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# Titanium mononitride as an antireflection layer on aluminium metallization for submicron photolithographic patterning

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**Abstract.** Titanium mononitride (TiN) as an antireflection layer over aluminium metallization on a Si wafer (Al/Si) in submicron photolithography has been studied. Both notching and standing wave effects of non-dyed and dyed positive resists coated on TiN/Al/Si are eliminated with 0.8  $\mu\text{m}$  designed linewidth test patterns using a g-line stepper under defocus of 0, +1 and  $-1 \mu\text{m}$ . TiN/Al/Si has a sheet resistivity of about 45  $\text{m}\Omega/\text{square}$ , similar to Al/Si up to tested TiN thickness of 0.12  $\mu\text{m}$ . Thus, TiN in the TiN/Al/Si system functions not only as a conventional diffusion barrier, but also as an antireflection layer and as a metallization layer. Selective reactive ion etching between Al and TiN can be achieved in an etchant gas mixture of 3 : 7  $\text{CHF}_3:\text{CF}_4$  with a dc bias of  $-100 \text{ V}$ .

## 1. Introduction

The antireflection layer (ARL) is critical to eliminate or reduce the standing wave and notching effects caused by optical reflectivity from the substrate, such as silicon, aluminium silicon metallization and, especially, from the topographic features. ARL techniques include the use of resists containing organic dyes [1, 2], sputtered amorphous thin film of silicon [3], and oxygen plasma treated metals such as Ti and W [4]. Titanium mononitride (TiN) has been reported [5] to have several applications in microelectronics such as acting as a diffusion barrier in ohmic contacts, a low barrier Schottky diode, and a gate electrode in MOS transistors. Rocke and Schneegans [6] studied TiN as antireflection control and hillock suppression on aluminium silicon metallization. However, TiN as an ARL on the aluminium coated silicon wafer for submicron photolithographic patterning by use of non-dyed and dyed positive resists has not yet been studied thoroughly. In this paper, we report that the notching and standing wave effects of both non-dyed and dyed positive resists with 0.8  $\mu\text{m}$  linewidth test patterns on TiN/Al/Si are eliminated under varying defocus conditions of a g-line stepper. Sheet resistivity and selective reactive ion etching between TiN and Al are also reported.

## 2. Experimental

TiN is deposited on silicon (TiN/Si) and on aluminium coated silicon (TiN/Al/Si) wafers with a MRC-ECLIPSE

reactive sputtering system under the following conditions: substrate temperature, 350 °C; DC power, 6 kW; bias voltage, 300 V; nitrogen gas, 25 sccm; argon gas, 80 sccm; pressure, 5–10 mTorr. Aluminium coating on silicon wafer (Al/Si) is also carried out with the MRC-ECLIPSE reactive sputtering system under the following conditions: loadlock, 200 °C; target, 325 °C; power, 22 kW; argon gas, 80 sccm.

Reflectivity is measured from a Hitachi 330 spectrophotometer equipped with a 60 mm diameter integrating sphere and an automatic reflectivity calibration system.

Non-dyed positive resist is TOK TSMR-8900 with a thickness of 1.33  $\mu\text{m}$ . Dyed positive resist is TOK TSMR-8900-MD2 with a thickness of 2.05  $\mu\text{m}$ . Resists are developed with a TRACK-DNS 636 single puddling system by use of TOK NMD-W developer containing 2.38% TMAH at 23 °C for 45 s.

Lithographic images are taken from a Nikon 1505 G6E g-line stepper with a NA value of 0.54 and a degree of coherence of 0.6.

Photographs of scanning electron microscopy (SEM) are taken from an Akashi Beam Technology Corp. SSRSE-2-4-401CL.

Sheet resistivity is recorded from a PROMATRIX-OMNIMAP RS-30 system by the method of four-point probe with a unit of  $\text{m}\Omega/\text{square}$ .

Reactive ion etching (RIE) is performed with an Applied Materials Precision Etch 8300A in an etchant gas mixture of 3 : 7  $\text{CHF}_3:\text{CF}_4$ .

