Pure & Appl. Chem., Vol. 62, No. 9, pp. 1757–1760, 1990.
Printed in Great Britain.

The effect of non-reactive ions on the properties of PECVD (plasma enhanced chemical vapor deposition) TEOS (tetraethoxysilane) oxides

A.S.Harrus, G.W. Hills, M.J. Thoma

AT&T Bell Laboratories 555 Union Boulevard Allentown, PA 18103

Abstract

In this paper, we investigate the effects of argon and oxygen ions on previously deposited oxide films. Ion bombardment is used to modify the step coverage of plasma oxide films to improve their performance for multilevel metal technologies. The films discussed include PECVD TEOS and Ozone TEOS. We report on the contaminants introduced and on the physical and electrical modification of the films characteristics.

1 INTRODUCTION

The process sequence for interlevel oxide, i.e. the dielectric between metal levels in advanced multilevel metal technologies, presents a large number of challenges. In the 0.9 um /1//2/ and 1.25 /3/ -minimum dimension two level metal CMOS technologies currently in production at AT&T, plasma-enhanced TEOS, PETEOS is used /4/. One of the important issue with the use of PETEOS as an interlevel dielectric is the quality of the step coverage, the formation of "low-density" regions and sufficiently smooth final profiles to ensure acceptable aluminum step coverage at all line spacings within the device. This paper focuses on the use of physical sputtering as a mean of profile control for PETEOS. We also consider Ozone based TEOS films which are of poorer quality (hygroscopic) but have the advantage of a far superior step coverage. We are attempting to improve the film physical characteristics with physical sputtering.

2 EXPERIMENTAL METHOD

Multiple depositions were performed by turning the RF on and off at regular intervals. With a slight HF decoration, the outline of each layer can be seen with Scanning Electron Microscope. This method allows an easy measurement of growth contours, stress lines, void and low density region formation, etched profiles and sputter etch rates. The depositions were done in a single wafer reactor, at high frequency and high power. The sputter conditions were as follows: AMAT P5000 single wafer etcher, pressure 30-120 mTorr, flow 50sccm, magnetic field 80 Gauss, power 300-500 Watts, gas Ar or O_2. Film deposition and sputtering were done on aluminum patterns and SEMs were taken to analyze the profiles. The wet etch rate was measured in 100:1 H_2O:HF as a function of time to try to measure in-depth film modification induced by the sputtering. Electrical properties were measured using the Triangular Voltage Sweep Technique /5/. This methods allows measurement of leakage current through the dielectric and mobile ions contaminants that are electrically active (sodium). Finally, SIMS analysis was performed to provide information on contaminants introduced by the sputtering (Na, Cr, Al).

3 RESULTS AND DISCUSSION

Figure 1 shows a TVS trace of a PETEOS film submitted to 8 minutes of Argon sputter. The leakage current has not been affected and has approximately the same value than the as-deposited PETEOS (Refer to Figure 2). The amount of electrically active sodium is high (3.7 E 11) and this level would impact negatively on the device performance /6/.

Figure 2 shows the increase in the sodium level as a function of the sputter times. The measurement were performed using TVS and SIMS analysis. The numbers are in very close agreement, showing that the sodium present in the film is electrically active. There is no significant difference in the amount of sodium introduced by Argon sputtering and Oxygen sputtering. On the right axis of Figure 2 we show that the leakage characteristics of the dielectric does not seem to be affected by the sputtering.

Figure 3 shows TVS curves for an Ozone film with 4 minute of Argon sputter. Note that the voltage sweep is now from -10 V to +10 V as opposed to -100 V to +100 V for the PETEOS case. Higher voltages would lead to enormous leakage currents. Already, at 10 V, the leakage of the Ozone film is already far greater than the leakage of PETEOS at 100 V. The leakage current is attributed to the presence of moisture in the film /5/, as further evidenced by the successive traces denoted run 2, 3 and 4. The test is performed at 300 C and the wafers remains on the hot chuck for about 20 minutes. When the test is repeated a second, third and fourth time, the leakage current decreases as a function of the time spent at elevated temperature. This also shows that the Argon sputter has not "densified" the film and made it less hygroscopic.

