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THE SYSTEMIC ANALYSIS OF METALS MANUFACTURING USED IN MEMS FABRICATION

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Abstract: The metals take a apart place in the materials range used at MEMSs fabrication, in special of associated materials, while of thin metals films are used in mediums with different capacities to obtain of masks for microsensors and microactuators. From this group the aluminium, titanium, copper, etc. are distinguished. In that case, the manufacturing problem of them in specific MEMSs conditions is tight linked of technological microsystem characteristics, as micro-machine tools, micro-tool, micro-devices and micro-part. This paper has a systemic analyzing of manufacturing process for aluminium, titanium and those alloys.

1. INTRODUCTION

At the construction of Micro/Nano Electro Mechanical Systems (MEMS/NEMS) a multitude materials are used [27, 35]. These are characterized by mechanical, electrical, magnetic and chemical properties [27, 33, 42], such as: Young's modulus-E, density-ρ, Poisson's ratio-v, fracture strength-σ_f, yield strength-σ_Y, fracture toughness-K_{IC}, coefficient of thermal expansion-α, residual stress-σ_R, etc.

The selection of each material is mainly conditioned of those properties by type of application, range and time usage of MEMSs. In addition, can be added and general difficulties of techniques and technological conditions of material processing for MEMS's parts, etc. In this sense, Pratap [29] emphasized 3 basic requirements for used material in MEMS construction: 1st - compatibility with electronics micro-technologies, 2nd - good electrical and mechanical properties, 3rd - intrinsic properties to limit of internal stresses generated by high stresses during of material processing (Fig.1).

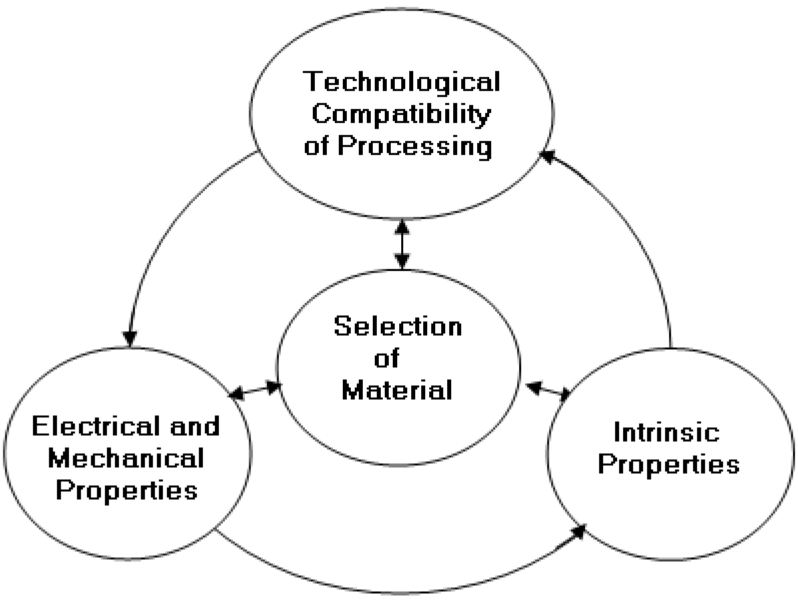

Fig.1. Basic criterions at selection of MEMS materials.

The classification of MEMS materials can be made after more criterions. So, Srikar [4] made of them rating in 4 groups that is similar at metal rating to macro scale: 1st –

metals and alloys, 2nd – glasses and ceramics, 3rd – polymers and elastomers, and 4th – composites. Other classification under 3 functional-constructive criterions is made at Vilnoy [37]: a. – substrate, b. – thin films, and c. – packaging (Fig.2).