Thickness measurements are taken from a TENCOR m-gauge 300 for Al, and a DEKTAK 3030 surface profilometer for TiN.

### 3. Results and discussion

Reactive sputtering coated TiN film on Al metallization or on Si wafer has a golden colour. TiN (3000 Å)/Si has a sheet resistivity ( $\rho_s$ ) of 2085 m $\Omega$ /□ which equals 62.6  $\mu\Omega$  cm. This value is very close to the reported value for TiN (Ti:N = 1:1) which is in the range of 65–75  $\mu\Omega$  cm [6]. TiN/Al/Si has a sheet resistivity of about 45 m $\Omega$ /□, similar to Al/Si up to the tested TiN thickness of 1200 Å as indicated in figure 1. The thickness of Al in Al/Si is 6400 Å which is often the thickness used for metallization. Al in TiN/Al/Si has the same thickness as that in Al/Si. TiN as ARL stabilizes the aluminium underlayer by compressive stress much the same as the glass passivation and results in the enhancement of electromigration. Consequently, TiN/Al/Si has a much lower  $\rho_s$  value than that of TiN/Si. Thus, by controlling the thickness of TiN within a reasonable range (less than 0.12  $\mu$ m is suggested), TiN/Al/Si can also be used as a metallization layer, the same as that often used Al/Si.

Figure 2 shows TiN/Al/Si reducing reflectivity at 436 nm (g-line) up to 75% compared to the reflectivity from surfaces of Si wafer or Al/Si. The reflectivities of the Si wafer and Al/Si under a g-line are about 99% and 98%

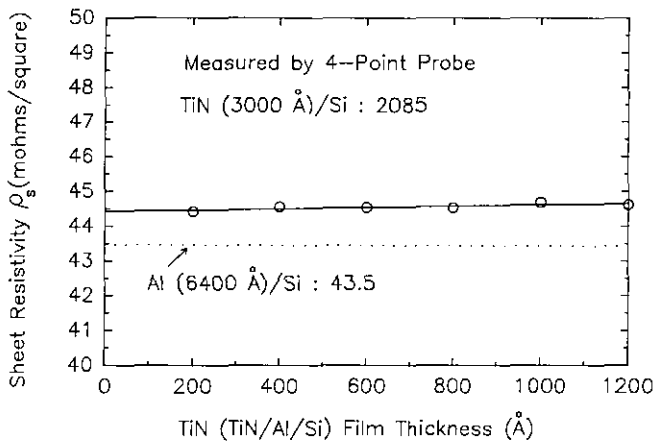


Figure 1. Sheet resistivity of TiN/Al/Si versus TiN thickness.

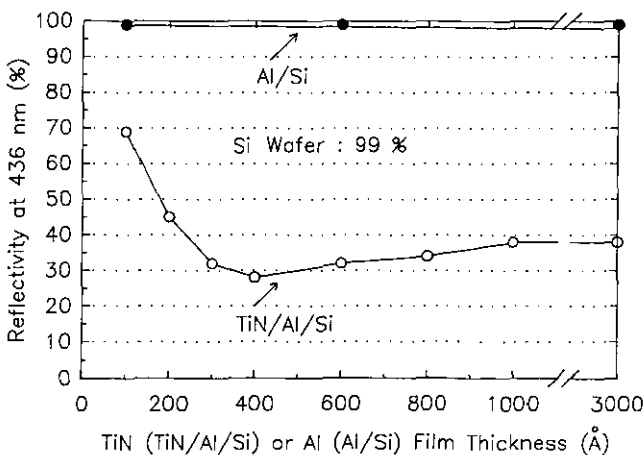


Figure 2. Reflectivity of TiN/Al/Si at 436 nm (g-line) as a function of TiN thickness.

respectively, as also shown in figure 2. The suitable thickness range for TiN as an antireflectivity layer of a g-line in TiN/Al/Si is 300–800 Å. The various reflectances at 365 nm (i-line) are shown in figure 3. The reflectivity of i-line can be reduced up to 85% by TiN/Al/Si. The suitable thickness range for TiN as an antireflectivity layer of i-line is 200–400 Å. The light wavelength (nm) at minimum reflectivity drifts to a longer wavelength and begins to level off around the g-line as the thickness of TiN in TiN/Al/Si increases up to the tested thickness of 3000 Å, as shown in figure 4.