Figure 4 shows the effect of the sputtering on the Wet Etch rate. The film thickness was measured after successive exposure to 100:1 H_2O:HF and plotted versus time. The slope of the curve represents the etch rate. If the film is uniform throughout, the curve should be a straight line without any break. Furthermore, the higher the

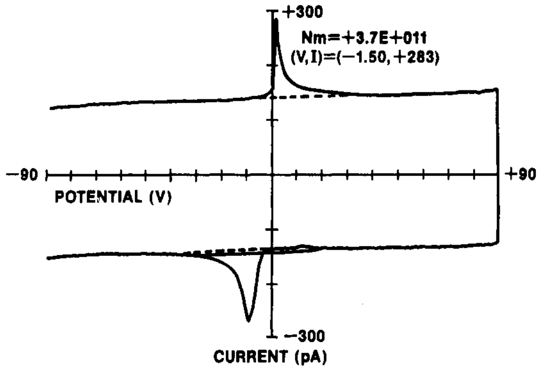


Figure 1: TVS of PETEOS + 8 minutes Argon Sputter, Na Contamination

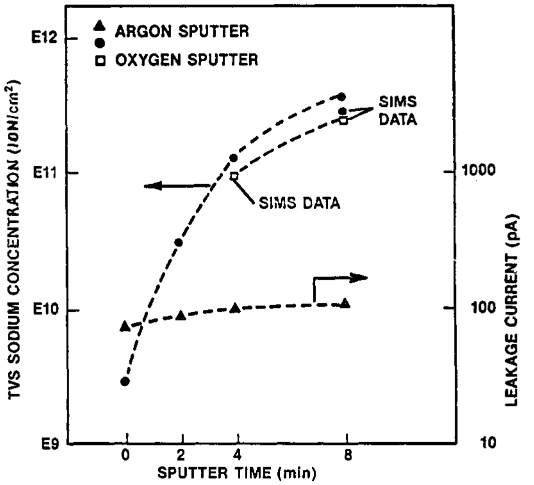


Figure 2: Sodium Contamination (TVS and SIMS) versus Sputter Time

5000 OZONE + 4 MINUTE ARGON SPUTTER

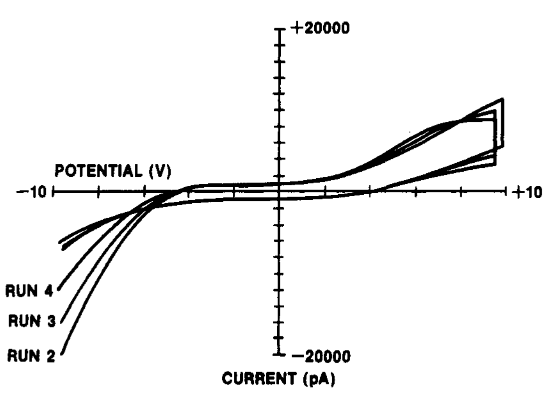


Figure 3: TVS of Ozone TEOS versus Time. Effect of water degassing on leakage current.

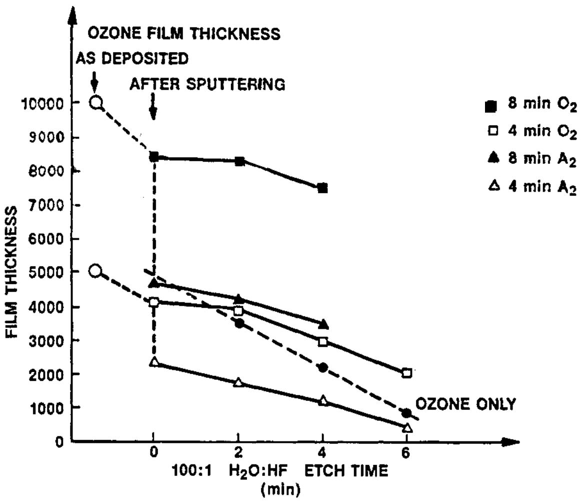


Figure 4: Wet Etch Rate for Sputtered Films.

