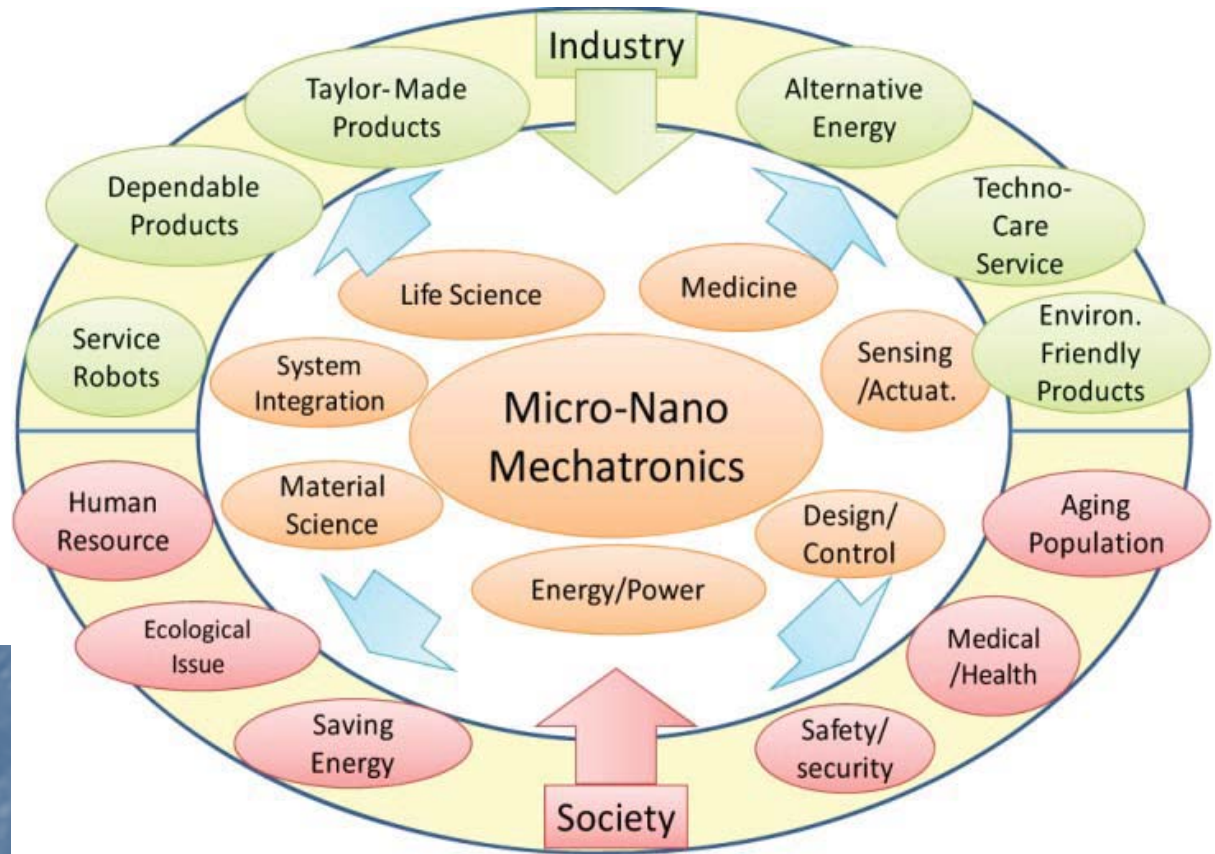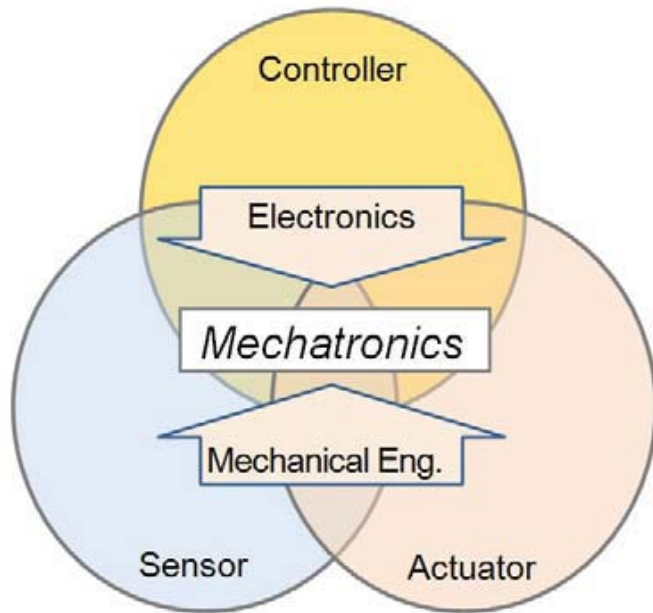# Nano-mechatronics

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Nano-mechatronics

- Nano-mechatronics is currently used in broader spectra, ranging from basic applications in robotics, actuators, sensors, semiconductors, automobiles, and machine tools. As a strategic technology highlighting the 21st century, this technology is extended to new applications in bio-medical systems and life science, construction machines, and aerospace equipment, welfare/human life engineering, and other brandnew scopes. Basically, the miniaturizing technology is important to realize high performance, low energy consumption, low cost performance, small space instrumentation, light-weight, and so on.

