

# **Laser Patterning of TiN Films from Metal Sacrificial Layers for Surface Micromachining Applications**

by

**Andrew Dowling**

**Erol Harvey**

**Derry Doyle, School of Engineering and Science, SUT**

## **Abstract**

This paper presents the results of our investigations on the laser micromachining of titanium nitride (TiN) films. Machining performance was evaluated in terms of layer selectivity and patterning quality. TiN was arc-deposited onto (100) silicon substrate with chromium (Cr) and copper (Cu) sacrificial layers. Films were also deposited onto bare silicon substrates under the same conditions. These samples were laser micromachined using a KrF excimer laser at 248 nm. The effect of fluence and number of shots on the machined features has been investigated in detail. The patterned features were examined under optical, confocal and scanning electron microscopes. The characteristics observed were analysed and compared in all three sets of samples. The results showed selective removal of TiN films from Cr and Cu sacrificial layers under different conditions. The machining of TiN from (100) silicon showed relatively poor definition of patterned features. The analysis of these results indicated that laser machining of TiN from Cr and Cu layers is best explained using the explosion mechanism of removal.

## **1. Introduction**

TiN has received considerable attention in recent years for applications in tribology, microelectronics, solar cells and decorative coating applications. It is used extensively in the tooling industry as a wear resistant coating on tools such as drills, taps, dies etc. TiN is a CMOS compatible material and has been widely investigated as a diffusion barrier in microelectronics [1]. Because of its CMOS compatibility and outstanding mechanical properties, TiN could be considered a potential candidate for surface micromachined sensors and actuators in applications such as switches and valves. The machining of TiN films for surface micromachining has only recently been adopted and usually requires solutions or reactive gases. These methods of processing require labour-intensive pre-process masking step. Masking typically involves resist deposition, baking, exposure and development. One method of reducing the number of fabrication steps is to machine TiN using excimer laser micromachining.

The excimer laser micromachining of different materials has recently gained increasing interest because of its ability to machine structures in various materials

including ceramics [2,3] glass and polymers [4,5]. Excimer laser machining of thin metal films using various wavelengths, fluences and dielectric substrates has been investigated [6-9]. Three basic mechanisms namely, pure vaporisation [10], explosive removal, caused by pressure built up at the film-substrate interface [11] and two-phase removal induced by partial film vaporisation and subsequent liquid expulsion [12] have been proposed to explain the experimental observations in different investigations.

## **2. Industrial Implications**

This research has investigated a technique for the selective machining of TiN film without the need for photolithographic steps involving photoresists, hazardous solutions or reactive gases. Since TiN is a hard and wear resistant material, application of this technique to the manufacture of micromachined sensors and actuators could enable the realisation of more hard-wearing and functional micromachines.

## **3. Experimental**

### **3.1 Sample preparation and thin film deposition**

The fabrication process in this work started with the RCA cleaning of the (100) silicon substrates. These substrates were initially coated with copper and chromium films of different thicknesses. Two different thicknesses, 400 nm and 1000 nm thick chromium and 400 nm and 700 nm thick copper films were prepared using a JAVAC<sup>TM</sup> DC magnetron sputtering system. TiN films (400 nm thick) were arc-deposited onto the metal layers and bare silicon using a dual source filtered arc deposition system.

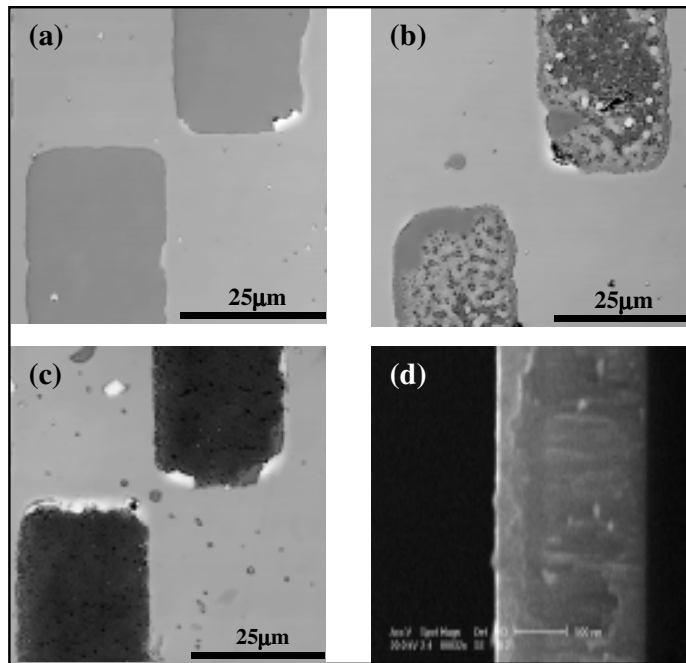
### **3.2 Excimer Laser micromachining of TiN films**