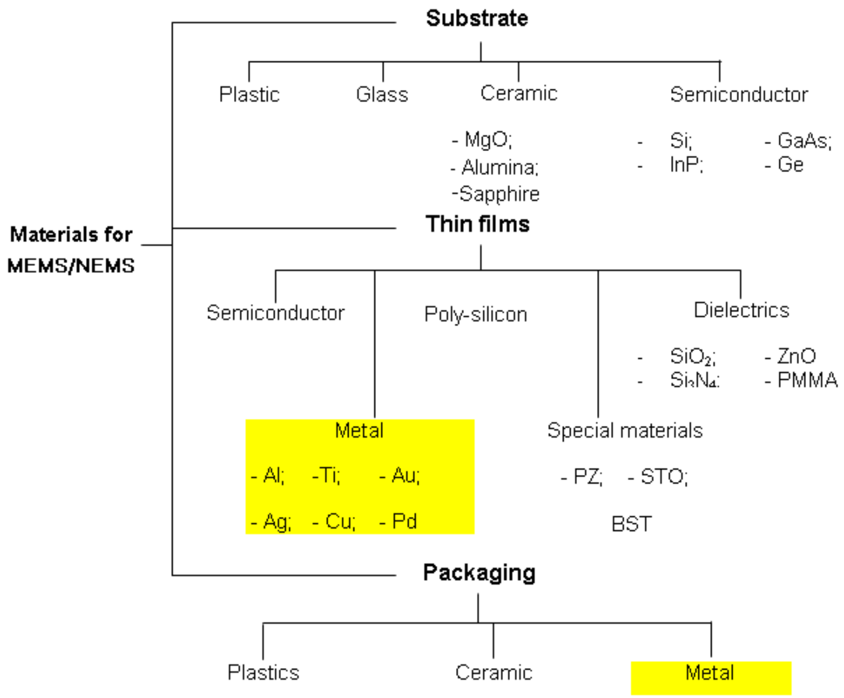

Fig.2. The classification of MEMS/NEMS materials [37].

As a correlation with Fig.2, in the papers [28, 47] is underlined that the metals have a main role from all the materials used at MEMSs construction. These are used in diverse applications, such as fabrication of thin metal films and electrical conductors, and occasionally for structural elements of microsensors and microactuators [12, 34, 40, 41]. The metal alloys are used under form of thin films, at construction of magnetic actuators for micro-devices. Ones widely material used of MEMSs fabrication and in multiple macroscopic applications is titanium alloy-Ti-6Al-4V. In Tables 1-2 are presented some examples about technological behavior of multiple MEMS materials.

Tab.1. Selection conditions of certain metals as plating materials for fabrication of multiple dies of disks [1].

Requirements of Metallic Layer	**Categories of Metal**					
	Al	Ag	Au	Ni	Cu	Cr
Great reflection coefficient	+	+	+	-	+	-
Stability at contact with air	-	+	+	+	-	+
Stability in pool of nickel-plating	-	+	+	+	+	+
Properties of air separation	-	+	-	+	+	+
Selectivity at etching to Ni	+	+	-		+	-
Electrical conductibility	+	+	+	±	+	±

Tab.2. Material applicability of various technological operations [20]

Technological Operations	Material			
	Aluminium	Super alloy	Titanium	Refractories
Electrical discharge machining	Fair	Good	Good	Good
Laser beam machining	Fair	Fair	Fair	Poor
Ultrasonic machining	Poor	Poor	Fair	Good
Electrochemical machining	Fair	Good	Fair	Fair
Abrasive jet machining	Fair	Good	Fair	Good
Electron-beam machining	Fair	Fair	Fair	Good
Chemical machining	Good	Fair	Fair	Poor
Plasma arc machining	Good	Good	Fair	Poor
Machining	Good	Good	Fair	Fair

Metals used at fabrication of MEMS are ductile [31, 34]. The “strain-stress” diagram from Fig.3 is showing the yield elongation area of metal in zero loading condition. This characteristic is important for capacity of manufacturing by plastic deformation for MEMS’s part.

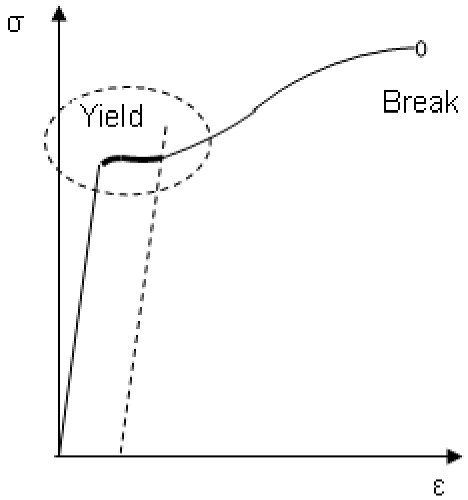

Fig.3. Stress-Strain diagram for a ductile material [35]

Now, two types of metals – aluminium and titanium - are more used in fabrication of MEMSs for variety applications, such as: aeronautics, biomedical, military, etc. [39, 40]. So, after Ding [6], titanium “is an attractive candidate for harsh environment MEMS RF switches”. While, the aluminium is described as exhaustive qualities by Epstein [7], Kissell [18] that 1^{st} – high strength-to-weight ratio, 2^{nd} – high electrical and thermal conductivity, 3^{rd} – ready fabrication, 4^{th} –formability, 6^{th} – corrosion resistance, 6^{th} – reflectivity and 7^{th} – finishability.

Titanium is a transition metals group from “d” block of periodic table, which is a dimorphic allotrope who’s hexagonal α- form change into a body-centered cubic lattice β-form at 882^{o}C [52]. By alloying with multiple elements, as manganese, cobalt, cooper, etc., soluble in certain technological conditions (under or up 882^{o}C), it’s forms diverse type of Ti alloys. These are found to 3 allotropic forms: alpha, alpha-beta, and beta alloys (fig.4).

