SOCIAL AND ETHICAL IMPLICATIONS OF MICRO AND NANOTECHNOLOGIES

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Abstract. *This paper approaches technologies which gain more and more interest in the latest period, because they contribute to the accomplishment of some very important 3rd millennium issues: soil pollution, water and air pollution, natural resources depletion, demographic growth, global worming. The technical posibilities and devices of micro, nano, pico and even femto type open up new and revolutionary perspectives in science and applications. Research and development of nanotechnologies implies controlled manipulation of nanostructures and their integration in materials, systems and architectures. Nanotechnologies have many applications in all fields of engineering and will contribute with certitude at the amplification of the social effects of other technologies.*

Keywords: nanotechnologies, microtechnologies, ethical implications, legal issues, social implications

1. Introduction

Long time ago novelists considered the amazing possibilities of living beings much bigger or much smaller than us. Back in 50's, the physicist Richard Feynman foresees the fabrication of machines much smaller than their makers. The human's length scale, at slightly more than 10^0 m, remarkably fits right in the middle of the smallest subatomic particle, which is approximately 10^{-26} m, and the extent of the observable universe, which is of the order of 10^{26} m.

The next Industrial Revolution is already here. Fourth generation nanotechnology (molecular manufacturing) will radically transform the world, and the people, of the 21st century. Whether that transformation will be peaceful and beneficial or horrendously destructive is unknown.

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Even if nanotechnology carries great promise, unwise or malicious use could seriously threaten the survival of the human race.

Healthy public and private policy can be built only upon a solid foundation of knowledge and tested ideas. Humanity needs better methods to exchange knowledge and to subject new ideas to effective intellectual scrutiny.

Nanotechnology will allow control of the structure of matter within the broad limits set by physical laws. Other limits will be necessary to prevent abuses by individuals, groups and nations bent upon undesirable ends. Global competitive forces and continuing progress in molecular sciences will lead ultimately to the realization of nanotechnology. Nanotechnology must be developed openly to serve the general welfare and the continued realization of the human potential.

2. General Considerations

Micro systems technologies, MST and especially microelectromechanical systems, MEMS, refer to devices that have characteristic length of less than 1mm but more than 1 µm, that combine electrical and mechanical components and that are fabricated using integrated circuit batch-processing technologies.

This multidisciplinary field has witnessed explosive growth during the last decade and the technology is progressing at a rate that far exceeds that of our understanding of the physics involved. Electrostatic, magnetic, electromagnetic, pneumatic and thermal actuators, motors, valves, gears, cantilevers, diaphragms, and tweezers of less than 100 µm size have been fabricated. These have been used as sensors for pressure, temperature, mass flow, velocity, sound and chemical composition, as actuators for linear and angular motions, and as simple components for complex systems such as robots, lab-on-a-chip, micro heat engines and micro heat pumps.

Nanotechnology is "a branch of engineering that deals with the design and manufacture of extremely small electronic circuits and mechanical devices built at the molecular level of matter." The term has evolved over the years via terminology drift to mean "anything smaller than microtechnology". By taking advantage of quantum-level properties, it allows unprecedented control of the material world, at the nanoscale, providing the means by which systems and materials can be built with exacting specifications and characteristics. Many materials, once they are individually reduced below 100 nanometers, tend to display unique characteristics based on quantum mechanical forces that are exhibited at that level. Due to these effects, materials may become extra conducting, be capable to transfer heat better, or have tailored mechanical properties.

