

BUSINESS NEWS

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ACTIVITY IN NANOTECH

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NEW PRODUCTS

NANOTECH PRODUCTS ON THE
MARKET THIS MONTH

NANOTECHMAG

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FLASH FORWARD

Carbon nanotubes and the future of electronics from leading product developer Nantero.

FROM MANIPULATING TO MASTERING OF LIGHT

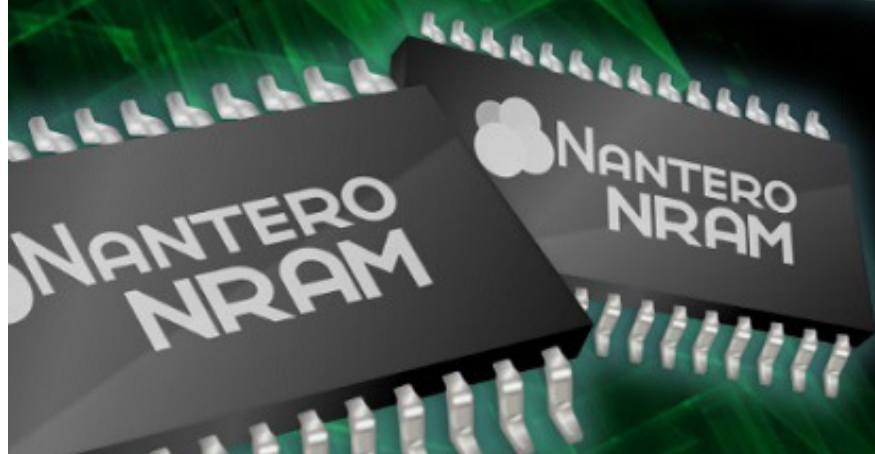
How the commercialization of Metamaterial Technology will change how we interact with light.

NANO LUBRICANTS

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WHO, WHAT, WHERE, WHEN

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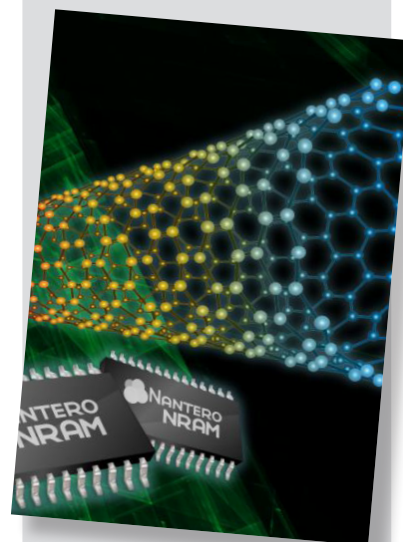
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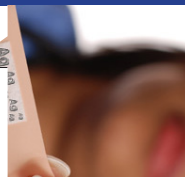


Cover Story

Nantero has developed a new generation of memory called NRAM® (non-volatile random access memory)-a CNT-based memory faster and more durable than flash, and as fast and lower power than DRAM.

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Issue 38 Nanotech

Welcome to Nanotech Magazine, now in it's fourth year and continuing to bring you the latest products and innovations from electronics to medicine.

Carbon nanotubes coming to the fore in electronics

With the recent announcement by IBM of a significant breakthrough in carbon nanotube (CNT) transistors it is timely that this month we feature leading NRAM developer Nantero. The company is at the forefront of CNT memory device development. Also featured this month and continuing our focus on new materials, not just nanomaterials, Canadian company Metamaterial Technologies Inc. provide an insight into how they are working to commercialize metamaterial technologies to master light in many different environments. We also provide an insight into nanomaterials additives

for the lubricants market and how they are meeting the new technology and regulatory demands of the industry.

As a trustworthy provider of high quality market research to the technology community we have become aghast recently at the profusion of fraudulent organizations, mainly based in India and China, that are peddling sub-standard or non-existent market reports. These organizations generally claim to have offices in the USA/UK and India/China and have been illegally replicating table of contents and report descriptions from reputable companies. One such organization has recently been sued in India for this practice, and there are a number of other cases pending. A rule of thumb is that over night these companies have enormous catalogues of products and also claim to provide in depth regional information that they would be unable to attain. Reputable market research companies generally have smaller, focused catalogues and in depth tables of contents. Beware the false prophets.

