Experimental analysis of conformality of E–beam deposited thin films for MEMS applications

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ABSTRACT

KEYWORDS

Metal Thin Films,
Conformality,
Bulk- Micromachined,
E- Beam Evaporation Tool.

The uses of metal thin films are versatile and very well established in the field of CMOS and MEMS devices. Although, today's many system manufacturing units provides facility to control the physical parameters such as thickness uniformity and deposition rate. However, the impact of tool parameters must be optimized to understand and quantify for better process control. In this work, we have studied a qualitative conformality of metal thin films deposited with E- beam evaporation method. This is very important parameter for realization of MEMS devices, particularly for Through Silicon Via (TSV), MEMS Probe Card and G Switches. In this work, we present detailed qualitative study of metal filling over the bulk micro machined trench patterns and estimate the conformality values with two different types of rotation setup provided in E-beam tool for batch process of MEMS on to the 6" Si wafers.

1. Introduction

Thin film deposition is one of the primary process step for the MEMS batch production [1-3], and is commonly used with standard lift off and non –lift off process to define the various metal interconnects, eutectic bonding and common electrical wiring. Physical Vapor Deposition (PVD) [4-6] is the method to deposit metals and dielectric materials. In this process, a material is released from a target or evaporation source and deposited on to the desired substrates like Silicon wafers. Evaporation (E-beam) and plasma (Sputtering) are two most commonly used methods by semiconductor manufacturing units. PVD process basically involves few steps, first metal is released from the target material either by evaporation or plasma bombardment, then allowed to travel to the desired location under low pressure and finally allowed to deposit over the substrate to form a metal thin films. The e- beam evaporation techniques has an advantage over the other PVD process, that is high purity control over the flux materials and ability to deposit the materials which are not etch compatible. Some of the examples are tungsten, tantalum etc.

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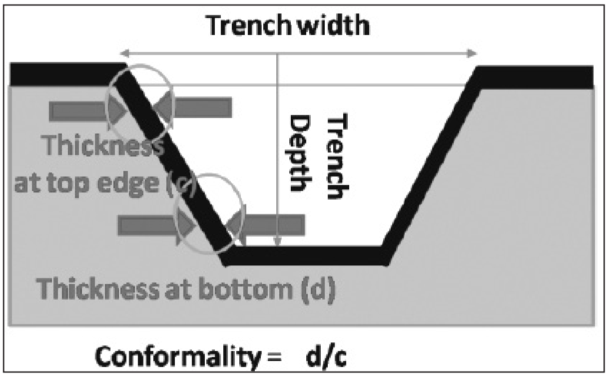

Fig. 1. Illustration for conformality.

However, biggest challenges with E–beam depositions are their uniformity and conformality over the curved surface. Conformality is defined as the differential ratio of the metal film thickness deposited over the side wall of trenches as depicted in figure 1.

The conformal filling of vias is necessary aspect and impacts the device performance. In this work, we report an Aluminum thin film deposition on the trenches possessing aspect ratio of 1: 2. The two sets of deposition experiments were performed, by using two sets of rotation configurations provided by system manufacturer as shown in figure 2. The process development was done, keeping in view the requirements of conformal metal depostion in Gyroscope, G switch and RF devices. In this context, first set of experiments was performed with rotation set up only and deposition was checked with two set rotation speed i.e 12 and 25 % of max available speed (50 rpm) of motor. In second set of experiments, depositions were performed with planetary rotation set up, keeping the other parameters same as used for previous one. Further to estimate the conformality values, the scanning electron microscopy (SEM) was performed.

2. Experiments, Results and Discussion

2.1 Materials & Methods

For optimization experiments, the four 6” silicon wafers were taken and lithographically patterned to open the etched window of square shape of size 100 x100, 200 x200, 500x 500 and 1000x 1000 μm^2 as shown in figure 3 with standard micro fabrication process. Thereafter, trenches were opened with standard KOH based anisotropic wet etching process (80% KOH, 80 ^0C). For these experiments, the aspect ratio was kept same for all the trenches. The details parameters used for the process are shown in table 1.

2.1.1 Metal depositions: (Rotation)

After defining the trenches, the 6”wafers were cut into the four quarter pieces and distributed into a subset of samples as per experiment requirement. Thereafter, ~500 nm thin film of aluminum metal was deposited on four chosen samples (W1 (100 x 100), W5 (200 x200), W9 (500 x500), and W13 (1000 x 1000)) with E-beam evaporation technique.

The rotation speed was kept at 12 %, with base vacuum of ~ $3.5*10^{-6}$ torr and deposition rate of~ $4A^0$/sec was used as deposition parameters. Another set of deposition experiments for second subset (W2, W6, W10, and W14) was performed at set rotation speed of 25 % and other parameters were kept fixed as first subset. In order to evaluate, the conformality of metal thin films the scanning electron microscopy was performed and results for trench size of 100 x100 μm^2 are shown in figure 4 and 5 at set rotation speed of 12 and 25 % of max RPM.