Nano-mechatronics

- High efficiency
- High integration
- High functionality
- Low energy consumption, low cost,
- Miniature, etc.

- Nano-mechatronics and their social and industrial demands

Nanosensors

- Biological, chemical, or physical sensory points used to convey information about nanoparticles to the macroscopic world
- Small, require relatively less power to run, great sensitivity, good specificity

Nanosensors

- **Top-down lithography**
    - Starting out with larger blocks and carving out the desired form

- **Bottom – up assembly**
    - Starting with components such as molecules and atoms and placing them one-by-one into position to create the desired form

- **Molecular Self-Assembly (2 methods)**
    - Method 1:
        - Using a piece of previously created or naturally formed nanostructure and immersing it in free atoms of its own kind, making it more prone to attract more molecules and captures free atoms and continue creating more of itself, thus larger components of nanosensors
    - Method 2:
        - Starts with a complete set of components that would automatically assemble themselves into a finished product

Nanosensors

- A substance found in the shell, called chitosan, is a key component used in a nanosensor, a "system on a chip" at the nanoscale
- Detects minute quantities of explosives, bioagents, chemicals, and other dangerous materials in air and water
- This could lead to security and safety developments for airports, hospitals, etc.
- The chitosan
  - is a biological compound that readily binds to negatively charged surfaces
  - Multiple mini vibrating cantilevers, which resemble diving boards, are coated with the chitosan
  - Optical sensing technology is used to see when the cantilevers vibrations change
    - Different cantilevers detect different substances and concentrations
  - When the targeted substance enters the device from the air/water, the chitosan on a specific cantilever interacts with the substance and causes that cantilever's vibration to change
    - The optical sensing system sees the vibration change and indicates that the substance has been detected

Types
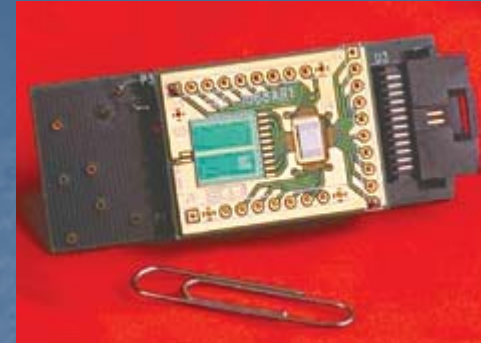
- <u>Electrometer</u>: consists of a torsional mechanical resonator, a detection electrode, and a gate electrode used to couple charge to the mechanical element
- <u>Chemical Sensor</u>: incorporates capacitive readout cantilevers and electronics for signal analysis andsensitive enough to detect single chemical and biological molecules

Applications

- Transportation
- Communications
- Integrated Circuits
- Building and Facilities
- Medicine
- Safety
- Aerospace

In the future

- Could lead to tiny, low power, smart sensors manufactured cheaply in large quantities
- Service areas could include:
    - Sensing of structural materials
    - Sensor redundancy in systems
    - Size and weight constrained structures

Actuators

- The exceptional electrical and mechanical properties of carbon nanotubes have made them alternatives to the traditional electrical actuators for both microscopic and macroscopic applications. Carbon nanotubes are very good conductors of both electricity and heat, and they are also very strong and elastic molecules in certain directions. These properties are difficult to find in the same material and very needed for high performance actuators. For current carbon nanotube actuators, multi-walled carbon nanotubes (MWNTs) and bundles of MWNTs have been widely used mostly due to the easiness of handling and robustness. Solution dispersed thick films and highly ordered transparent films of carbon nanotubes have been used for the macroscopic applications.

Actuators

- ## Microscopic applications
  - Carbon nanotube tweezers have been fabricated by deposition of MWNT bundles on isolated electrodes deposited on tempered glass micropipettes. Those nanotube budles can be mechanically manipulated by electricity and can be used to manipulate and transfer micro- and nano-structures. The nanotube bundles used for tweezers are about 50 nm in diameter and 2 μm in lengths. Under electric bias, two close sets of bundles are attracted and can be used as nanoscale tweezers.
  - Carbon nano-heat engine
    - A research group in Shanghai University led by tienchong Chang have found a dominoes like motion in carbon nanotube which can be reversed translating direction when apply different temperatures. This phenomenon make it possible to use carbon nanotubes as a heat engine working between two heat source.