The lithographic images of 0.8  $\mu$ m designed linewidth of non-dyed and dyed positive resists on TiN/Al/Si and Al/Si are shown in figures 5 and 6, respectively. SEM micrographs indicate that the notching and standing wave effects are eliminated from both non-dyed and dyed resists on the TiN/Al/Si, but not from the Al/Si. Defocus has a much greater effect on dyed resist than on non-dyed resist. The variations of profile dimensions are summarized in table 1 and are concluded as follows:

(1) The linewidth of non-dyed positive resists on TiN/Al/Si is found to be much larger than on the Al/Si under identical exposure doses and developing time. For dyed

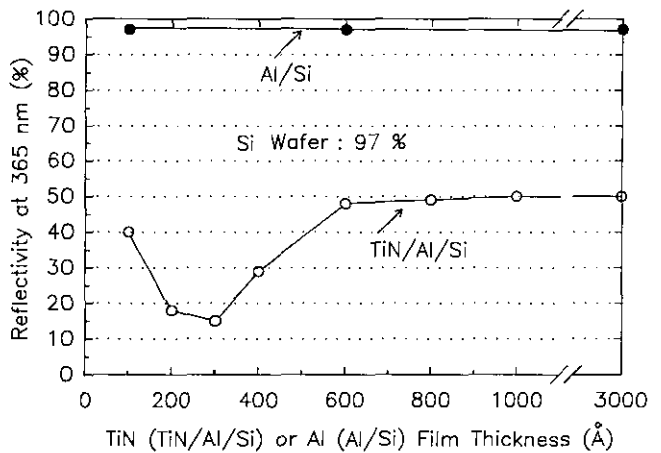


Figure 3. Reflectivity of TiN/Al/Si at 365 nm (i-line) as a function of TiN thickness.