These samples were micromachined using an excimer laser system Series 8000 (Exitech Limited, UK) equipped with a Lambda Physik LPX210I laser source. At each fluence, machining was carried out using 1, 2, 4, 8, 16, 32, 64 shots. In all the experiments the laser repetition rate was kept constant at 5Hz. Laser pulse energies were calibrated at the surface of the workpiece using a pyroelectric energy monitor (Molelectron Type JD25). A JEOL JSM840 scanning electron microscope equipped with a backscatter electron detector and a Tracor Northern X-ray detector for energy dispersion spectroscopy (EDS) has been used throughout this work. Confocal microscopy was performed using an Olympus OLS1100 He:Ne laser scanning microscope.

## 4. Results

### 4.1 Laser machining of TiN films on chromium sacrificial layers

These films patterned using excimer laser machining. Figure 4.1 (a,b,c) shows the confocal images of the TiN film patterned using 1, 2 and 4 shots at a fluence of  $1.6 \text{ J/cm}^2$  respectively. Figure 4.1 (d) shows an SEM cross-section of the films. In this case the chromium layer thickness is around 1000 nm and TiN is deposited to a thickness of 400 nm.



**Figure 4.1 - Confocal micrographs of  $50 \mu\text{m}$  pitch feature after (a) 1 shot (b) 2 shots (c) 4 shots at  $1.6 \text{ J/cm}^2$  (d) SEM cross-section.**

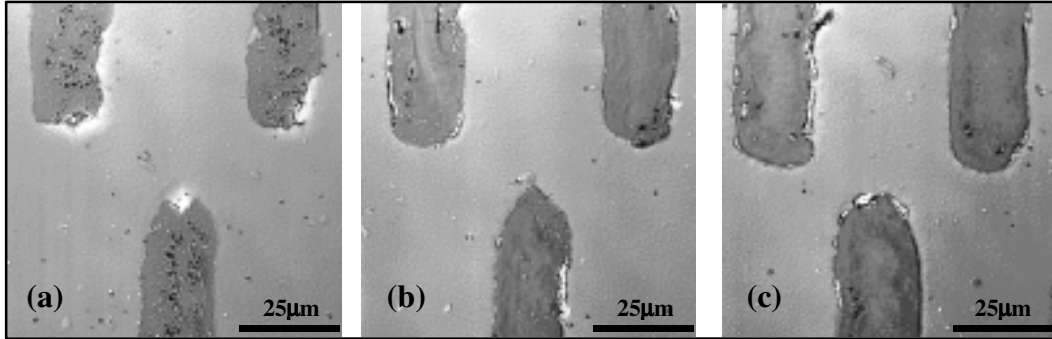
The single shot ablation of the TiN film shown in Figure 4.1 (a) clearly indicates the removal of the first layer of the film with an excellent colour contrast between the patterned area and the film area, which is not subjected to laser machining. In order to confirm the complete removal of TiN layer in the patterned region EDS analysis was performed (not shown).

From Figure 4.1 (b), it may be noted that continued machining to two shots resulted in the damage of the underneath chromium layer. When the laser machining is continued till four shots, the damage initiated has increased further. This damage appears to be a result of the melting of the chromium layer, when exposed to more number of shots.

In order to understand the effect of thickness of the chromium layer, we have laser machined another sample with a chromium layer thickness of 400 nm, while keeping the

TiN layer thickness 400 nm. Even at this chromium layer thickness, we were able to achieve selective machining of TiN at the same fluence in a single shot.