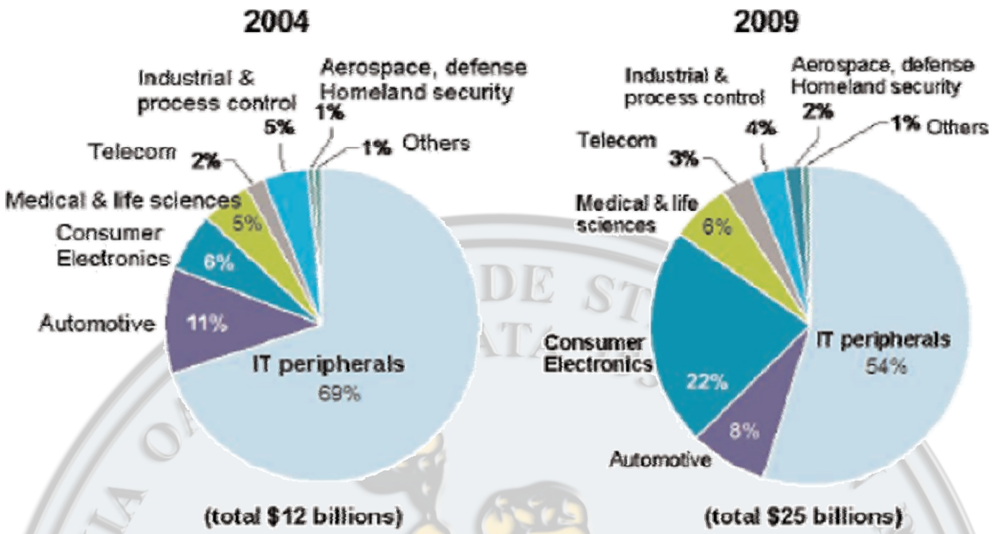


Fig. 1. MST applications market integration in the last 5 years

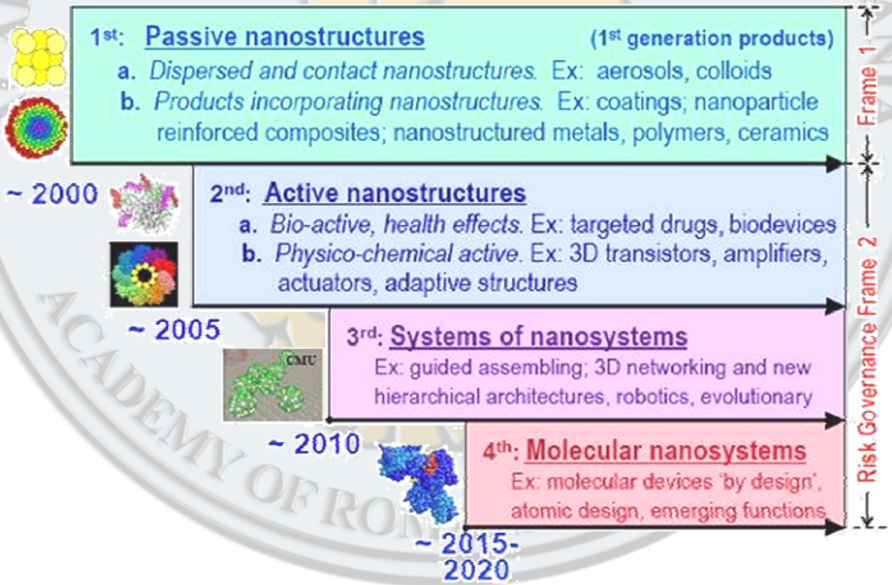


Fig. 2. Applications evolutionary scale for nanosystems

3. Technical Considerations

The following devices and capabilities appear to be both physically possible and practically realizable:

- Programmable positioning of reactive molecules with ~0.1 nm precision
- Mechanosynthesis at $>10^6$ operations/device • second
- Mechanosynthetic assembly of 1 kg objects in $<10^4$ s
- Nanomechanical systems operating at $\sim 10^9$ Hz
- Logic gates that occupy $\sim 10^{-26}$ m^3 ($\sim 10^{-8}$ m^3)
- Logic gates that switch in ~0.1 ns and dissipate $<10^{-21}$ J
- Computers that perform 10^{16} instructions / second / watt
- Cooling of cubic-centimeter, $\sim 10^5$ W systems at 300 K
- Compact 10^{15} MIPS (million instructions per second) parallel computing systems
- Mechanochemical power conversion at $>10^9$ W/m^3
- Electromechanical power conversion at $>10^{15}$ W/m^3
- Macroscopic components with tensile strengths $>5\times10^{10}$ Pa
- Production systems that can double capital stocks in $<10^4$ s

Of these capabilities, several are qualitatively novel and others improve on present engineering practice by one or more orders of magnitude. Each is an aspect or a consequence of molecular manufacturing.

Some things that become practical with mature Nanotechnology are:

- Nearly free consumer products
- PC's billions of times faster then today
- Safe and affordable space travel
- Virtual end to illness, aging, death
- No more pollution and automatic cleanup of existing pollution
- End of famine and starvation
- Superior education for every child on Earth
- Reintroduction of many extinct plants and animals
- Terra forming Earth and the Solar System

