MICRO-ELECTRO-MECHANICAL SYSTEMS (MEMS) AND APPLICATIONS IN MEDICINE

Marinescu Maria-Roxana[1], Ghiculescu Liviu-Daniel[2]
[1] Phd. Student, M.Sc. Ing., National Institute for Research and Development in Microtechnologies - IMT Bucharest, roxana.marinescu@imt.ro
[2] Professor, PhD, Eng, "Politehnica" University of Bucharest, daniel.ghiculescu@upb.ro

ABSTRACT: The paper presents the MEMS devices and their applications that provide micro and nanodimensional functions in all the important areas. These are microsystems obtained by integrating mechanical elements, materials with special properties (ferrous, piezo- etc.) and electronic components on a common substrate (usually encapsulated on silicon/glass plates) by specific micro-manufacturing technologies. Miniaturized systems have a much faster reaction time, faster analyzes and results, automated increased possibilities with lower risks and costs. For this reason, most researches are made in order to realise small-scale versions of the existing systems for micro and nano levels. One of the most important areas in wich MEMS are in continous development is Medicine.
KEYWORDS: Nanotechnology, MEMS, biosensors, micro, medicine.

1. INTRODUCTION

1.1 Introduction in Nanotechnology

„NANOTECHNOLOGY” is a collective term for technological developments on a very small, nanometric scale [1].

Nanotechnology is the science that works with atoms and molecules, representing any technology that relies on the ability of building complex structures, respecting atomic specifications and using mechanical synthesis [6]. Its purpose is to build extremely small devices. The design, characterization, production and application of structures, devices and systems is achieved by controlling the form and the size on a "nanometric" scale [3]. In a restrictive sense this is the science of materials whose properties depend on dimensions [4].

A nanometer represents the billionth (10^{-9}) part of a meter, that is, 0.000 000 001 meters or a millionth part of a millimeter. Nanotechnologies manage materials with nanometer scale sizes, approximately between 1 and 100 nm. This scale is called nanoscale. Some examples that define this scale are presented in Figure 1[5] and Figure 2 [17].

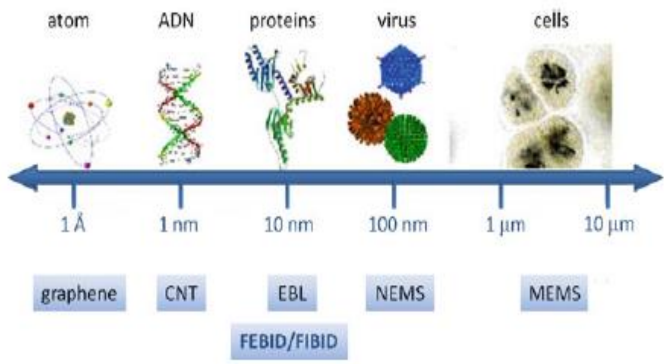


Figure 1. Nanoscale examples [17]

