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Micro and Nano Electrical Discharge Machining Techniques in Mems and in Nanotechnology

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ABSTRACT

This paper discusses a technological Potential application of micro-EDM for MEMS in micro nanotechnology. Micro electromechanical systems (MEMS) (also written as micro-electro-mechanical, Micro Electro Mechanical and micro electromechanical systems) is the technology of very small devices; it emerges at the nano-scale into nano electromechanical systems (NEMS) and nanotechnology. MEMS are also referred to as micro machines (in Japan), or micro systems technology – MST (in Europe). Nanotechnology is a rapidly growing field with many and important applications. Technologies associated with this field aim towards the manufacture of improved quality products that are suitable for devices that are lighter, faster, more reliable, efficient and safer and in those respects more economical for sophisticated industrial products that perform better and are more advantageous in many other ways than any other devices manufactured so far. The aim of this paper is to describe some micro and nano processing techniques, present their applications in contemporary industry and make speculations for the future. It is not possible to discuss all the techniques available today within this paper but some of the most applied and the most promising for the future are selected; their main characteristics, capabilities and applications are outlined. Most of the techniques presented are material removal processes. Material removal is achieved by various methods according to the principle the process is based on. In the following paragraphs the processes presented are categorized according to these principles.

Key words
Micro electrical discharge machining, EDM, Micro technology, Nanotechnology.

1. INTRODUCTION

The demands of today's industry lead towards the continuous refinement of manufacturing processes as far as the achieved precision is concerned. Large-scale components such as precision moulds, machine elements, mirrors and lenses require micrometer or sometimes nanometer tolerances and surface finishes. At the same time micro parts are introduced in several applications, whose functioning would otherwise be impossible. The most characteristic example is the integrated circuit (IC) industry, which creates parts that have micrometer dimensions or possess features with nanometer size. Furthermore, micro electromechanical systems (MEMS), which usually contain micro sized mechanical parts, are becoming more. MEMS has 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.

Micro-electromechanical systems (MEMS) are a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimeters. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale.

Micro-EDM is a non-traditional method in which there is a huge demand in the production of microstructures. EDM process is based on the thermoelectric energy between the work piece and an electrode. Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining Process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis. Work material to be machined by EDM has to be electrically conductive.

2. BACKGROUND OF MICRO-EDM TECHNIQUES

The history of EDM Machining Techniques goes as far back as the 1770s when it was discovered by an English Scientist. However, Electrical Discharge Machining was not fully taken advantage of until 1943 when Russian scientists learned how the erosive effects of the technique could be controlled and used for machining purposes. The new concept of manufacturing uses non-conventional energy sources like sound, light, mechanical, chemical, electrical, electrons and ions. With the industrial and technological growth, development of harder and difficult to machine materials, which find wide application in aerospace, nuclear engineering and other industries owing to their high strength to weight ratio, hardness and heat resistance qualities has been witnessed.

3. TYPES OF MICRO AND NANO PROCESSES

Micromachining and nanotechnology can be achieved by means of various methods and techniques. However, in all the cases examined the trend towards smaller dimensions, higher accuracy and production of components that are highly functional is common. The development of new technologies follows mainly two directions: the downscaling of manufacturing processes that have an existing background as conventional ones and are already widely used in industry, and the development of new ones that are suitable only for this kind of manufacturing. The non-lithography based processes include mainly machining operations that use mechanical, thermal, electro thermal or electrochemical energy in order to achieve material removal category conventional and non-conventional machining processes are included, suitably altered to perform in the micro world. Some of the processes examined are micro cutting, micro- Electrical Discharge Machining (micro-EDM), laser processes and electrochemical machining.

Our aim is not to describe all micro and nano processes thoroughly and in detail; for that an adequate number of references to the relevant literature are provided. The aim is rather to describe some of them, depict some of their important characteristics and emphasize the differences that make these processes unique and promising. In the case of lithography-based processes, photolithography is the main subject. NGL are also analyzed and their advantages or disadvantages in comparison to photolithography are pointed out. In the case of non lithography- based processes, a variety of them are described and compared. Furthermore, owing to the fact that they are also realized as macro as well as micro processes, the differences between the two types are elaborated. This analysis points out the difficulties arising from transferring technology between the macro- and micro worlds and leads to the fact that sometimes a feature that is considered as an advantage in one world may be a disadvantage in the other and vice versa. Some important applications are described so that the reader can have an idea about how these technologies are applied in everyday life.

