Journal of Manufacturing Engineering, 2009, Vol.4, Issue.1

NOVAL ATOMIC LAYER DEPOSITION FOR ADVANCED TUGSTEN NUCLEATION LAYER FOR NANO STRUCTURES

Jagadeesha T[1] and Daping Yao[2,] Kimberly Branshaw[3] and **Louis Kim[4]**

[1] AIT, Chikmagalur
[2] Process Engineer,Applied Materials, Singapore,
[3]Section Manger-CVD,CSM Technologies, Singapore

ABSTRACT

As the contact size shrinks below 0.13 micron with high aspect ratio, the conventional CVD W can not achieve compete fill due to inadequate step coverage of nucleation process. Thin film of W grown by atomic layer deposition (ALD) with WF_6 and B_2H_6 chemistry technique, on the other hand, shows 100% step coverage confirmed by TEM. It can be applied as an advanced nucleation layer for CVD W deposition. In this paper, we discuss process development for 300mm ALD W chamber and present film characterization results

Keywords: Nucleation layer, CVD, W deposition, CVD Film

1. INTRODUCTION

ULSI Chips use dielectric materials to store charge and to isolate the metal lines that connect circuit elements. The later application , Inter meta- dielectric or IMD requires that approximately 1 micron thickness or even less to be deposited between the metal layers and that sub- micron gaps between lines within a layer to be completely filled. IMD is also used to planarise each layer of metal globally in order to comply with optically lithography depth of focus limitations. HDP CVD is needed for IMD gap fill because of deficiencies in other technologies. HDP-CVD will also be needed, although to a lesser extent, for PMD and STI

The wafer industry is in process of developing a low dielectric constant material that offers the capability to gap fill narrow metal interconnects in 0.18 micron and 0.15 micron devices. Many chemistries have been tried that either CVD or spin-on technologies. A material deposited with CVD includes fluorosilicate glass, parylenes, and polymides. Spin –on dielectric includes poymides, methyl silsesquinoxanes, and hydrogen silsesquinoxanes (HSQ). The later has been widely used in the 2.9-3.3 range, and good planarization. On the other hand, CVD fluorosilicate glass deposited in an HDP reactor has shown good gap-fill capability and film stability for a dielectric constant as low as 3.5. Despite a higher bulk dielectric constant than HSQ, FSG for sub-0.25 micron applications has exhibited a dielectric constant that is competitive with integrated HSQ. Conformity of a film refers to its capability to exactly reproduce the surface topography of the underlying substrate. The need for conformity arisesbecause microelectronic processing proceeds by successively depositing and patterning features on thin films. If the successive films do not follow the patterns created on the previous layers, voids in deposited layers begin to form , etching these layers may be difficult and result in stringers. These can lead to electrical shorts and opens or to failures caused by trapped materials in the voids. Voids can also be opened by later CMP steps and filled with corrosive slurry material.

Conformality over a right angled step is termed step coverage and refers to thinning of the film when covering a surface normal to substrate plane. Uniform step coverage results when reactants or reactive intermediates adsorb on the surface with sticking coefficients big enough for a reasonable net deposition rate, yet, small enough to allow for multiple desorption and re-adsorption to the surface before chemisorption. The multiple surface collision behaviors results in a uniform surface concentration, regardless of topography and gives a uniform film thickness.

Multiple surface collision behaviors is usually associated with a relatively weak bonding of the film precursor to the substrate, physisorption with energies less than 0.5eV. An example of such a mechanism and step coverage is oxide with TEOS, either plasma enhanced (PECVD) or with ozone/TEOS (SACVD). When film precursor adsorbs initially with stronger bonding to surface, chemisorption with energies in excess of 2eV takes place very few surface collisions and the deposition rate is proportional with the arrival angle of the gas molecule.