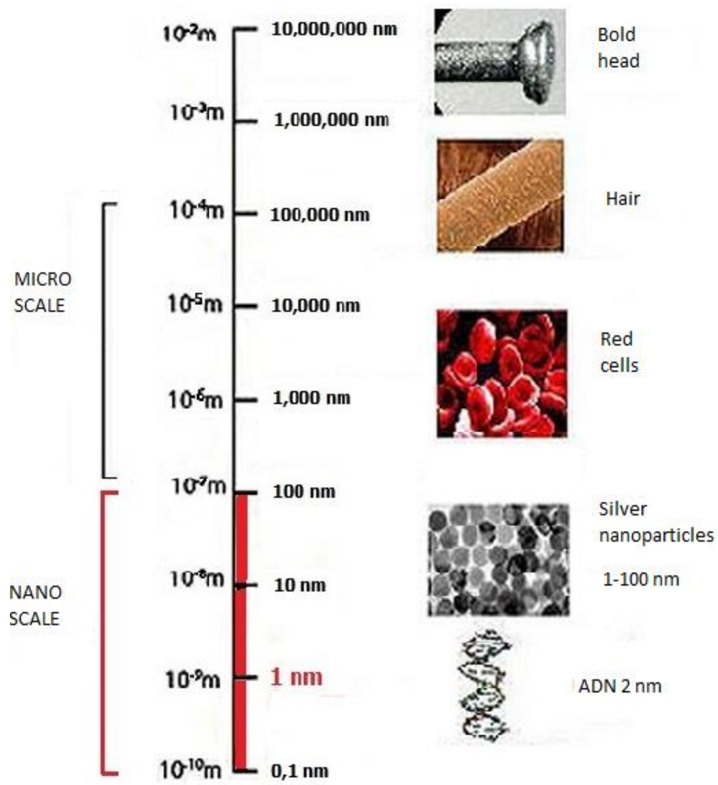


Figure 2. Micro and Nano scale [5]

Miniaturization is important for the development of macroscopic systems and devices, because the benefits of scaling laws can be used effectively. Among all these reasons, which confirm the fact that miniaturization presents so many innovation opportunities of the products in different areas, we find the following:

- Minimizing energy and materials consumption during the manufacturing process;
- Redundancy and matrix;

- Integration with electronic systems, simplifying the systems (eg.: single point vs. multipoint measurements);
- Reducing the power budget;
- Improved thermal management;
- Increasing selectivity and sensitivity;
- Minimal invasiveness;
- Wider dynamic range;
- Cost / performance benefits;
- Improved reproducibility;
- Improved accuracy and reliability;
- Self-assembling and biomimetics with nanochemistry;
- Smarter materials with nanoscale structures [1].

The small size of the microsystems can be crucial in medical and space applications..
The branches of Nanotechnology are represented by:

- Nanofabrication;
- Nanomechanics;
- Nanorobotics;
- Nanostructured Nanocomposites and Composites;
- Nanobiotechnology;
- Nanomedicine;
- Molecular electronics;
- **MEMS**
- NEMS (micro/nanoelectromecanic systems);
- Microfluidics;
- Intelligent Medicines;
- Smart textiles;
- Biosensors;
- Econanotechnology [4].

1.2 What is MEMS

The term used to define MEMS varies from "MEMS atoms", "Microsystems technologies" to "microprocessing devices" [7].

Electromechanical microsystems were introduced for the first time in the 1960s as pressure sensors. The acronym for microelectromechanical systems - MEMS - was officially adopted in 1989 at a scientific conference by Dr. Albert P. Pisano who used the term MEMS for the first time to describe the resonant structures that were manufactured to be used in frequency stabilizers.

MEMS devices are commonly produced using lithography-based processing technologies, generally described as "surface microtechnologies or volume microtechnologies", borrowed from the Integrated Circuits (IC) process [8].

Over the years, numerous applications of these micro-electro-mechanical systems have resulted in a multitude of MEMS acronyms, such as:

- ➢ BioMEMS = MEMS applied in the medical and biological field;
- ➢ MOMS (micro-optical mechanical systems - MEMS applied in the optical field;
- ➢ MOEMS - micro-optic electromechanical systems;
- ➢ NEMS (Nanoelectromechanical systems) - MEMS applied in the nano-electro-mechanical field;
- ➢ C-MEMS (carbon / ceramic MEMS);
- ➢ Power-MEMS;
- ➢ HI-MEMS (hybrid insect) - hybrid microelectromechanical systems;
- ➢ RF-MEMS - Radio Frequency MEMS;
- ➢ P-MEMS (MEMS polymer) - MEMS applied in the field of polymers, etc. [9].

MEMS technology is considered to be mainly made up of two main sub-areas: ultra-precision engineering and integrated circuit technology (IC) [10].

