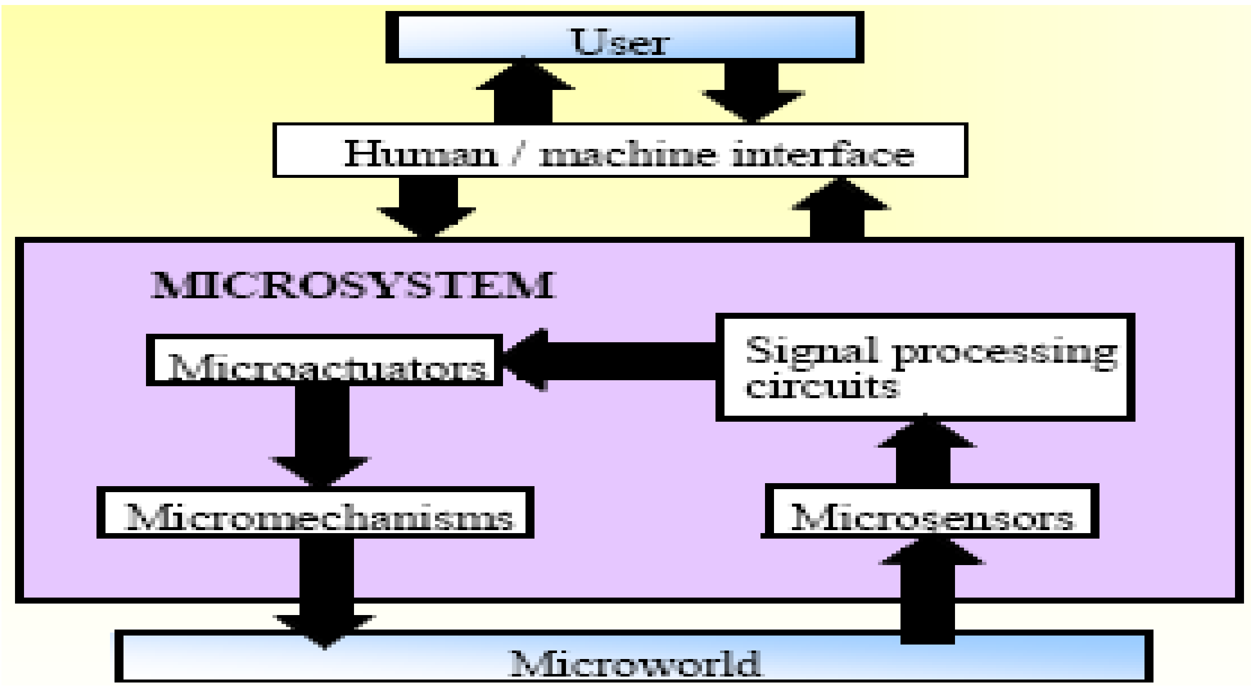
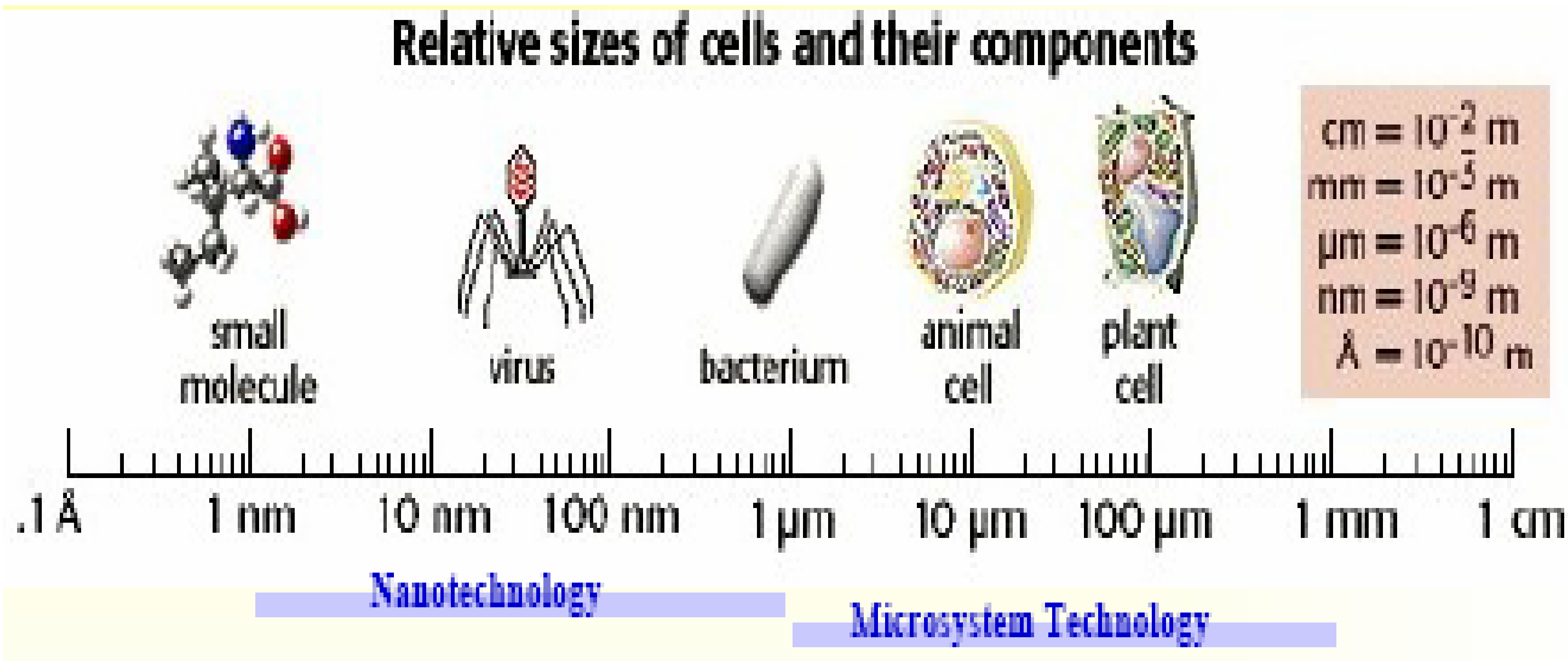
Lecture 1: Introduction to Microsystem technology

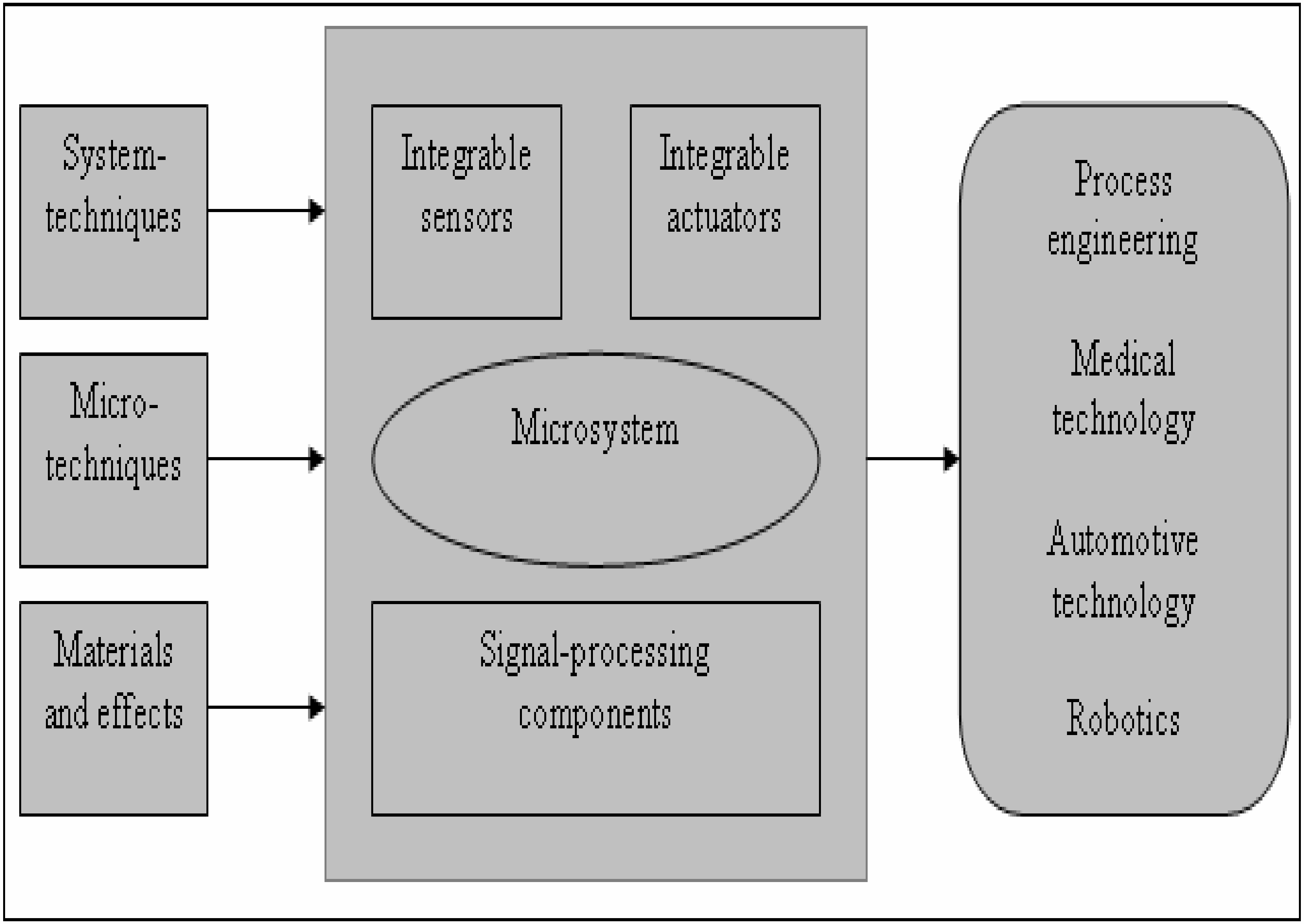
- **Microsystem Technology is miniaturization of systems and components**
- **No general agreement concerning the dimensions of a microsystem (cm...µm)**
- **One compromise is to refer microsystems as systems realized within a very small space and having at least one microfabricated component**
- **Consists of microsensors, microactuators and microprocessors**
- **Microsystem processes also matter not only information**





