DIAMOND SEMICONDUCTOR GROUP, LLC (DSG)

Lowering the Cost and Improving the Quality of Computer Chips

Billions of integrated circuits — the tiny chips that run personal computers and thousands of other electronic devices — are fabricated every year in the United States through ion beam implantation, a technique for introducing carefully controlled impurities, or dopants, into specific locations on the semiconductor wafers from which chips are cut. Dopants control the electrical properties of the semiconductor, forming the transistors and other microscopic components of each chip.

COMPOSITE PERFORMANCE SCORE
(Based on a four star rating.)
★ ★ ★

Ion Beam Implantation for 300-mm Wafers

With chip components getting smaller and denser, the need for more accurate control of dopant implantation has risen. At the same time, competitive manufacturing has driven the size of production wafers up, making increased accuracy problematic because of the difficulty in precisely scanning the implantation beam across the wafer.

. . . the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make.

This ATP project allowed Diamond Semiconductor Group (DSG), a two-person start-up company when it applied to the ATP, to develop a new and better way to implant dopants on large silicon crystal wafers measuring 300 mm or more in diameter, compared with the previous industry standard of 200 mm. Because the area of a 300-mm wafer is 2.25 times that of a 200-mm wafer and some waste always occurs at wafer edges, the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make. The use of DSG's new technology in production equipment makes it possible to lower the cost and improve the quality of computer chips and other integrated circuits.

Worker holding the world's first 300 millimeter silicon wafer populated with electronic components using the wide beam ion implantation technology.

Multiple Advantages of Wide-Beam Technology

A key innovation in the new technology is passing the wafer under a 350-mm-wide ion beam for implantation, rather than scanning the ion beam across the wafer. The broad beam is very stable and therefore highly accurate. The new equipment incorporating this technology is also significantly simpler than earlier machines and so is cheaper to build and maintain and is more reliable. Use of the DSG technology has already improved fabrication quality substantially relative to the existing industrywide standard. It doubled the mean time between failures, which means that on average, failures occur only half as often as with current equipment.

PROJECT HIGHLIGHTS

PROJECT:
To develop a novel approach for introducing dopants — substances that alter the electrical properties of semiconductor materials — into large semiconductor wafers to enable faster, less costly fabrication of larger wafers with smaller, more-densely packed components.

Duration: 3/1/1993 — 6/30/1994

ATP Number: 92-01-0115

FUNDING (in thousands):

ATP	$1,326	77%
Company	393	23%
Total	$1,719	

ACCOMPLISHMENTS:
DSG developed broad-beam ion-implantation technology (now embodied in Varian's SHC80 Serial High-Current Implanter) that successfully implanted the first commercially viable 300-mm semiconductor wafer. The new technology doubled the existing industrywide mean time between failures and provided additional ways to increase the quality and reduce the cost of chip fabrication. The company:

- received two patents for technology related to the ATP project:
  "Compact High-Current Broad-Beam Ion Implanter"
  (No. 5,350,926: filed 3/11/1993, granted 9/27/1994) and
  "High Speed Movement of Workpieces in Vacuum Processing"
  (No. 5,486,080: filed 6/30/1994, granted 1/23/1996);
- applied for two additional patents for technologies related to the ATP project;
- licensed the technology developed during the ATP project to Varian, which incorporated it in its SHC80 implant system and is actively selling the equipment to commercial customers; and
- licensed its technology to Mitsui Electronics and Shipbuilding for a flat-panel display application, after U.S. companies declined the licensing opportunity. DSG used $6.1 million from Mitsui to develop a 650-mm flat-panel component for displays. In 1997, Mitsui signed its first contract to supply the displays to a customer.

CITATIONS BY OTHERS OF PROJECT'S PATENTS: See Figure 4.6.

COMMERCIALIZATION STATUS:
The technology has been commercialized in one application and is very near commercialization for a second application. Chip manufacturers using the Varian SHC80 implant system (which incorporates the technology) are producing larger (300-mm) wafers than before (200-mm) and making them faster, with higher quality and at lower cost.

OUTLOOK:
The outlook is excellent. Varian is already selling semiconductor fabrication equipment that incorporates the new technology, and a flat-panel display application is under way. The technology generates cost savings not only for companies using it to make computer chips but also for those who ultimately buy the chips and the products containing them. The benefits directly captured by DSG will likely be only a small fraction of the total net benefits the technology generates for the economy.

