Excimer laser patterning of TiN film from metal sacrificial layers

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ABSTRACT

In this work, the relative performance of patterning TiN film from metal sacrificial layers using a 248nm excimer laser is presented. Patterning performance was determined by investigating etching behaviour in terms of edge quality, film delamination and layer selectivity. Using <100> silicon as a substrate, TiN was arc deposited onto sputtered Cr and Cu sacrificial layers and silicon in a partially Filtered Arc Deposition (FAD) system at 150°C. The TiN films were directly patterned into matrices of fluence verses number of shots. The results show excellent patterning of TiN from Cr sacrificial layers in terms of pattern quality and film selectivity. The TiN ablated from a Cu sacrificial layer produced poor patterning and no layer selectivity. The experimental results are presented and discussed in relation to the explosion mechanism of ablation.

Keywords: Excimer laser, Laser ablation, Titanium Nitride, TiN, Sacrificial layer, Thin film

1. INTRODUCTION

Titanium Nitride (TiN) has received considerable attention in recent years for applications in tribology and microelectronics. It is CMOS compatible and has been widely investigated as a diffusion barrier in microelectronics1,2. Titanium Nitride is a hard coating and possesses a Vickers microhardness of 2500-3000 and a coefficient of friction typically around 0.65 on steel. It is these properties that have contributed to its popularity in the tooling industry as a wear resistant coating on high-speed tool steels3. Because of its outstanding tribological characteristics and CMOS compatibility, TiN could be considered a potential candidate for surface micromachined sensors and actuators in applications such as switches and valves. The mechanical behaviour and properties of TiN have been investigated using bulk micromachining techniques. Johansson4 investigated the influence magnetron sputtered TiN films had on the elasticity, residual stresses and fracture properties of silicon microbeams, while Karimi5 conducted bulge tests to determine Young’s modulus and residual stress of r.f. magnetron sputtered TiN films. These investigations provide insight into the behaviour of TiN films and their potential in surface micromachining applications.

Selecting desirable materials and understanding their mechanical behaviour is crucial to success in surface micromachining. Another requirement is detailed understanding of limitations associated with surface micromachining fabrication processes and post fabrication annealing steps. Material compatibility and mechanical integrity must exist between structural and sacrificial layers during all stages of fabrication. During patterning, a high degree of selectivity between contacting layers is desirable and can be motivated by either physical or chemical differences6. It is important that structural layers be patterned with minimal interference to the sacrificial layer beneath. This is so multilayer designs can be realised according to design. The importance of fabrication limitations becomes most apparent when integrating MEMS and ICs. In most cases MEMS require a high temperature fabrication step or annealing stage. If integrating MEMS onto ICs, strict adherence to the available thermal budget is crucial. Exposing ICs to temperatures over 500°C is undesirable as migration can occur and irreversible damage can result. By considering the two processes separately successful integration can be possible7.

This paper investigates excimer laser patterning of TiN from Cr and Cu sacrificial layers and <100> silicon. A PVD method for TiN was chosen as it is possible to deposit the films below 500°C, whereas CVD TiN is achieved at 1000°C8. This makes PVD TiN a suitable choice for possible MEMS / IC integration. A 248nm excimer laser was selected to pattern the TiN as thermal effects associated with the ablation process are localised.
2. EXPERIMENT

The fabrication process and patterning step is shown in Fig. 1. The starting material used was 525 ± 25µm thick 4-inch n-type <100> silicon wafer, which underwent a standard cleaning process. Metal sacrificial layers of 0.4µm Cr, 1µm Cr and 0.4µm Cu with a 50nm Ti adhesion layer were sputter coated onto silicon. Titanium nitride films of 0.4µm thickness were then deposited on the sacrificial layers and silicon in a plasma-assisted Filtered Arc Deposition (FAD) system under partially filtered conditions at 150°C. In the case of TiN on silicon with no sacrificial layer, a 50nm Cr adhesion layer was deposited using the FAD system prior to TiN deposition. Direct laser patterning using an Exitech S8000™ 248nm excimer laser with 20ns pulse duration was used to pattern the TiN films. A test pattern with pitch lengths ranging from 50µm to 2µm was used to determine the quality of TiN ablation in terms of edge quality and layer selectivity. Matrixes of fluence verses number of shots were used to pattern the TiN. Shot sites consisted of 1, 2, 4, 8, 16, 32, 64 shots with a repetition rate of 5 Hz.

