Fabrication and characterisation of RF MEMS structures

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ABSTRACT

Development in MEMS technology has resulted in various RF-MEMS components and structures such as low loss and high isolation RF MEMS switches, filters, high-Q passives and low loss phase shifters that can replace some of the bulky passive RF components. MEMS fabrication techniques empower conventional integrated circuit fabrication processes to produce 3-dimensional mechanical structures. In this techniques the 3-D structure is built by orchestrated addition and removal of a sequence of thin film layers to/from the wafer surface called structural and sacrificial layer respectively. At SSPL , surface micromachining techniques have been used to fabricate the suspended metallic membrane. The photoresist is used as the sacrifical layer and Au as the structural layer to form the membrane. The fabrication process involves oxidaton, photolithography, metallization , electroplating and etching. SSPL has fabricated a RF MEMS structure with varying thickness of sacrificial layer and bridge thickness. The gap and thickness of the bridge are very critical for the actuation of the membrane. The suspended membrane is released by dry etching of the photoresist. These parameters along with the surface morphology have been characterized by Surface Electron Microscope (SEM) after every unit process. The fabrication details along with its characterization by SEM is reported and discussed in this paper.

Keywords: Surface micro-machining, Oxidation, Photolithography, SEM, Ashing, Actuation.

1. INTRODUCTION

Micro Electro Mechanical Systems (MEMS) are the integration of mechanical elements, sensors, actuators and electronics on a common substrate using integrated circuit process sequences. The electronics are fabricated using standard IC processing, micro-mechanical components are fabricated using compatible micro-machining, processes that can selectively etch parts of the substrate or add sections on to the top surface, leaving free standing structures. The evolving nature of MEMS has evolved RF and millimeter-wave MEMS from the sensor based technology, RF MEMS use the same fabrication techniques and have become an area of significant interest. RF MEMS devices find application in a variety of areas, including filter tuning, phase shifters, reconfigurable matching networks, receive/ transmit switches, and duplexers. There are three main commonly used fabrication techniques for RF MEMS devices like bulk micro-machining, surface micro-machining and LIGA. RF MEMS devices based on surface-micro-machining technology are more suitable for integration with circuit as it is very similar to usual IC fabrication process.

The most critical issue in the development of RF MEMS technology is the fabrication and release of suspended structure. In this paper we report in detail the fabrication process of the suspended metallic membrane above the silicon substrate fabricated in-house by surface micro-machining. This process will be incorporated to fabricate complete RF MEMS devices.

2. FABRICATION OF SUSPENDED MEMBRANE

Surface micro-machining is a process to fabricate free standing and freely moving structures in a large two dimensional design space. The basic fabrication process sequence involved in surface micro-machining are oxidation, photolithography metallization, electroplating and etching. Firstly, for electric isolation, a 0.4 μm silicon oxide layer is grown on the high resistivity silicon substrate by the process of thermal oxidation at 1100°C Fig1 (A). It is carried out in a furnance where a process sequence of dry-wet-dry oxidation is followed to meet the required thickness. A 30/100 nm of Cr/Au seed layer is deposited by Ultra high Vacuum (UHV) techniques Fig1(B). This is followed by the deposition of the sacrificial layer also called the spacer layer on the top of the metallized layer. There are many materials, which are used as the sacrificial layer like SiO_2, PSG (Phosphosilicate Glass), photoresist. The thickness required for sacrificial layer is around 2 to 3 μm, which is very difficult to achieve with SiO_2 deposition , as it requires very long time. We do not have the facility for deposition of PSG, So we have used photoresist (PR-9260) as the spacer layer Fig1(C). The photoresist is deposited by Karl Suss spinner (Model No. RC-5) . The thickness of the photoresist deposited determines the gap between the membrane and the substrate. The gap and thickness of the metallic layer are very critical for the actuation of the membrane. To achieve the required gap, the thickness of the resist has been optimized by spinning the resist at different speeds. It is found that thickness of ~3 um has been achieved at 3500 rpm with the uniformity of 30angstroms over the full 3″wafer which has been measured by DEKTEK. After the spinning of photoresist, the substrate is prebaked for 60 minutes at 90°C, to evaporate the solvent from the resist. Then, the anchor for the membrane is defined by photolithography, using the mask Fig1(D). The substrate is then hard backed in an appropriate temperature sequence of 90°C to 150°C to ensure good step coverage and to avoid resist cracking during metallisation process . The wafer is now again metallised with the Au thickness of 100nm. The final bridge pattern is defined by photolithography method. The bridge structure is then thickened to ~1.5 μm by cyanide electroplating bath Fig1(E) . The deposited photoresist has to be removed to release the bridge structure. Acetone can be used if the post bake is not too long or happens at low enough temperature. But with a post bake at 150°C , the resist develops a tough "skin" and has to be burned away in an oxygen plasma by the process called ashing. Also , to ensure high yields, contact between structural elements and the substrate should be avoided during processing. In a liquid environment, however, this may become very difficult due to the large surface tension effects . The surface tension of the liquid tends to pull down the MEMS switch to the substrate resulting in sticking to the downstate position. To avoid the problem of stiction, we have released the structure by ashing. The ashing process is isotropic and etches under and around the openings in the membrane. The etching time depends on the dimensions of the membrane and the thickness of the sacrificial layer and it is around 45 minutes in our process Fig1(E). The plasma etching process results in a very clean surface with appropriate dimension of the released structure . The fabrication sequence is shown in the figure below.

