Fabrication Techniques for a Micro Device: A Review

G Mohanty[1,*]

[1]*Department of Physics, School of Computer Science and Engineering, Lovely Professional University, Punjab, India*

Abstract

The start of micro-fabrication technology in the integrated circuit (IC) industry is the new revolution of the latter part of the 20th century. Micro-fabrication technology currently plays a significant role in many engineering, mechanical, chemical and biomedical applications, and there are number of ways to fabricate the required microstructure in the micro meter scale. So the micro level fabrication and its integration is a challenging task for all scientific communities. In this review, a few basic micro-fabrication techniques for the development of a micro device are discussed briefly.

Keywords: *Micro-fabrication, MEMS, Cleaning process, Pattern transfer, Film deposition*

1. Introduction

In order to develop a micro scale device for potential applications, a basic knowledge of the standard micro-fabrication processes is a must. Most of the time it is necessary to deposit one layer over another layer in micro/ nano meter scale which is a challenging task for everyone. Thus the study on micro fabrication techniques is very much necessary to achieve the goal. The micro-electro-mechanical-system (MEMS) is a new technology which was first initiated in the 1960s, but it was not commercialized until the 1980s [1]. MEMS technology is basically describes fabrication of device structure in small scales using different process on Silicon (Si) and other wafers such as glass, polymer, quartz or even on metals. The MEMS technology offered unique advantages i.e. miniaturization of existing device and direct integration with electronics. The miniaturization reduces material consumption which allows batch fabrication and also cost effective and low power consumption [1], [2]. Also, it is more reliable due to direct integration with electronics on the same chip or in the same package. This new technology is an opening for all domains such as physics, electronics, mechanical, automobiles, and biomedical Engineering [3]. This technology was first used to fabricate automotive airbag system for the detection of a crash in 1982 [4]. The functionality of this MEMS technology has a wide range of applications such as microphone, microsensor, accelerometers, pressure sensor, DMD chip, inertial sensor, micro motor, gears, valves, gyroscopes, and many mores[5]-[10]. Also. This technology is also very helpful for the whole health care industry to fabricate various biomedical devices such as BioMEMS, microfluidics, Lab-on-chip, biosensor [11[-[13]. The MEMS markets are continuously growing for the new innovations (shown in Figure 1). Figure 2 shows the top manufacturers of MEMS in the worldwide [14].

Thus, this MEMS technology allows to realize the things in smaller dimension which is benefits for all human beings in the globe. In this review, the basics microelectronics unit processes has been discussed briefly.

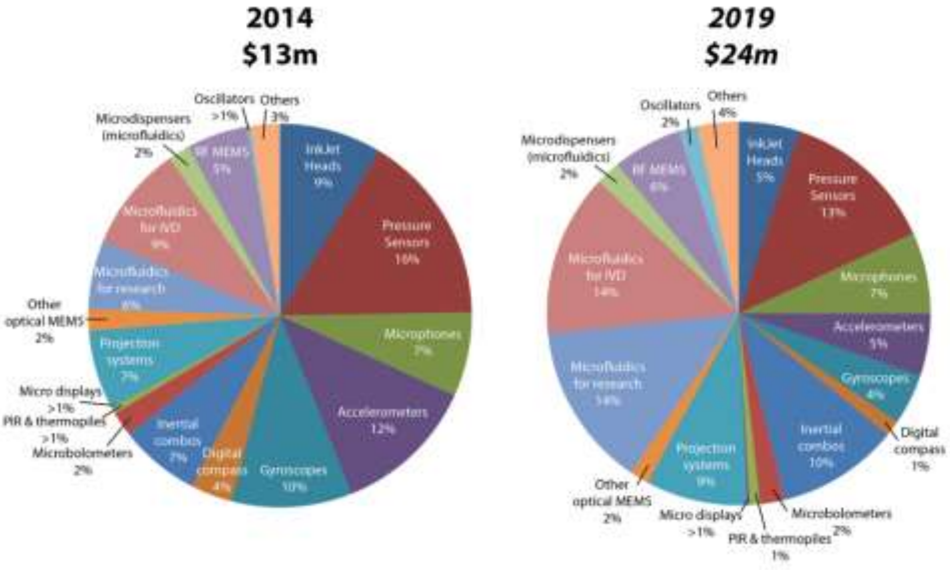

Figure 1. Growing strategy of MEMS market (Source: Yole Developpement)