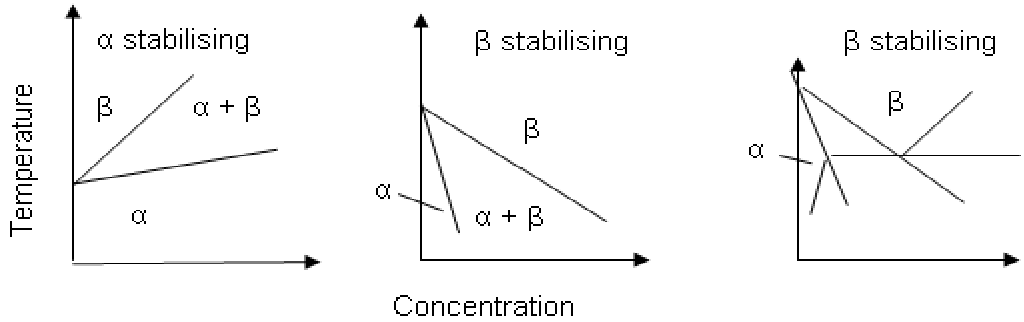

Fig.4. Phase diagrams of Ti alloys [51].

Ti and its alloys present a "unique combination of physical and mechanical properties, and corrosion resistance" versus other materials [51], which conferring Ti important applications in aerospace, biomedical and energy fields [3, 43, 50]. Ti and its alloys have a multiple characteristics than can be classification in following groups [19, 27, 43, 44, 48-50]:

a) *Primary characteristics*: expressed by high ratio between mechanical strength and density; higher corrosion resistance and erosion; excellent properties at elevate temperatures, until 600^{o}C.
b) *Functional-constructive properties*: good mechanical strength; low linear dilatation coefficient; high intrinsic strength at shock; essentially nonmagnetic; high melt point; high ballistic resistance to density ratio; non-toxic; non-allergic and fully biocompatibility; excellent cryogenic properties.
c) *Technological properties*.

2. MACHINABILITY CONDITIONS FOR ALUMINIUM, TITANIUM AND THEIR ALLOYS

It's well-known that the machinability of ferrous or nonferrous material is differently exhibited, and is influencing of 4 factors [26, 28, 53]:

- Nature of material manufacturing;
- Material of tools;
- Machining conditions, which is synthetic expresses by chip form;
- Parameters of machining process.

In this condition, the cutting of metals in fabrication of MEMS/NEMS, with priority from Al, Ti and their alloys, have specific and different aspects versus macrosystem level where the problems are clearly (Tab.3).

Tab.3. Machining evaluation of Al alloys by the forming mode of detachable chips point of view [28]

Forming Mode of Detachable Chips	Type of Production		
	Individual and series production	Production in flux and in great series	Automated lines
Optimal	Spiraled with length of 50-150 mm	Spiraled with length of 30-80 mm	Spiraled with length of 30-80 mm
Good	Continue spiraled	Strong crashed in ring or semi-ring form	Strong crashed in ring or semi-ring form
Fair	Strong crashed in ring or semi-ring form	Continue spiraled	Low crashed
Poor	Low crashed, low and tangled ribbon	-	Continue spiraled, straight and tangled ribbon

About the machining of Ti, some aspects are presented in papers [2, 8, 45, 46].

For fabrication of MEMS/NEMS are required certain typical proceedings of micro production (size from 1/1000 to 1/10000 from structural traditional sizes) that involve using of diverse and specifically micro-technologies [10, 11, 28, 35], micro and nano processing technologies, etc. The MEMS/NEMS fabrications can be classified by Davies [4] in 3 main categories:

1. *Microsystem Technologies* (MST): included specialized technologies in MEMSs and MEOMSs fabrication, which are Bulk Micromachining (Wet Etch and Dry Etch), Surface Micromachining, Soft Lithography Processes, LIGA Process. The selection conditions of these technologies are presented in papers [1, 15, 21, 30, 32].
2. *Micro-engineering Technologies* (MET): are used for fabrication of mechanical components, micro-molds and microstructured surfaces, etc.
3. *Energy Assisted Processes,* such as laser micromachining.

In this case, the small size of parts can generated the "size effects" [14, 24] with serious aspects about mechanical machining of these micro-parts, in special at nano-machining.

Some these difficult aspects about micro and nano-machining have presented by Higo [14], Liu [23], etc., which are linked by the followings:

a) Handling and fixing methods,
b) Accuracy of dimensions (nano-meter accuracy required),
c) Accuracy of measurement method,
d) Surface effect (high surface/volume ratio).