A microsystem combines at least two of the following areas:

- Mechanical - force, pressure, speed, acceleration, position;
- Thermal - temperature, entropy, heat, heat flux;
- Chemical - concentration, composition, reaction rate, humidity;
- Radiation - electromagnetic wave intensity, phase, wavelength, reflection polarization, refractive index, ultraviolet, visible, infrared;
- Magnetic - field strength, flux density, magnetic moment, permeability;
- Electric - voltage, current, charge, resistance, capacity, polarization [1], [7]

Microelectromechanical (MEMS) systems include a large field that represents the technology development over the last decades. MEMS are included in all areas, in everything that surrounds us.

Basically, there no longer exists an application that does not start with a sensor, continues with a microprocessor and a database and ends with an actuator. Automotive or consumer electronic equipments can no longer be imagined without MEMS sensors

2. MEMS CLASIFICATION

MEMS are microsystems obtained by integrating mechanical elements, sensors, actuators and electronic components on a common substrate (usually a silicon wafer) using specific micro-manufacturing technologies [7].

To make a successful MEMS device, the basic physics principles and the operating principles (including scaling laws) must be fully understood and appreciated at both macro and micro levels.

Microsystems can be grouped in the following way:

- Sensors
- Actuators
- Intelligent integrated microsystems [5].

2.1 Sensors

Sensors are devices that take the information from a particular environment by measuring a certain physical magnitude (mechanical, thermal, chemical, magnetic, etc.) and generate a signal proportional to the measured magnitude.

Sensors are made from very simple to very complex. They are classified in different categories, such as the nature of the signal, the selective material or the signal level [10].

Sensors are primarily used to observe the temporary effects of the environment. Sensors make possible the obtaining of real-time information about things we can see, touch, smell and hear, but also about other things that we can not detect (things that can be harmful or useful) [4].

The microsensors detect the changes from the system environment by mechanical, thermal, magnetic or chemical measurements or by electromagnetic information. MEMS process this information and sends a signal to the microactuators in order to react and create some changes in the environment. These values will be calibrated in order to obtain meaningful information [10].

As examples, we have different types of sensors: sensors for temperature, humidity, water level, smoke, gas, voltage and current intensity, motion and position, airflow, proximity (inductive), liquid presence (for pump protection), mechanics (measure the force), pressure, stress, movement, velocity, or acceleration on atomic, molecular, thin, or bulk scale [11].

A classification of the sensors can be done as follows:

- Physics
- chemistry
- **Biosensors**

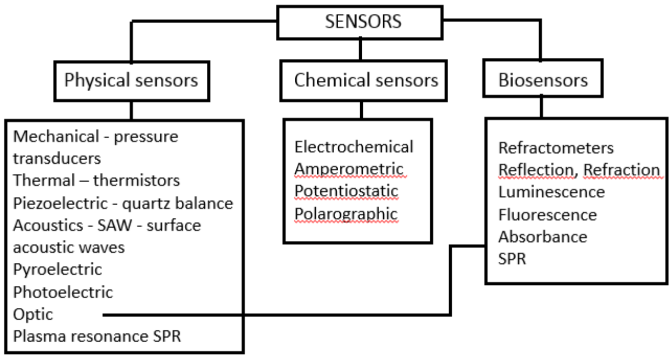


Figure 3. Classification of sensors by the nature of the processes measured by the detector [4]

2.1.1 bioMEMS and biosensors

MEMS extends from its roots in electromechanical devices to multiple directions. One important direction from today is **bionanotechnology** and **bioMEMS**.

A key factor for the development of biosensitivity systems is the need of new and expanded technologies for environmental monitoring and control - identification of toxic materials in the environment.

The biosensor applications in which an efficient combination of MEMS and interfacial materials can have a major international impact include diagnostic devices that rapidly measure cellular, genetic and proteomic signatures and models, unlike single analytes; new approaches to the mass parallel drug discovery process with high information content; as well as multiple false positively biopsied and biochemical detection are very important [11].