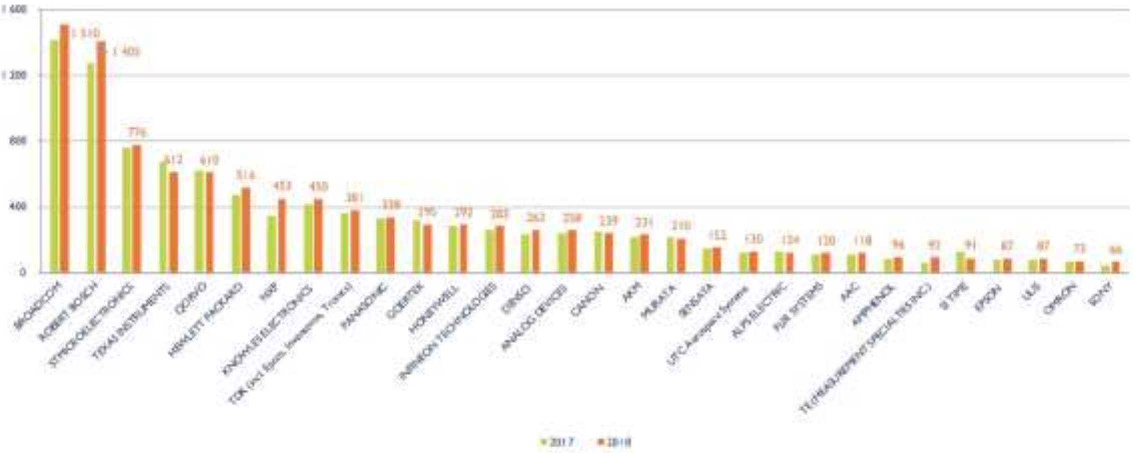

Figure 2. World’s Top MEMS manufacturers in US$ Million (Source: Yole Developpement)

2. Microelectronics unit process

In micro-fabrication industry, a number of individual process steps are used in the manufacture of even simple microelectronic devices. However, the fabrication sequence uses many of the same unit processes numerous times. The microscale fabrication can mainly be classified into three category such as material deposition process, material patterning process and material removal process. These unit processes are very common for the fabrication of micro devices which are discussed below [16], [17].

2.1 Cleaning process

In the fabrication industry, one of the most important task is the substrates/ wafers surface should be contamination free before processing. The substrates may be Silicon (Si), glass, semiconductor or any other types of materials. Most cases, peoples are conducting all processes on the Si- substrate (N-type / P-type). So this substrate should be cleaned before handling. Generally, silicon substrate is contaminated, when it comes in contact with air, which holds large number of contaminants such as organic particles. To remove such contaminants from the Si- substrates the following cleaning steps can be followed. *Degreasing*: Prepare three baths with trichloroethylene (TCE), acetone and methanol at boiling temperature (550-600) respectively for 10 minutes each. After each bath is complete, rinse in DI water and blow dry the Si-substrate with N_2. It is required to remove oils and organic residues from wafer surface. *Piranha bath*: Prepare bath with piranha solution (i.e. 1:3 ratio of H_2O_2 and H_2SO_4) for 10 minutes and rinse in DI water and dry with N_2 blow. It is required to remove any residual organic and metal contaminants from wafers. *HF dip*: Prepare bath with the solution of 1: 3 ratio of

DI water and hydrogen fluoride (HF) for 1-2 minutes. Then rinse in DI water and blow dry the Si-substrate with N_2. This HF dip is required to remove thin oxide films.

