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Advancement in Research of Smart Metals and Materials Used For Fabrication of "MEMS" Components-Review

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Abstract: ***Even, numerous polymers and composites of materials developed so far, the adopting them in MEMS components is still challenging .The mechanical properties, electrical properties of those materials varies independently. In addition to, the components used in MEMS have micro level dimensions and different specifications. Tedious work and concentration is need for Choosing of suitable metals and materials for specific application while fabricating MEMS Components. In this survey paper ,advancement in research for finding the metals and materials used for fabrication MEMS parts and components, metal micro films fabrication and metal conductors, structural parts of micro sensors and micro actuators magnetic actuators for micro-devices, are try to explore to researchers . Various research papers related to MEMS material were collected from the literature. The name of metal and materials are mentioned and described briefly in an order. The MEMS fabrication methods are not discussed.***

Index Terms: MEMS, Matels, materials, alloys, fabrication.

I. INTRODUCTION

MEMS fabrication is a modern world privileged technique, because of its vast application starting from bio medical to space application invariably. For that, different deposition methods, micro machining, bulk machining, etching methods are recommended so for fabricating components of MEMS devices. While machining, as the film thickness is in micron, the metals and materials should not withstand the machining or operating conditions. In addition, supporting metal or materials are required to support the actual metal which is undergone machining operations. So a suitable Metals and materials selection is a most important for MEMS devices.

II. REVIEW

i) Titanium nitride

In the year 1994 A.Peter Jardine John et.al.published their article. They analyzed that TiNi deposition for thin film and cycling speed for micro actuators. They found some results in memory of TiNi coatings [1].

ii) Silicon Carbide

In the year 1998, N Rajana et.al. published their research article on erosion resistance of silicon micro machined atomizers by compatible very thin film hard coatings, tested on SiC and other materials , silicon nitride, silicon dioxide, and carbon equal to diamond. The coating of Single-crystal SiC obtained the best result[2].

iii) Lead Zirconate Titanate

In 1999 D.F Bahra et.al published a research papers in which they analyzed PZT thin films deformations. They considered the hardness of the MEMS films with a bulk PZT ceramic and concluded that the hardness of MEMS films 5 and 8GPa lesser than PZT. The area of grain boundary developed in the films, posses 100 nano meter of sizes grains, help to deform plasticity[4].

iv) Lithium Manganese Oxide

In 2001 D. Singh et.al.published a research work that they are tried to integrate a sensor chip, an actuator, power source and power storage. They found a high durable thin film for power source. The $LiMn_2O_4$ thin films are good choice for power source in MEMS [5].

v) Aluminum Nitride, Wurtzite, Gallium Nitride

In the year 2002, Henry Baltes et.al. are tried in complementary metal oxide semiconductor technology. They proposed the technology for fabrication of integrated circuit using SiC and Aluminum nitride, wurtzite, gallium nitride. Lead zirconate titanate**,** Zinc oxide are also tried for comparison purpose[17]. In 2003, G. Jeffrey snyder et.al. Published their research paper. They made an attempt an cheapest techniques to manufacture MEMS with various kinds of metals[7].

vi) Diamond

In 2004, Orlando Auciello et.al tried to manufacture of diamond films. The authors described to use of micro wave plasma. The argon is the media for plasma. By using above they produce a lamina of ultrananocrystalline diamond (UNCD). They lamina have good mechanical properties and morphological properties. They found that they are highly reliable for MEMS[8].

vii) Gold

In 2005, Mohsen Shahinpoor et.al. proposed a–metal composites called as ionic polymers. They may be used for MEMS robots actuators and muscular contraction in medical application. The mini-pumps were fabricated by them with flexible IPMC diaphragms actuating with rectangular and circular chamber. In which the circular/rectangular flexible membrane were fit in between two gold-plated ring .The ring made into either any one shape and then gold plated[9].

