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The National Nanotechnology Initiative: Potential Impact on DoD

Dr. James S. Murday
University of Southern California
murday@usc.edu

I. Introduction

Nanoscience involves materials where some critical property is attributable to a structure with at least one dimension limited to the nanometer size scale, ~1 – 100 nanometers[1]. Below that size the disciplines of Chemistry and Atomic/Molecular Physics have already provided detailed scientific understanding. Above that size scale, in the last 50 years Condensed Matter Physics and Materials Science have provided detailed scientific understanding of microstructures. So the nanoscale is the last “size” frontier for materials science. When the size of the structure is nanometer, one can expect “surprises” – new materials behavior that may be technologically exploitable.

Why is nanotechnology the current rage? First, beginning in 1980, the discovery and development of proximal probes – scanning tunneling microscopy/spectroscopy, atomic force microscopy/spectroscopy, near-field microscopy/spectroscopy – have provided tools for measurement and manipulation of individual nanosized structures. Those tools needed 10-15 years for reliable commercial instruments to come onto the market; there has been a rapid increase in refereed nanoscience publications beginning in the early 1990s. The properties of the individual nanostructures can now be observed, rather than the ensemble averaged values. In turn, those properties can be understood in terms of composition / structure, and with that understanding comes the possibility for control.

Second, the disciplines of biology, chemistry, materials, and physics and have all reached a point where nanostructures are of interest – chemistry building up from simpler molecules, physics/materials working down from microstructures, and biology sorting out from very complex systems into simpler subsystems. Finally, there are several economic engines driving the interest with information technology (electronics), biotechnology (pharmaceuticals and healthcare), and materials the more certain beneficiaries. Various organizations have estimated the potential commercial impact of “nano-inside” – products enabled by nanostructures – as more than \$1T/yr. In addition to the civilian markets, there will clearly be security applications for nanostructured materials. This projected market has contributed to the roughly uniform geographical distribution across the globe of science articles published in 2005. The fact that there is rough global equivalence in the nanoscience/nanotechnology investments raises some interesting problems for both the US economic and security paradigms.

II. Nanostructure-Enabled Technology for Defense

Nanostructures might be expected to provide innovative properties affecting almost all technologies dependent on materials. The DOD was early to recognize this potential. It was funding the Ultrasubmicron Electronics Research (USER) program already in the late 1970s; that program could have been labeled nanotechnology. By 1997, the DOD had created a Strategic Research Objective in nanoscience. So, with NSF, DOD was well positioned to take a leadership role in the late 1990s toward the formation of the U.S. National Nanotechnology Initiative. As is evident from Table 1, DOD is a major contributor to the ~\$1B/yr NNI funding in FY07.

Table 1. Estimated DOD Nanoscience Funding ($M)

	FY01		FY05		FY07
	6.1	6.2/6.3	6.1	6.2/6.3	
Air Force	9	3	33	14	60
Army	8	4	29	5	30
Navy	46	3	35	0	30
DARPA	34	20	47	120	210
CBDP					9
DDR&E	24	2	5	0	5
Total	153		325	345	

The implications for nanotechnology in defense have been addressed in a number of places[2,3,4,5,6]. Amongst the areas the National Nanotechnology Initiative has identified for significant technology impact[7], several are particularly important for the defense implications: Information technology - Nano-Electronics, Photonics and Magnetics; Energy Conversion and Storage; and Nanostructured Materials by Design.

IIA. The Next Generation of Information Technology Devices

The military has been and will continue to be an important consumer of high performance information technology devices. By roughly 2015, further miniaturization in Si will slow or stop due to physics limitations at the small size scale, growing fabrication costs, and heat dissipation problems [8]. The Nanoelectronics Research Initiative[9] has been created by the semiconductor industry to examine "Beyond CMOS" alternatives. The NRI goal is the demonstration of novel computing devices with critical dimensions below 10 nanometers and to exercise them in simple computer circuits with the objective of enabling the industry to extend Moore's Law far beyond the limits of CMOS. Integrated, nanostructured systems offer the potential to sustain the revolution in information technology devices rivaling that of silicon-based microelectronics in the last 30 years. But realizing that potential will not be easy.