• **The ambitious goal of MST is to fabricate monolithic or integrated chips that cannot only sense (with microsensors) but also actuate (with microactuators), that is, to create a micro system that encompasses the information-processing triptych. The technology employed to make such a micro- system is commonly referred to as MST.**

• **MST is related to different applications areas. Early efforts focused upon silicon technology and resulted in a number of successful micromechanical devices, such as pressure sensors and ink-jet printer nozzles.**


System-techniques
Micro-techniques
Materials and effects
Integrable sensors
Integrable actuators
Microsystem
Signal-processing components
Process engineering
Medical technology
Automotive technology
Robotics

MEMS = Micro Electro Mechanical Systems

MST = Micro System Technology

Micro Machines

- MEMS
  - ⇨ Used mainly in the USA
  - ⇨ Background in IC technology => mass-production
- MST
  - ⇨ Used mainly in Europe
  - ⇨ System approach, covers both MEMS and micro machines
- Micro machine
  - ⇨ Used mainly in Japan
  - ⇨ Background in precision engineering

MEMS Technology

• **Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology.**

• **While the electronics are fabricated using integrated circuit (IC) process sequences (e.g., CMOS, Bipolar, or BICMOS processes), the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.**

• **MEMS promises to revolutionize nearly every product category by bringing together silicon-based microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip. MEMS is an enabling technology allowing the development of smart products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding the space of possible designs and applications.**

• **Microelectronic integrated circuits can be thought of as the "brains" of a system and MEMS augments this decision-making capability with "eyes" and "arms", to allow Microsystems to sense and control the environment, and can range in size from micrometers to millimeters. These systems can sense, control and actuate on the micro scale, and function individually or in arrays to generate effects on the macro scale.**

• MEMS have been identified as one of the most promising technologies for the 21st Century and has the potential to revolutionize both industrial and consumer products by combining silicon based microelectronics with micromachining technology. Its techniques and micro system based devices have the potential to dramatically affect of all of our lives and the way we live. If semiconductor microfabrication was seen to be the first micromanufacturing revolution, MEMS is the second revolution.

History

•The invention of a transistor in the end of 1940´s started the microelectronics revolution

•The integrated circuit (IC) concept was proposed in the middle of 1950's

•The first monolithic integrated piezoresistive pressure sensor was built in 1971

•The first high-volume commercial pressure sensor in 1974

•The first monolithic integrated capacitive pressure sensor was reported in 1980

•Development of silicon microsensors often required the fabrication of micro-mechanical parts

•Parts were fabricated using etching techniques

•The term bulk micromachining in 1982

•Surface micromachining was born in 1985

•Fabrication techniques to fabricate moving micromechanical parts were introduced in 1987