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viii) Platinum/Ruthenium

In 2006, Shi-Chune Yao et.al tried platinum/ruthenium materials in the fuelcell applied in MEMS. In fuel cell, they select the Pt/Ru (platinum/ruthenium) metals as anode (electrodes)[10].

ix) 3C-SiC and Nickel Chromide

In the year 2007, Michele Pozzi et.al published an article in Journal Of Physics D . They analysed lamina of 3C-SiC (at 600 ◦C). They are tested the properties of MEMS materials at Recrystalisation Temperature and 600◦C. The contactors used were made up of NiCr. They are deposited along on the edges of the die. This arrangement help the SiC devices to use the current field exist between substrate(Si) and the beam(SiC) to exhibit the electrostatic action[11].

x) Aluminum Nitride

In 2008, R. Elfrink, et.al, published an article about piezoelectric components made-up of Aluminum Nitride in Proceedings of Power MEMS + microEMS. Japan. They are dealt producing power from components. They constructed a piezoelectric capacitor on top of the beam. One electrode is platinum. The other is AlN lamina and an aluminum. The acceleration is set to 2g .The resonance vibration is 571 Hz. Output power of 60 W has been obtained. This is as much equivalent to PZT components power. They did Modeling and validation of Au perforated lamina air damping and silicon lamina MEMS [14].

xi) Gold (AU)and Silicon

In 2009.Giorgio De Pasquale et.at. studied the Dynamic behavior of oscillating perforated plates due to effect of squeeze film damping applied MEMS applications. Sample plates of gold(AU)and silicon were created plate and then holed on it. The damping characters were studied on vibrating sample plates, because of electrostatic force. The fluid flow characters of wind around the vibrating member were also found out[15].

xii) Aluminum (Al-1050)

In 2010,Xiao Guang Qiao et .al., The researchers considered less than 10µm sized thermal conducting components in this work. The plates are fabricated using embossing method. Only very few researchers used so far the embossing methods at micrometer scale on aluminum (Al-1050). Here one of most available pure aluminum with composition Al-0.18 Fe-0.12 Si (in wt. %) with lowest impurities is used. An extruded rod of Al-1050 was (4 m length and 9.53 mm diameter) made as specimen. For that, the microstructure, and grain characterization, misorientation distribution of subgrain boundary are obtained using ESBD (The Electron Backscattered Diffraction) for UFG aluminium (Al-1050). Next, using 9510 Instron Testing Machine, the cold embossing process is done at ambient Temperature(300°C).Using the same machine hot embossing is also carried out .Cold embossing products are so smooth than hot embossing products. Finally The micro silicon mould pattern is fully transferred to the foil surface[16].

xiii) Titanium alloy

In 2010 Dzung Viet Dao et.al., selected and produced, SiNWs direct writing by electron beam (EB) and etching[17]. In 2011, Adrian P. Pop, et.al,submitted their manuscript to Fascicle of Management and Technological Engineering. In this article they analysed different metals and materials suitable for technical machining and fabrication methods applied in micro sensors and actuators. The aluminum, titanium and those alloys are ductile, and are mostly recommended for fabrication of MEMS. In stress-strain diagram, the yield area for the ductile materials should be large enough. This property is very need and useful for plastic deformed MEMS's parts and its alloys those have corrosion resistance, multiple characteristics. Ti and its alloys can be classified as Primary *characteristics*: the primary characteristics are a) high strength to density ratio; good resistance to corrosion, high erosion resistance; best properties at high temperatures, (until 600°C). *Functional-constructive properties*: (mechanical strength; shock strength; inert to magnet; melt at high; high ballistic resistance to density ratio; not harm to human.-; biocompaction; best cryogenic characters.) *Technological properties*. Titanium alloy-Ti-6Al-4V used of manufacturing of components of MEMS by fabrication[18].

