

Nanotechnology in Military Development

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Abstract—Nanotechnology is the new cyber, according to several major leaders in this field. Just as cyber is entrenched across global society now, nano is poised to be major capabilities enabler of the next decades. Expert members from the National Nanotechnology Initiative (in U.S.) representing government and science disciplines say nano has great significance for the military and the general public. It is predicted that after next 15 years nanotechnology will replace information technology as the most economic technology platform. Nanotechnology has even wider applications than information technology.

Keywords—Nanomaterials, nanowires, nanotechnology, sensors.

I. INTRODUCTION

NANO is enabling technology, not an industry itself. Looking into the future, we can see the trend towards pervasive nanotechnology. We're going to see nanotechnology at the core of many new products and processes. Nanotechnology represents a frontier area of science and technology (S&T) that impacts global innovation, manufacturing and competitiveness. Looking from military perspective, we can foresee two complementary trends in the next decade. The first is maturation, which involves more opportunities to incorporate engineered nanomaterials into defense and other products. The second is blending of nanotechnology knowledge with traditional science fields.

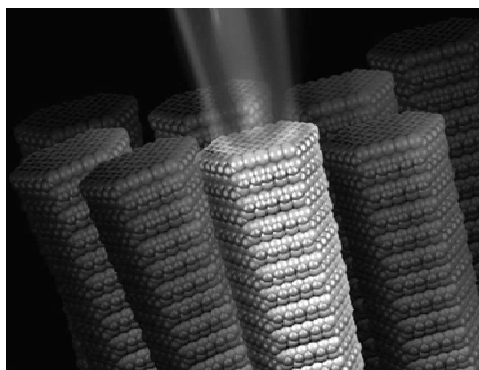


Fig. 1 The nanowire lasers [1]

Fig. 1 can be used as an example of the nano pervading technologies.

Nanotechnology may stop becoming its own field as much as it will become part of various fields. As processes and product become more reliable, scalable and inexpensive, nano

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will branch into more applications. Fundamental research also is likely to continue, though term nanotechnology may fall out of favor. There is not one single nanotechnology, there's a very wide complex spectrum of work going on.



Fig. 2 The nanosensor device for cellphone integration and chemical sensing network [2]

According to Fig. 2 this nanosensor device demonstrates why experts believe nano may be the next information technology, applying to almost all facets of future development.

In defense industry, we already can see the period started in which military will exploit intensively the understanding of nanoscale phenomena, nanoprocesses and nanomaterials for more specific defense applications, listing few as example:

- Flexible display devices
- Energetic materials, safer explosives, nanoparticulate powders
- Polymer reinforcements, nanoclays

Defense industry is supporting universities to consider intellectual opportunities in the nanoscale and bring them to the attention of defense officials. Nanotechnology is important for the capabilities that is brings to the potentially every facet of national scene. Defense projects have expectations that nanotechnology will enable new long-life maintenance free components that will save significant funding spent on repair and replacement. Another expectation involves major advancements of electronics to facilitate advanced computing.

The results will allow users to tailor properties in computers. Advanced medical capabilities through better nanotechnology will help not only stateside, but also on the battlefield. Nanotechnology will become like information technology, contributing to almost all facets of life and creating unprecedented functionality.

II. FABRICATION OF NANOMATERIALS

A new printing tool could move production of nano-sized electronic components from multibillion-euro facilities into the hands of users, including military users in the field. Currently nanomaterials are fabricated in the multibillion-euro facilities known as foundries; but with the new technology, those materials can be produced at low cost at the point of use. The research, largely funded by the Defense Advanced Research Projects Agency (DARPA), the Air Force Office of Scientific Research and the National Science Foundation, one day may provide the military unprecedented flexibility. Technology enables to make all sorts of electronic devices—resistors, actuators and acoustic wave devices. The military has all kinds of needs for electronics and optics devices. Sometimes, they need them fast. They need them on the fly and they need them sometimes generated in the field.

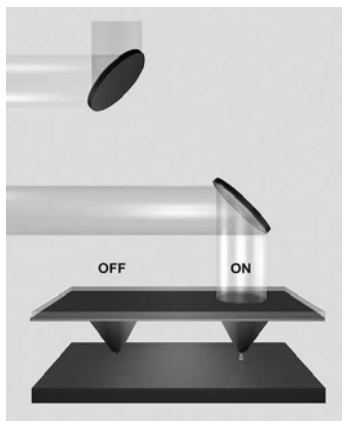


Fig. 3 Printing of nanomaterials [3]

Nanomaterials can be printed (see Fig. 3) by dot-matrix style using an array of sharp probes coupled to microheaters. When given heater is turned on, the thermal expansion of the rubber backing layer presses that probe against the print surface, transferring material and resulting in the desired pattern.