•An electrostatic micromotor in 1988

•The term MEMS came into use around 1987

Fabrication techniques

1) Basic layer techniques

•Etching

•lithography

•lift-off Techniques

•Thin and thick film techniques

•Masking

•Doping and ion implantation

2) Material deposition methods

•Surface micromachining

•LIGA

•LCVD and LECD

3) Material removal methods

•Bulk Micromachining, laser Micromachining and milling

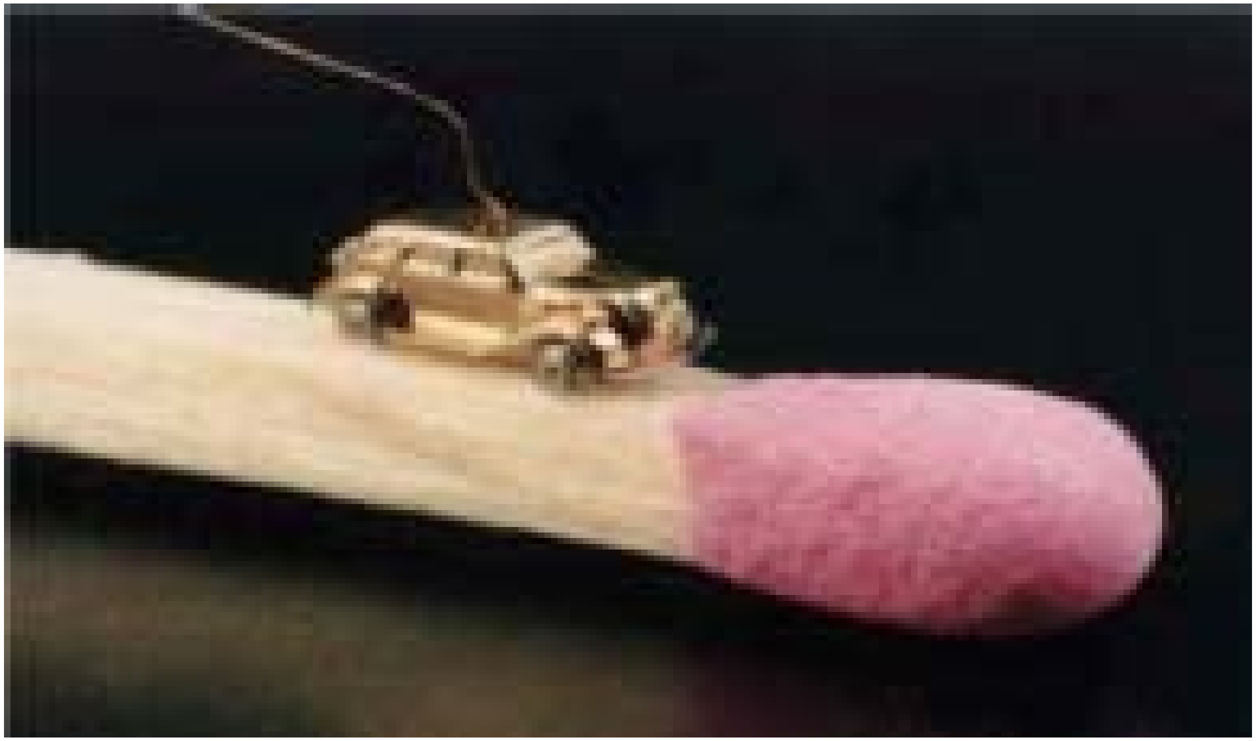
•Microelectro discharge techniques

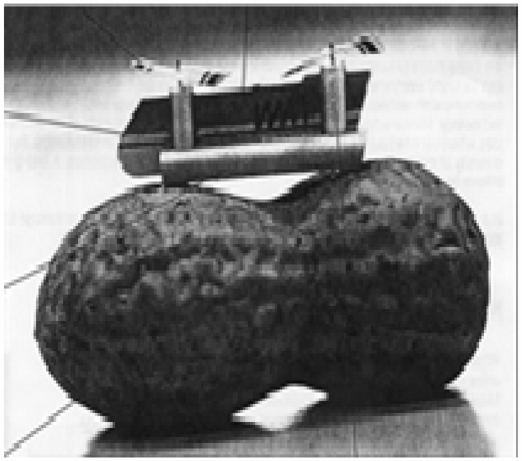
•powder blasting,

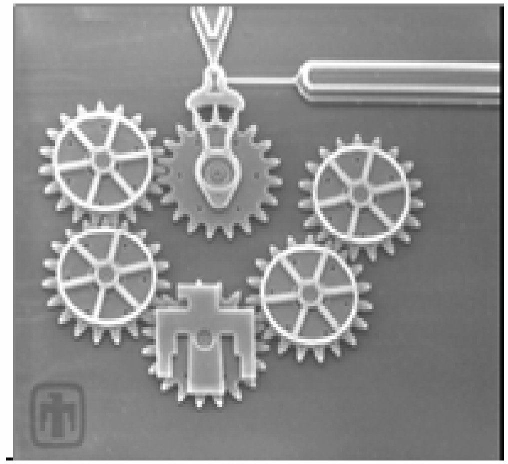
•micro ultrasonic machining

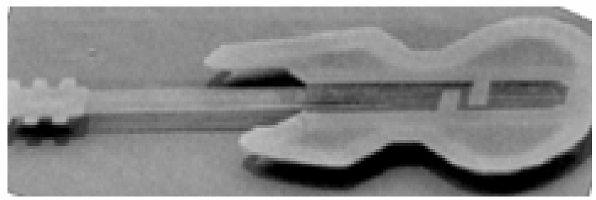
Microfabrication Examples

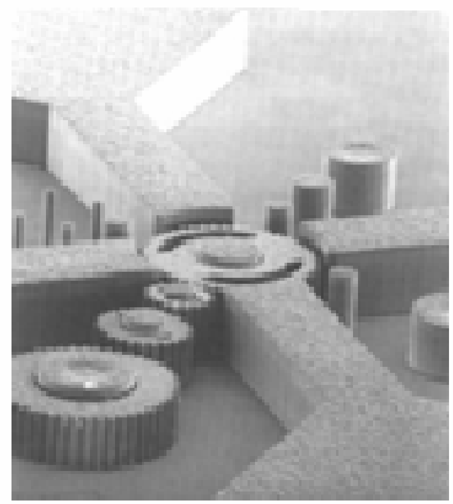
• MEMS devices are extremely small, for example, figure shows a Micro-Car as a miniature version of Toyota's first passenger car. Fabricated using MEMS, at 1/1000th the size of the original, it consists of a 0.67 mm magnetic-type working motor and when supplied with 3 V 20 m A of alternating current through a 18 µm copper wire, the engine runs at 600 rpm equivalent to 5-6 mm/s.











Benefits of Microsystems

1) Cost savings

• Mass production

• Simplification of structures and machines

•Less materials

•Reduced reagent consumption

•Lower power consumption

2) Reduction of size

•Portable devices

•Integration as a part of a larger system possible

•Access to data that cannot be collected using conventional methods

3) Products "more intelligent" and easier to use

4) New features and functions

5) Integrated functions in a single device, multifunctionality

6) Faster processes

7) Improved service and maintenance

8) On-line fault diagnostics using microsensors

9) Enhanced safety

10) Revolution in production from parallelism

11) Miniaturization of machines and processes

- **Miniaturized paper machine**
- **Microfactories**
- **Chemical microplant**

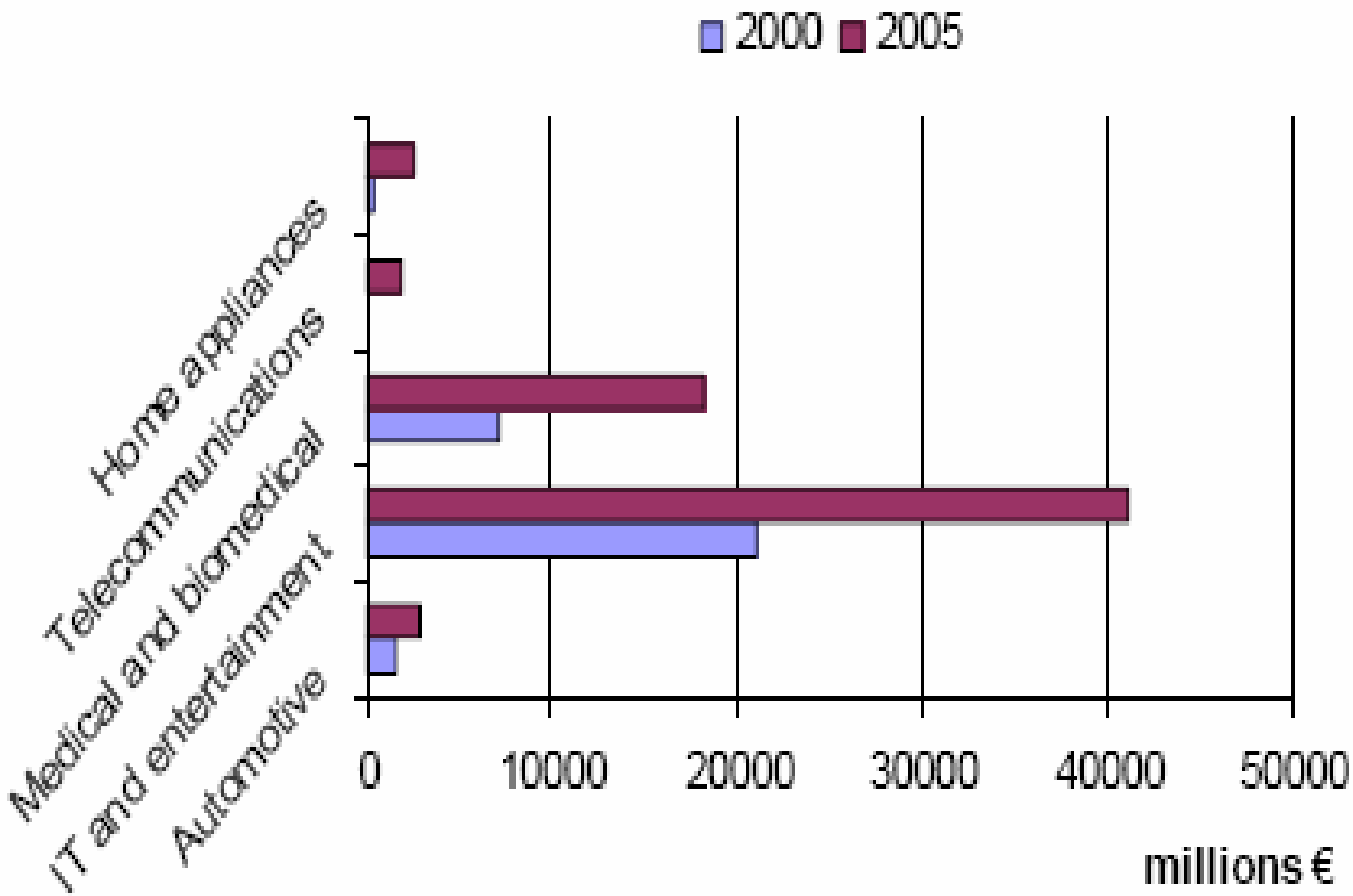
12) Environmental aspects

- **Monitoring and control of pollutants in machines**
- **Monitoring of environment (air, soil, water)**
- **Less materials**
- **Less waste**
- **Lower power consumption**

Application Area

- **Automotive industry**
- **Medical devices**
- **Biotechnology and environmental technology**
- **IT and consumer electronics**
- **Communication industry**
- **Smart clothes**
- **Process industry**
- **Machinery**
- **Manufacturing, service and maintenance**
- **Aerodynamics**

Market


2000
2005
Home appliances
Telecommunications
Medical and biomedical
IT and entertainment
Automotive
0
10000
20000
30000
40000
50000
millions €

Challenges

1) High investment costs (especially in silicon fabrication)

2) Small-volume production has not been profitable

3) Early stage of development

- **High design costs**
- **Many technological challenges remain**

4) Technological challenges (examples from microfluidics and microrobotics)

- **Lower detection signals**
- **Impurities**
- **Formation of bubbles**
- **Reliability**
- **Effects of environment**

Comparison between the Japanese and American activities in microsystem fields:

- Overall, Japanese industry is emphasizing approaches to MEMS that are similar to those taken by U.S. industry. These efforts are primarily based on silicon integrated-circuit technology and are focused on sensor applications. Japanese industrial capabilities in these areas are comparable to those in the United States.