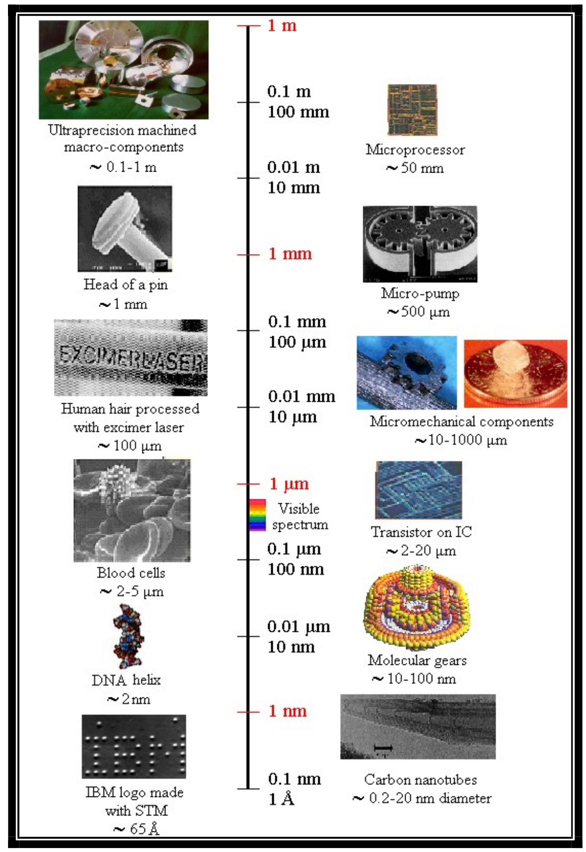

Figure: - 1.1 Size scale and examples of micro- and nano components.

4. TECHNIQUES

4.1 Lithography-based processes

Lithography is a combination of two Greek words, namely *lithos* (stone) and *graphein* (and refers to a kind of art invented in the late 1700s involving the transfer of an original image or pattern carved on a stone onto paper. This kind of art has been the inspiration for a technology, the most widely used form of which is photolithography (from another Greek word meaning light), used in the IC industry for the production of chips.

4.2 Non-Lithography Based Processes

The processes included in this section are conventional and non-conventional machining processes, which are being used in traditional manufacturing as well as in the nano realm. They are at the forefront of industrial integration and their applications have reached a high level of production maturity. Some of them have the prefix "micro" in their names to declare that they are processes following the same principles as the original macroscopic ones, but particularly designed as micro processes.

4.1.1 Mechanical processes

Mechanical processes are probably the most popular among the micro processes in current use. They involve mechanical interaction between a sharp tool and the work piece causing the removal of unwanted material in the form of a chip. Conventional machining operations such as turning, milling, grinding and drilling belong to this subdivision. Advances in the subsystems involved in macroscopic machining such as positioning, automation, numerical control, metrology and tools have made it possible to apply them in micro fabrication.

4.1.2 Electro thermal and thermal processes

In electro thermal and thermal processes thermal energy is provided by a heat source that is used to melt or vaporize the material to be removed. Machining forces are very small, and that permits the use of small and thin tools. The mechanical properties of the work piece do not influence the machining process but thermal properties and in some cases electrical ones are important. In these processes it must be taken into consideration that because the tool is not in contact with the work piece. Furthermore, heat affected zones (HAZ) may appear in the work piece. Heat effects include resolidifying debris on the surface, and metallurgical transformations undergone by the layers just below the surface, which alter the properties of the material as a whole and may cause problems.

Micro-EDM is already widely used for micromachining. The work piece (anode) and the tool (cathode) are submerged in a dielectric fluid and subjected to a high voltage. When the electrodes are separated by a small gap (whose dimensions can be precisely calculated) a pulsed discharge occurs. Sparks are generated and material is removed through local melting and evaporation. Both electrodes are worn away but the tool wear ratio varies depending on the tool material, and can reach values up to 70:1 for carbon electrodes. Because there is no contact between the electrodes, machining forces are negligible and the hardness of the work piece is not critical, making the process eligible for machining conductive, hard and brittle materials. Machining of non-conductive ceramics is possible under certain conditions, but the method is still under development. Machining accuracy and repeatability of the process are good and the structures are burr-free, but the material removal rate is slow. By suitably adjusting process conditions surface roughness's of 0.1 m can be obtained, but the material removal rate is slower than if rougher surfaces are achieved

Micro-ultrasonic machining (micro-USM) is another mechanical micro process having its origins in a traditional macroscopic process. It employs a tool and a mixture of a fluid (water or oil) with abrasive particles. The tool is vibrated at ultrasonic frequency and drives the abrasive to create accurately shaped cavities on the surface of the work piece. The shape and size of the cavities depend on those of the tool. In micro-USM, micro tools and fine abrasives are used, with which ±10 m tolerance can be achieved. Since the tool does not exert any pressure on the work piece the method is suitable for machining hard and brittle materials such as aluminum oxides, silicon and glass.