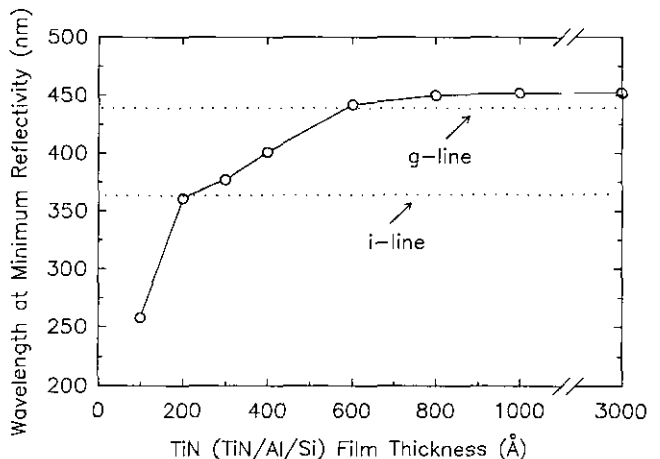
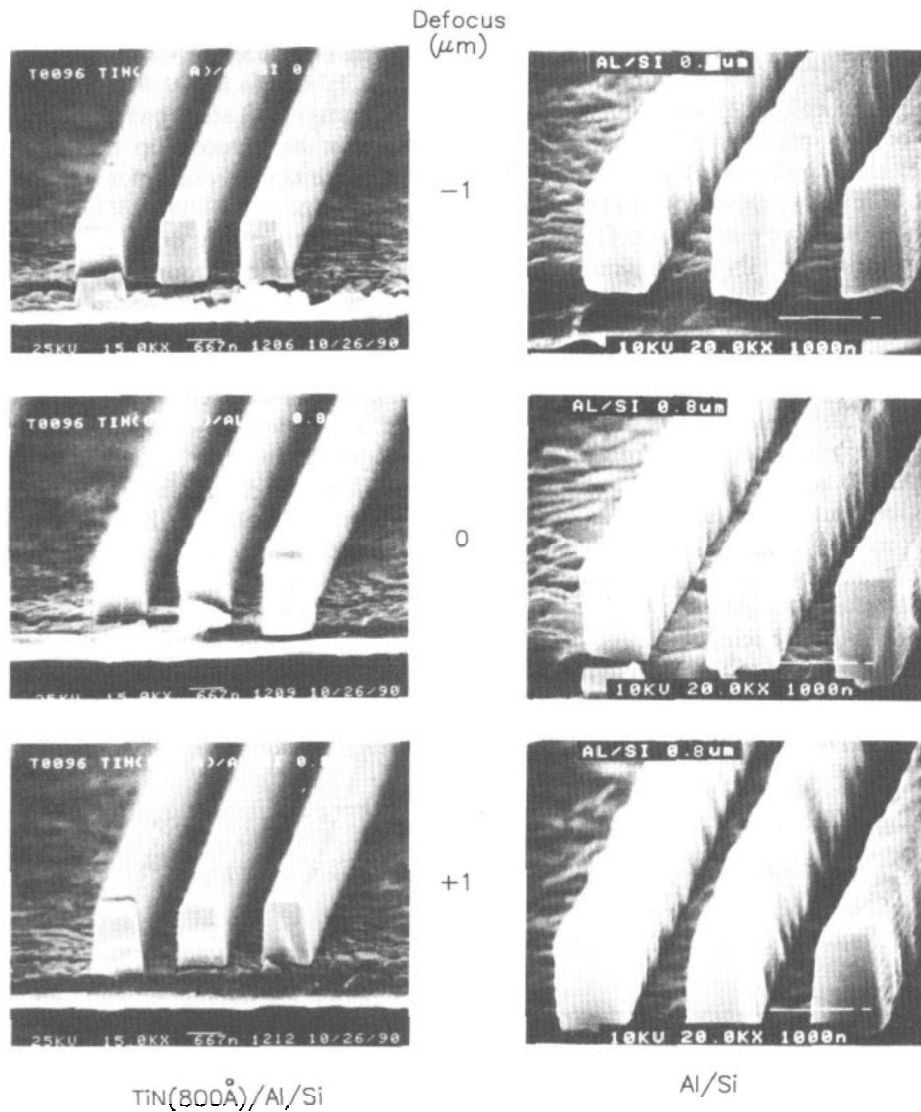


Figure 4. Wavelength at minimum reflectivity for TiN/Al/Si as a function of TiN thickness.



**Figure 5.** SEM micrographs of 0.8  $\mu\text{m}$  designed linewidth profiles of non-dyed positive resist (TOK TSMR-8900) on TiN/Al/Si and on Al/Si under defocus conditions of  $-1$ ,  $0$  and  $+1 \mu\text{m}$ .

**Table 1.** Measured profile dimensions of non-dyed and dyed positive resists on Al/Si and on TiN/Al/Si under varying defocus conditions.

Resist:	Non-dyed†			Dyed‡		
	-1	0	+1	-1	0	+1
Defocus ( $\mu\text{m}$ ):	-1	0	+1	-1	0	+1
Linewidth§						
Al/Si	0.70	0.70	0.75	0.83	0.81	0.81
TiN/Al/Si	0.93	0.93	0.87	0.84	0.82	0.83
Sidewall angle						
Al/Si	84	86	83	81	83	80
TiN/Al/Si	82	83	82	81	82	80

Designed linewidth:  $0.8 \mu\text{m}$ ; mask line = mask space.

† Non-dyed resist:  $1.33 \mu\text{m}$  thickness; exposure doses, developer and developing time are constant.

‡ Dyed resist:  $2.05 \mu\text{m}$  thickness; exposure doses, developer and developing time are constant.