From this reason a new approach of these categories of factors is required than means a systemic analysis with technological microsystem μ(MFTW), with M-micro-machine tools, F-micro-fixture, T-micro-cutting tool, W-micro-workpiece [16, 17, 36].

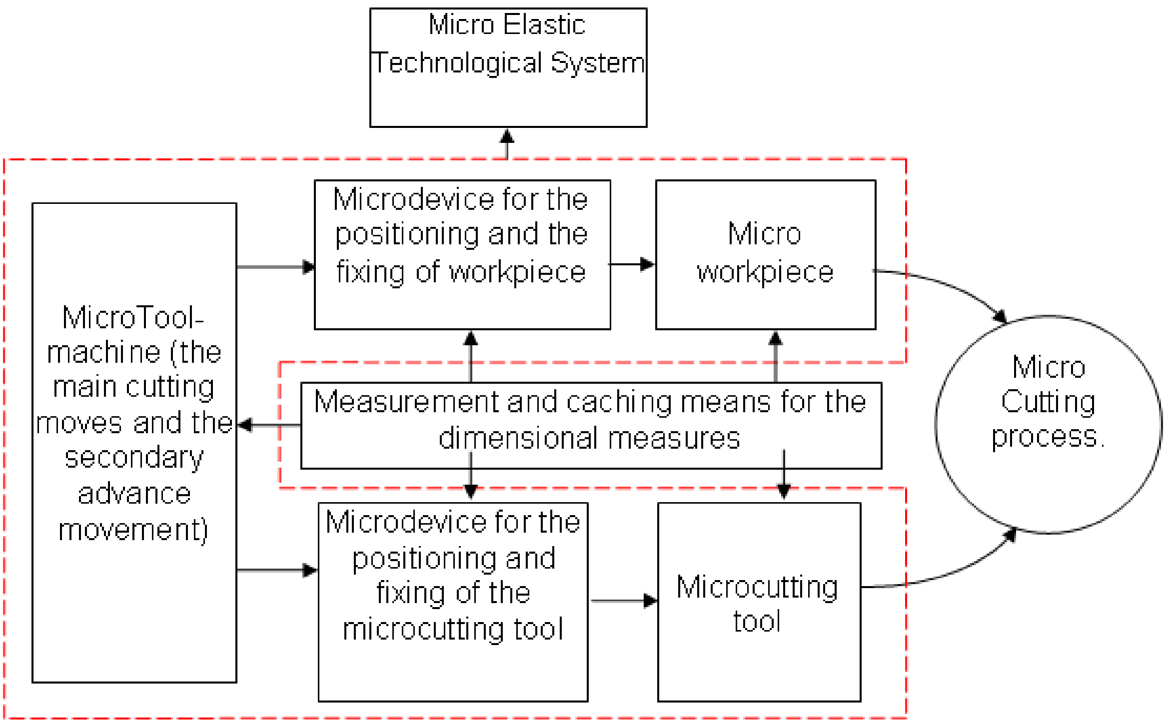

Fig.5. The microtechnological cutting system

This microsystem presented in a structural form in Fig.5, is functional if is respected some technological conditions of process development for micro/nano machining of cutting materials, both ductile and brittle. Taniguchi [35], Davies [4], Lawson [22], Hansen [13] have a systemic presentation of these cutting conditions, expressed by: broken of ductile and brittle materials, specific stresses of materials nano-cutting, cutting geometry for the model of micro/nano cutting used, etc.

Like this are studied models so much the removing conditions of layer material with nano sizes [5, 8], for achievement of gloss surfaces for smooth materials and nonferrous, such as alloys of aluminium, copper, titanium, etc.

In these conditions, the problem of metals cutting, and in particular of aluminum and titanium with their alloys, used in fabrication of MEMSs/NEMSs get a priority for authors by two base requirements:

1. The analysis and dimensioning of technological microsystem μ(MFTW),
2. The study of micro/nano cutting process.

3. CONCLUSIONS

The problematic usage of materials and punctual of metals for construction of MEMSs/NEMSs is well-known and large presentation in specialty papers. A particular case represents the presentation of using for aluminum, titanium and their alloys. Knowledge that are situations when these materials are used in construction of some component parts of MEMSs/NEMSs (by some micro/nano cutting process) is supposed to analysis of technological microsystem μ(MFTW) allowing a concrete conditions of machining for aluminium, titanium and their alloys. It's remarked that in this situation the analysis of microsystem of cutting process must to be analyzed only at micro/nano metric level. As the principal, at this level, the mechanism of removing the chip presents specific aspects, which are mentioned in specialty papers, but fewer references about in range of titanium and its alloys.

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