2.2 Pattern transferring techniques

In this process, the desired pattern can be transferred onto the substrate surface. The creation of pattern and transfer it to the substrate is known as photolithography [18]. The procedure for this process is described as follows with schematic diagram shown in Figure 3. In Figure 3, (a) Substrate with SiO_2 layer, (b) Addition of Photoresist (PR) layer, (c) Mask on the top of the configuration, (d) exposure of UV light, (e) After exposed to UV light (-ve PR), (f) Opening portion of SiO_2 is etched by BHF, (g) Final phase of lithography, (h) After exposed to UV light (+ve PR), (i) Opening portion of SiO_2 is etched by BHF, (j) Final phase of lithography. This technique can be used frequently to pattern a wide varieties of feature on the required surfaces. This process can be repeated for the generation of a complex layered structures by the use of multiple photo mask and can be aligned each newly deposited or etched layer to previously created features.

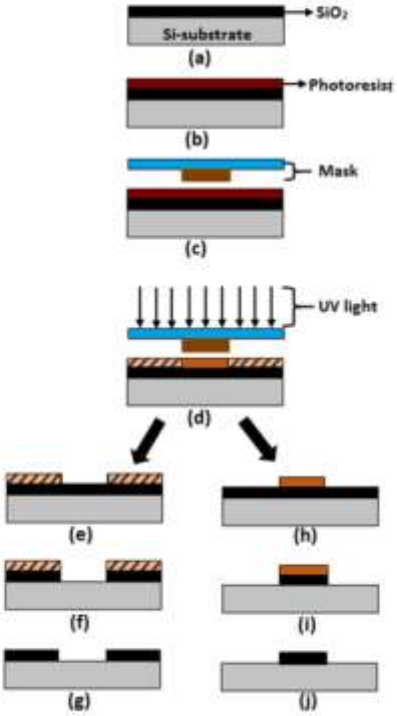

Figure 3. Schematic diagram for Photolithography process

Thermal oxidation process: Oxide films having thickness few micro-meter is easily grown through this process [19]. The oxidation occurs in a diffusion furnace which typically consists of heating units, temperature measurement and control unit and process chamber where the wafers undergo oxidation. A schematic diagram for oxidation process is shown in Figure 4 Thermal oxidation is classified as dry oxidation and wet oxidation. Mathematically, it can be expressed as follows [19]:

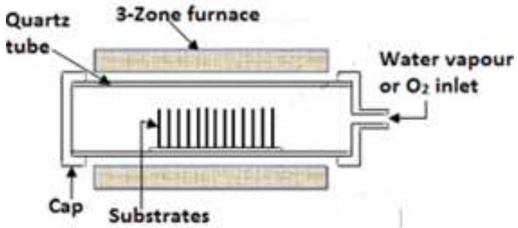

Figure 4. Schematic diagram for oxidation furnace

Spin coating process: In spin coating the substrate can be rigidly placed on a rotating base known as vacuum chuck [19]. The positive photoresist can be placed on the solid substrate. Here the solvent is volatile in nature. Then rotor can be allowed to rotate at a high speed and that rotation can be caused to spread solutions over the substrate surface whereas volatile solvent evaporates. The rotation can be continued until the required thickness and uniformity. Figure 5 shows the schematic diagram for spin coating process.

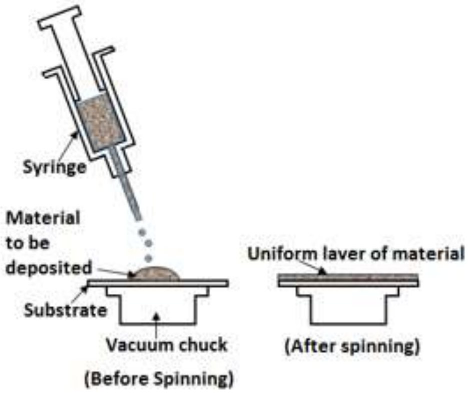

Figure 5. Schematic diagram for spin coating process

2.3 Material Removal Processes

In this process removal of substrate or materials can be done selectively. This process is commonly called etching [20]. It is classified in two categories i.e. wet etching and dry etching. In *wet etching*, the dissolving power of a chemical solution can be utilized to remove the materials. Here the desired portions of the material is covered with a mask which can resist. However, in the *dry etching*, the material can be removed by bombardment with high energy ions. This dry etching are different types such as Reactive ion etching (RIE), Sputter etching and Deep Reactive Ion Etching (DRIE). RIE and sputter etching are commonly used but DRIE is used for the deeper etching.