For comparison and estimation of qualitative conformality values, following measured thickness data were extracted from the SEM analysis and given in table 2 and 3.

2.1.2 Metal depositions (planetary+ rotation)

Then similar experiments were performed with “Planetary+ rotation setup” to check the impact of setup on deposition patterns. The scanning

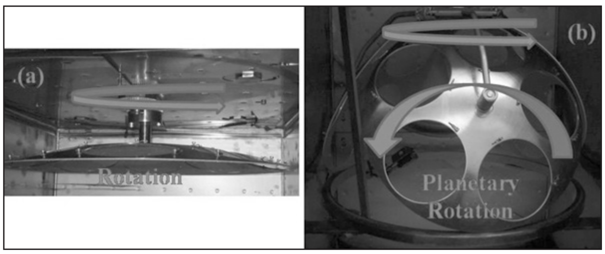

Fig. 2. Experimental setup configuration (a) Rotation (b) Planetary Rotation.

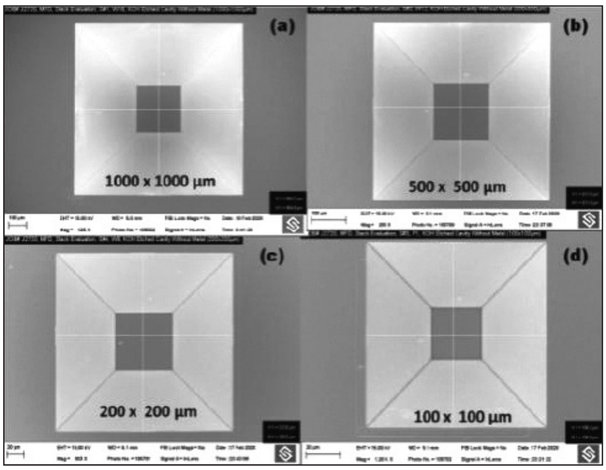

Fig. 3. Scanning electron microscopy images of KOH etched trenches in silicon wafer.

Table 1
Physical dimensions of etched trenches.

Trench Size (µm)	Max Etch Stop (W/ 1.414)	Aspect ratio	Etch depth (µm)	Etch Time (min)
100 x100	70.72 µm	1:2	50	33
200 x200	141 µm	1:2	100	66
500 x500	353 µm	1:2	250	166
1000x1000	707 µm	1:2	500	333

Table 2
Thickness measurement performed for metal films at rotation speed 12 % of max rpm.

Trench Size (µm)	Metal Thickness at top edge of trench (nm)	Metal thickness bottom edge of the trench (nm)	Conformality
100 x100	302	304	1.00
200 x200	301	290	0.96
500 x500	304	301	0.99
1000 x1000	294	288	0.97

Table 3
Thickness measurements performed for metal films at rotation speed 25% of max rpm.

Trench Size (µm)	Metal Thickness at to edge of trench (nm)	Metal thickness bottom edge of the trench (nm)	Conformality
100 x100	340	346	1.01
200 x200	333	313	0.93
500 x500	345	353	1.02
1000 x1000	358	328	0.91

Table 4
Thickness measurement performed for metal films at rotation speed 12 %.

Trench Size (µm)	Metal thickness at top edge of trench (nm)	Metal thickness bottom edge of the trench (nm)	Conformality
100 x100	425	309	0.72
200 x200	332	338	1.01
500 x500	479	479	1
1000 x1000	415	413	0.99

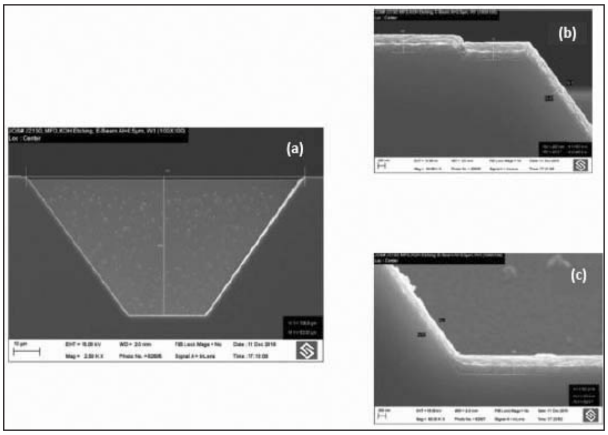

Fig. 4. (a) Scanning electron microscope images for wet etched cavity of dimension 100 x 100, (b & c) Cross-sectional image of Al metal deposited at Top and Bottom edge of cavity at set rotation speed of 12 % of max rpm.