Emerging Technology Example: Non-volatile, high density memory

Nanostructures hold promise for the development on non-volatile, radiation hard, high density (terabit/cm^2) memory with nanosecond read/write times. The IBM "Millipede" uses an array of microcantilevers to create a pattern of nano-indentations in a deformable polymer storage medium[10]. Researchers at Nantero in the US and in Korea are developing a carbon-nanotube based memory concepts [11]. Freescale (as well as IBM) has a GMR memory on the market with 4 Mbits; researchers at NRL are developing a next generation GMR memory that may reach terabit densities[12].

IIB. Energy Conversion and Storage

Inexpensive energy underlies economic prosperity and is crucial to many military applications. A nation's ability to develop new energy sources within its own borders can reduce the dependency on international energy sources and also reduce the current reliance on finite oil reserves. A key challenge is to understand how deliberate tailoring of materials at the nanoscale can lead to innovations in energy conversion, storage and conservation [13]. There are many possibilities. The conversion of chemical or solar energy into electricity necessitates rapid, high-efficiency conversion of chemical or light (photon) energy into electrical energy. Nanostructured materials offer several important advantages toward this goal. A deeper understanding of the physics of phonon and electron transport in nanostructured materials may facilitate production of practical all-solid-state and environmentally clean thermoelectric energy-conversion devices. Nanostructures may also enhance the controlled release of chemical energy toward specific goals such as higher efficiency combustion, and greater thrust in rocket propulsion.

Emerging Technology Example: Rapid rechargeable battery electrodes

The energy and power densities of batteries depend critically on the efficiency of charge transport – both electrons and ions. Nanostructures offer new approaches to the control of that transport. Altair is working with nano-sized lithium titanium oxide with the goal of three times the power of existing Li ion batteries and recharge times measured in minutes[14]. Toshiba has announced a Li-ion battery anode based on nanomaterials that can be recharged in only a minute. A123 has a nanophosphate technology touted to eliminate thermal runaway or fire[15].

IIC. Nanostructured Materials by Design

Military platforms are always pushing the state-of-art for materials performance. Nanotechnology involves structures with a limited number of atoms or molecules – larger than traditionally handled by chemistry and smaller than traditionally handled by materials science or solid state physics. This departure from traditional materials can fundamentally change the way nanostructured materials behave. A Chemical Research Council sponsored Vision 2020 workshop has identified the challenges/opportunities facing the goal of nanostructured materials by design[16]. By gaining understanding and control at the nanoscale, materials scientists will be able to develop novel, high performance, affordable and environmentally benign materials. Modeling and simulation, aided by the expected continuation of advances in computational power, will play a major role in the realization of this vision. However, creating reliable, cost effective, hierarchically assembled nanostructured materials will not be easy. The problems can be illustrated by carbon nanotube composites where there has been considerable work, but limited results[17].

Emerging Technology Example: Nanoclay Composites

The early (1993) demonstration of nanoclay – polyimide composites with promising new properties[18] has been followed (albeit somewhat slowly for the same reasons cited above for CNT composites) with additional successes. A number of automotive manufacturers are now utilizing nanoclay composites[19].

III. Summary and Conclusions

There are an appreciable, and rapidly growing, number of science papers addressing the discovery of nanostructure fabrication and properties, and their incorporation into nanostructured materials and devices. The impact of technologies, commercially enabled through the use of nanostructures, is just now beginning to emerge. There will be clear impact on military technologies. The United States will have to pay careful attention to the worldwide efforts in nanoscience / nanotechnology if is to retain the technological edge it has enjoyed for the past fifty years.

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DERRICK R. SHACK