xiv) Gold

In 2012, A G P Kottapalli et.al. researched on the pressure sensor which is applicable and suitable for undersea and depth of rivers . They considered a liquid crystal. They are flexible crystals. The aim of investigation of researchers is replacing silicon with suitable Liquid Crystal (LCP) backing for the velocity and distance of a non-oscillatory stimulus. In it, underwater application of MEMS sensor is tried to fabricate. Initially the flexible membrane is fabricated by LCP. In each membrane, ten sensors are arranged in matrix form. Then the Au piezo resistors are fit on the LCP flexible membrane. Then the piezoresistors are connected to Wheatstone bride circuit. The pressure difference between the inside sensor and water medium is transduced, as the change in resistance occured in piezo resistor. The membrane madeup of LCP is high sensitive which is to be 19%, than Si membrane. An 600 Ω Au resistor is coated along the membrane circumference. It is in the serpentine pattern[19].

xv) Si Ox, and Aluminum

In 2013, Fabio Alves et.al. reported a metamaterial structure of THz high sensitivity detectors design, fabrication, and characterization in detail. Finite Element simulations were also performed for Al/SiO2/Al structures. They chose aluminum and SiOx as Meta materials. Since SiOx and Al are good electro-optical and also are good absorbers. Even though the dimension of metal thick is lower to 50% of the dielectric thick, the Al/SiO2 maintained the best sensitivity. As usual, the sensors were manufactured using micromachining fabrication technology only. Then by using e-beam evaporation technique aluminum (Al) film with 100 nm thick was fabricated on 300 µm thick silicon (Si) substrate by deposition. Then, the ground plane absorber is created layer of Al by patterned method and subsequently undergone wet etching. After that, using plasma, a layer of 1.1 µm high SiOx and another one 100 nm thick Al film was created sequentially by the technique of chemical vapour deposition (PECVD) at 300 °C. The second Al layer was then patterned and plasma etched to define the absorber metamaterial squares. Then a 170 nm thick Al layer was deposited, then patterned and finally lifted off to form the bi-material legs. The sensor structure was then created by reactive ion etching of the SiOx layer.

Then, for defining the absorber metamaterial squares, lamina of Al was then patterned and by etching process of plasma. Then for lifting the bi-material legs, a 170 nm dimension lamina of Al was deposited, patterned and lifted. Next, the layer of SiOx is formed by reactive ion etching, which used to manufacture a sensor structure.

The detectors are provided with a metamaterial sensing element with shape of square at the middle. It is connected to symmetrically locate rectangular bi-material legs pairs by conductors. The complete arrangement is made communicated with folded substrate SiOx anchors and is then thermally isolated. The dimensions of the Al ground plane and squares is 100 nm, biomaterial legs of lamina 170 nm of Al is on the top side. Uniformly everywhere the thick of the structural SiOx 1.1 μm is maintained.

Initially a lamina of 100 nm aluminum (Al) was deposited on 300 μm width substrate(silicon Si) by method of e-beam evaporation. Then patterned and wet etching is done. Then using Plasma Enhanced Chemical Vapor Deposition (PECVD) method a 1.1 μm SiOx thick layer was manufacture by depositing at 300 °C, followed by another 100 nm thick Al film. Again the second lamina of Al layer is defined as like earlier step. Again patterning and lifted off from the bi-material legs are done upto 170 nm dimension layer.

The sensor structure was then got into shape by reactive ion etching of the SiOx layer. At Last, using the Bosch etch process,the structures were released through backside trenching[20].

xvi) Germanium alloy

In 2015 S.Maflin Shabya et.al.presented a research paper on nanowired Piezoresistive sensor made up of Ge. It is a pressure sensor.

The authors explained the nano wired germanium alloy made pressure sensor detail in their presentation. It is belongs to double polysilicon germanium nanowires piezoresistive sensor type. It has a pressure sensor diaphragm with a diameter of 1000nm and 20nm thickness. RIE (Reactive Ion Etching) was used to manufacture the parts. Finite element analysis (FEA) is done to optimize output of sensor. The 10nm wire is placed at middle of edges of diaphragm. In case of double wire two wires are used in circular diaphragm. They have high sensible property and compact[21].