- Substantial efforts to develop microactuators, microelectromechanical systems, and micromachines based on advanced lithographic processes exist in both countries. The United States is perceived to have the lead in these areas and in sensor-circuit integration, although the Japanese programs are quite competitive, especially in realizing commercial products.

- Research efforts on MEMS in Japanese universities are generally less well equipped than their U.S. counterparts and involve a more diverse array of approaches and processes. While university research is one of the real strengths of MEMS in the United States, the research potential of Japanese universities is probably underdeveloped and underutilized.

- Japan is perceived to lead in nonlithographic approaches to MEMS, although it is not clear that such approaches can achieve the batch-fabrication and compatibility with electronic signal processing that most high-volume applications would appear to require.

- The ten-year large-scale ($250 million) MITI-sponsored program in micromachine technology (formally titled the Micromachine Technology Project) emphasizes the miniaturization of more traditional (nonlithographic) machining processes and involves projects chosen to complement efforts already underway in industry. This program involves twenty-four Japanese companies, many of which have larger ongoing internally-funded programs in MEMS-related areas. Still other Japanese companies are strongly involved in MEMS, but do not participate in the MITI program. MITI is encouraging participation by foreign companies in its micromachine technology program, which currently has one Australian and two U.S. participants.

- Packaging technology is application-specific and is considered a major challenge in both countries. Japanese efforts in low-temperature wafer-to-wafer bonding are applicable to the realization of wafer-level device encapsulation/packaging as well as to the creation of advanced batch-fabricated microstructures.

- The infrastructures for MEMS development in the United States and Japan are different, but both are effective. Strengths of the Japanese efforts include the relatively high involvement of industrial residents at Japanese universities and the ability in Japan to set long-range goals and establish multidisciplinary multiorganizational teams to accomplish them.

II. MEMS applications

MEMS technology grown largely in the past decade, various applications on MEMS technology has been brought to reality and now used as commercial wise, yet the research is in progress to move forward to more applications and reducing its production cost. MEMS is used in a wide range in many applications, there are numerous possible applications for MEMS. As a breakthrough technology, allowing unparalleled synergy between previously unrelated fields such as biology and microelectronics, many new MEMS applications will emerge, expanding beyond that which is currently identified or known. Here are a few applications of current interest:

Medical applications

i. Microsurgery

ii. Implantable systems

iii. Measurement systems

iv. Drug delivery

i. Microsurgery

A) Active Tremor Cancellation

Eliminates vibration of the hand and other unwanted motions.

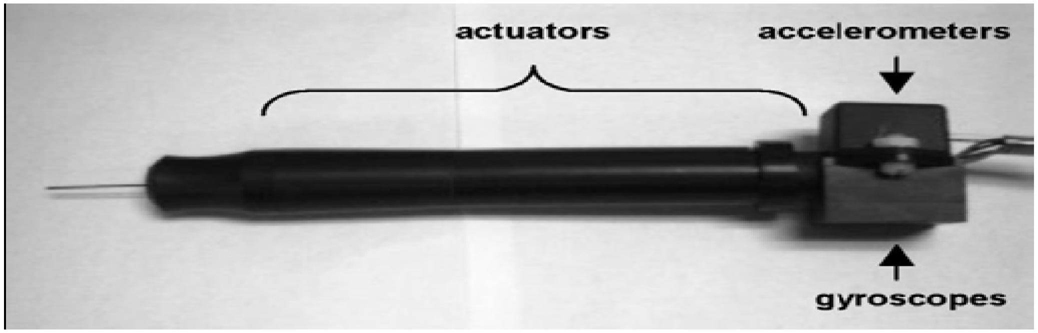
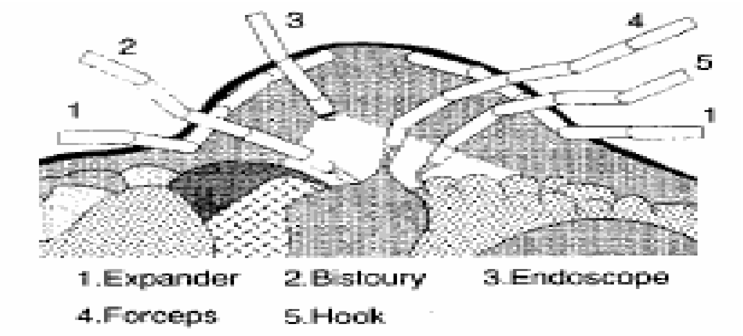


Figure 1: Active tremor cancellation

B) Minimally invasive surgery

To minimize the surgical impact on the body by inserting probes inside the body to view and solve the problem.



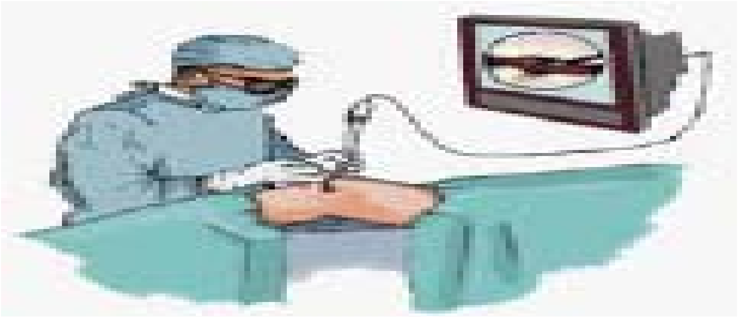


Figure 2: Probes surgery

Also using robots in operations Increasing rapidly in numbers, with many commercial devices like grippers and cutting tools, or using them as guiding systems.

Figure 3: Robotic surgery

And the telemanipulator systems for clinical experiments (test bed).

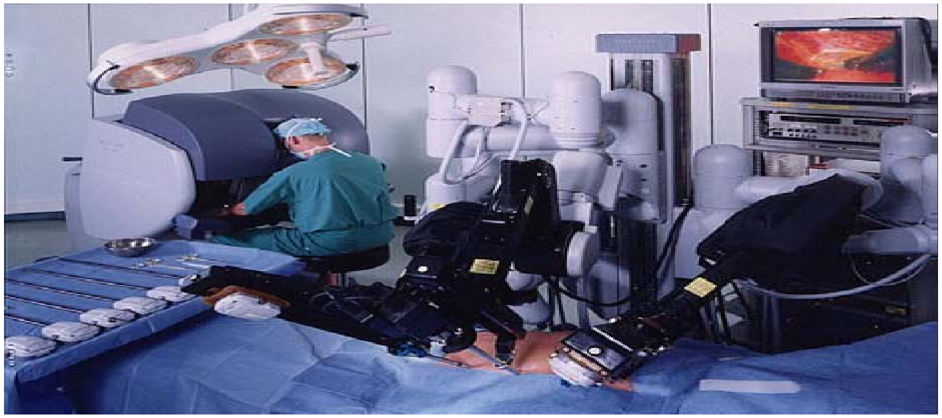


Figure 4: Telemanipulator system

C) Balloon pumps

Microaxial pump placed in front of the balloon to increase blood flow through the catheter.