The research focuses on a tip-based nanofabrication process referred to as dip pen nanolithography (DPN). DPN uses an atomic force microscope, which can produce an image on virtually any type of surface, including polymers, ceramics, composites, glass and biological samples. The atomic force microscope is used as a cantilever, the tip of which acts as a pen. We can coat these cantilevers with molecules that can transfer from the tip to a surface like ink transfers from a pen to paper. Researchers are able to design the molecules to react chemically to the imaging surface to generate a structure one molecule high. The structures are made in a particular pattern—a circuit, diagram or spots for some cases involving medical research on DNA or proteins. That was one of the first examples of nanomanufacturing. You could begin to make tiny nanostructures out of just about anything that could transfer from the tips to a surface. During the last 10 years, tools have been developed to use cantilevers in parallel.

Arrays of cantilevers can simultaneously deposit molecules onto a surface. Until recently, however, the technology was limited. The problem is that as you begin to scale using that particular approach, adding more cantilevers and more capabilities, the arrays become more complicated and frankly, prohibitively expensive.

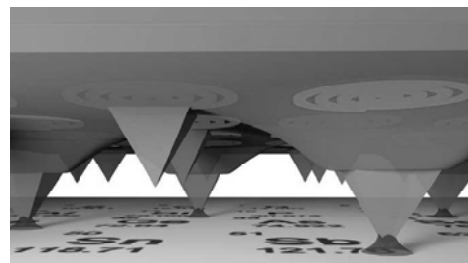


Fig. 4 A digital micromirror device functions as a light-based desktop nanofabrication [4]

A mirror array (see Fig. 4) directs light to the back of each pyramidal probe in a massive array, allowing the light to be funneled down each probe to a nanoscale aperture at each tip. The system allows the performance of near- or farfield optical lithography on a massive scale.

Next, the researchers began looking for a simpler, more scalable solution. They realized that the cantilever essentially acts as a spring, and they created a mold for producing a series of tiny pyramid shapes out of a spongy, polymer material to act as the tip. By filling the mold and placing a glass slide over it, they essentially create a rubber stamp of tiny pyramids. It turns out we can make a lot of pyramids really cheaply. For example, an array with 11 million pyramids scanning a 3-inch-diameter circular mold. Each of those tips then can become a replacement for a cantilever. And all of that costs less than a euro to make. Researchers can now coat the pyramids with molecules, put that into an atomic force microscope and perform nanoscale dot-matrix printing. It's a radical change in thinking where we're moving the spring defined by the cantilever to a spring in a tip made out of an elastic polymer material. The sponginess of the tip acts as the spring. The team next placed tiny heaters behind each tip, between the glass and the polymer stamp. If you heat locally one of those pyramids, it pushes it in contact with the underlying substrate. Now you can independently address each of these pens and simultaneously make different nanostructures on a surface in parallel.

The next innovation involved coating the polymer with a thin layer of gold and making a hole in each pyramidal tip to allow light to shine through it, a form of photo lithography in which chemicals are exposed to light to create an image or pattern. Normally, a photo mask, an opaque plate with holes or transparencies, is used with a photoresist, a polymer sensitive to light exposure, to form the pattern. We can use a process known as reactive ion etching to shave a tiny little aperture at each of the tips of the array. If you shine light on the back of the array, you create 11 million beams of light. We don't need a mask. We can take the array, shine light through the back of

it, squeeze the light through these tiny little apertures and develop the photoresists on the substrate with nanoscale control. This innovation offers other advantages as well. We can move the array with the precision of an atomic force microscope, so we can control how it moves on the nanoscale. There is also use of a micromirror device, which is used widely for televisions. It is used to break up a [light-emitting diode] beam into many thousands of beams of light, and then we channel that light down each of the pyramids independently. We can turn them on or off selectively. The device can work with virtually any nanomaterial. We can make anything. We can print anything that can be developed with light and anything that can be made to diffuse from a tip to a surface. And that's a lot of things; the potential uses are virtually unlimited. There are uses across the board, across every industry.

III. NANOWIRE SENSOR

A prototype nanotechnology-based sensor offers the possibility for ubiquitous, networked, real-time chemical agent detection and tracking. By using easily produced super-small components, the devices potentially can be installed in a variety of devices, such as smartphones, robots or commercial appliances. The silicon nanowires in a vertical array with a porous electrode (SiNVAPOR) sensor is a small, highly sensitive, lightweight, low power and portable sensor based on mature silicon fabrication technology. The technology offers the potential for affordable, ubiquitous, networked chemical sensors that can provide real-time data about hidden explosives or chemical weapons use.