Nanobiotechnology is a multidisciplinary science that uses nano / micro-fabrication tools and processes in order to build devices that study bio-systems, microanalyses of biomolecules by single-cell interfacing, elevating metabolism and biochemistry profiles, analyzing response to different analytes. It also studies biopsy-inspired nanoparticles, biosensors, microbial combustion cells, new types of markers, etc. [4].

Biodevice means an assembly of electrical, biological, mechanical, optical elements - as active elements – (transducers, amplifiers, characterizers, etc.) and interconnecting elements with the external environment, such as: capsules, terminals, microchannels, for the bioliquid connection. The biodevice may have complex functions. When it is built just to detect a certain substance it is called **biosensor** [8].

The biosensor is a self-contained device, sensible to a physical or chemical stimulant (eg heat, acidity) capable to transmit quantitative or semiquantitative analytical information about the vital processes using a biological recognition element (biochemical receptor) that is held in spatial direct contact with a transducer [23]. Biosensors deal with substance acquisition, physiological signal detection and their transformation into standardized "technical" signals, tharare often electric, in order to be quantified from analog to digital [4].

Due to their ability to be calibrated repeatedly, it is recommended that a biosensor be clearly delimitated by a bioanalytical system, requiring additional processing steps, such as adding the reagent [15].

MEMS biosensibilization systems, including microfluidic systems, have adopted many of the microfabrication methods common to the fabrication of MEMS, including lithography, dry and wet chemical processing, surface and thin film coating technologies, bulk and depth engraving, ionic implantation and engraving.

Biosensors and nanotechnology have boosted each other into development. Today we are talking about diagnostic platforms, molecular imaging and molecular diagnostic, characterization of biological processes and structures. All of this are based on the foundation and the development of biosensors [4].

Leland C. Clark Jr. (December 4, 1918 - September 25, 2005) is a biochemist who has become popular after inventing the Clark electrode, a device used to measure the oxygen from blood, water and other liquids. His researches are the base of the development of the first sensor device used by millions of diabetics to rapidly determine the amount of glucose in the blood. With its help, millions of diabetics can monitor their own daily blood sugar levels because rigorous monitoring is required. This makes glucose analyzes the most tested. [16]

His first sensor failed because the blood components were absorbed on the surface of the electrode which caused the distortion of the signal. Clark then had the idea of using a cellophane from his cigarette pack on his sensor. Only low molecular weight substances, mainly oxygen, could reach the electrode and thus could be measured. The reduction current indicated the oxygen concentration and thus the Clark electrode was created (Figure 4).

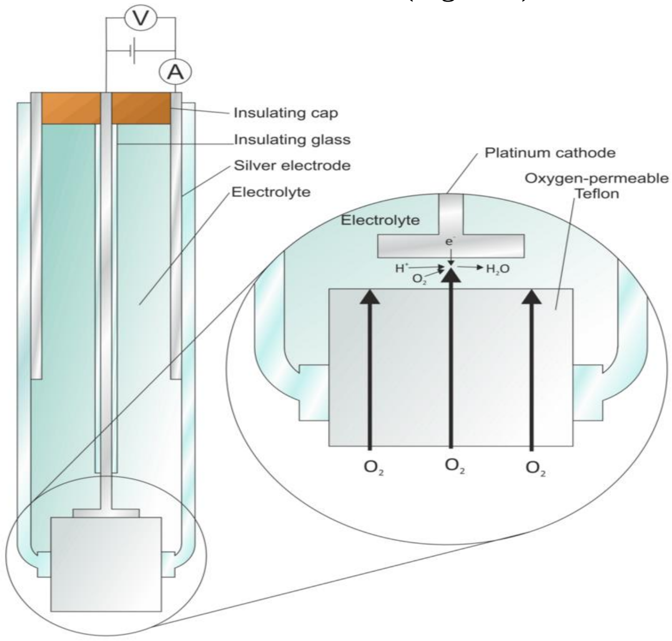


Figure 4. Clark Electrode [21]

Today, instead of that cellophane, teflon is used as a membrane, and this sensor remains a key tool in medicine and in environmental monitoring. To calibrate the sensor, Clark added a glucose oxidase enzyme (GOD) to the solution, and then continued developing it.