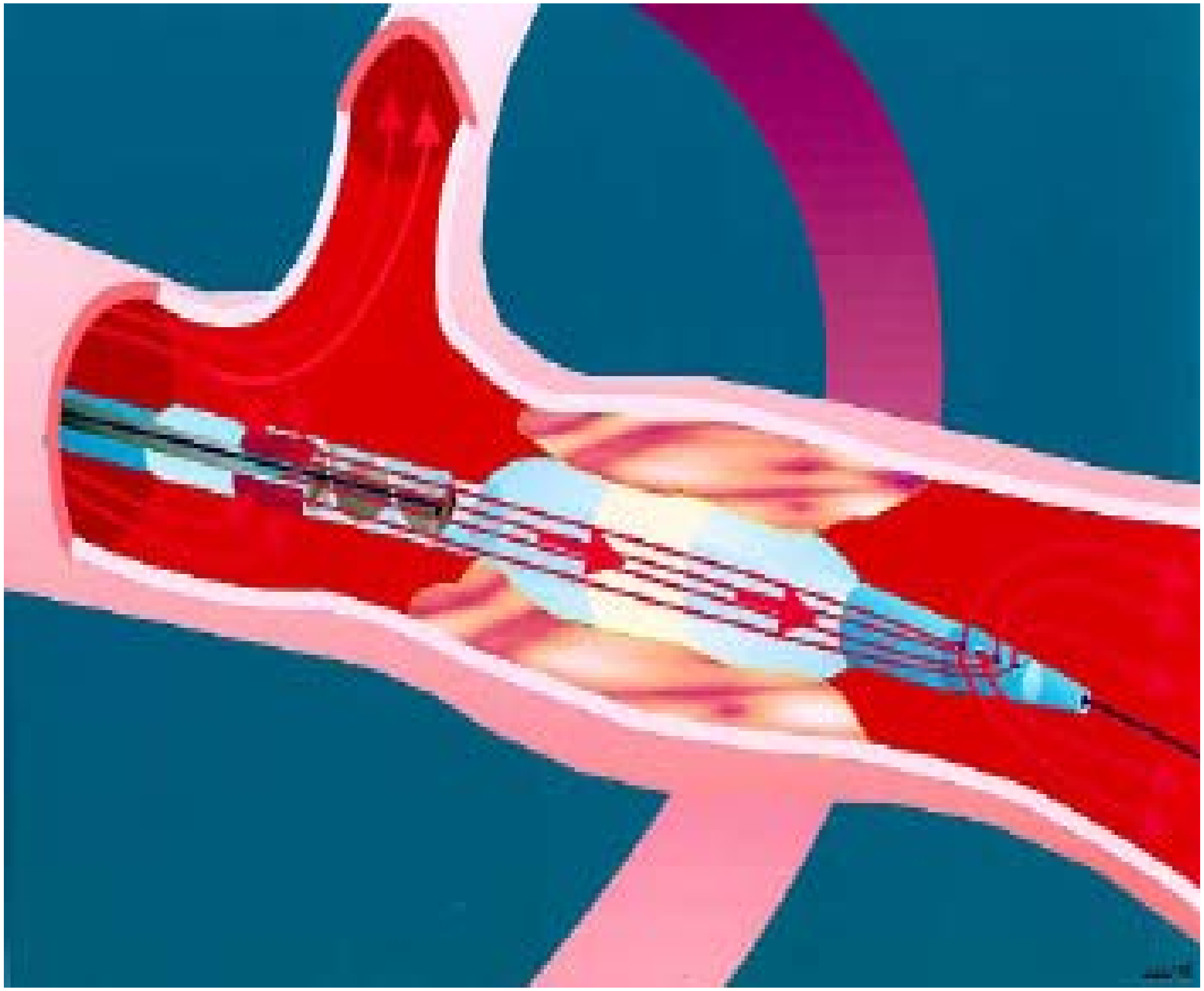


Figure 5: Balloon pump

d) Norika3

A device used for intestinal imaging, with wireless power and video transfer. The rotation control is done from outside.

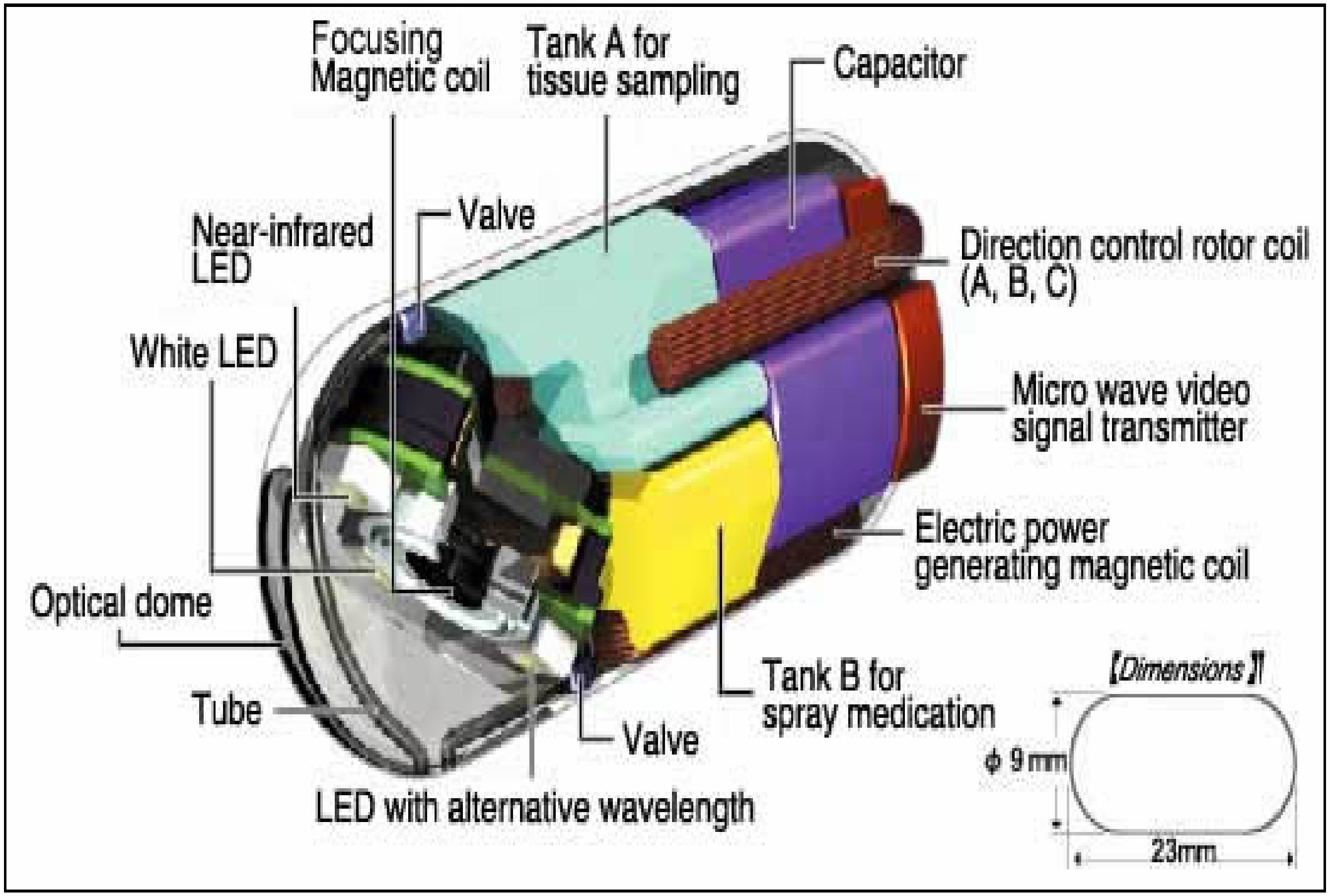


Figure 6: Norika3

ii. Implantable systems

A) Hearing aids

Implantable hearing aid systems using Microsystems technology becomes one of the most important medical applications, it consists of a michromachined microphone which receives the sound wave and digitize them, then by signal processing, this sound is amplified and reconverted to sound by a michromachined loudspeakers, an automatic gain control device maybe added to the system to protect the ear from the loud sounds. Figure 7 shows the components of the hearing aid systems.

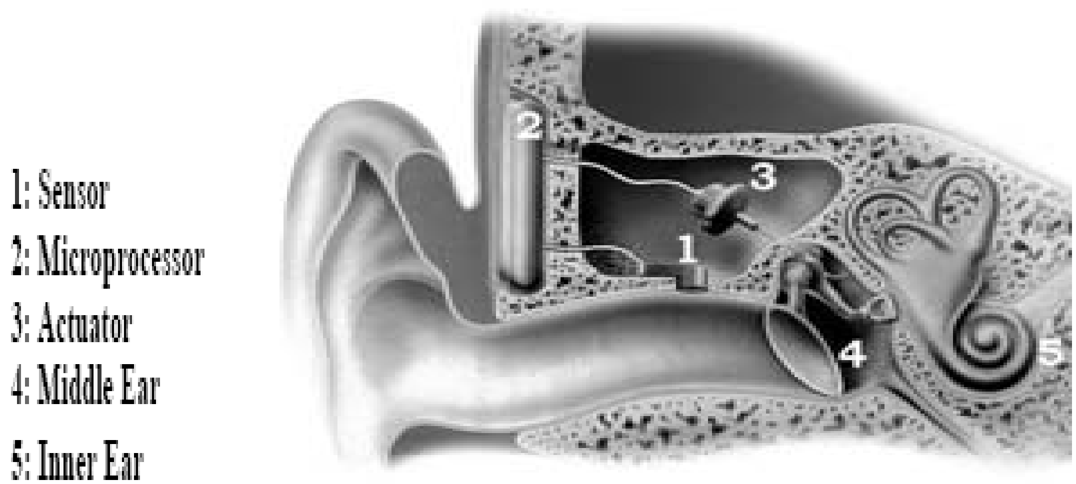


Figure 7: Hearing aids systems

B) Cardiac Pacemakers

Used to manage a heartbeat that is too slow or irregular. The modern rate-adaptive pacemakers monitor cardiac activity and pace the heart by sending a small electric current. This device is an Integration of an accelerometer to detect patient's physical activity. Nowadays, pacemakers market is around 600000 pieces / year, with weight of 25 gm which decreasing.