2.4 Thin film deposition techniques

In this process a thin layer of material can be deposited on the substrate surface. This process can be broadly classified into two types. i.e. Physical Vapour Deposition (PVD) and Chemical Vapour Deposition (CVD). In *CVD process*, a required number of gases are allowed into the reactor which contains the substrate [21]. The basic principle of this technique is that a chemical reaction takes place inside the reactor. Finally, the product is condensed on the substrate surface. Again this CVD technique is classified into two types i.e. low-pressure CVD (LPCVD) and plasma-enhanced (PECVD). The advantages of *first* technique are good uniformity of layer thickness and good material characteristics. Using this technique, films can be grown on both sides of at least 25 wafers at a time. But the drawbacks are high temperature requirement (>600^0C) and slow deposition rate. However, the advantages of *second* process is low temperature requirement (< 300° C) and drawback is poor quality of films. Using this technique, films can be grown on single side of the 1-4 wafers at a time.

Instead of CVD process, physical vapour deposition (PVD) process can also be used for the deposition of thin film on the surface of wafers [22]. The advantages of this PVD process are low process risk factor and cheap in cost. The basic principle of physical deposition method is that the solid material to be deposited by means of transportation of atoms from a source to the substrate surface inside a particular chamber. This can be achieved by two ways i.e. evaporation and sputtering.

Sputtering Method: In this method, the material is released from the source/target at a very low temperature than evaporation [23]. The substrate is positioned in a vacuum chamber with the inert argon gas and target material at a very low pressure. Then a high power DC is allowed to ionise the gas and the ion beams is then allowed to fall on the target surface. This cause the atoms of the source material to break down and form vapour phase which is finally condensed on the substrate surface. Figure 6 shows the schematic diagram for a typical RF sputtering system. RF sputtering can be used for metals, semiconductors and insulators.

Electron beam method: In this method, the wafer is positioned inside a vacuum chamber in which a source/ target should be present [23]. Then the source material is to be heated by electron beam (e-beam) which will evaporate the target material. This e-beam is produced by an electron gun which allows the emission of electron from the incandescent lamp. The emitted electrons are accelerated by a high potential. Then a magnetic field is applied to bend the trajectory of the electrons and allowed to position below the evaporation line. Then molecules are freely evaporated inside the chamber, and subsequently condense on all substrate's surface. An e-beam evaporated system is shown in Figure 7.

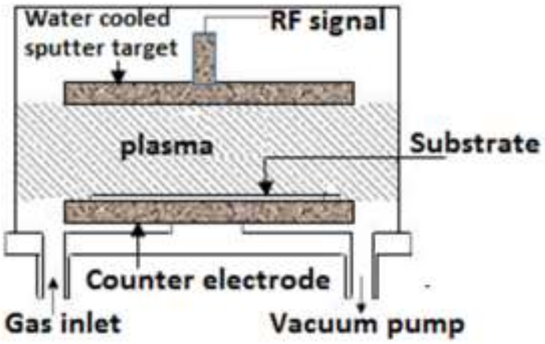

Figure 6. Schematic diagram RF sputtering

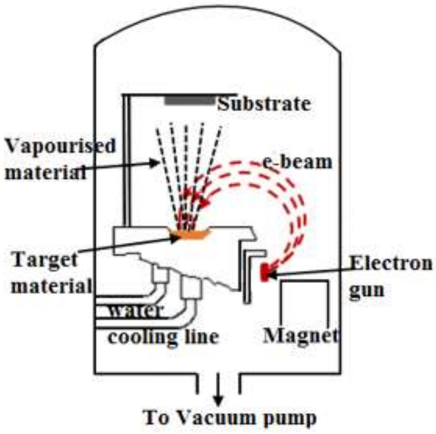

Figure 7. Schematic diagram for e-beam system

3. Conclusion

In this short review, the basic fabrication techniques for the micro device are discussed. The MEMS technology allows one to realize a device in micro meter scales. The numerous advantages of this technology are not allowed to constraint in IC industry but it is indicating to develop different micro-devices, biological devices and many mores. As the device size is continuously decreasing, the scientific communities are approaching towards the nano scale device fabrications. More technically, the nano-electro-mechanical-system (NEMS) is another technology which may replace the existing technology in near future. Finally, author hopes that this short review may provide a basic idea about microelectronic process units for the beginners.