Biosensors can be classified according to their biological specificity of the mechanism or, alternatively, to their physico-chemical signal transduction mode. The biological recognition element can be based on a chemical reaction catalysed by an equilibrium reaction with macromolecules that have been isolated, produced or that exist in their original biological environment. In the last case, the balance is generally reached and there is no additional net consumption of the analyte by the immobilized biocomplex agent incorporated in the sensor.

Biosensors may also be classified according to the analyzes or the reactions they monitor by directly monitoring of the analyte concentration or by the reactions that produce or consume such an analyte; alternatively, an indirect monitoring of an inhibitor or activator of the biological recognition element (biochemical receptor) can be obtained [21].

The term "BioMEMS" is used to refer to the science and the technology of micromachining manufactured for biological and medical applications. BioMEMS may or may not include electrical or mechanical functions. BioMEMS applications include biomedical, microfluidic, medical implants, microsurgical instruments and tissue engineering.

2.1.2 MEMS and BioMEMS on the market

The microscopic robots, undersized in order to be able to penetrate into the human body and move freely were designed and made by scientists many years ago for their use in a variety of purposes. Among these we have medical goals, such as cancer treatment, drug administration, and even the cultivation of new cells and tissues, as well as wider goals such as exploring cosmic space or simply improving human lifestyle (smartphones, laptops and tablets, game consoles, sports watches [6], [10]

Other benefits of using MEMS are: the high degree of reliability given by the use of integrated circuit construction technology with proven results, high reproducibility, low cost to a large production. Intelligent structures can help us in a better control of the environment and to increase devices energy efficiency.

An overview of the global market for microelectromechanical systems (MEMS), in the last 6 years can be seen in Figure 5; bioMEMS are presented in Figure 6, among which we find: pressure sensors, silicon microphones , accelerometers, gyroscopes, optical MEMS and image sensors, microfluidic chips, microdispensers for doctor transport, infrared temperature sensors, etc.

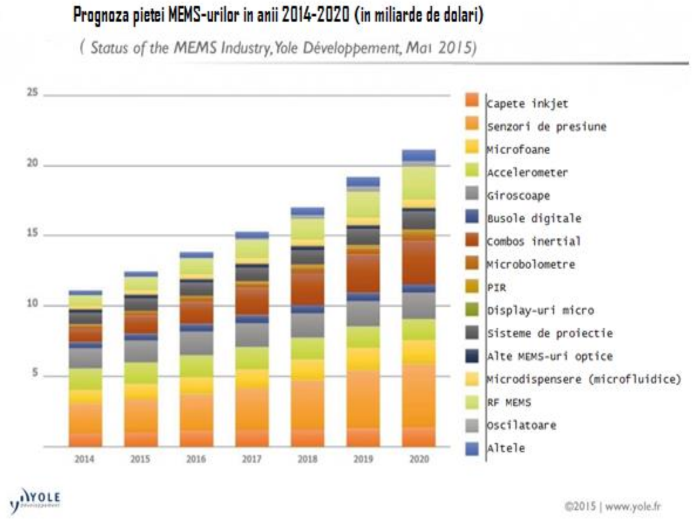


Figure 5. MEMS in 2014-2020 [18]

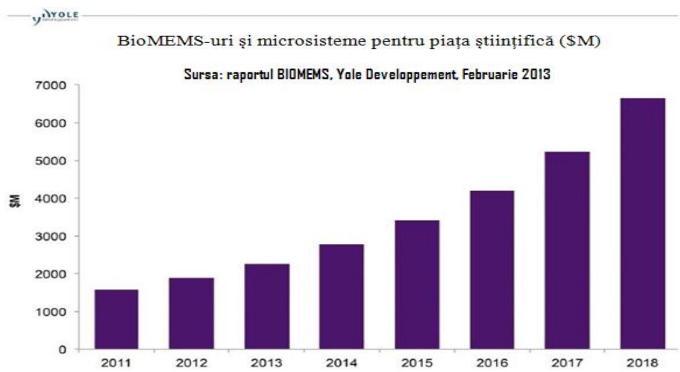


Figure 6. YOLE report of BioMEMS [19]