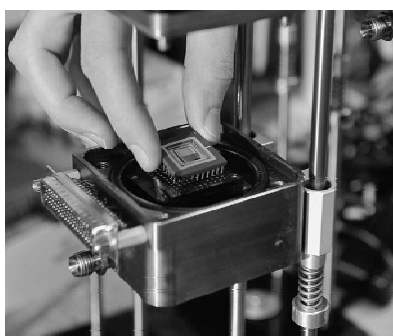


Fig. 5 The silicon nanowire in a vertical array with a porous electrode (SiN-VAPOR) chemical sensor [5]

This sensor (see Fig. 5) was developed by the U.S. Naval Research Lab as a means to provide warfighters and law enforcement personnel with a lightweight, low-power explosive detector. The sensor has been able to demonstrate sensitivity in the parts per billion levels for detecting chemical compounds.

An advantage of SiN-VAPOR technology is that the sensors can be manufactured in a basic microchip clean room production process without specialized facilities — as “wet bench” processing. The process is scalable, and in the future it can be built up into a production line. It is relatively easy to build a large batch of nanowires in short order.

One way to make the SiN-VAPOR sensors more selective is to apply a “dock and lock” process where different parts of the nanowire arrays can be separated and “locked” into an array of arrays to detect specific chemicals. The nanowire arrays can be built on top of a microchip, and pattern recognition algorithms can be applied to the chip to search for desired data coming in from the nanowire sensor arrays. This system should, in effect, create an electronic nose capable of detecting chemicals used in explosives and how much of those compounds are present in a dynamic and dirty field environment.

One of the big changes that SiN-VAPOR offers over the original 1990s research is that the prototype sensor has a very high sensitivity and it can work in humid environments. And any airport is full of compounds such as cigarette smoke, diesel fumes and perfume that can give off false positives. Sensors must be able to identify and ignore these false signals, and the devices must be tested to ensure that they can work out of the laboratory environment.

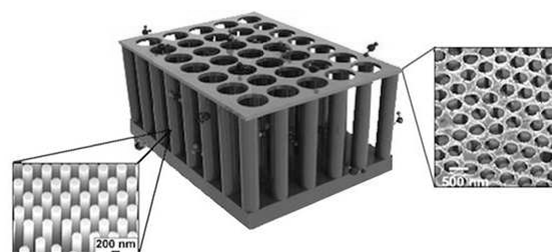


Fig. 6 The structure of SiN-VAPOR sensor [6]

This sensor (see Fig. 6) consists of an “array of arrays” of thousands of carbon nanotubes arranged vertically. This structure adds a third dimension to the sensor and increases its surface area. Because it is based on nanostructures, the sensor itself is small enough to be installed on handheld mobile devices or in small robots.

The key application for the SiN-VAPOR sensor is in explosives detection. A major goal is to use the devices in real-time distributed sensing by scattering the sensor arrays across a battlefield or operational zone. One way to obtain ubiquitous sensing would be to install the SiN-VAPOR arrays in mobile devices. Because the sensors are made with nanotechnology, the components are very small and use very little power. These two capabilities could allow them to be installed in a variety of devices to create a real-time chemical picture of the world in urban settings. On the battlefield, it would allow soldiers to detect and know what chemical agents they might be exposed to. Installing this capability into a mobile device effectively turns it into a multipurpose sensor.

Another application for the technology would be to help firefighters. Development of an autonomous firefighting robot is one example. A SiN-VAPOR chemical sensor would increase the robot's situational awareness during a fire by allowing it to detect harmful gasses. This would allow a firefighting robot to enter a room and, by sampling the

atmosphere, determine if it was safe for human firefighters to follow in after it.

Work is ongoing to have field-deployable prototype of the SiN-VAPOR sensor ready by January 2014. Researchers currently are miniaturizing an electronic infrastructure for the system. This sensor will be mounted in a quad-rotor helicopter robot that will be flown over a chemical plume (ethanol) to detect and map it. Another goal for January 2014 is to install a sensor on a Google Nexus 7 tablet computer and conduct some wireless sensor networking.

There's high possibility of being very successful by developing the sensors as a commercial product and integrating them with other systems.

IV. NANOWIRE-BASED MEMORY

Physical movement stored as memory in a microchip could lead to advances in touch screens, robot control devices and medical implants. Researchers are arraying nanowires on a microchip to form a write-read memory cell as part of ongoing work that could convert motions, such as a hand in a glove or pressing a display, into memory. Moving or putting pressure on the nanowires creates an electrical current that can be read and recorded as memory. Arrays of such cells offer the potential for a variety of user interface applications and for new ways to convert mechanical or biological actions into electronic data.

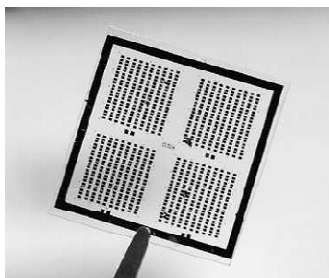


Fig. 7 A microchip that records and stores pressure and motion as memory [7]

The piezoelectrically modulated resistive memory (PRM) system (see Fig. 7) opens the way for new types of touch-screen interfaces, robotics control systems and prosthetics systems such as artificial skin.