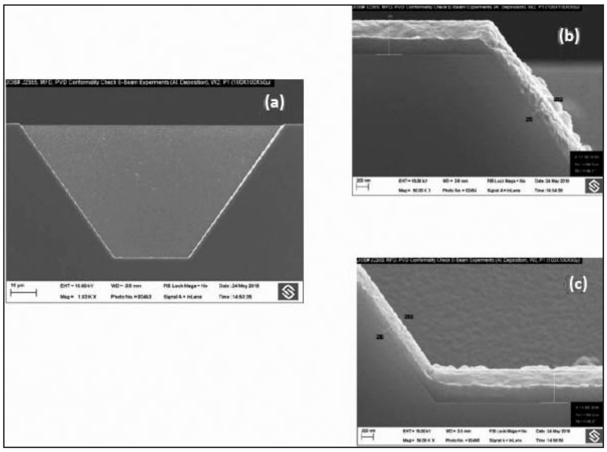

Fig. 5. (a) Scanning electron microscopy images for wet etched cavity of dimension 100 x 100, (b & c) Cross-sectional image of Al metal deposited at top and bottom edge of cavity at rotation speed of 25 % of max rpm.

Table 5
Thickness measurement performed for metal films at rotation speed 25 % of max rpm.

Trench Size (µm)	Metal thickness at top edge of trench (nm)	Metal thickness at Bottom edge of the trench (nm)	Conformality
100 x100	473	367	0.77
200 x200	463	389	0.84
500 x500	407	320	0.78
1000 x1000	329	314	0.95

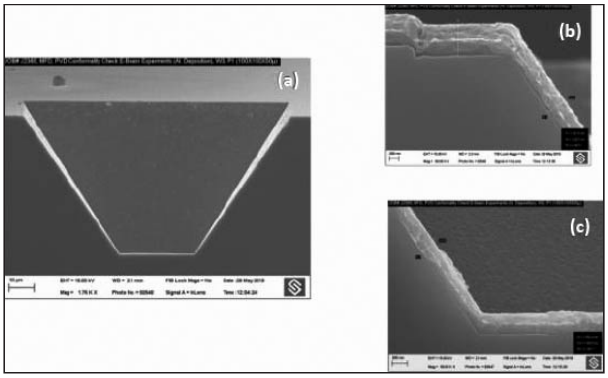

Fig. 6. Scanning electron microscopy images for cavity dimension of 100 x 100, (b & c) Cross-sectional image of Al metal at rotation speed of 12 % of max rpm.

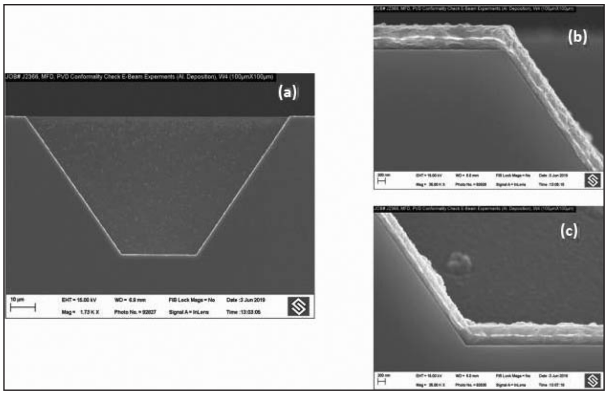

Fig. 7. Scanning electron microscopy images for cavity dimension of 100 x 100, (b & c) Cross-sectional image of Al metal at rotation speed of 25% of max rpm.

electron microscopy images with used set-up for trench size of 100 x100 micron are shown in figure 6 and 7 at rotation speed of 12 and 25 % of max rpm.

Similarly, in order to evaluate the qualitative conformality, SEM analysis was performed and extracted data are given in Table 4 & 5.

3. Results and Discussion

It is evident from these set of performed comparative experiments, the scanning electron microscopy results shows that, for the KOH etched anisotropic trench shape, the qualitatively good surface coverage was observed. It does not change much, with respect to the either use of rotation or planetary rotation configurations. This could be due to the wide angle opening available for incident evaporated Al metal molecular beam. Qualitatively, the conformalities average values were estimated to be in order of ~0.98 and ~0.97 in rotation speed of 12 and 25 % of max rpm in rotation set up. However, these average values were observed to be in the order of ~0.93 and ~0.83 in planetary rotation setup.

4. Conclusion

In summary, a process development of metal thin films was studied targeting the conformality. It has an important application for MEMS devices such as probe card, Through Silicon Via and G-switch applications. The e-beam evaporation was chosen as a method of deposition and the deposition conformailty was investigated with scanning electron microscopy. It was observed that, irrespective of chosen setup (Only rotation and with planteray motion), the metal films showed a good surface coverage. The average values, ~0.98 and ~0.97 were obtained with speed of 12 and 25 % with rotation set up. For the case of planetary rotation setup, these values are observed to be ~0.93 and ~0.83. This provides, a platform for development of MEMS devices, where trench filling processes are critical.

5. Acknowldgement

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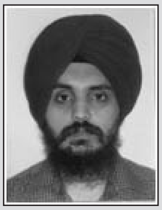

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