ABOUT NANOTECHMAG

Nanotech Magazine (www.nanotechmag.com) is published by Future Markets (www.futuremarketsinc.com), the world's leading provider of nanotechnology and nanomaterials market information. Future Markets provides leading-edge market research reports on advanced materials.

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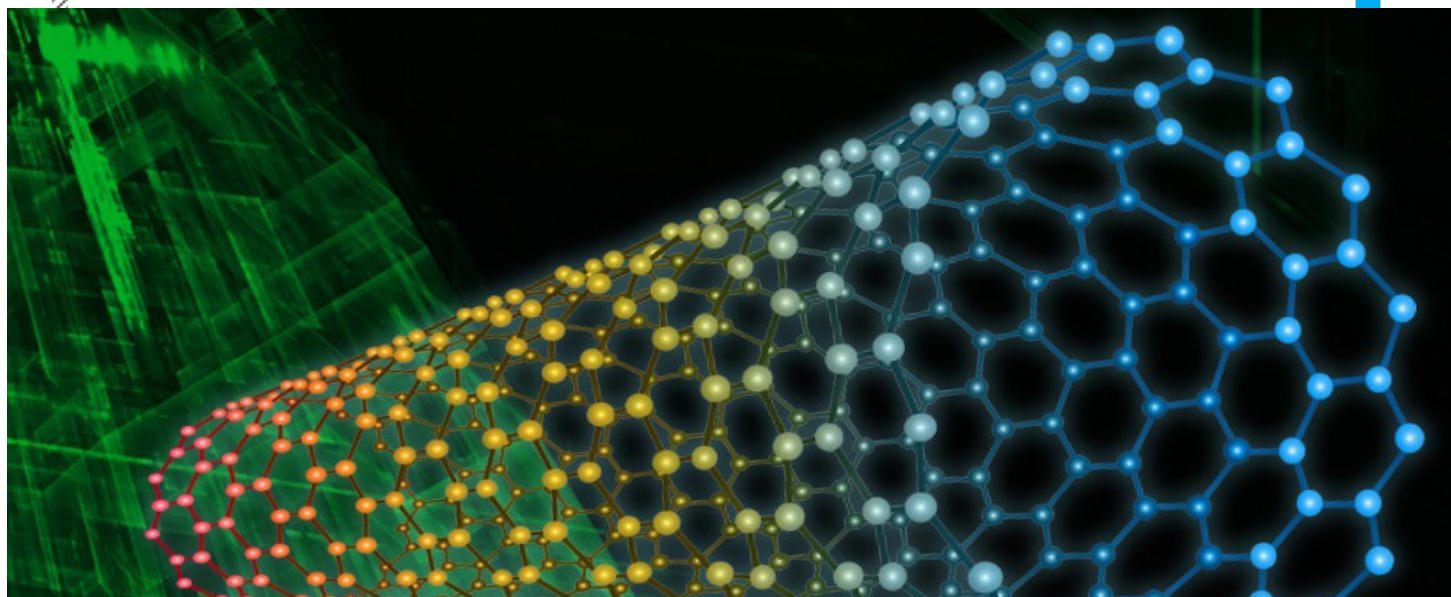
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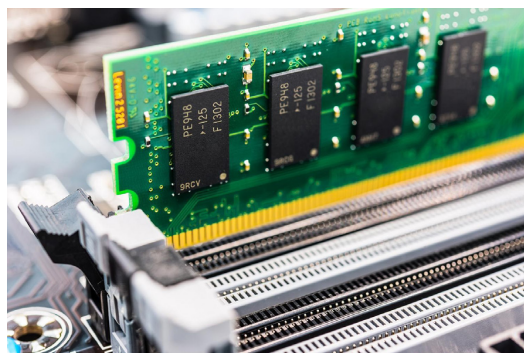
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Flash Forward

Carbon Nanotubes and the Future of Memory By Greg Schmergel, Co-Founder, CEO and President of Nantero, Inc.