Composite Performance Score: ★ ★ ★

COMPANY:
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Contact: Manny Sieradzki
Phone: (978) 281-4223
Number of Employees: 9 at project start, 25 at the end of 1997
Informal collaborator: Varian Associates Inc.

The DSG technology also lowers fabrication costs by allowing implant equipment to be designed to work on one wafer at a time. Although it seems counterintuitive, single-wafer processing is actually an advantage. Fewer wafers are lost if equipment fails, compared with current technology. The latter involves clamping 13 to 17 wafers to a large wheel, which then rotates at about 1,200 rpm under the ion beam. One failure may result in 13 to 17 unacceptable wafers. With single-wafer processing, only one wafer would be lost. In addition, single-wafer processing enables ion implantation to be coordinated much better with other fabrication steps, most of which are also performed one wafer at a time.

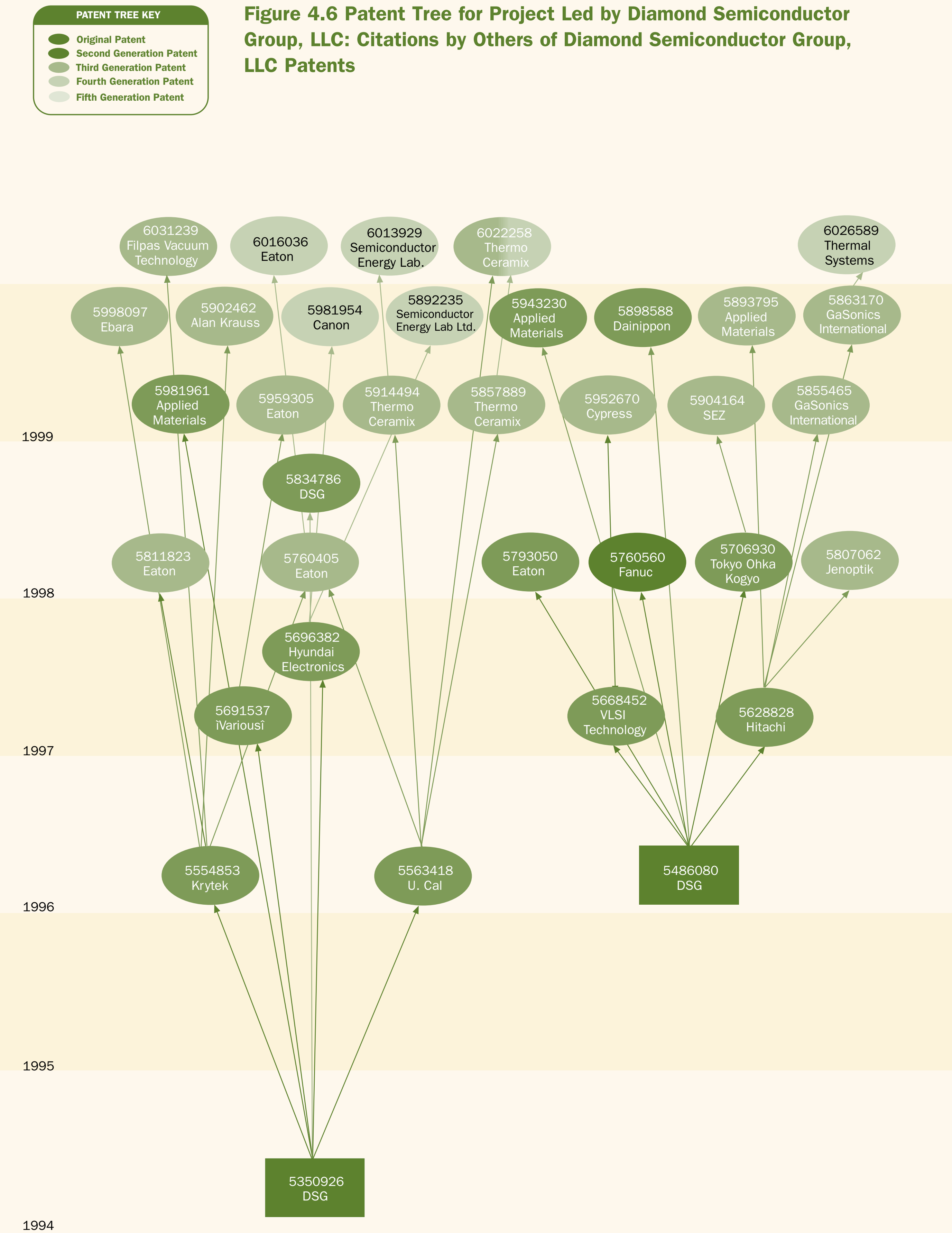
Licensing for Two Different Applications