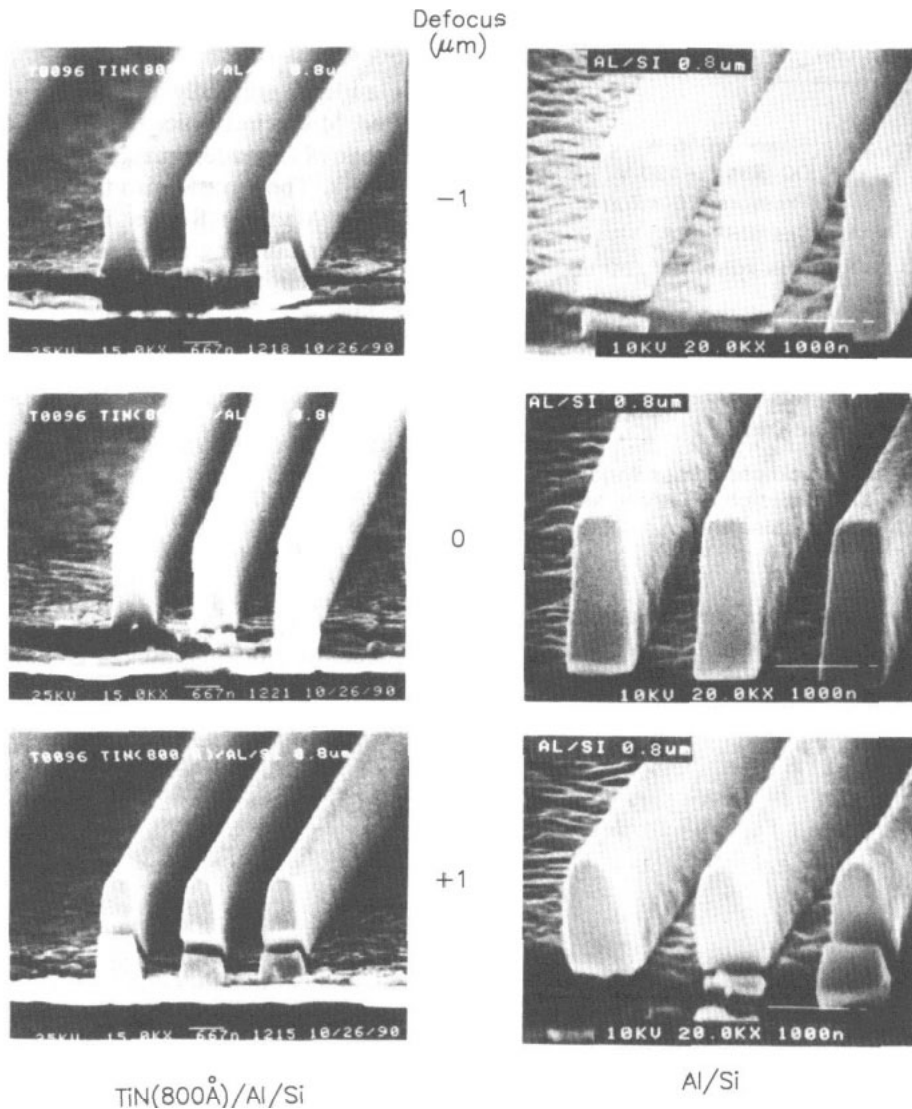
§ Linewidth: (bottom width of line/bottom width of pitch)  $\times 2 \times$  designed linewidth.

resist, the linewidth on TiN/Al/Si is only a little larger than on Al/Si.

(2) While the linewidth of non-dyed resist on TiN/Al/Si is larger than the designed linewidth of  $0.8 \mu\text{m}$ , the linewidth on Al/Si is smaller than  $0.8 \mu\text{m}$ . The linewidth of dyed resist either on Al/Si or on TiN/Al/Si is very close to the designed  $0.8 \mu\text{m}$ .