Advances in memory have enabled many innovations in the electronics industry for the last 30 years, but many experts now agree that a new high-speed, high-density nonvolatile memory is needed to drive the next wave of innovation. To meet this industry need, NRAM® (non-volatile random access memory) has emerged and it uses a unique material – Carbon Nanotubes (CNTs).



Following years of intense development and testing, CNTs have proven to be the most suitable material for

delivering a new generation of memory. Discovered in 1991 by Sumio Iijima of NEC Corp., CNTs are incredibly strong elastic cylinders of carbon atoms that bear a striking resemblance to a tube of rolled-up chicken wire. CNTs are members of the fullerene family and have amazing properties, including the ability to conduct electricity as well as copper while being stronger than steel and as hard as diamond.

With one CNT being just 1/50,000th the diameter of a human hair, these tiny cylinders are 50 times stronger than steel, half the density of aluminum, and have better thermal and electrical conductivity properties than any other material scientists are aware of today. CNTs can be either single-walled (SWCNT), double-walled (DWCNT), or multi-walled (MWCNT). Individual nanotubes can bind to one another or to nearby materials by van der Waals forces. Named after Dutch scientist Johannes Diderik van der Waals, these forces are the sum of the attractive or repulsive forces between molecules – or parts of the same molecule – other than those due to covalent bonds, the hydrogen bonds, or

the electrostatic interaction of ions with one another or with neutral molecules.

NRAM Overview

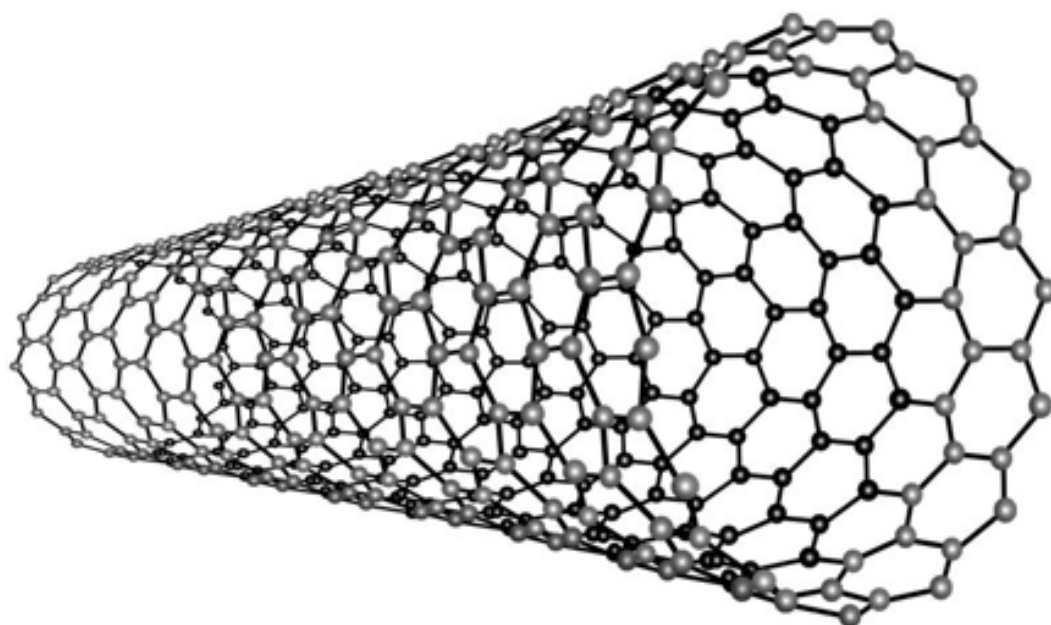
NRAM is the first CNT technology being readied for commercialization in the field of semiconductors. By leveraging the strength and versatility of CNTs, NRAM has DRAM-like speed, while being permanently nonvolatile, delivering potentially terabits of storage capacity and consuming very little power. The NRAM process has already been installed in multiple production fabs and is currently being designed into innovative new electronic products that require increased storage, low power consumption, high speed, reliability, and high endurance.