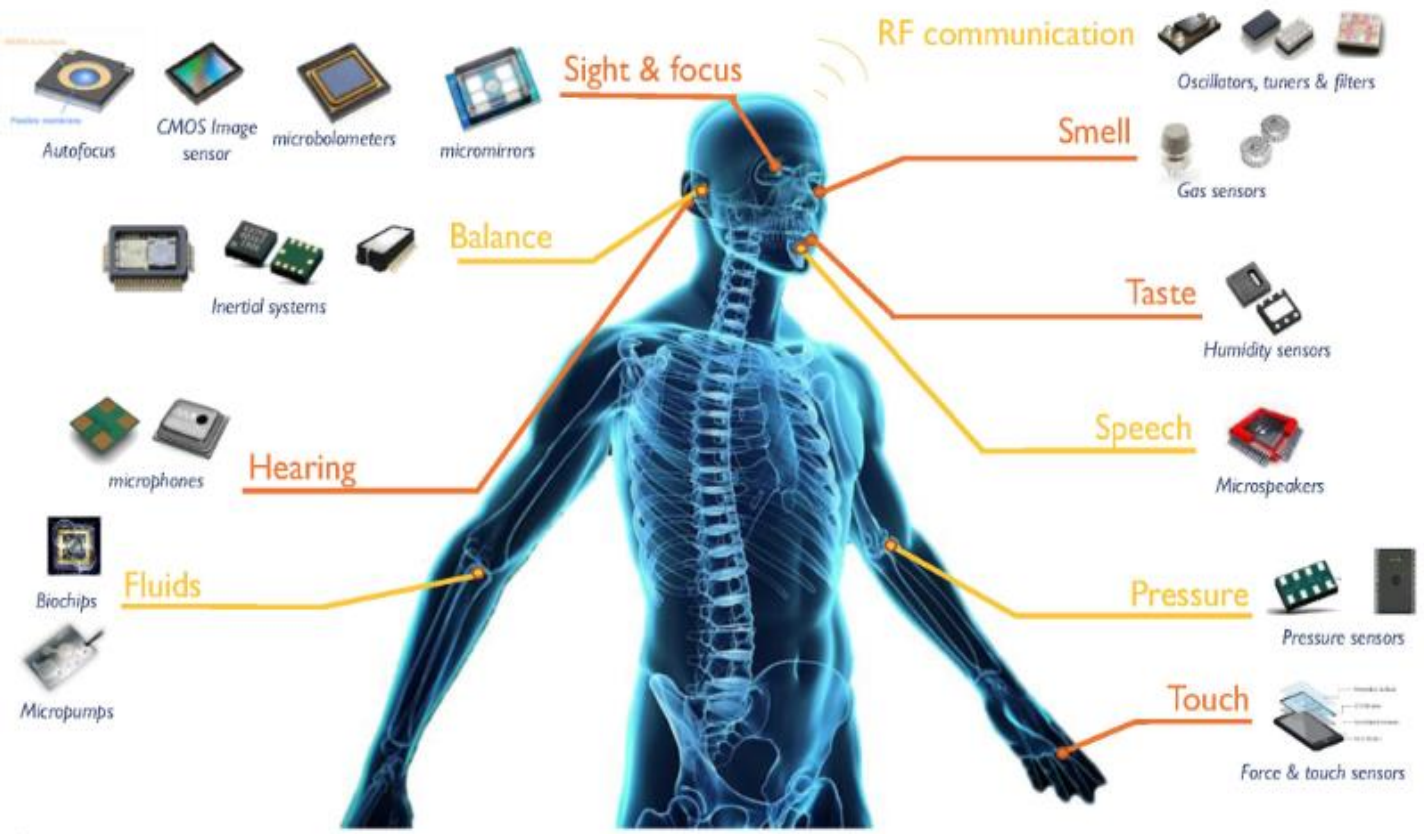


Figure 7. Applications of MEMS [20]

2.2 Microactuators

Actuators are devices that convert an electrical or thermal signal into mechanical work (moving parts) or heat (as thermal energy); can create a force to manipulate other mechanical devices or to perform some useful functions in the environment [10].

