ASML Special Applications enables emerging nanotube technology

We may be closer to nanochips than you think. ASML Special Applications (SA), in collaboration with its partners and customers, has played an instrumental role in fostering so-called NRAM memory chip technology that may well lead to a fundamental shift in the semiconductor industry from silicon to carbon and from volatile DRAM chips to non-volatile NRAM memory. Thanks to recent advances in feasibility testing with carbon-nanotube technology, a working prototype of an actual NRAM memory chip will likely be ready in the next one to two years, paving the way for a memory revolution.

ASML SA first recognized the tremendous potential of commercializing nanoelectromechanical switch technology using carbon nanotubes when nanotech firm Nantero introduced the concept in 2001. ASML SA acted quickly to assist Nantero in its efforts to develop and optimize an NRAM process, prove their concept in the lab, and move them into a production environment for fab feasibility testing. Results have been encouraging enough to get manufacturers on board and making plans for future full-scale production.

Creating opportunity on the nano level

In its role as a leader in identifying and enabling technological innovation, ASML SA is engaged in a constant search for promising technology to develop into commercially viable applications. In the case of carbon-nanotube technology, ASML SA was able to support Nantero with some of the vital resources it needed to develop its process efficiently and affordably in its labs. ASML SA introduced Nantero’s NRAM application to John Scadden of Strategic Solutions, an expert in outsourcing high-tech facilities and talent for exploring new tech opportunities. Scadden was impressed enough with the concept proof Nantero pulled off that he put Nantero together with Alta Microtec and custom ASIC manufacturer LSI and a feasible new technology was born.

What is a nanotube and how does it change the memory world?

Carbon nanotubes are cylindrical structures measuring just about a nanometer or less in diameter (Figure 1). The walls of a nanotube have the thickness of a single carbon atom, and their surface of hexagonal carbon rings looks like rolled-up chicken wire or a honeycomb tube. Carbon nanotubes have higher electrical conductivity than copper or gold, and greater thermal conductivity than diamonds. While possessing remarkable tensile properties, they are also quite rigid. In fact, they have the stiffness of diamonds and are more than fifty times stronger than steel.

In its NRAM memory application, ASML SA helped Nantero perfect a process wherein an SWNT crossbar architecture of nanotubes—a web-like swath of material—is suspended across a wafer surface and acts as a series of memory bits (Figure 2).

Figure 1
Carbon nanotubes are cylinders that resemble rolled up chicken wire measuring approximately 1 nm in diameter. Their tensile and conductivity properties have impressed researchers since their discovery in 1991.
This nanotube layer amounts to millions of electromechanical nano switches that store hundreds of gigabits of information, connecting and disconnecting at chip crosspoints in a mechanically bistable state.

When electrostatic energy is applied, the nanotube layer flexes downward into the etched gulf of the chip, connecting to the metal electrodes beneath (Figure 3, pg. 14). Nanotubes are so small and light, once bent they remain in that state, even when power is turned off. Van der Waals forces hold the switch in place until electrostatic energy is applied again, and the nanotube relaxes back into its straightened position. In this relay model, the up position represents the 0 state, and the down position represents the 1 state. This intrinsically bistable condition of nanotubes is what allows non-volatile operation that requires very little energy to carry out random-access memory in proportions never before achieved (Figure 4, pg. 14).

Nantero proved that you could get a layer of nanotube structures applied to the wafer surface in a CMOS environment by using a spinning solvent application that ASML SA helped Nantero perfect in the lab.

**Figure 2**

ASML SA helped nanotech firm Nantero optimize a process for suspending an SWNT crossbar architecture of nanotubes across a silicon wafer that acts as a series of electromechanical nano memory switches.

**Technology Leadership**

- Lithography solutions that enable promising technology to develop into commercially viable applications
- Application support for early concept validation
Making NRAM work at the flip of a switch

The enormous power savings that carbon-nanotube memory would produce, coupled with its potential for memory storage in the terabit range, presents tremendous potential for NRAM in the marketplace. It is radiation-hardened and for that reason particularly well disposed to military and space applications. But the real potential for this technology is only now being realized with the recent announcement by LSI that it has produced a working nanotube switch in a CMOS environment. The production of this viable carbon-nanotube memory cell points to the argument that it’s only a matter of time before non-volatile NRAM memory and all of its advantages will eventually replace standard volatile DRAM memory in the semiconductor industry.

If it does, ASML SA and its innovation partners wouldn’t be a bit surprised.

For more information please contact Keith Best at keith.best@asml.com. You can also read more about carbon nanotubes in the February edition of Scientific American Magazine.

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**Figure 3**
Nanotubes act as non-volatile memory elements that require very little energy to switch on and off. Their small size and composition makes them intrinsically bistable. In the relaxed position they represent the OFF (“0”) state. When electrostatic energy is applied, they bend down into the ON (“1”) state, connecting to the electrode in the silicon channel beneath them. Van der Waals forces hold them in place until energy is reapplied and they relax back into the OFF state.

![Nanoelectromechanical Array](image1)

OFF State

ON State

**Figure 4**
Photographs below show a single nanotube suspended over a number of electrodes on a wafer surface.

![Photographs courtesy of Nantero](image2)