References

[1] S. Franssila, “Introduction to microfabrication”, John Wiley & Sons **(2010)**

[2] R. Zaouk, B. Y. Park, and M. J. Madou, “Introduction to microfabrication techniques”, In Microfluidic Techniques, Humana Press **(2006)**

[3] R. Bogue, “Recent developments in MEMS sensors: A review of applications, markets and technologies”. Sensor Review, vol. 33, no. 4, **(2013)**, pp.300-304

[4] C. Y. Chan, “Fundamentals of crash sensing in automotive air bag systems” SAE**.(2000)**

[5] H. Du, and R. Bogue, “MEMS sensors: past, present and future”. Sensor Review**.(2007)**

[6] W. P. Eaton, and J. H. Smith, “Micromachined pressure sensors: review and recent developments”. Smart Materials and Structures, vol. 6, no. 5, **(1997),** pp. 530

[7] N. Yazdi, F. Ayazi, and K. Najafi, “Micromachined inertial sensors. Proceedings of the IEEE, vol. 86, no. 8, **(1998)**, pp.1640-1659.

[8] K. Tanaka, Y. Mochida, S. Sugimoto, K. Moriya, T. Hasegawa, K. Atsuchi, and K. Ohwada, “A micromachined vibrating gyroscope”. In Proceedings IEEE Micro Electro Mechanical Systems**. (1995)**, pp. 278.

[9] A. K. Au, H. Lai, B. R. Utela, and A. Folch, “Microvalves and micropumps for BioMEMS”. Micromachines, vol. 2, no. 2, **(2011),** pp.179-220.

[10] K. L. Gabriel, and W. S. N. Trimmer, “Micro gears and turbines etched from silicon. Sensors and Actuators, vol. 12, no. 4, **(1987),** pp.341-348.

[11] S. S. Saliterman, “Fundamentals of BioMEMS and medical microdevices”. Bellingham, WA: Wiley-Interscience. **(2006)**

[12] P. Gravesen, J. Branebjerg, and O. S. Jensen, “Microfluidics-a review”. Journal of micromechanics and microengineering, vol. 3, no. 4, **(1993),** pp. 168.

[13] A. T. Giannitsis, “Microfabrication of biomedical lab-on-chip devices. A review”. Estonian Journal of Engineering, vol. 17, no. 2, **(2011),** pp.109.

[14] A. Saito, “Fabrication process of biosensor”. U.S. Patent 5,445,920, **(1995)**

[15] http://www.yole.fr/Top30_MEMS_Manufacturers.aspx#.XfdKj_zhXDc (accessed on 10th Dec 2019)

[16] M.P. Groover, “Introduction to manufacturing processes”. Wiley**. (2012)**

[17] M.J. Madou, “Fundamentals of microfabrication: the science of miniaturization”. CRC press **(2002).**

[18] R. Ghodssi, and P. Lin, “MEMS materials and processes handbook”. Springer Science & Business Media**. (2011)**

[19] D. Mitzi, “Solution processing of inorganic materials”. John Wiley & Sons**. (2008).**

[20] R.J Shul and S. J. Pearton, “Handbook of advanced plasma processing techniques”. Springer Science & Business Media**. (2011)**

[21] J.H. Park and T. S. Sudarshan, “Chemical vapor deposition”. ASM international. **(2001)**

[22] J. E. Mahan, “Physical vapor deposition of thin films”. Physical Vapor Deposition of Thin Films, by John E. Mahan, pp. 336. Wiley-VCH, **(2000)**

[23] P. Williams, “The sputtering process and sputtered ion emission”, Surface Science, vol. 90, no. 2, **(1979)**, pp. 588-634.

Author:

Goutam Mohanty received his Ph. D. degree from National Institute of Technology Raipur, India. He is working as an Assistant Professor in the Department of Physics, School of Computer Science and Engineering, India. He has presented his research outcomes in both India and abroad. His research interest includes Computational Modeling of microstructure, SPR Sensor, Biosensor, BioMEMS and Biomedical Electronics.