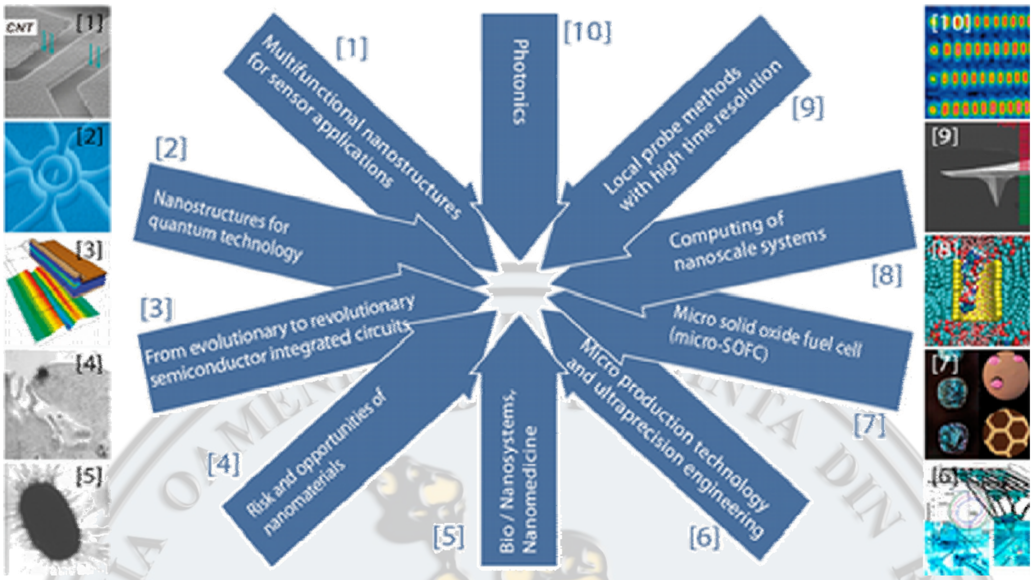


Fig. 3. Scientific domains convergence

Potential benefits

Manufacturing
Precision Manufacturing
Material Reuse
Miniaturization

Medicine
Pharmaceutical Creation
Disease Treatment
Nanomachine-assisted Surgery

Environment
Toxin Cleanup
Recycling
Resource Consumption Reduction

Potential threats

Weapons
Miniature Weapons and Explosives
Disassemblers for Military Use
Rampant Nanomachines
The Gray Goo Scenario
Self Replicating Nanomachines

Surveillance
Monitoring
Tracking

4. Ethical, legal and Social Aspects - ELSA

Considering the potential threats inherent in nanotechnology, we must seriously examine its potential consequences. Granted, nanotechnology may never become as powerful and prolific as envisioned by its evangelists, but as with any potential, near-horizon technology, we should go through the exercise of formulating solutions to potential ethical issues before the technology is irreversibly adopted by society. The ethics of developing nanotechnology must be examined and policies to be created to aid in its development so as to eliminate or at least minimize its damaging effects on society.

Professional Issues

- Currently, nanotechnology research is primarily funded by PNCDI and the FP7 so the research agenda is primarily controlled by the government
- Since nanotechnology is being developed in many different fields, how can everyone's principles be synchronized?

Ethical Issues

- Nanotechnology will give us more "god-like" powers
- It has the potential to eliminate other ethical issues (e.g., assembling beef instead of slaughtering cows, constructing cells rather than getting them from reproduction, etc.)
- May lead to undetectable surveillance; Right to privacy could be jeopardized
- Do we have a duty to help and provide for others with this technology?

Legal/Policy Issues

- Since nanotechnology concerns many different fields, who should create and enforce policies regarding its R&D?
- What international laws should be made regarding the safe development of nanotechnology? And who can enforce them?

Along with the development of Nanotechnology comes the necessity to develop reasonable guidelines, procedures, and laws in order to protect humanity from misuse of the technologies.

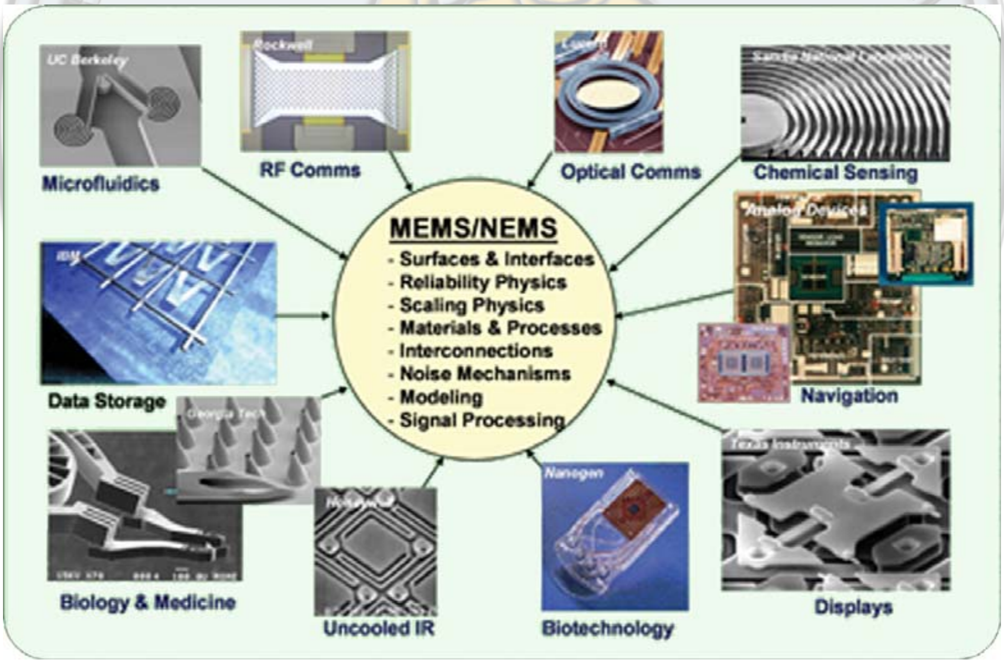
A critical point will be reached, where technology will be able to enable complex molecular machines. Molecular assemblers and disassemblers could be developed from this technology, which would have great potential for both good and bad. The two greatest threats from development of nanotechnology are catastrophic accidents and misuse.