Developed by Nantero, a company based in Woburn, Massachusetts with a large presence in Sunnyvale, California, NRAM is as fast as and denser than DRAM, non-volatile like flash, has essentially zero power consumption in standby mode and 160x lower write energy per

bit than flash, and is highly resistant to environmental forces (heat even up to 300 degrees C, cold, magnetism, radiation, vibration). In addition, NRAM is compatible with existing CMOS fabs without needing any new tools or processes, and it is scalable even to below 5nm.

Given that it requires a small number of process steps and minimal additional mask layers, NRAM can be fabricated at low cost and is compatible with 3D multilayer architectures. This makes NRAM the ideal solution for the next generation of memory technology for both standalone and embedded applications. Its key attributes include:

- CMOS Compatible: Can be fabricated in standard CMOS fabs with no new equipment needed
- Limitless Scalability: Can scale below 5nm in the future
- High Endurance: Proven to operate for orders of magnitude more cycles than flash
- Faster Read and Write: Same as DRAM, 1000s of times faster than NAND



Carbon Nanotube used to create Nantero's NRAM®
50 times stronger than steel
1/50,000th the diameter of a human hair

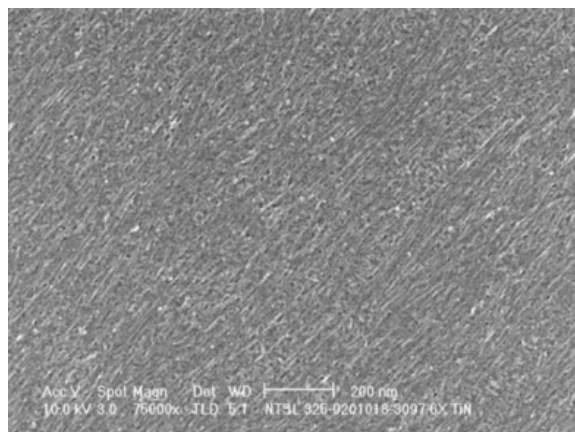
- **High Reliability:** will retain memory for >1,000 years at 85 degrees Celsius or more than 10 years at 300 degrees Celsius
- **Low Power:** Essentially zero in standby mode, >100x lower write energy per bit than NAND flash
- **Low Cost:** Simple structure, can be 3D multi-layer and multi-level cell (MLC).

All of these characteristics are highly desirable as a next-generation memory technology. In fact, independent researchers and engineers around the world have been independently testing and validating the benefits of CNT non-volatile memory for years now. The Takeuchi Lab at Japan's Chuo University published a report in 2014, based on wafers fabricated in earlier years, that showed a <5ns array program, low power operation, endurance in excess of 10¹¹, and multilevel cell potential. Likewise, a joint paper published in May 2014 by Nantero and Cisco engineers at the International Memory Workshop in Taiwan demonstrated multiple favorable characteristics for scaling of NRAM to small dimensions, including a 10,000x ON/OFF resistance ratio, improved data retention, and current and voltage scaling as device sizes shrink.

How NRAM Works

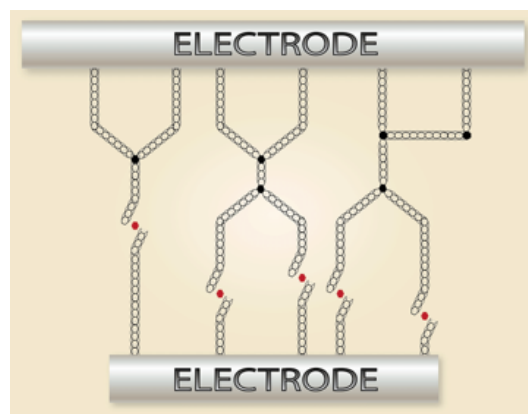
NRAM is based on proprietary concepts and methods derived from leading-edge research in nanotechnology. NRAM is based on forming a film of CNTs that are deposited onto a standard silicon substrate that contains an underlying cell select device and array lines (typically transistors or diodes) that interface the NRAM switch. Figure 2 is a SEM image of the deposited film (or fabric) of crossed nanotubes that can be either touching or slightly separated depending on their position.

