not only are NIL tools and molds likely to cost far less than optical lithography equipment, he says, but NIL could also greatly simplify the chip making process. Recent research suggests that NIL tools can fabricate a chip's metal conducting lines and vias (connections between chip layers) in just eight steps, compared to the 24 required by conventional processes. In an eight-level chip, he notes, chip makers could eliminate 128 out of 600 steps.

"It's got potential," says Trybula, "but the jury is still out. There's a whole lot of learning that has to happen before it can go into production." Even its most ardent proponents concede that NIL needs further development. But they also note that it doesn't have to displace optical lithography to be useful. NIL tools could be used, for instance, just in processes requiring extremely high resolution.

Meanwhile EUV, the leading next-generation optical lithography competitor, has plenty of its own problems. A recent Lux Research report notes that industry support for EUV is declining, as "problems persist with every component" of the technology, including its X-ray light sources, optics, masks and photoresists. Lux calls NIL the strongest contender of nearly a dozen technologies vying to pattern next-generation nanoscale semiconductors.



Molecular Imprint's uses a transparent template as the "mold" to make chip circuits and other tiny parts from liquid polymer. Ultraviolet light hardens the material before the mold is removed.

"The reasons for considering imprint lithography are not that it's ready for high-volume semiconductor manufacturing today—it is clearly not," says Matthew Nordan, Lux's vice president of research. "Our belief is that it's the least-worst technology."

Nordan says NIL's biggest challenge may be to change the industry's preconceptions. "Optical technology is what the semiconductor industry knows," he says. Anything else provokes "not just apathy but even downright hostility, because there are a lot of people who are out of a job if NIL succeeds, or are at least forced to relearn their job."

Jim O'Connor, head of Motorola's technology incubator program, which bought Molecular Imprints' first NIL tool, understands the chip industry's misgivings. "It's going to stick with optical lithography as long as it can ride that horse," he says. But with the latest optical steppers already expected to cost up to $30 million and EUV steppers perhaps $50 million, imprint lithography is looking increasingly attractive. Says O'Connor, "From an economic point of view, you've taken optical lithography almost as far as you can take it without making the costs so obscene that you can hardly move forward."

Will imprint technology make headway in the semiconductor industry? Send your thoughts to feedback@eb.reedbusiness.com.

Imprint-tool makers Company	Location	Comments
EV Group	Schärding, Austria	A maker of mask aligners and wafer bonding equipment, it claims to have sold 40 imprint machines.
Molecular Imprints	Austin, Texas	A University of Texas spin-off, it may be the most semiconductor-focused imprint tool maker. With more than 100 employees and $12 million in venture capital raised, it's also the largest.
Nanonex	Monmouth Junction, N.J.	A Princeton University spinoff, it's the oldest nano-imprint company and sells resists and masks as well as imprint tools.
Obducat	Malmö, Sweden	A leading seller of imprint tools, it also makes scanning electron microscopes and electron-beam lithography tools.
Suss MicroTec	Munich, Germany	A maker of mask aligners and wafer bonders, it offers a new imprint stepper that does automated wafer handling.

Source: Electronic Business

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