![Fabrication processes of TiN on (a) a sacrificial layer and (b) silicon.](image)

(1) Adhesion layer and/or sacrificial layer deposition
(2) TiN deposited in FAD system
(3) Irradiation with 248nm excimer laser
(4) Patterned TiN film

Fig 1. The fabrication processes of TiN on (a) a sacrificial layer and (b) silicon.
3. RESULTS

3.1. TiN ON 1µm CHROMIUM SACRIFICIAL LAYER

The confocal micrographs of Fig. 2. show that TiN has been patterned using direct laser ablation. The ablation site is a 50µm pitch test feature. The site was exposed to 1 shot at a fluence of 1.6 J/cm². This value is 0.2 J/cm² above the one-shot TiN ablation threshold for this combination, which was found to be 1.4 J/cm². A EDS plot (Fig. 3.) shows that selective removal of TiN from the Cr sacrificial layer has occurred. The presence of Si on the EDS chart can be contributed to the Si(Li) detector chip in the SEM.

![Confocal micrographs of 50µm pitch test pattern exposed to 1 shot of 1.6 J/cm². (a) 50x and (b) 25.5x in 3D](image_url)

Fig. 2. Confocal micrographs of 50µm pitch test pattern exposed to 1 shot of 1.6 J/cm². (a) 50x and (b) 25.5x in 3D
Figure 4 is confocal micrograph after 2 shots at 1.6 J/cm$^2$. The second shot has caused melting of the Cr layer and edge cracking of the TiN. Analysis of the melted zone using EDS (not shown) reveals the presence of Cr only. The results obtained for the TiN on 0.4µm Cr sacrificial layer are consistent with those of the 1µm Cr layer.

Figure 4 is confocal micrograph after 2 shots at 1.6 J/cm$^2$. The second shot has caused melting of the Cr layer and edge cracking of the TiN. Analysis of the melted zone using EDS (not shown) reveals the presence of Cr only. The results obtained for the TiN on 0.4µm Cr sacrificial layer are consistent with those of the 1µm Cr layer.

Fig. 3. EDS analysis of underlying Cr sacrificial layer.

Fig. 4. 200x Confocal micrograph of 50µm pitch test pattern exposed to 2 shots at 1.6 J/cm$^2$.
3.2. TiN ON 0.4µm COPPER SACRIFICIAL LAYER

The confocal micrograph in Fig. 5. shows patterned TiN on a 0.4µm Cu sacrificial layer. This site is also a 50µm pitch test feature. The site was exposed to 1 shot at a fluence of 1.6 J/cm². The TiN ablation threshold for this combination was found to be 1.5 J/cm². An EDS plot (Fig. 6.) taken from the centre of an ablation site reveals the presence of silicon only.

Fig. 5. 50x Confocal micrograph of 50µm pitch test features exposed to 1 shot at 1.6 J/cm².

Fig. 6. EDS analysis of ablation site reveals the presence of Si only.
3.3. TiN ON (100) SILICON WITH NO SACRIFICIAL LAYER

The confocal micrographs of Fig. 7. and Fig. 8. show patterning of TiN on Si with no sacrificial layer. Figure 7. shows test features ranging from a 50µm (far left) to a 10µm pitch. The site was exposed to 1 shot at a fluence of 1.6 J/cm². This value is 0.4 J/cm² above the one-shot TiN ablation threshold for TiN on Si, which was found to be 1.2 J/cm². The removal of TiN is patchy on the 50µm to 20µm pitch test features, with the 15µm and 10µm pitch features showing increased TiN removal, but with minimal resemblance to the intended features. Figure 8 show the results of increasing the number of shots to 32 with the same fluence. The TiN has been ablated to 30µm pitch feature, however the ablation quality is poor due to edge features being rough and damaged.