#### 4.2 Laser machining of TiN films on copper sacrificial layers

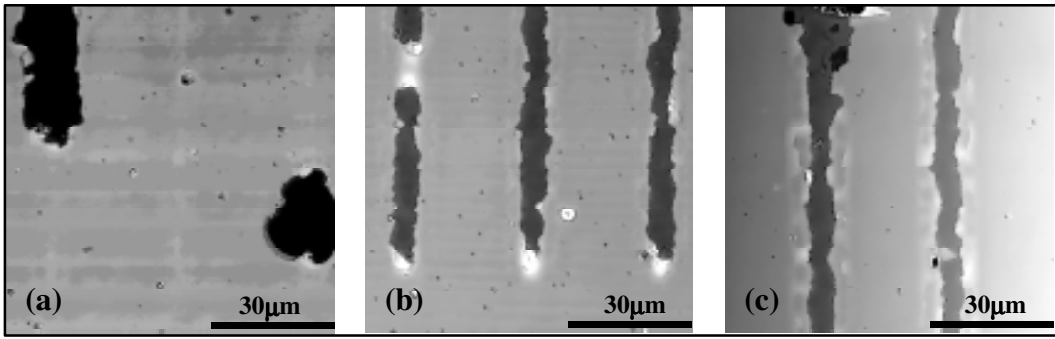


**Figure 4.2 - Fig.7: Confocal images of the patterned TiN film with a copper layer on silicon substrate (a) 1 shot (b) 2 shots (c) 4 shots at  $1.5 \text{ J/cm}^2$ .**

Figure 4.2 shows the images of the patterned TiN film with a copper layer on silicon substrate obtained using a confocal microscope. In this sample the copper layer thickness is 700 nm, while the TiN thickness is kept the same as in the previous case at 400 nm. The sample was exposed to 1, 2 and 4 shots at a fluence of  $1.5 \text{ J/cm}^2$  respectively. It may be observed that in all the three images TiN film is removed. Confirmation of the complete removal of TiN layer was obtained by using the EDS analysis (not shown).

#### 4.3. Laser machining of TiN films on silicon

Figure 4.3 (a,b,c) shows the confocal images of the machined patterns on TiN films deposited directly on silicon for 8, 32 and 64 shots respectively. Interestingly, the laser machining of this film showed a different behaviour compared to those machined on sacrificial layers. After the exposure to first laser shot (at the fluence  $1.6 \text{ J/cm}^2$ ), the film developed microcracks in the machined regions of the film. As the number of shots increased, the microcracks propagated further and finally leading to the delamination and ejection of the film from the substrate. Confocal images of Figure 4.3 clearly shows that the line (edge) definition in this case was rather poor compared to the samples with copper and chromium layers. Laser machining results for TiN deposited directly on silicon were found to be inconsistent.



**Figure 4.3 - Confocal images of the patterned TiN film on silicon substrate (a) 8 shots (b) 32 shots (c) 64 shots at a fluence of  $1.6 \text{ J/cm}^2$**

## 5. Discussion

The selective removal of TiN from Cr and Cu observed in these studies can be explained on the basis of explosion mechanism proposed by Zaleckas and Koo [11]. According to their model, whenever the evaporation or decomposition temperature of the dielectric substrate is lower than the melting temperature of the film, a positive pressure develops under the film causing an explosive removal of the top metallic film. Interestingly, the melting point of TiN ( $2930^\circ\text{C}$ ) is higher than the evaporation or boiling temperature of Cr ( $2671^\circ\text{C}$ ) or Cu ( $2562^\circ\text{C}$ ) as indicated in the Table 5.1. The other reason that favoured the explosive mechanism model is the observation that there is no evidence for any melting of TiN on the surface, for a wide range of laser operating conditions. However, in case of chromium machining on silicon substrate, our results showed agreement with the observations made by Lee and Na [6]. It appears that the chromium film melts initially and then vaporises. As the vaporisation temperature or boiling point of silicon is higher than the melting point of chromium, this seems a plausible explanation.

## 6. Conclusions

This paper reports the micromachining characteristics of TiN from Cr and Cu sacrificial layers and bare (100) silicon substrate using KrF excimer laser at a 248 nm wavelength. Machining performance was determined by investigating layer selectivity and quality of patterned features. Results show that TiN has been selectively removed from 400 nm and 1000 nm thick Cr sacrificial layers. The machining of TiN from Cr with one shot shows overall excellent results with high quality edge patterning. The TiN film has been completely removed and no visible cracking or peeling can be seen. Results also show that TiN has been selectively etched from 700 nm thick Cu film, although the quality of patterned features is poorer than that of TiN on Cr. It was not possible to selective remove TiN from 400 nm thick Cu layer. These results showed that the TiN machining might follows the explosion mechanism, while chromium removal follows the conventional melting and vaporisation process. Copper removal and patterning still requires further investigation.

## 7. Acknowledgements

Part of this work has been performed under the ANSIE grant No. 01/170. We acknowledge the help received from Dr. Ken Short, and Dr. Peter Evans from ANSTO. The authors would also like to thank Surface Technology Coatings for providing access to the Filtered Arc Deposition unit for carrying out this work. Also thanks to Mr. Martin Lloyd-Diviny of Olympus Australia Pty. Ltd., for helping and also providing training to use the Laser scanning confocal microscope OLS1100. Finally, thanks to Mr Hans Brinkies for SEM imaging and EDS analysis work.

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