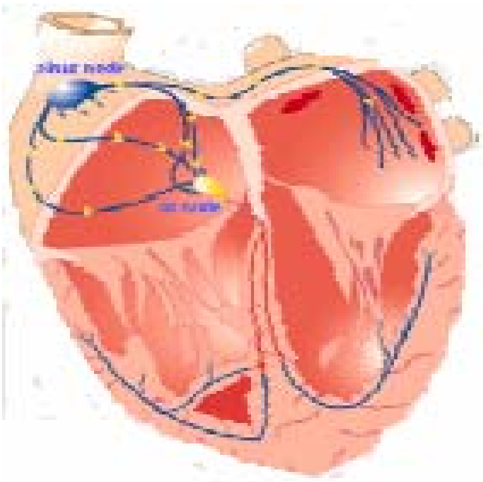


Figure 8: Cardiac pacemaker

C) Implantable sensors

Sensor systems for wireless monitoring of different body functions, like temperature, glucose for diabetics, body fluids, electrical activity and pressure.

D) Implantable electrodes

Polyimide foils electrodes with thickness of 10µm implanted in rats more than 10 months.

Figure 9: Implantable electrodes

E) Implantable electrical stimulators and artificial limbs

If there are problems in nervous system, electrical stimulators are added to activate the nerves. Artificial limbs are one of the promising technologies in the future.

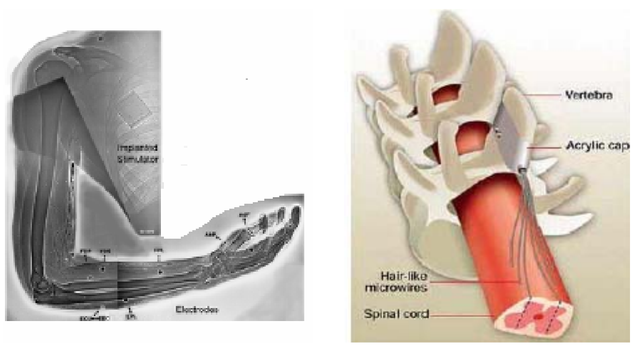


Figure 10: Electrical stimulators

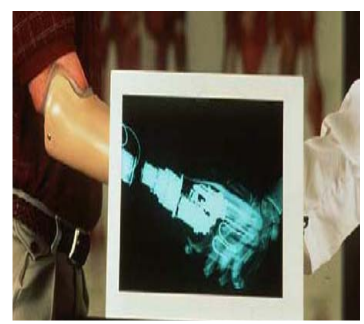


Figure 11: Implantable artificial limbs

iii. Measurement systems

A) Personal Healthcare Systems

These systems consists of several microsensors, for temperature, pulse, mobile activity, smoke, etc. and alarms for emergency situations.

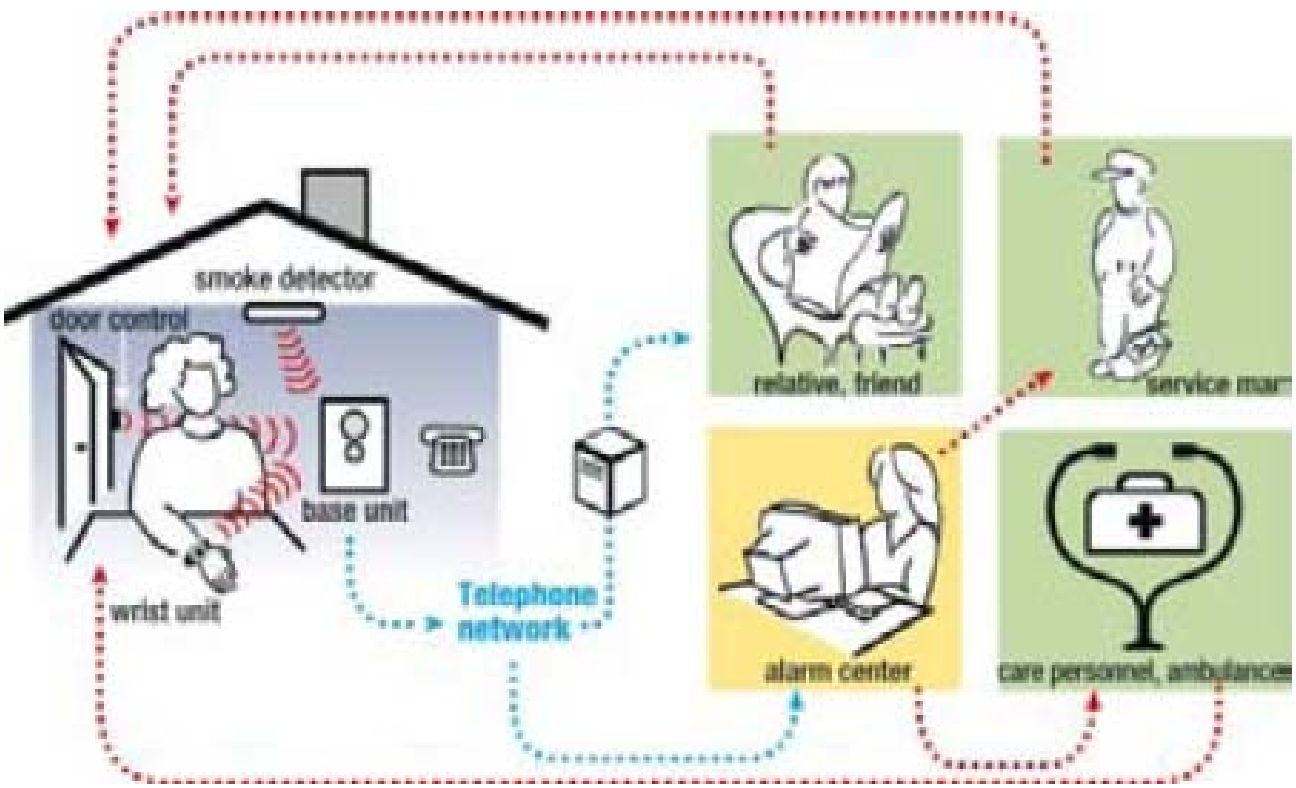


Figure 12: Personal Healthcare Systems

B) Non-invasive measurements

To limit the surgical impact on the body, by using new ways for measurements, for example, the Intraocular Pressure Measurement, which is an acoustic stimulation, by sending high frequency acoustical waves to the eye, and then an optical measurement of the simulated micro vibrations is made. No surgery and non contact method, and easy to use.

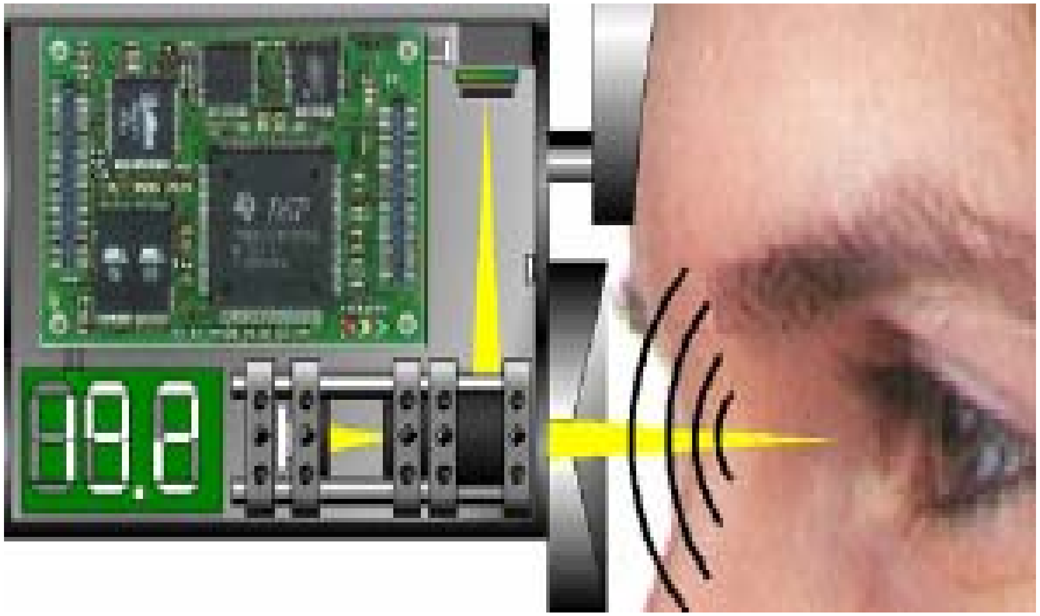


Figure 13: Intraocular Pressure Measurement

iv. Drug delivery

To release drugs in a predetermined order, dozens of tiny 25 ml containers are filled with drug and sent to the body.