Nanotechnology research should be allowed to continue but with a non-government advisory council to monitor the research and help formulate ethical guidelines and policies. Generally, nanomachines should NOT be designed to be general purpose, self replicating, or to be able to use an abundant natural compound as fuel. Furthermore, complex nanomachines should be tagged with a radioactive isotope so as to allow them to be tracked in case they are lost.

It would be difficult to deny the potential benefits of nanotechnology and stop development of research related to it since it has already begun to penetrate many different fields of research. However, nanotechnology can be developed using guidelines to insure that the technology does not become too potentially harmful. As with any new technology, it is impossible to stop every well funded organization who may seek to develop the technology for harmful purposes. However, if the researchers in this field put together an ethical set of guidelines (e.g. Molecular Nanotechnology Guidelines) and follow them, then we should be able to develop nanotechnology safely while still reaping its promised benefits.

In not too many decades humanity should have a manufacturing technology able to: Build products with almost every atom in the right place; Do so inexpensively; Make most arrangements of atoms consistent with physical law. Often called nanotechnology, molecular nanotechnology or molecular manufacturing, it will let us make most products lighter, stronger, smarter, cheaper, cleaner and more precise.

5. Applications



Specific Design Guidelines

1. Any self-replicating device which has sufficient onboard information to describe its own manufacture should encrypt it such that any replication error will randomize its blueprint.
2. Encrypted MNT device instruction sets should be utilized to discourage irresponsible proliferation and piracy.
3. Mutation (autonomous and otherwise) outside of sealed laboratory conditions should be discouraged.
4. Replication systems should generate audit trails.
5. MNT device designs should incorporate provisions for built-in safety mechanisms, such as: A) absolute dependence on a single artificial fuel source or artificial "vitamins" that don't exist in any natural environment; B) making devices that are dependent on broadcast transmissions for replication or in some cases operation; C) routing control signal paths throughout a device, so that subassemblies do not function independently; D) programming termination dates into devices, and E) other innovations in laboratory or device safety technology developed specifically to address the potential dangers of MNT.

Development Principles

1. Artificial replicators must not be capable of replication in a natural, uncontrolled environment.
2. Evolution within the context of a self-replicating manufacturing system is discouraged.
3. Any replicated information should be error free.
4. MNT device designs should specifically limit proliferation and provide traceability of any replicating systems.
5. Developers should attempt to consider systematically the environmental consequences of the technology, and to limit these consequences to intended effects. This requires significant research on environmental models, risk management, as well as the theory, mechanisms, and experimental designs for built-in safeguard systems.
6. Industry self-regulation should be designed in whenever possible. Economic incentives could be provided through discounts on insurance policies for MNT development organizations that certify Guidelines compliance. Willingness to provide self-regulation should be one condition for access to advanced forms of the technology.
7. Distribution of molecular manufacturing development capability should be restricted, whenever possible, to responsible actors that have agreed to use the Guidelines. No such restriction need apply to end products of the development process that satisfy the Guidelines.

Conclusions

Conclusion (1)

Nanotechnology's highest and best use should be to create a world of abundance where no one is lacking for their basic needs. Those needs include adequate food, safe water, a clean environment, better housing, medical care, education, public safety, fair labor, unrestricted travel, artistic expression and freedom from fear and oppression.

High priority must be given to the efficient and economical global distribution of the products and services created by nanotechnology.

Conclusion (2)

Military research and applications of nanotechnology must be limited to defense and security systems, and not for political purposes or aggression.

Scientists developing and experimenting with nanotechnology must have a solid grounding in ecology and public safety, or have someone on their team who does.

All published research and discussion of nanotechnology should be accurate as possible, adhere to the scientific method, and give due credit to sources.

Business models in the field should incorporate long-term, sustainable practices, such as the efficient use of resources, recycling of toxic materials, adequate compensation for workers and other fair labor practices.

Conclusion (3)

Industry leaders should be collaborative and self-regulating, but also support public education in the sciences and reasonable legislation to deal with legal and social issues associated with nanotechnology.

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