Corresponding author: *jagdishsg@yahoo.com*

2. PROBLEM ADDRESSED

As feature size shrink continues for advanced interconnect for IC fabrication, the requirement for the unit process gets increasingly stringent. For tungsten plug application, it means smaller contact/via size and higher aspect ratio. For 0.10 micron generation device, the contact size is ~0.13 micron with an aspect ratio exceeds 15 for some DRAM applications. Most common problem with conventional CVD W process is the void or seam formation due to incomplete fills on high aspect ratio vias. The problem can be attributed to poor step coverage of nucleation layer deposited by WF_6/SiH_4 chemistry

3. METHODOLOGY USED

We approach this nucleation problem of CVD tungsten with new method of depositing a film with Atomic Layer Deposition (ALD). ALD process consists of self-limiting surface reactions, and control the film growth by sequential flow of two reactants separated by inert gas as illustrated in **Figure 1.0**. and **Figure 2.0** ALD process eliminates any gas phase reaction, and provides a film deposition with superior conformality. The concept of ALD in film deposition has been demonstrated in many different materials such as oxides, nitrides, and single component metals [1-4]. For W nucleation application, WF_6 chemistry with B_2H_6 as reducing agent was used

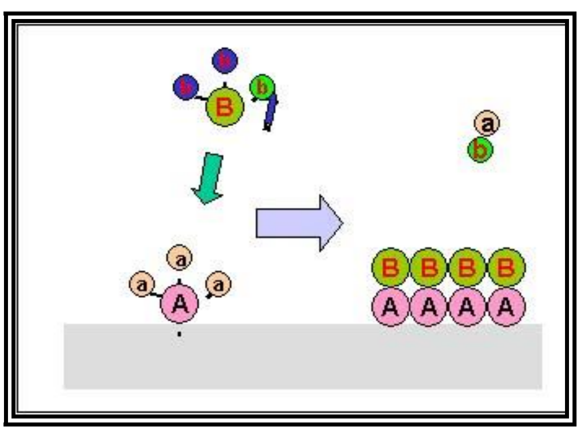


Figure 1.0 The principles of Atomic Layer Deposition

ALD W chamber is installed on an Endura SL W CVD system. After nucleation layer deposition, bulk W film can be deposited on any WxZ chambers on the same mainframe. After installation all the necessary procedures are followed as per the installation guides and process is set up according and process is set up according to the needs of the experiments to be conducted on the chamber.

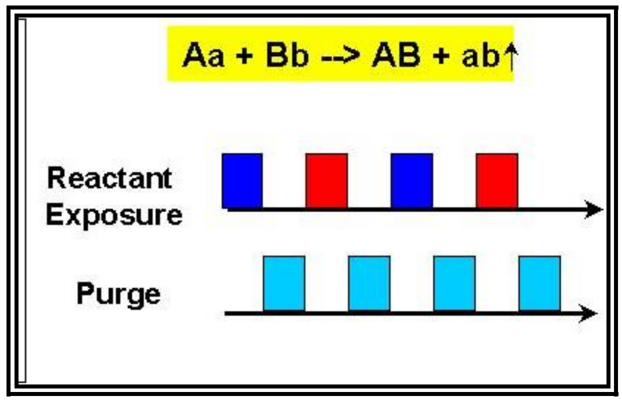


Figure 2.0 The principles of Atomic Layer Deposition

4. EXPERIMENTAL DATA AND NALYIS

In order to verify whether the process is truly in ALD mode, the film thickness (deposition rate per cycle) was first measured as a function of reactant gas flow and exposure. As shown in **Figure 3.0** and **Figure 4.0** , the film thickness saturates with the reactant gas flows or exposure.