Microactuators apply the principles of miniaturization in mechanics, having a wide range of applications: micro-pumps, micro-valves (used in medicine), microgrippers (clamping elements), linear and rotary positioning elements, console type actuators, artificial muscle systems, etc.

Beyond electrostatic, piezoelectric or electromagnetic microactuators, there are increasingly being used the microactuators built with 4 magneto- and electro-strictive materials and shape memory alloys. These microactuators open new possibilities for applications because they are based on completely different operating principles than conventional actuators. They generally use direct drives without mechanical transmission elements.

Among the most known and used examples of actuators we find: Trunk Opening Actuator; 2-wire central locking actuator (for car tank); Actuator for floor heating system [19].

Microsensors and microactuators are classified as "transducers" and are defined as devices that convert energy from one form to another [24], forming the interface between the enviroment and the control element. These two are vital for an artificial system. They measure electrical, mechanical, thermal, biochemical, magnetic parameters, etc. of the tested media.

2.3 Integrated microsystems

The integrated circuit (C.I.) represents the electronic device that can perform a transformation function and signal processing. It is built in a single technological process and put into a hermetically sealed capsule.

For real-time operations, most dynamic electromechanical systems are interfaced with the required electronic circuits, units and subsystems. The basic circuits, units and subsystems are arithmetic units, logic circuits, registers and memory units, analog to digital converter and digital to analog converter, parallel-serial and parallel-parallel conversion units, amplifier, filter, etc. [10].

There are certain qualities of electronic devices developed with integrated circuits:

- high operating reliability; this is due to the automated technological process that reduces the number of connections between discrete devices; Integrated circuits are safer than discrete diagrams in order to reduce mounting errors.
- small weight;
- substantial reduction of the time required for the product development, due to the fact that existing subassemblies and blocks are being used; due to the emergence of integrated circuits with these features, large calculation systems have been achieved.

Achieving integrated circuitry simplifies the organization of production by reducing the number of operations and reducing the number of completion parts. It can be considered that the electronic information equipment is currently only with integrated circuits.

Integrated circuits are classified according to:

a) way of processing the information:

- Analog integrated circuits:

- Processes continuous signals or continuous variations in time or frequency
- performs amplification functions, modulation, demodulation, etc.;
- can be made using discrete components, such as capacitors, inductors, transistors and diodes;

- Digital Integrated Circuits:

- Processes discontinuous signals as value, in form of levels or pulses
- performs code-based and/or memorized logical arithmetic

- Integrated Interface Circulars:

- Process both analog and numerical signals,
- contain analogue - digital and digital - analog converters
- • connect the analog and the digital devices.

b) type of the realization technology:

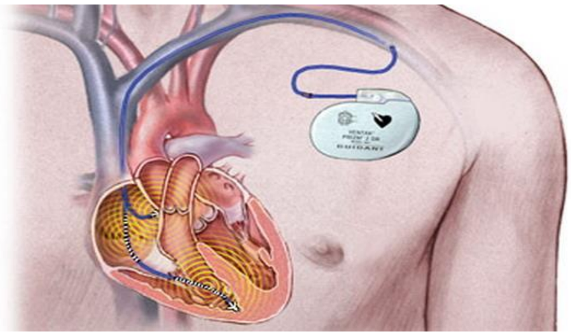
- monolithic integrated circuits - a semiconductor crystal (chip), in the thickness of which all the components of the diagram (diodes, transistors, resistors, etc.) are made.
- hybrid integrated circuits [2], [6]