Developed by researchers at the Georgia Institute of Technology (Georgia Tech), the piezoelectrically modulated resistive memory (PRM) system relies on the piezoelectric effect, where some materials, in this case zinc oxide nanowires, will generate electrical current when they are put under pressure or moved, which causes them to temporarily bend or deform. Piezoelectric materials also create mechanical strain (movement) when they are exposed to an electric current. PRM technology allows the creation of a new type of transistor that is switched on or off through movement or mechanical activity.

At the core of PRM technology is a new effect that determines how devices can convert mechanical energy into data called the piezotronic effect. Traditional transistors

manage the flow of electrical current through the device, controlled by a gate voltage; a set current level determines if it is on or off. Piezotronic devices rely on the electric charge created when piezoelectric materials such as zinc oxide nanowires are put under strain. PRM devices use the piezoelectric charge created by the wires' deformation to control the current flowing through the nanowires, which is the basic principle of piezotronics. Much like a voltage gate in a transistor, the charge creates polarity in the nanowires that increases the electrical resistance.

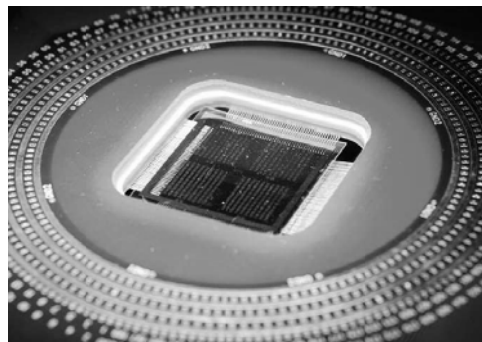


Fig. 8 The PRM technology for arrays of nanowires [8]

In PRM technology, arrays of nanowires (see Fig. 8) create an electrical current when temporarily bent. This bending can be through pressure or acceleration, allowing PRM-based sensors to be installed potentially in variety of systems.

Mechanical strain on the nanowires is a key operating principle for PRM systems. Control of the charge across the interface is done with strain.

Potential applications for PRM systems include sophisticated medical implants in humans, such as artificial skin where the PRM cells could be used to provide a sense of touch, or to power small implants and devices through body movements, such as a heartbeat.

The next step in the technology is to improve the stability of the nanowire devices for practical applications. Another goal is improving the devices' density and resolution for very-high-resolution applications. Researchers also want to interface PRM technology with other electronic technologies, such as silicon-based microprocessors or biologically related technology. The goal is to create interfaces that can be used directly in practical applications. Aiming to make something that is really high performance and which is really useful.

V. CONCLUSIONS

Nanotechnology will inevitably lead to disruptive technologies. If such technologies could lead to the development of a new generation of weapon systems and combatants, they could also give rise to the growth of disturbing factors affecting the international security and future military balances.

In [9], some of the most expected risks that could be induced by nano structured or nano manufactured weapon systems are analyzed.

REFERENCES

- [1] On the Nano Horizon: Emerging Technologies (Online). Available: http://www.nsf.gov/news/news_summ.jsp?cntn_id=108969
- [2] NASA Ames Scientist Develops Chemical Sensor for the iPhone (Online). Available: <http://spaceref.com/onorbit/nasa-ames-scientist-develops-chemical-sensor-for-the-iphone.html>
- [3] Nanotechnology Printer on the Horizon (Online). Available: <http://txchnologist.com/post/56139361872/nanotechnology-printer-on-the-horizon>
- [4] Nanomaterial Fabrication Moving to Desktop (Online). Available: <http://www.afcea.org/content/?q=node/11969>
- [5] NRL SiN-VAPOR Technology Improves IED Detection (Online). Available: <http://www.nrl.navy.mil/media/news-releases/2013/nrl-sin-vapor-technology-improves-ied-detection>
- [6] New Detectors could Turn Smartphones into Explosive Detectors (Online). Available: http://defense-update.com/20130820_sin-vapor_explosive_detectors.html
- [7] Nanowire-Based Memory Technology Records Movement, Pressure (Online). Available: <http://www.afcea.org/content/?q=node/11970>
- [8] Biological Interface Using Piezotronics: Resistive Switches based on Piezoelectric Nanowires Allow Electrical Signals to be Produced from Mechanical Actions (Online). Available: <http://www.gtresearchnews.gatech.edu/piezotronics-resistive-switches/>
- [9] Military Uses of Nanotechnology and Converging Technologies: Trends and Future Impacts (Online). Available: <http://www.irsd.be/website/media/Files/Focus%20Paper/FP08.pdf>