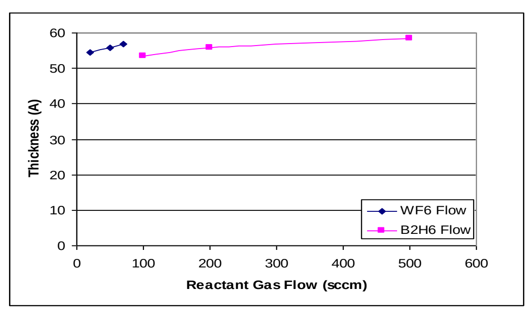


Figure 3.0 Film thicknesses as functions of WF_6 and B_2H_6 flow at 300°C with 20 cycles

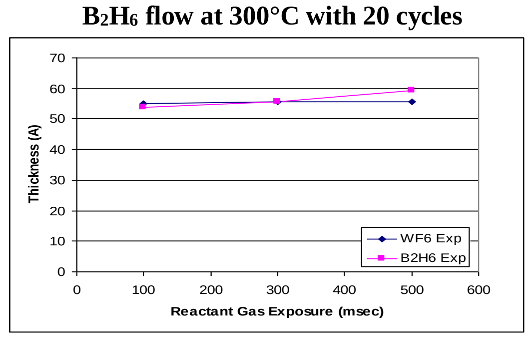


Figure 4.0 Film thickness as functions of WF_6 and B_2H_6 exposure at 300°C with 20 cycles

The other test for ALD process is a linearity test, which examines the film thickness as a function of cycle number in film deposition. **Figure 5.0** shows the linearity test with three different B_2H_6 soak step times prior to deposition step. No incubation cycle was observed for substrates used for these tests (2x50 or 2x30 MOTiN).

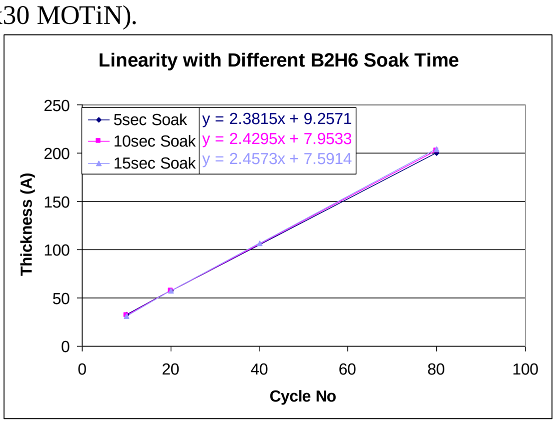


Figure 5.0 Film thickness as a function of cycle number in deposition step with different B_2H_6 soak step. On MOTiN (either 2x50 or 2x30) no incubation cycle was observed with B_2H_6 soak step

Step Coverage

As mentioned earlier, due to the self-limiting nature of ALD process, it yields superior step coverage as shown in **Figure 6.0 and Figure 7.0**

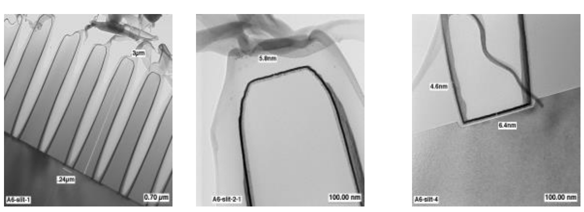


Figure 6.0 TEM pictures of ALD W film deposited on TiN. - 100% step coverage on 0.24micron feature with 12.5:1 aspect ratio

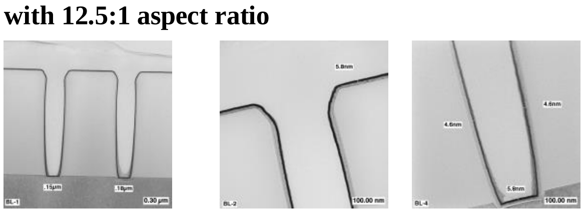


Figure 7.0 TEM pictures of ALD W film deposited on TiN. - 100% step coverage on 0.15micron feature with 8:1 aspect ratio

Film Properties

Film properties are summarized in following **Table 1.0** , along with process engineering specifications