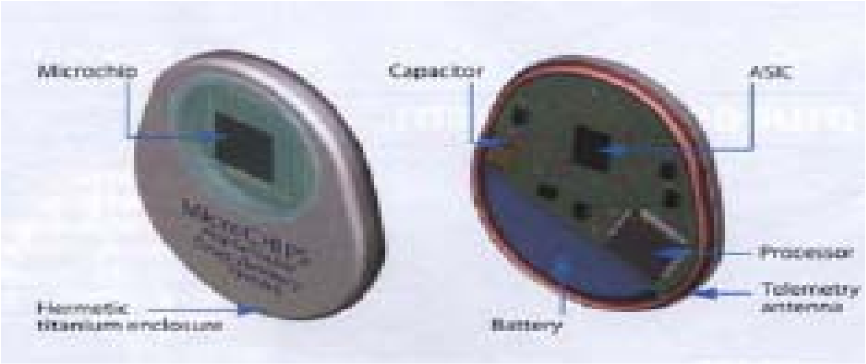


Figure 14: predetermined order drug delivery containers

To release drugs according to measurements, one bigger container that can be closed and reopened depends on the measurements results.

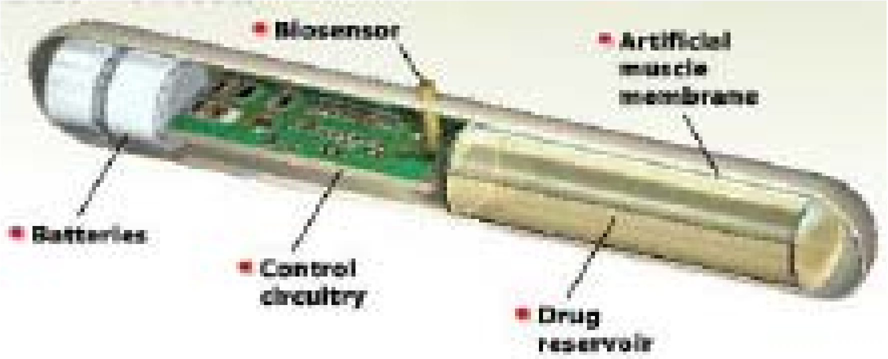


Figure 15: Measurement dependant drug delivery containers

Also, microneedles are used instead of the traditional multi injection method, which is painless, and does not reach to nerves.

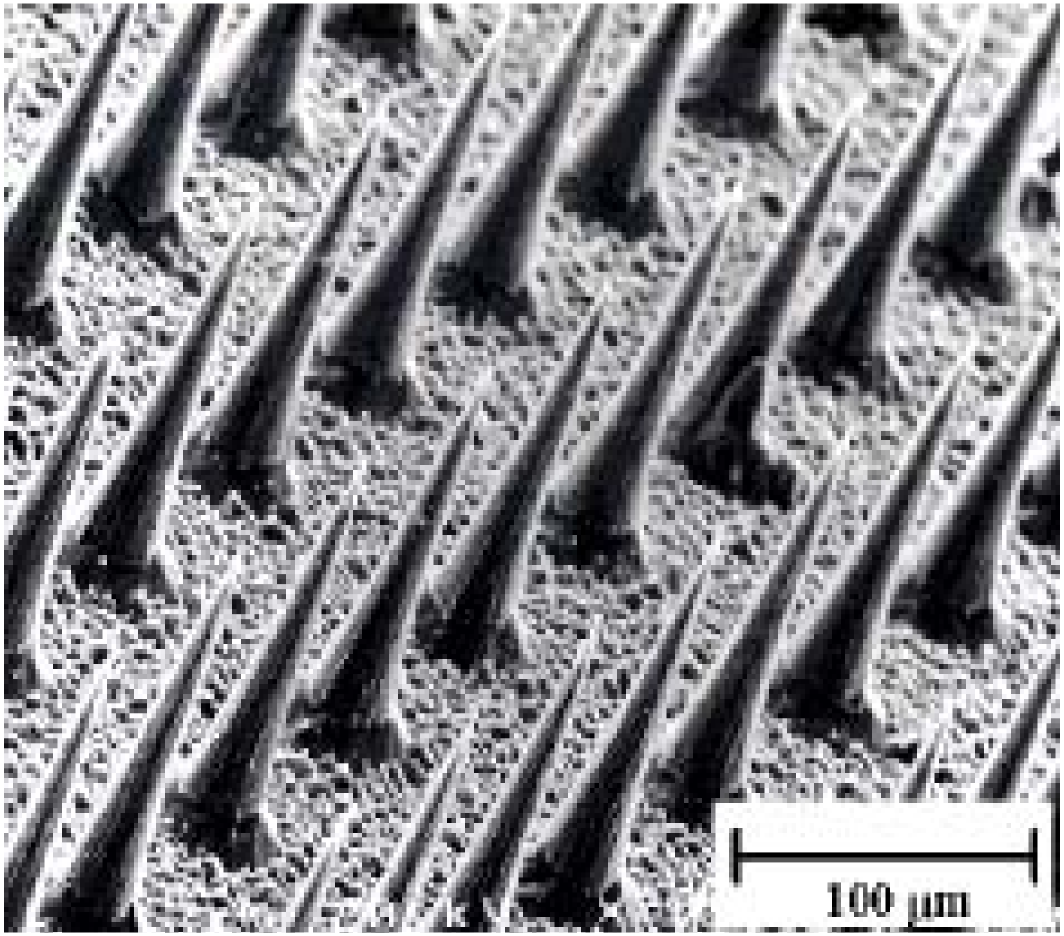


Figure 16: Microneedles

Biotechnology and Chemistry Applications

Lab-on-a-Chip Technology

An emerging MEMS technology that can sense chemical and biological properties. The chip typically combines silicon fabrication technology with microfluidics. A simple but useful definition of microfluidics is the device has one or more channels with at least one dimension less than 1 mm. Lab-on-a-chip products can evaluate any number of chemicals but the most talked about topic is DNA analysis.

Labs-on-a-chip technology has several advantages: fluid volume inside the channels is very small (usually on the order of nanoliters); the amount of reagents and analytes used is quite small; and fabrication techniques are relatively inexpensive and adaptable to mass production.

In a manner similar to that for microelectronics, microfluidic technologies enable the fabrication of highly integrated devices for performing several different functions on the same substrate chip. One of the long term goals in the field of microfluidics is to create integrated, portable clinical diagnostic devices, thereby eliminating time consuming laboratory analysis procedures.

Microfluidics

There are two common techniques to force fluid through microchannels. In pressure driven flow, in which the fluid is pumped through the device via positive displacement pumps, such as syringe pumps. Electrokinetic flow is more involved and depends on a phenomenon called electro osmotic pumping.

If a microchannel's walls have an electric charge (as they generally do), then an electric double layer of counter ions will form at the walls. When an electric field is applied across the channel, the ions in the double layer move towards the electrode of opposite polarity. This causes the fluid near the walls to start moving and this transfer into convective motion of the bulk fluid. If the channel is open at the electrodes, the velocity profile is uniform across the entire width of the channel. However, if the electric field is applied across a closed channel (or a backpressure exists that just counters that produced by the pump), a recirculation pattern forms in which fluid along the center of the channel moves in a direction opposite to that at the walls. By modifying the electric field, the motion of the fluid can be controlled.