(Figure 2)



The NRAM acts as a resistive non-volatile random access memory, and can be placed in two or more resistive modes depending on the resistive state of the CNT fabric. When the CNTs are not in contact, the resistance state of the fabric is high and represents a "0" state (see Figure 3). When the CNTs are brought into contact, the resistance state of the fabric is low and represents a "1" state.

(Figure 3)



Target Markets

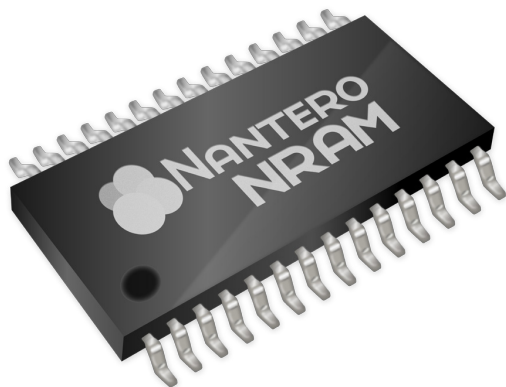
Product development projects are in process today for both standalone NRAM and embedded NRAM. Standalone NRAM is being sought for three purposes: for DRAM replacement, for NAND flash replacement (longer-term), and for applications neither DRAM nor NAND flash can address (aka, "storage class memory"). In the embedded memory space, there is ongoing work on using embedded NRAM to replace embedded non-volatile memory, including embedded flash or embedded RAM – either SRAM or DRAM.

NRAM is ideal for a wide range of markets that can take advantage of a new form of memory that delivers low power, high speed, reliability, and endurance.

- **Consumer and Mobile Electronics** - In the trillion-dollar consumer and mobile electronics industry, consumers expect their devices to continually become more powerful, deliver new functionality with greater speed, and store more movies, pictures and music. New wearable devices demand high speed with very low power consumption. NRAM meets these needs by being very fast, providing massive amount of storage in a small space and consuming very little power. For the consumer electronics industry, NRAM delivers the potential for terabits of storage in a single chip, as

fast as DRAM while still non-volatile like flash, and can withstand extreme temperatures and harsh conditions. With Nantero's NRAM, consumer and mobile electronics manufacturers can develop new, exciting devices that were never before possible.

- **Enterprise Systems and Networks** - The explosion of big data has created a critical need in enterprises to not only effectively capture and store vast amount of data, but to also analyze and share it to bring competitive advantages throughout the organization. With user- and machine-generated data increasing at a rapid rate, traditional data processing applications and storage devices are having trouble keeping up with these tasks. Therefore, NRAM's speed and nonvolatility can dramatically increase system performance and reduce power consumption by methods such as allowing companies to design in a new cache layer with gigabits of very fast non-volatile memory in front of the SSD or hard drive.
- **Automotive** - Today's automobiles are intelligent, connected and starting to offer innovative new features such as advanced infotainment systems and self-driving modes. NRAM will enable this trend to continue through its ability to process large amounts of data quickly and efficiently while also being able to endure the rough conditions and high temperatures found in vehicles. This endurance, along with NRAM's low power, small size and high performance, makes it the ideal memory to power the more sophisticated and intelligent cars of the future.



The Carbon Nanotube Future

NRAM can enable valuable innovations in the future for both consumer electronics and enterprise computing. While the first CNT-based semiconductor technology being readied for commercialization is NRAM, the potential for CNTs to be used in other areas as well is significant. The industry can expect to see a number of devices fabricated with CNTs in the future, beginning with NRAM

and moving on to CNT sensors, CNT transistors, and CNT interconnects. The time has come to flash forward to NRAM and a new generation of memory.



The Global Market for Carbon Nanotubes, 2010-2025 is available now from Future Markets, Inc. Go to <http://www.futuremarketsinc.com/carbonnanotubesmarket/> for further information.