Item	Alpha exit	Current Performance
Process Temperature (heater)	<400 C	300C
Rs Non uniformity (50Å), WIW	<5.0%, 1s	2.5%, 1σ
Rs Non uniformity (50Å), WTW	<5.0%, 1s	3.95%, 1σ
Thickness Non uniformity (50Å), WIW	<5.0%, 1s	3.95%, 1σ
Thickness Non uniformity (50Å), WTW	<5.0%, 1s	1.88%, 1σ
Bulk Resistivity	≤ 180 μΩ-cm	161 μΩ-cm
Step Coverage	> 95%	100%
Film reflectance (@480nm)	>100 %	>100%
Stress	<1.0 E10	8E+09
F content	<5E18	7E+17

Table 1.0 Summary of ALD W film properties

Several analyses were carried out for 300Å thick ALD W film deposited on MOTiN substrate. SIMS analysis **Figure 8(a)** shows F level of $7x10^{-17}$ atoms/cm^3 in ALD W film, which is more than one order of magnitude lower than F level in CVD W film. However, ALD W film from WF_6 and B_2H_6 chemistry contains a high level of boron in the film as shown in **Figure 8(b).**

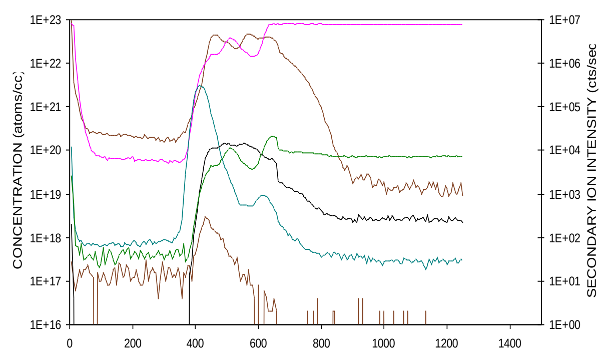


Figure 8(a) Film composition analysis of 300Å ALD W deposited on TiN (a) SIMS analysis, (b) Depth-profile XPS analysis results

X-ray diffraction (XRD) results indicate that ALD W film has a nano crystalline structure with 10Å grain size. AFM reveals surface roughness of 300Å film was measured to be 6.81 Å, rms. **Figure 9** is the XRD spectrum of ALD W and grain size analysis

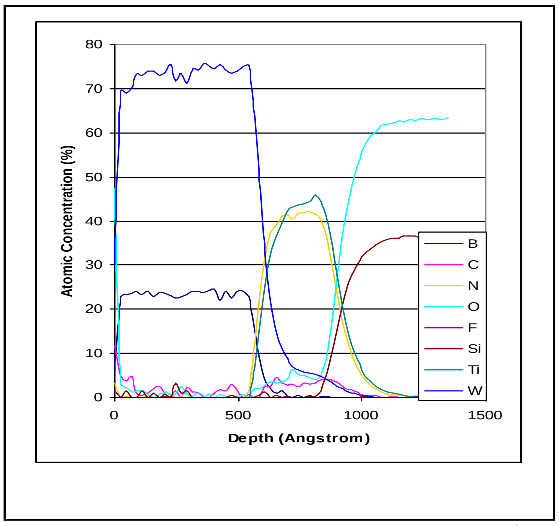


Figure 8(b) Film composition analysis of 300Å ALD W deposited on TiN Depth-profile XPS analysis results