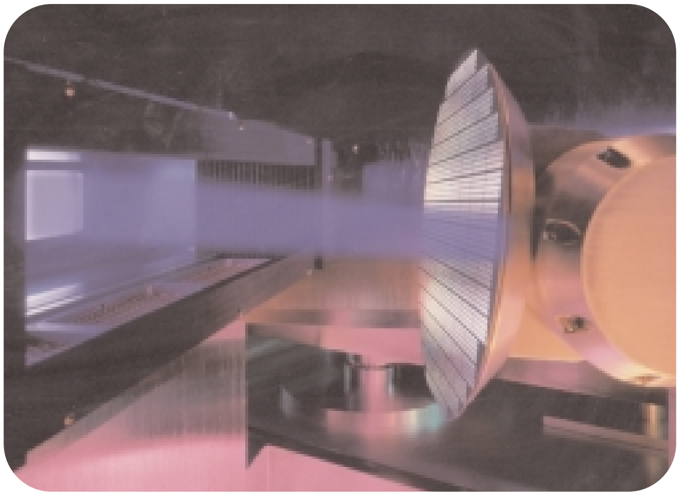
The ATP project is already a commercial success. DSG licensed the technology to Varian Associates, an ion-implant equipment manufacturer, which has incorporated the new technology into products now being sold.

Worldwide sales of ion implanters total $1 billion to $1.2 billion per year, and Varian has 40 percent to 50 percent of the market. Most of the equipment currently sold is for 200-mm wafers, and Varian was the first to market equipment that handles 300-mm wafers. Over the next five years, industry analysts say, the majority of implanters sold will be for 300-mm wafers. All 300-mm-wafer ion implanters currently manufactured by Varian include the DSG technology, and those produced in the future are expected to, as well.

DSG is also developing the technology for another application: flat-panel displays, such as those used in notebook computers. The company has completed the development work through a licensing agreement with Mitsui Electronics and Shipbuilding, which invested $6.1 million in the effort. In late 1997, Mitsui announced it had already won a contract to supply the panels to a customer. Prior to licensing the technology to Mitsui, DSG attempted to interest U.S. flat-panel display companies in it. But most of this industry is off shore, and there were no interested parties in the United States.

Figure 4.6 Patent Tree for Project Led by Diamond Semiconductor Group, LLC: Citations by Others of Diamond Semiconductor Group, LLC Patents





The uniform ribbon beam vertically scanning a wafer, in an ion implanter manufactured by Varian Associates.

Benefits All Along the Supply Chain

DSG's broad-beam technology enables the generation of substantial economic benefits. Varian sells its ion implanters to chip-fabrication companies such as Intel, Motorola, and Texas Instruments. These companies, in turn, sell their chips to manufacturers that use computer chips in their products — computer companies like Apple, Gateway, Hewlett-Packard, and IBM, as well as firms that make automobiles, appliances, consumer electronics, and communications equipment. All along this chain of production, the new technology is saving costs and improving quality.

The new equipment . . . is cheaper to build and maintain and is more reliable.

End users of these products can also expect to benefit from the new technology. Businesses that use desk-top computers containing chips made with this technology, for example, will get lower-cost, higher-quality machines. These will enable better services at lower costs, producing economic benefits for the businesses and their customers. Ultimately, company officials say, the profit DSG earns from its new technology will likely be only one percent to two percent or less of the total incremental economic benefits the technology is apt to generate across the economy, that is, the spillover benefits are likely to be large.

ATP Award Invigorates Small U.S. Company

DSG reports that without the ATP award, it would probably have been unable to do the research or survive as a company. Its only other alternative then was to become part of a foreign company. All the high-risk research and development work on DSG's broad-beam technology was done during the ATP project, and there was a high likelihood of failure. In addition, the company's status as an ATP participant facilitated the agreement it negotiated with Varian to help DSG meet its cost share for the project and, later, to include the technology in Varian's wafer implantation equipment.

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