xvii) Aluminum -zinc- manganese-alloy

In 2016 Yoshihiko Uematsu et.al., published the Effect of Grain Size on Fatigue Behavior of AZ61 Mg Alloys Fabricated by MDFing. The material used is AZ61 Mg alloy, whose alloy compositions are (mass. %) ; Aluminium(5.9), Zinc(0.66), Manganese(0.3),Copper(0.002)Silica(0.009), Ferrous(0.002),Nickel(0.002),Magnesium(balance).Magnesium (Mg) alloy (AZ61) was formed by forging method in a die, by multi-direction (MDFed) under reducing temperature conditions. It is observed that the average grain size reduced with increasing MDFing pass number. The grain size of specimen is reduced from 21.6 micrometer to 0.3 micrometer for as-annealed specimen gradually by MDFing could be attained for 8 passes. Also Hardness and tensile strength is getting increased first pass to eighth pass. In the mechanical properties such as hardness and tensile strength the Hall-Petch relationship was held. Subsequently, tension- tension axial loading fatigue tests were conducted for as-annealed specimen. Likewise, cumulatively, passes the Fatigue strengths were increased by MDFing. After third pass it is almost become saturated. The Hall-Petch relationship is observed that breaking-up of fatigue limit proportionate intiation of GBS results with, crack initiation and propagation along grain boundaries[22].

xix) Silicon-Germanium, amorphous Silicon, &Copper

In 2017. M. Linares Aranda,et.al presented their manuscript on MEMS fabrication by generic monolithic integrated process. Usually in the fabrication process the sensors and actuators separately prepared. They are integrated finally. Now they proposed monolithic integrated fabrication process is modelled using an intra-CMOS method, and a CMOS module (to fabricate the electronic devices) with a 3 μm high as least feature. The microstructures module is made up to three polysilicon layers, and aluminum as electrical interconnecting material. From simulation results, using the SILVACO® suite (Athena and Atlas frameworks), it is noted that there is no considerable degradation on the Performance of CMOS devices; The electrode material aluminium is deposited with 1000 Å film and undergo lithography process. Polysilicon and aluminum were the base materials of the trial specimen.Nevertheless, another materials with Young modulus near the range of the mentioned materials, like silicon-germanium, amorphous silicon, even copper can be selected to fabricate the mechanical structures, and the same design will be enough to characterize the residual stress in the films[23].

xx) Nickel-Molybdenum-Tungsten alloy

In 2018, Gi-Dong Sim et.al., They did a wonderful job finding a alloy suitable for sputtering process.The researchers tried an unique alloy for MEMS applications in such a manner that should have density equivalent to diamond, highly electricity conducting property and thermal conductivity . The alloy posess high strength, and can withstand changes in dimension. Ni-Mo-W (Ni83.6Mo14W2.4) alloys possess a remarkably lower Coefficient of thermal expansion (CTE) than pure Ni metal.

They proposed an alloy film Nickel-Molybdenum-Tungsten deposited by direct current (DC) magnetron sputter and followed by necessary heat treatment i.e annealed at different temperature range. The films have 3 GPa tensile strengths, with very low ductility. Mo-rich precipitates grain growth and nucleation are developed by different heat treatment process treated at various stages. Sputter deposition intermittent annealing is strongly recommended by them in their work [24].

III. RESULT AND DISCUSSION

In this review paper, few matels and some materials are found to use fabricate MEMS parts. They are TiNi, SiC, Silicon nitride, Silicon dioxide, Carbon equal to diamond, ultrananocrystalline Diamond, Lead zirconate titanate PZT, Aluminum nitride, wurtzite, gallium nitride, Gold-plated ring, Platinum/ruthenium, NiCr, Al-1050, SiNW, Titanium, Titanium alloy-Ti-6Al-4V, Liquid Crystal (LCP), SiOx, Ge, AZ61 Mg alloy, Silicon-germanium, Amorphous silicon, Copper, Polysilicon. Among them Ni-Mo-W has most suited for MEMS fabrication.

IV. CONCLUSION

Nearly about 20 different kinds of fabrication are considered for this review work. This review work of MEMS metals and materials will help the researchers to get idea while selecting the metals and materials and which are mostly used in MEMS and to intend the future MEMS materials.

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