BEHIND THE MASK

A NOVEL METHOD OF PRINTING SEMICONDUCTORS TRANSFORMS AN INDUSTRY

Photomasking technology developed with the support of the SBIR program is bringing semiconductor manufacturing into sharper focus.

As semiconductors and other computer components have grown smaller and more complex over the years, the traditional methods of etching circuits onto chips—processes which share a terminology and technology with ink-on-paper printing—have been challenged by the microscopic features in modern chip designs.

Much as traditional printing lithography once used etched limestone printing plates (*lithos* is Greek for "stone") and now uses etched metal or plastic printing plates to transfer images to paper, photolithography in semiconductor manufacturing involves creating a mask, or template, out of quartz and chrome. That mask is then used to transfer the chip design to a silicon wafer through a printing process similar to the way ink is applied to photosensitive paper. But some features in chip designs have shrunk to the point that they are smaller than the wavelengths of light used to pattern them on the wafers, potentially leading to unpredictable results.

At first, simulation software helped predict what the chip's tiny components would look like after the photomask was created. Designers could then make any adjustments to the photomasks they felt were needed. But as chip features shrank below 20 nanometers (by comparison, the diameter of a human hair is about 75,000 nanometers), the simulation process began to break down, according to George Bailey, director of technical marketing within the silicon engineering group at Synopsys, a developer of tools for silicon chip design, verification, IP, and security software.

Inverse lithography technology, or ILT, emerged in the early 2000s as a new take on this longstanding challenge. Rather than simulating what the chip would look like based on the mask, ILT used simulation software to solve the problem in reverse—by determining what the mask should look like based on the desired characteristics of the chips.

Simulating these complex processes required new algorithms and mathematical models. Enter Luminescent Technologies, a Mountain View, California-based company founded in 2002. Funded by venture capital, Luminescent faced many of the same funding challenges as other high-tech startups, with an added level of complexity. "It was developing software and manufacturing processes," Bailey said.

> "The momentum was there, and the SBIR helped make it happen," Bailey said.

In 2003, Luminescent was awarded a Phase I SBIR contract from the Defense Advanced Research Projects Agency (DARPA), followed by Phase II in 2004, to support its work developing software algorithms to support the creation of ILT-powered photomasks. DARPA was seeking new advances to increase device densities without major changes to existing fabrication facilities, which would enable greater chip computational power while generating higher yields, resulting in decreasing costs to both DoD and the civilian sector. The contracts helped in the development of Luminescent's first commercial computational lithography solution, which was called Explorer and released in 2005.

"The momentum was there, and the SBIR helped make it happen," Bailey said. "As a startup, Luminescent was limited on resources, and the contracts helped keep them afloat."

Like many other venture capital-funded startups, Luminescent began looking for ways to scale its intellectual property, and in 2012, Synopsys acquired Luminescent's ILT technology.

George Bailey

This technology, according to Bailey, "provided the missing pieces" of Synopsys' own Proteus ILT platform of software products for chip manufacturers. (Luminescent would ultimately go on to sell itself and its remaining technology to another company, KLA-Tencor, in 2014.)

Today, chips continue to grow smaller and more complex—the advanced features in memory modules, for example, are now approaching 10 nanometers, and the demands of the growing universe of drones, sensors, and wearable devices that make up the Internet of Things will continue to place a premium on smaller, more sophisticated designs. As a result, ILT has matured as a manufacturing process and is now used by a wide range of chip manufacturers.

According to Bailey, the Luminescent technology developed with the support of the DARPA SBIRs accelerated the creation of new hardware solutions for chip manufacturing, including multi-beam technology capable of "writing" free-form photomasks at a faster rate than earlier, variable-shaped beam systems. That's critical given that, as chips have become smaller and more complex, the time it takes to create free-form photomasks using conventional methods has increased dramatically—by 25 percent a year, according to one estimate.

The overall economic impact of the chips manufactured using these hardware and software tools will only continue to grow as semiconductors become ever more sophisticated, according to Bailey. And the Luminescent technology developed with the help of the SBIR contracts, he said, "promoted the manufacturing of the new mask hardware that has continued to scale. There wouldn't be as high demand if it wasn't for the ILT technology maturing."

Luminescent Technologies, Inc. (Synopsys/KLA) • Mountain View, CA (Milpitas, CA)
Modernization Priority: General Warfighting Requirements (GWR)
SBIR contract: W31P4Q-04-C-R209 • Agency: DARPA • Topic: SB031-004, Sub-Wavelength Lithography Employing Phase Masks