MEMS present both unique market opportunities and major manufacturing challenges. These MEMS devices often have to be exposed to the environment but they also need to be protected from environmental factors such as mechanical shocks, vibrations, high acceleration, particles, and other physical damage. At small MEMS structures, both internal physical effects (eg, static friction due to the very tight micro-distance) occur as well as external effects such as temperature, humidity and particle contamination that can damage the devices or impair their reliability long term. As with any mechanical devices, corrosion and wear can degrade performance over time. Aging components used in the manufacturing process can ultimately cause failures of these complex devices [14].

3. EXAMPLES OF MEMS DEVICES USED IN MEDICINE

- **MEMS accelerometers used in defibrillators and pacemakers**

- restore a normal heart rate by providing electrical shock to the heart or maintains a rate of heartbeat by transmitting electrical impulses directly to its muscles (Figure 7).



Figue 7. Defribilator[25]

- **Cancer cells detected in real time**

- biosensitivity technologies include portable devices and systems used to identify, monitor and control biological phenomena [22] (Figure 8).

Figure 8. Biosensitive microscope [22]

- **Determining HIV**

- the number of blood CD4 and CD8 T cells can tell the condition of the patient's immune system, whether he is infected with HIV (Figure 9) [9**]**

Figure 9. Bloood testing [9]

- **Contact lenses that measure the level of glucose from tears**

- the device is equipped with a lacrimal fluid slider to measure the amount of glucose so that it can control diabetes (Figure 10) [22].

Figure 10. Contact lenses [22]

- **Minuscule robotic mechanisms**

- by their remote control, they are able to travel through the human body, diagnose diseases and treat them [6] (Figure 11);

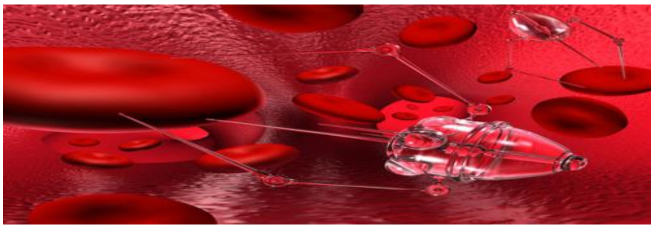


Figure 11. Microrobots [6]

- **Miniaturized classical tools**

- the benefits of microsurgery include less pain, minimal tissue damage, minimal scarring, reduced recovery time, shorter hospital visits, faster time to return to normal activities (Figure 12 a, b)

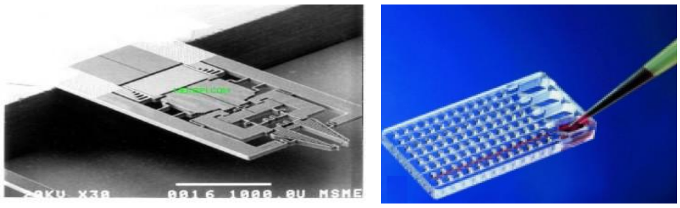


Figure 12. Microsurgery tools a,b [23]

4. ACKNOWLEDGMENTS

The paper is elaborated within the doctoral training regarding the research theme "Processing in the manufacturing processes of the micro-electro-mechanical systems".

5. CONCLUSIONS

Micro-electro-mechanical-systems (MEMS) give microscopic products technology.

They represent a technological product used to create small integrated devices or systems that combine mechanical and electrical components. They are manufactured using integrated circuits

(IC), processing techniques, and their sizes can range from a few micrometers to millimeters. These devices / systems have the ability to feel, control and act on a micro scale and generate macro effects.

Biosensors have the same application areas as all the other types of MEMS, but are most commonly used and developed in the "Medicine" field. Used for food processing; and the detection of bacteria, viruses and biological toxins for biological defense [11].

An increased development of biosensors is noticd in the field regarding the determination of tumor cells.

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