There are several ways to separate the elements of the sample; one that is illustrative in principle is the H filter, which was developed at the University of Washington in the mid 1990s. The H-filter (Figure 17) allows continuous extraction of molecular analytes from fluids containing interfering particles, blood cells, bacteria, microorganisms, dust, and viruses for example, without a membrane filter or some other component that requires cleaning or replacement.

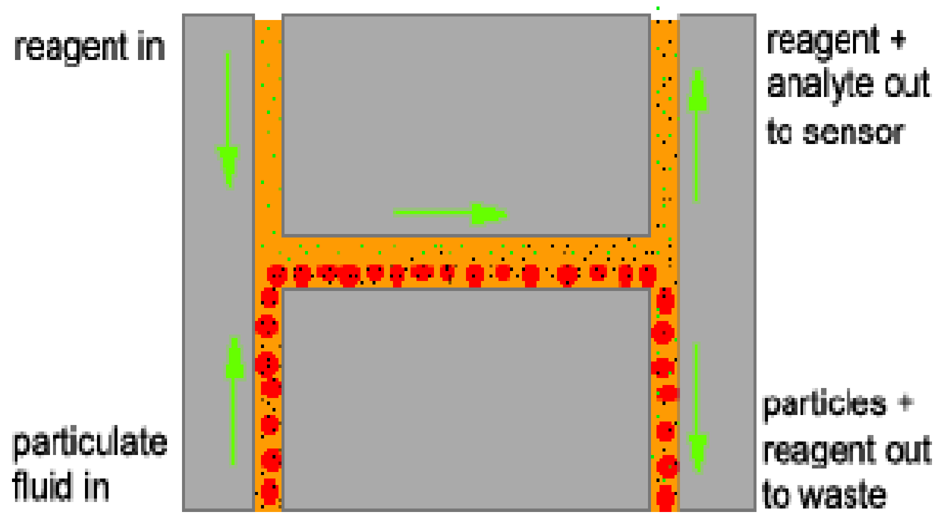


Figure 17: The H-filter

This device is designed to process the small fluid volumes (nanoliters to microliters) analyzed by microfluidic instruments, although it can be scaled up to process fluids at arbitrarily high flow rates. Products based on H-filter separatation tend to be inexpensive enough to be disposable. After the molecules are isolated by the filter, it must be analyzed. The T sensor is one option. In a typical T-sensor assay one input stream contains an analyte of interest, such as a protein or a drug. The other fluid stream contains a receptor molecule such as a fluorescent indicator, an antibody, a PH indicator, an enzyme, or some other reactive species. The flow of the two streams is kept completely laminar and no convective mixing occurs. The only way molecules in opposite streams can mix is by molecular diffusion across the interface of the two fluid streams. The chemical binding or other reaction events than occur along this centerline produce a

measurable signal, usually fluorescence, which can be used to calculate a parameter of interest for the analyte, such as concentration or diffusion coefficient. A diagram of a T sensor is shown in Figure 18.

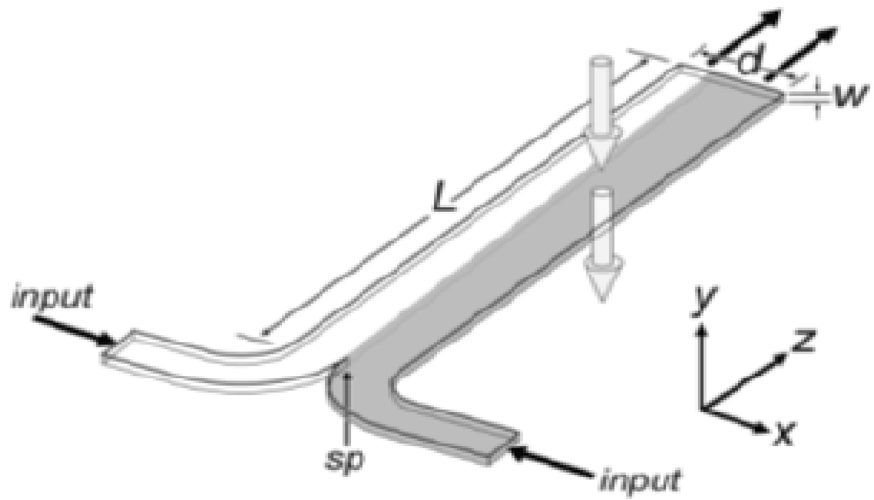


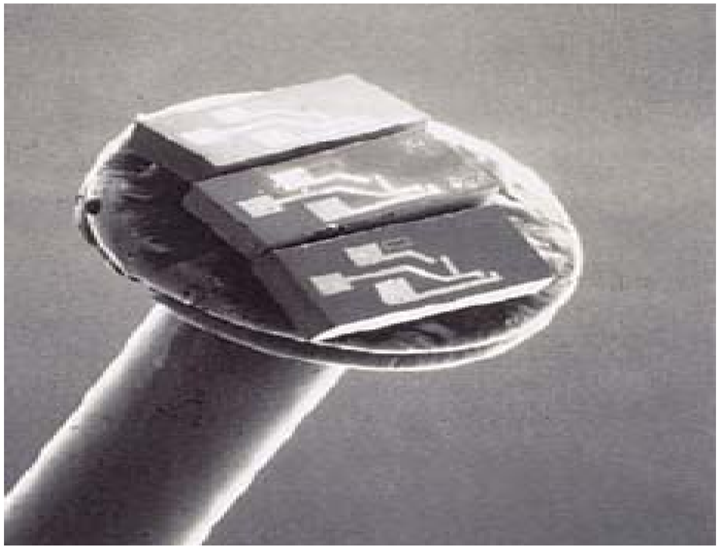
Figure 18: T sensors use parallel microfluidic channels to identify molecules

T sensors and H filters have complementary attributes for product design with the most important being that they are relatively inexpensive to manufacture and therefore can be used in disposable products. T sensors have been used in the following applications:

- **Clinical chemistry analyzer**
- **Drug and hormone analyzer**
- **Enzyme and protein analyzer**
- **Chemistry/coagulation system**

Blood-Analysis System on a Chip (in the future)

MEMS makers are concentrating on developing micron-sized chemical sensors and fluid-flow devices. Building biomedical test instruments in which micromachined fluidic chips are key components.



The MEMS transducers shown in figure are used in inter cardinal catheter-tip sensors for monitoring blood pressure during cardiac catheterization. The instrument contains all the electronics that interface with the MEMS chip and a display and control keypad as well as the actuators to operate the fluidic components, and can eliminate the hours required for traditional laboratory analysis. The instrument automatically performs the calibration measurements, directs the blood sample over the sensor chip, records measurements of the sample, and displays the results on the handheld instrument.

DNA Analysis

A lab-on-a-chip specifically designed for DNA research. DNA analysis chips are used to diagnose genetic diseases, perform drug discovery, test livestock and monitor water supplies.

Figure 19: The In Check Lab-on-a- Chip speeds DNA analysis

Other Biomedical applications include:

- **Upstream in-line blood plasma separator (replaces centrifuges)**
- **Separator, reactor and extractor for bio-pharmaceutical and drug discovery**
- **Artificial kidney**
- **Genomic analysis systems, sequencers and mass spectrometry**

Environmental Applications

1) Lowering consumption

•Small devices need less energy

– Miniaturization of devices

• Better manufacturing methods

– Mini factory

– From molecules to whole structures approach could be more energy efficient

• Less people need less energy (stabilization of population growth) vs. increasing life time

• Multifunctional – more value through less resource and less waste and emissions

2) New energy resources

•Solar Photovoltaic

• Energy of sea waves

• Biomass

• Kinetic

• Wireless power transmission

3) Soil quality

- **Precision application of nutrients**
- **Analytical tools for on-spot measurements**

– Nutrient status of soils and hydroponics systems in glass houses

– Pesticide persistence in soils

– Plant diseases, insect pests

– Basically chemical analysis…but very challenging, since the the variables are different in time and space

4) Measuring environment

- **Weather observations**

– Metrology

– Aviation

– Thunderstorm

– Road, runway, rail weather (ice)

- **Environmental measurements**

– Relative humidity

– Barometric pressure

– Microsensors and weather systems

5) Reducing waste

• Using more efficient methods

– Minimal invasive therapy

– Lab-on-a-chip

– Mini factory

– Life cycle of products

6) Air and water quality

• Sensors

– Ensuring feedback and thus improving the performance of devices (e.g. gas sensor)

• On-spot analysis

– Lab-on-a-chip

•Better methods ensuring less pollutant

•Transport, production and agriculture