Actuators

- Microscopic applications
  - Nanotube on/off switches and random access memory
    - Harvard researchers have used the electrostatic attraction principle to design on/off switches for their proposed nanotube Random Access Memory devices. They used carbon nanotube bundles of ~50 nm in diameter to fabricate their proof-of-concept prototypes. One set of MWNT bundles are laid on the substrate and another set of bundles is trenched on top of the underlying nanotube bundles with air gap in between. Once electrical bias is applied the sets of nanotube bundles are attracted, thus changing the electrical resistance. These two states of resistance are on and off states. They have managed to get more than 10 times difference between off and on state resistances. This idea can be used as very highly packed arrays of nanoswitches and random access memory deivces if they can be applied to arrays of single-walled carbon nanotubes, which are about 1 nm in diameter and hundreds of micrometres in length. The current technical challenge with this design is the lack of control to place arrays of carbon nanotubes on substrate. This method is followed by some researches at Shahid Chamran University of Ahvaz as well.

- Nanotube sheet electrodes could be used as actuators
- Artificial muscles and giant strokes by MWNT aerogel sheets

Nanotube-based transistors

- Nanotube-based transistors, also known as carbon nanotube field-effect transistors (CNTFETs), have been made that operate at room temperature and that are capable of digital switching using a single electron. However, one major obstacle to realization of nanotubes has been the lack of technology for mass production. In 2001 IBM researchers demonstrated how metallic nanotubes can be destroyed, leaving semiconducting ones behind for use as transistors. Their process is called "constructive destruction," which includes the automatic destruction of defective nanotubes on the wafer.This process, however, only gives control over the electrical properties on a statistical scale.

- The first nanotube integrated memory circuit was made in 2004. One of the main challenges has been regulating the conductivity of nanotubes. Depending on subtle surface features a nanotube may act as a plain conductor or as a semiconductor. A fully automated method has however been developed to remove non-semiconductor tubes.

- Another way to make carbon nanotube transistors has been to use random networks of them. By doing so one averages all of their electrical differences and one can produce devices in large scale at the wafer level.This approach was first patented by Nanomix Inc. It was first published in the academic literature by the United States Naval Research Laboratory in 2003 through independent research work. This approach also enabled Nanomix to make the first transistor on a flexible and transparent substrate.

Future applications

- As a result, carbon nanotubes have been shown to be great materials for actuation related applications. The subfield of carbon nanotube actuators have been quite successful and ready for scalable applications considering there are quite a few conventional and scalable methods for the synthesis of large scale carbon nanotubes. Carbon nanotube sheets used as electrodes in electrolyte solutions offered low voltage operations at room temperature with actuation strokes and rates comparable to the conducting polymer actuators, but with higher work densities per cycle and life times. However the actuation strokes are much smaller than those of the electrostrictive rubbers which operate at three orders of magnitude higher voltages. On the other hand, realization of carbon nanotube aerogels made giant strokes possible comparable to electrostrictive rubbers at room temperature, but carbon nanotube aerogels can perform at a very wide range of temperatures, and with very high actuation rates, which are even better than the actuation rate of the human muscles.

- The applications of nano mechatronics are mainly categorized into the mechanical, electrical, and biological/medical applications The key point for the categorization is inorganic (wet) and organic (dry) mechanical applications are relatively based on thinorganic materials or technologies, such as lithography technique

- On the other hand, biological/medical applications, the organic materials or technologies are used, such as self-assembly technique in between them, electrical applications are placed for delivering orcalculating information and so on

