Characterizing TiN Resistivity using Plasma Enhanced Atomic Layer Deposition with TDMAT

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Abstract:

The effects of multiple deposition parameters on the plasma enhanced atomic layer deposition (PEALD) of conductive titanium nitride (TiN) films were investigated. Specifically, effects of plasma pressure and time on TiN resistivity were characterized. Optimum growth conditions for minimum film resistivity was determined to be: plasma power of 500W, precursor gas of ammonium (NH_3), chamber pressure of 2 mTorr, and a plasma time of 30 seconds. The minimum achieved resistivity was found to be 175 $\mu\Omega$cm.

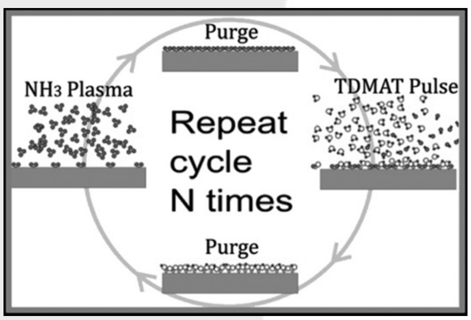

Figure 1: ALD process.

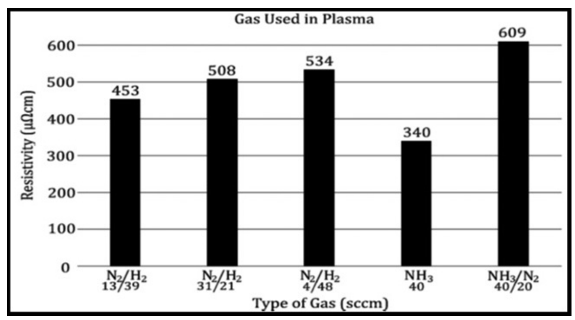

Figure 2: Plasma composition on resistivity.

Introduction:

There is a constant need for faster devices and communications. As devices are pushed to faster speeds though, frequency becomes a limiting factor. Atomic layer deposition (ALD) conducting films are used in modern electronics due to their properties of low resistivity and ability to evenly coat high aspect ratios allowing for more advanced devices. Titanium nitride (TiN) is often chosen due to its ideal properties of low resistivity. TiN is deposited by flowing tetrakis (dimethylamido) titanium (TDMAT) into the ALD chamber followed by, an argon (Ar) purge, a N_2/H_2 plasma treatment, and another Ar purge. This cycle is shown in Figure 1 and is repeated until the desired thickness is reached. This study provides an investigation of the effects of NH3 plasma pressure on film resistivity as well as a review of these other reported variables regarding TiN.

Experimental Procedure:

The ALD system used was an Oxford FlexAL remote plasma system. Silicon <100> substrates involved were coated by an insulating layer. The plasma parameters in the ALD cycle were varied one at a time to observer their effects on resistivity. An SEM/ellipsometer and four-point probe were used to record results.

Results and Discussion:

Plasma Power. The dependence of resistivity on plasma power was studied. Increased plasma power enhances film density by compacting layers [1] and more completely removing ligands contained in TDMAT. The denser film prevents oxygen diffusion into the material upon exposure to atmosphere [2, 3] preventing the formation of TiO_2 and other compounds that increase the resistivity [2, 4]. Plasma power increased to the maximum allowed of 500W provided the lowest resistivity.

Plasma Composition. The dependence of plasma composition was studied and results are listed in Figure 2. A stoichiometric ratio of 1:3 N:H was found to be optimal. Implementing this ratio in N_2/H_2 plasma yielded the lowest resistivity for any combination. Preserving this stoichiometric ratio, NH_3

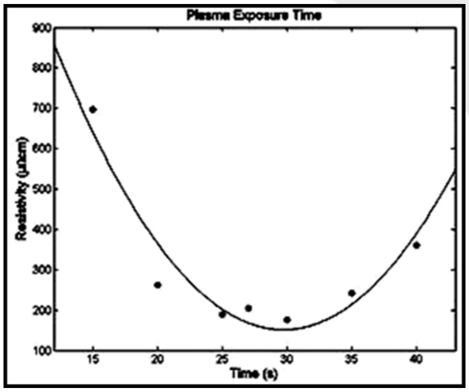

Figure 3: The effect of plasma exposure time on resistivity.

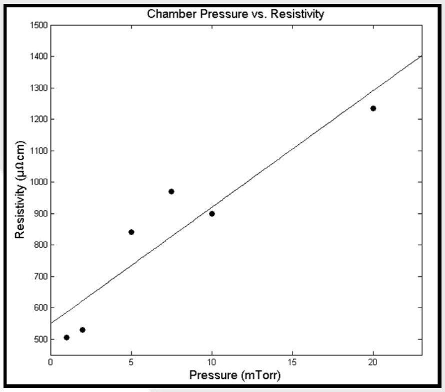

Figure 4: Chamber pressure effects on resistivity.

was also used, which yielded a lower resistivity. A possible explanation for this is that more NH_x radicals are formed [5].

Plasma Time. The duration of the plasma was found to have a significant impact on the resistivity. As Figure 3 shows, the effect of timing exhibits a parabolic like effect on the resistivity. Short timing can lead to greater carbon contamination while longer timing gives higher resistivity also, possibly due to plasma damage. An ideal time of 30 seconds was experimentally determined to give the lowest resistivity.

Chamber Pressure. For the first time, chamber pressure was varied during the plasma exposure and effect on resistivity studied. A trend was observed that has you decrease chamber pressure the resistivity is significantly lowered. This is shown in Figure 4.

Combining all optimal parameters described above, the minimum TiN film resistivity achieved was 175 $\mu\Omega$cm for a 35 nm thick film. The optimal process determined is outlined below:

1. Dose TDMAT: 2 seconds, 200 mT, 100 sccm Ar
2. Purge TDMAT: 5 seconds, 20 mT, 200 sccm Ar
3. Pump TDMAT: 5 seconds
4. Plasma Dose: 30 seconds, 2 mT, 10 sccm NH_3, 500W
5. Purge NH_3: 5 seconds, 20 mT, 200 sccm Ar
6. Pump NH_3: 4 seconds

Repeat.

Conclusions:

The effects of chamber pressure and a review of additional plasma parameters on ALD TiN film resistivity were studied. It was found that NH_3 plasma as a precursor more effectively reacts with TDMAT. Increased plasma power and plasma exposure time (t < 30 seconds) decrease film resistivity due to a denser film. Combining all optimized parameters, a resistivity of 175 $\mu\Omega$cm for a 35 nm thick film was realized. Denser, less resistive, ALD TiN films have many advantages for future integration into microelectronic devices.

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References:

[1] S. Chang, et al., Surface and Coating Technology, 203, (2008).
[2] H. Kim, JVSTB, 21, (2003).
[3] G. Cho and S. W. Rhee., JVSTA, 31, (2013).
[4] J. Musschoot, et al., Microelectronic Engineering, 86, (2009).
[5] M. Hua, et al., Wear, 260, 11-12 (2006).