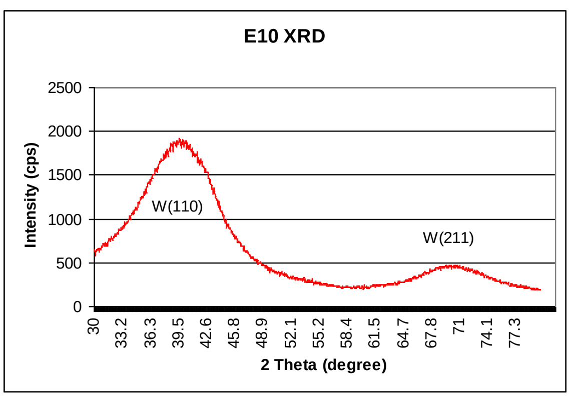
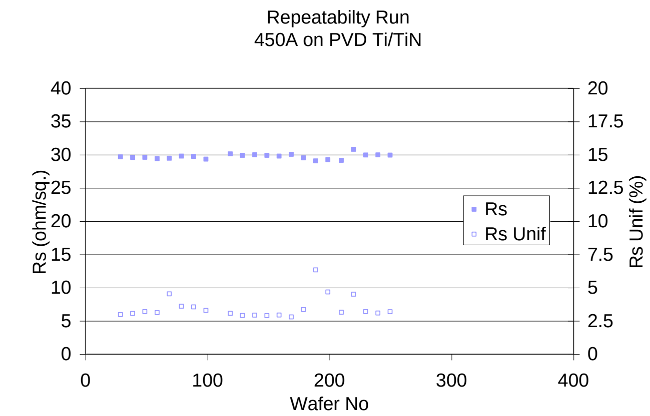


Figure 9. XRD of 300 Å ALD W on TiN/SiO2 substrate. The grain size from the peak width turns out to be 10 Å.

5. CONCLUSION

ALD W film provides an advanced nucleation layer for bulk W film. The integration of ALD W and CVD bulk film is the key to process integration and device performance. The issue in W ALD nucleation / W CVD bulk deposition includes film adhesion on different Ti/TiN substrate, F attack of WF6 on substrates, edge exclusion for entire film stack, gap fill capability and device data such as contact resistance and leakage current. Through internal tests and selective customer demos, we have started to collect data on integration of ALD nucleation and CVD bulk deposition.Meanwhile, the process stability as well as the system reliability on Endura SL mainframe will be verified through a marathon, which is underway. Initial



350-wafer process stability check reveals a stable deposition process for 450Å film as illustrated in

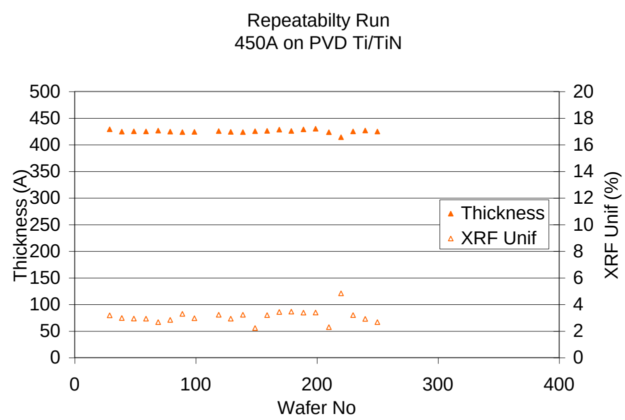


Figure 10. 350-wafer process stability for 450Å ALD W film (a) Rs and Rs uniformity (b) Thickness and XRF uniformity

6.REFERENCES

[1] T. Suntola, Thin Sold Films, 216, 84 (1992)
[2] J.W. Klaus, A.W. Ott, A.C. Dillon and S.M George, Surf. Science., 418, L14 (1998)
[3] A.W. Ott, J.W. Klaus, J.M. Johnson and S.M George, Thin Sold Films, 292, 135 (1997)
[4] J.W. Klaus, S.J Ferro and S.M George, Applied. Surface. Science, 162, 479 (2000)
[5] Hichem M'saad, Manoj Vellaikal. Integration of HDP-FSG as ILD materials in multilevel interconnect devices. DUMIC catalogue #999IMIC-444D (1999), 210-220.
[6] T. Suntola, "Atomic Layer FSG", Materials Science Reports, Volume 4, number 7, December 1989, 0920-2307/89, Elsevier Science Publishers B.V