5. MICRO EDM MACHINE

Compact micro EDM machine with high resolution technology commonly used by the AFM-STM community. We use a combination of micrometric and nano metric positioning actuators in order to achieve large working volume and high accuracy. It consists first in a motorized XY table with an independent motorized Z stage holding the working electrode (all stages are driven by stepper motors with 2.5 µm/step and speed up to 1000 steps/s). A second table driven with XYZ piezo actuators is mounted on the first XY one. We use Melles-Griot piezo actuators, with feedback correction, which provide 10 nm displacements along 30 µm range. The piezo-driven table carries a PTFE tank vat for keeping EDM dielectric liquid (50:50% vol glycerol:deionised water in our case).

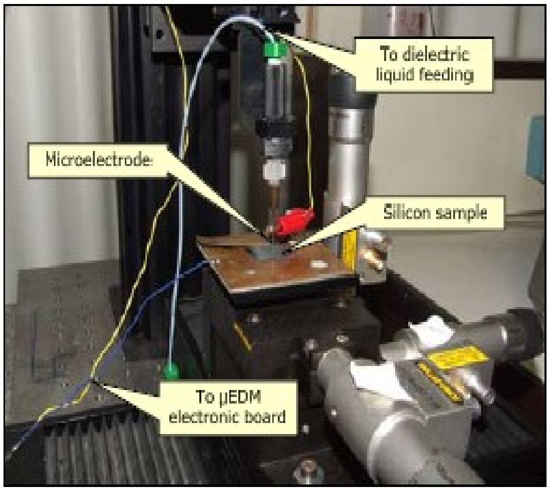

Figure:-1.2 Micro EDM machine with the Pt-Ir microelectrode, XYZ piezoelectric actuators and XY-Z micrometric translation stage (PTFE vat removed).

6. NANOFABRICATION METHODS

This section is dedicated to methods that are used for manipulating matter atom by atom in order to fabricate stable structures at the nanometer scale. This "bottom-up" approach, where instead of subtracting matter, atoms are placed in prescribed positions to form a complicated, functional structure, is somewhat different from the methods described so far. Some scientists have even envisaged the fabrication of nano mechanical components consisting of atoms, like the planetary gear.

7. APPLICATIONS

In this section, applications of micro and nano processes are briefly considered.

- Lithographic processes are already deeply embedded in manufacturing in many fields of science and engineering, and especially in the IC industry.
- The other processes, although little used in the IC field, are preferred for the commercial production of e.g. computer hard disks, ink-jet printer nozzles, mirrors, lenses, compact disk reader heads, photocopier drums, telecommunications devices.
- On the other hand, devices such as MEMS, which are made for very specific purposes, are produced in low volumes and typically use non-IC materials. For such devices, for which low cost is not as important as for e.g. computer chips, other processes may be useful.
- The modern automotive industry extensively incorporates electronic devices into cars. These devices are mainly miniaturized sensors. Pressure sensors, fuel and air flow control systems, gyroscopes, accelerometers and micro actuators are some of the current devices in automotive applications.
- In space applications, the trend towards miniaturization is probably greater than in any other field.
- The internet, mobile telephones, television stations and other applications all require satellites. Companies are trying to make them smaller because they are then easier to put into and maintain in orbit, and Medical applications are legion and very important for the improvement of the quality of life. They include prosthetic implants and surgical tools that are ultra precision finished.

8. CONCLUSION

In this paper the micro- and nano processes used today and considered to have the potential to play a major role in tomorrow's micro fabrication have been presented. Both lithography and non-lithography-based processes have been considered and their main characteristics have been described and compared. Furthermore, some nanofabrication methods have been discussed. Finally, some current and potential uses of these processes have been analyzed to show their importance in today's industry and life. Even though the impact of nanotechnology is already great, expectations for tomorrow are even greater, since it will make communication, transportation, data storage, health treatment and many other technological applications faster, safer and cheaper. The benefits of such advanced products and applications in many technological areas will be significant and the fields to which they will be applied will lead to a new era. International interest is greatly increasing and leads to a concomitantly growing research activity, in the very vanguard of modern science and technology.

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