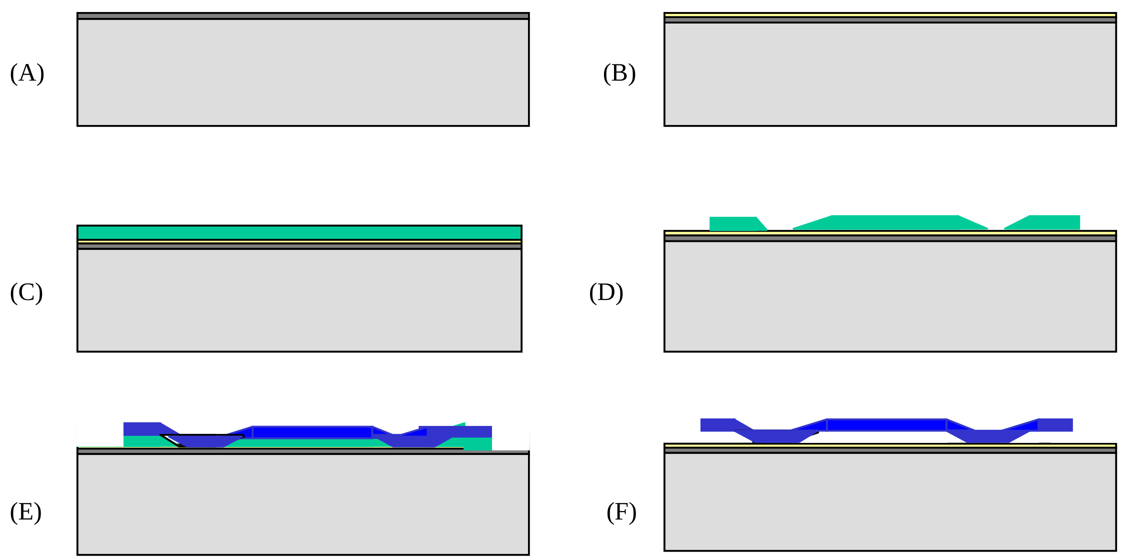
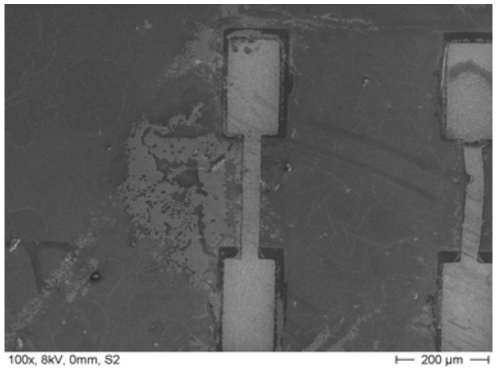


Fig.1. Basic surface micromachining process sequence . (A) Oxidation (B) Metallization (C) Spacer Layer deposition. (D) Anchor pattering with mask (E) Electroplated film deposition (F) Etching of the spacer layer.

3. STUDY OF MEMS STRUCTURES BY SEM

The final released structure has been studied by Scanning Electron Microscope (SEM) model no. JEOL-JSM-840 SEM. The various pictures showing the gap, thickness and surface morphology are shown in figures below.



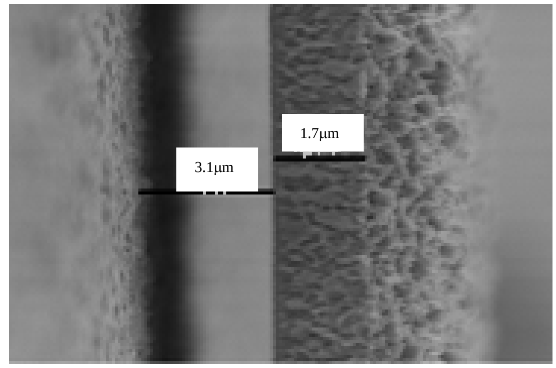
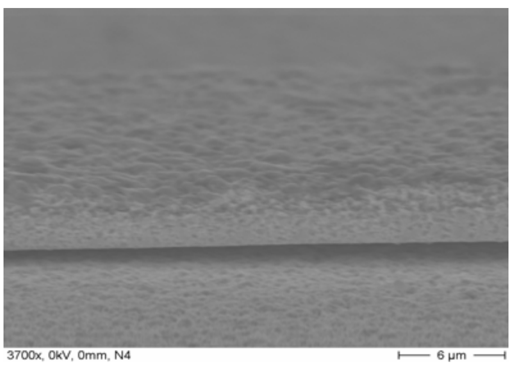


Fig. 2. Top view of Released bridge structure.

Fig. 3. Crossectional view of the released structure.



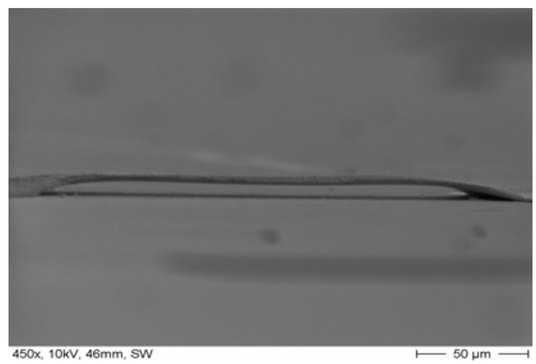


Fig. 4. Surface morphology of the Au electroplated suspended bridge

Fig.5. Suspended bridge structure after ashing.

4. CONCLUSIONS

It is found after SEM that the gap between the bridge and the substrate is around 3.1µm and the thickness of the Au membrane is around 1.7µm. It is seen from the figures that the morphology of the electroplated gold is regular and uniform. The unit processes required for the fabrication of the suspended structure has been optimized and will be used to fabricate the RF MEMS devices like capacitive switches, DMTL phase shifters and filters.

5. ACKNOWLEDGEMENTS

The authors wish to thank the Director, Solid State Physics Laboratory for his permission to publish this paper.

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