(3) Under g-line exposure of no defocus (defocus = 0), the sidewall angles of all cases are closer to  $90^\circ$  (vertical profile) than those under exposure with defocus ( $-1$  and  $+1 \mu\text{m}$ ). The sidewall angle of non-dyed resist on Al/Si is nearer  $90^\circ$  than on TiN/Al/Si. The sidewall angle of dyed resist does not show much difference between Al/Si and TiN/Al/Si. From comparison between non-dyed and dyed resists, the general conclusion is that non-dyed resist has a sidewall angle nearer to  $90^\circ$  than dyed resist.

The above conclusions obviously result from the various intensities of reflectivity at the bottom of resists of the exposed areas which are dissolved by the deve-



**Figure 6.** SEM micrographs of  $0.8\ \mu\text{m}$  designed linewidth profiles of dyed positive resist (TOK TSMR-8900-MD2) on TiN/Al/Si and on Al/Si under defocus conditions of  $-1$ ,  $0$  and  $+1\ \mu\text{m}$ .

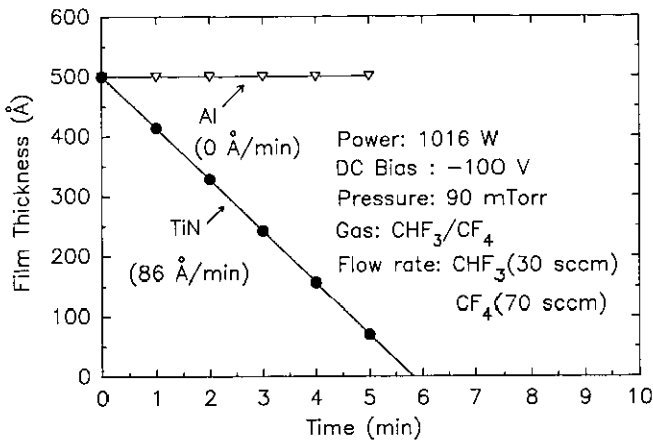
loper. The higher intensity of reflectivity at the bottom of a non-dyed resist in an exposed area results in a narrower unexposed area after developing. Consequently, the linewidth is smaller and the sidewall angle is nearer  $90^\circ$  for non-dyed resist on Al/Si than for TiN/Al/Si. For dyed resist, the intensity of reflectivity from the substrate is weak. Therefore, its effects on the linewidth and sidewall angle are also very small or not obvious.

Figure 7 shows the selective reactive ion etching between TiN/Si and Al/Si in  $3:7\ \text{CHF}_3:\text{CF}_4$  under  $-100\ \text{V}$  DC bias. It was found that the DC bias is very critical to achieve this selective etching. Under the condition of a DC bias more negative than  $-100\ \text{V}$ , Al will also have a certain etch rate. Etching selectivity between TiN and Al is decreased in such a case. If the DC bias is less negative than  $-100\ \text{V}$ , the RIE system for this study has difficulty in maintaining the plasma glow. The plasma glow is quenched very often in such a case. The good selective etching between TiN and Al in the TiN/Al/Si

system is useful for electrical connection. By etching away the top layer of TiN and maintaining the bottom layer of Al, improved electrical contact via hole to Al layer can be achieved.

#### 4. Conclusions

TiN as an antireflection layer in TiN/Al/Si has been demonstrated to be effective for a g-line stepper. Both notching and standing wave effects of non-dyed and dyed positive resists are eliminated. While the sidewall angle of non-dyed resist on TiN/Al/Si is nearer  $90^\circ$  than on Al/Si, there is little difference in sidewall angle of dyed resist between those on TiN/Al/Si and on Al/Si. Since TiN also reduces reflectivity at the wavelength of i-line ( $365\ \text{nm}$ ) up to 85% of the reflectivity of the Al surface, reduction or elimination of notching and standing wave effects are



**Figure 7.** Plots of remaining thickness versus various RIE etching times for Al and TiN coated on Si wafers. RIE conditions and etching rates are also shown.

also postulated for an i-line stepper. Besides, as a conventional diffusion barrier, TiN/Al/Si can also function as an antireflection layer and a metallization layer.

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