- Since the nanomechatronics is the composite academic fields, the required technologies are mainly categorized in to basic/middle/high integration levels
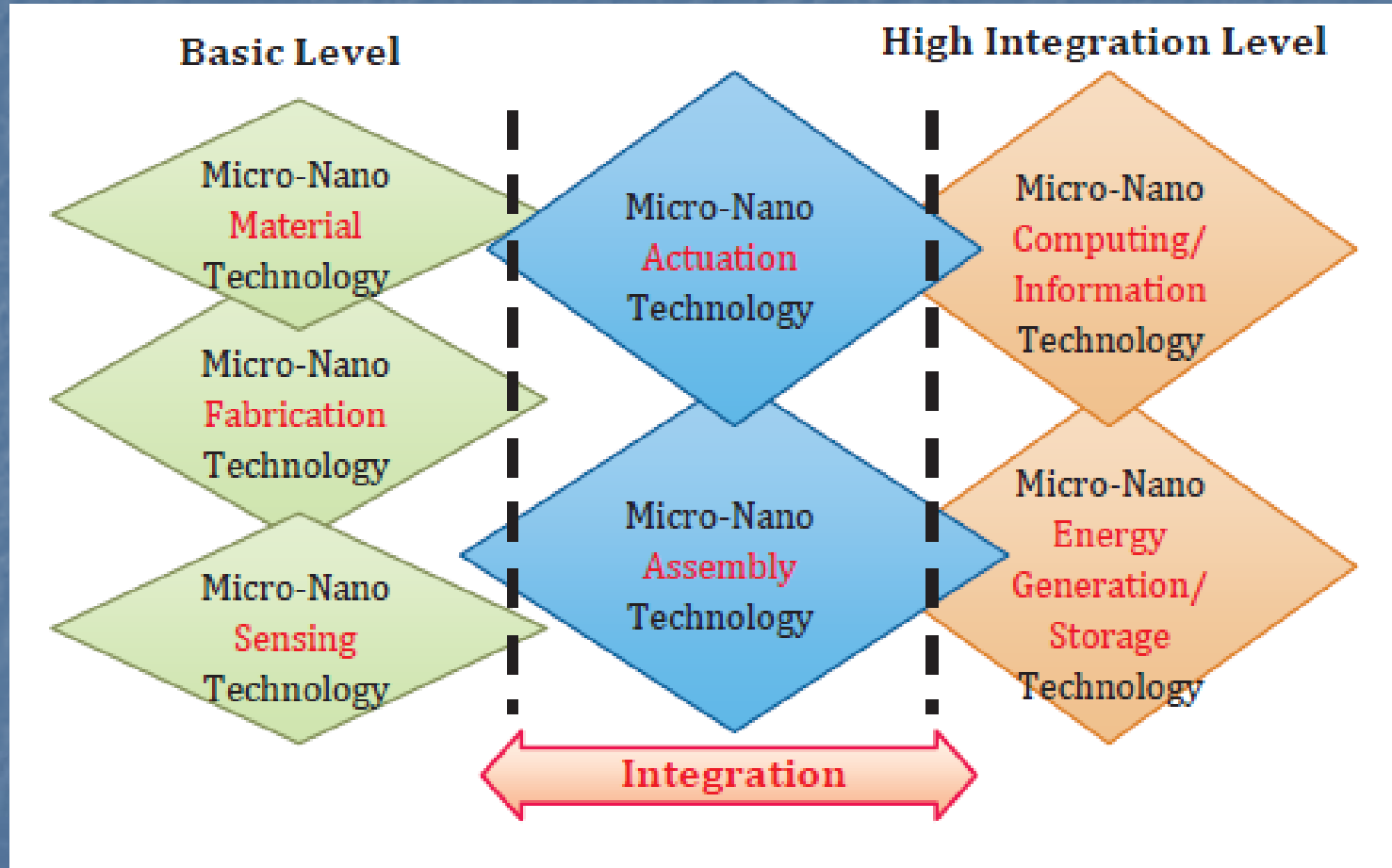
- Basically, nanotechnology is placed in the combinations of the top-down and bottom-up approaches. The possibility to control the structure of matter atom by atom was first discussed by Richard Feynman in 1959 seriously. One of the approaches to fill the gap between top-down and bottom-up approaches is "nanomanipulation", which realizes controlling the position at the nanometer scale, is considered to be one of the promising ways. The top-down fabrication process, or micromachining, provides numbers of nanometer structures at once. On the other hand, the bottom-up fabrication process, or chemical synthesis such as self-assembly, also provides numerous nanometer structures. In fact, both approaches reach nanometer scale with the limitations of physical/chemical aspects at present. Hence, the technology to fill its gap is considered to be one of the important at this moment for nanomechatronics. Especially, current research directions are mainly two flows, "green innovation" and "life innovation". These innovations will be achieved in various research and developments.
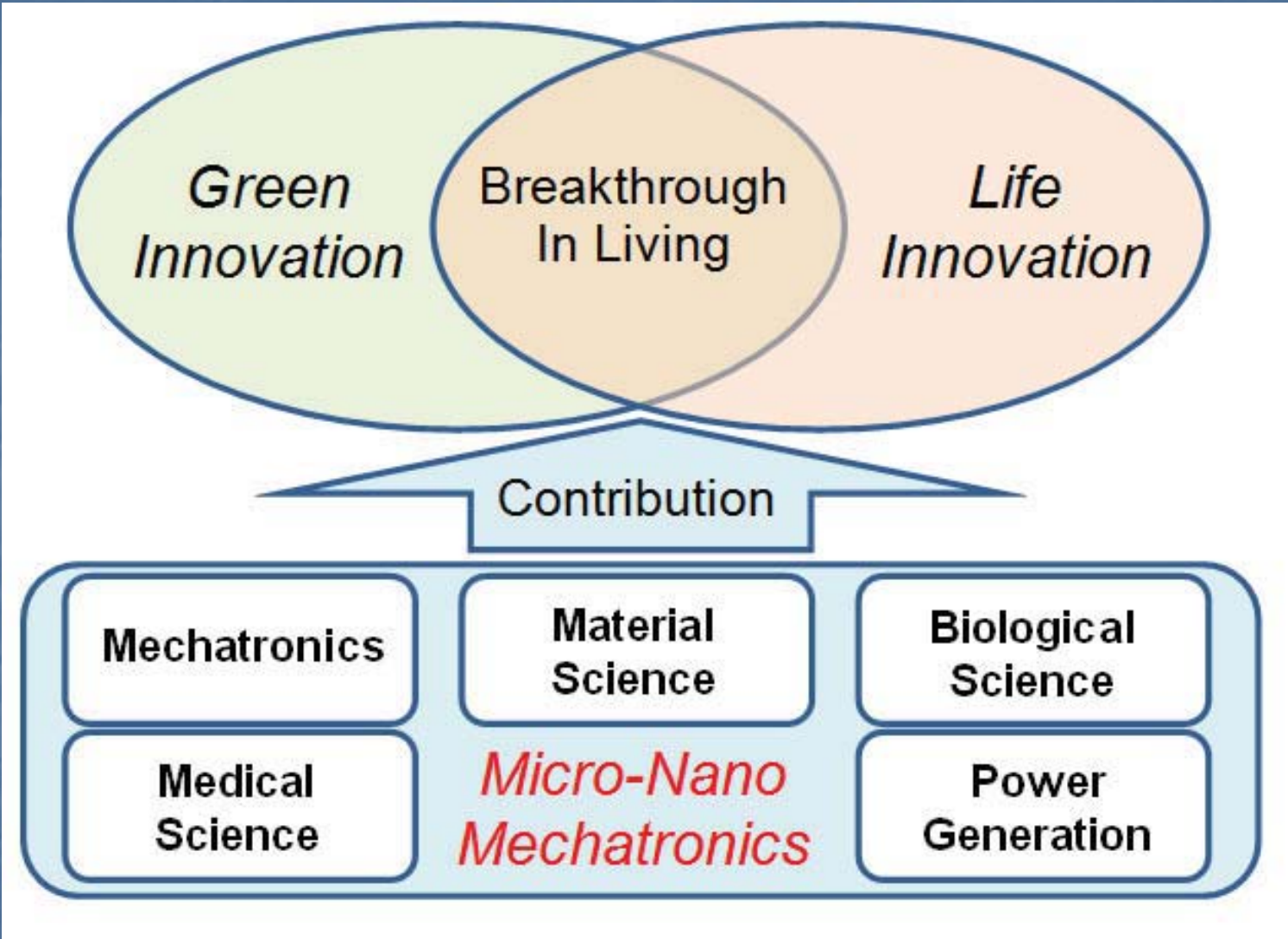
Green innovation	Technological Challenges
Natural Resources	Micro/nano devices for Discovery of oil resource, Management of water resources, Prevention of forest destruction, etc
Environmental Pollution	Monitor, control and management of Environment, Distributed sensing & control, Pollution control, Green vehicle, etc
Energy Development	Energy saving, harvesting and alternatives , Energy grid and management, Power control and green electronics, etc
Food and Agriculture	Safety, testing and tracing, Efficient harvesting, nutritious products, genetically-modified products, etc

Table 1. Challenges for green innovation by micro-nano mechatronics

Life innovation	TechnologicalChallenges
Medicine for life	Inspection and diagnosis , Re-generative medicine, Gene therapy and life science, monitoring diseases, Neuro Science, In-situ diagnostics, Cell diagnosis and surgery, New drug and medicine, DDS, Minimally invasive surgery, Rehabilitation, Techno-care, Wearable robots, Cyborg, QoL, etc
Biology–Analysis and Synthesis	Sensing , manipulation and automation, New species, DNA diagnosis & manipulation, Cell screening, transport, cultivation, and function and differentiation control, Artificial cell, Life in chip, Cloning of stem cells, etc

- Challenges for life innovation by micro-nano mechatronics

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Thank you for your attention!

The End