4. DISCUSSION

The confocal micrographs in Fig. 2, Fig. 5. and Fig. 7. illustrate the differences in quality between one-shot TiN ablation from the respective sacrificial layers and silicon. The ablation of TiN from Cr with one shot shows overall excellent ablation with high quality edge patterning. The TiN has been completely removed and no visible cracking or peeling can be seen. In comparison, the ablation of TiN from Cu is of considerably poor quality due to visibly rough edges and evidence of peeling. In this case the TiN has not been removed cleanly. The ablation of TiN from Si with one shot also produced poor results. Sporadic ablation of larger features is present. Titanium nitride was removed from the smaller features, however it is not characteristic of the intended pattern. Increasing the number of shots to 32 produced the most recognisable replication of the mask pattern, however the results are poor due to the film showing incomplete removed. Regions in the film also appear to be cracked and suffering from delamination.

Results also show that TiN has been selectively removed from 0.4 and 1µm thick Cr sacrificial layers. Figure 2 (a) and (b) illustrate the quality of the TiN removal with a EDS plot (Fig. 4.) showing that the Cr sacrificial layer has not been removed. In the case for TiN on Cu, selective etching did not occur. The films were ablated through to the silicon with one shot. The EDS plot in Fig. 6 confirms this. An explanation for the selective removal of TiN from Cr can be found in the explosion mechanism proposed by Zaleckas10. The explosion mechanism describes the ablation process on terms of vaporisation at the film-substrate interface and is essentially based on the mechanism of heterogeneous vapour nucleation at the interface. It suggests that instantaneous gasification occurs at the interface due to the high temperature.
reached across the film. This model is more likely to be relevant for cases where the substrate has a lower melting or decomposition point than that of the thin film\textsuperscript{11}. Applying the explosion mechanism to the ablation of TiN from metal sacrificial layers appears possible if the metal sacrificial layer is viewed as the substrate material. This relationship appears to be suitable for TiN on Cr, but not for TiN on Cu. The data in Table 1. suggests that TiN on Cu should show selective etching like that of TiN on Cr, since both have a lower ablation threshold and melting point than TiN. However, it must be noted that Cu has a far greater difference in ablation threshold and melting point than Cr. This relative instability of Cu could be the reason for poor selectivity with TiN. Also, the Cu layer investigated was only 0.4\( \mu \text{m} \) thick. A thinner sacrificial layer is more likely to be affected by material vaporisation at the interface, as proposed by the explosion mechanism.

<table>
<thead>
<tr>
<th>Thin Film</th>
<th>Ablation Threshold (J/cm( ^2 ))</th>
<th>Melting Point (K)</th>
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<tbody>
<tr>
<td>Chromium</td>
<td>&gt; 1.1</td>
<td>2180</td>
</tr>
<tr>
<td>Copper</td>
<td>( \leq 0.7 )</td>
<td>1358</td>
</tr>
<tr>
<td>Titanium Nitride</td>
<td>( \approx 1.4 ) (from this work)</td>
<td>3203</td>
</tr>
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Table 1. Ablation thresholds of thin films for 248nm excimer laser and melting point.

**NOTE:** TiN ablation threshold was obtained from this work. (See Table 2.)

<table>
<thead>
<tr>
<th>TiN / Metal Combination</th>
<th>Ablation Threshold (J/cm( ^2 ))</th>
</tr>
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<tbody>
<tr>
<td>TiN Film (0.4( \mu \text{m} )) on Chromium (0.4 and 1( \mu \text{m} ))</td>
<td>1.4</td>
</tr>
<tr>
<td>TiN Film (0.4( \mu \text{m} )) on Copper (0.4( \mu \text{m} ))</td>
<td>1.5</td>
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Table 2. Ablation thresholds of TiN on metallic sacrificial layers.

5. **CONCLUSION**

This paper reports the patterning quality of TiN from metal sacrificial layers of Cr and Cu and TiN from silicon using a 248nm excimer laser. Ablation performance was determined by edge quality and layer selectivity. The results show that TiN has been selectively ablated from Cr film with best quality ablation being achieved using one laser shot. In terms of TiN on Cu film, selective removal of TiN was not achieved.

**REFERENCES**