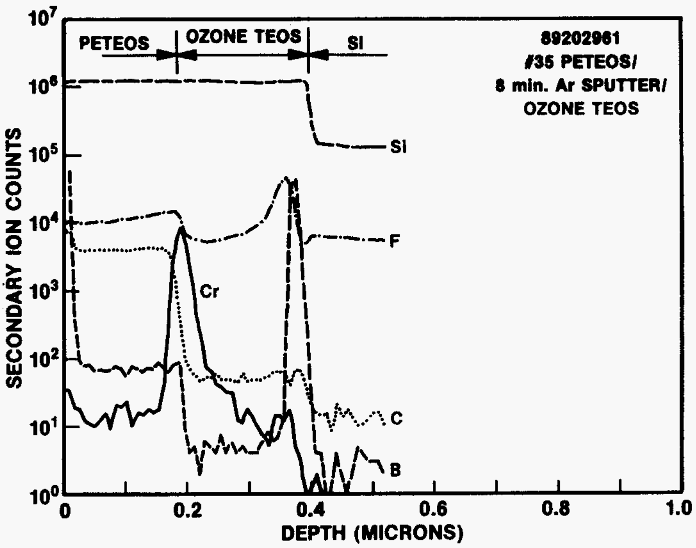
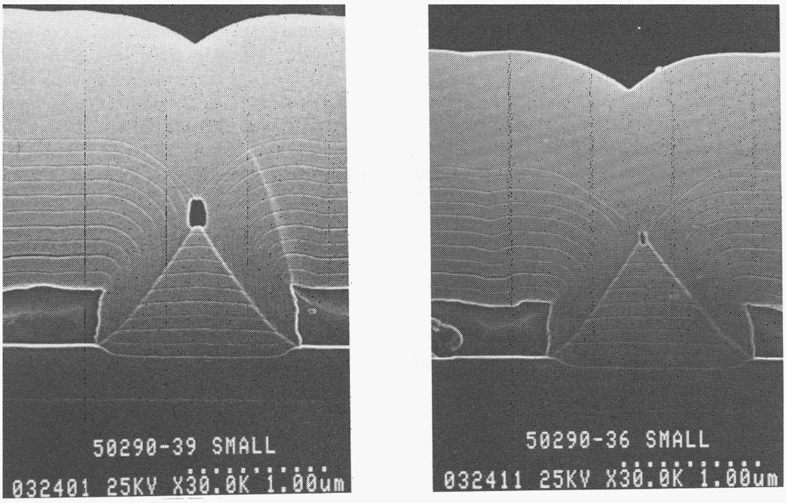
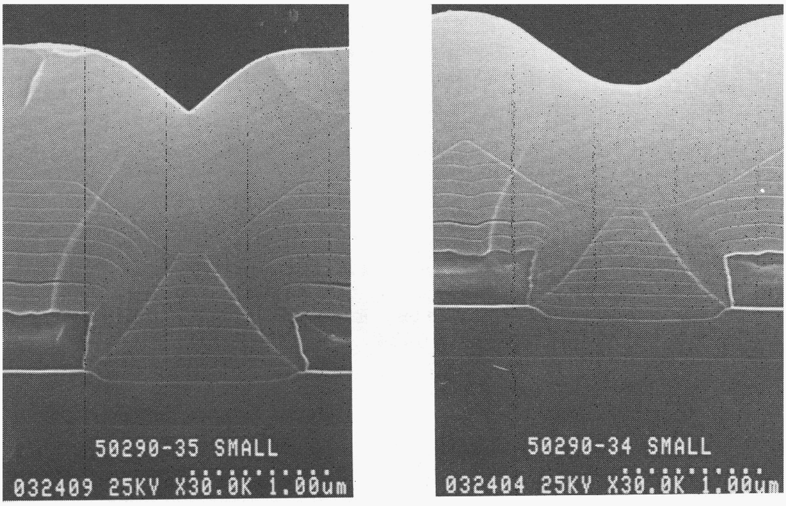


Figure 5:
SIMS Profiles for Cr, C and F for 8 minutes Argon Sputter.



(a) 1 min **(b) 2 min**



(c) 4 min **(d) 8 min**

Figure 6:
PETEOS: Ar SPUTTER ETCH PROFILE – VOID ELIMINATION

Process: 12.5kÅ (multiple); Ar sputter; 10kÅ (single)

slope, the higher the etch rate. All the sputtered films show a lower slope than as-deposited Ozone TEOS. Furthermore, there seems to be a slight break in the line at the 2 min mark for the Oxygen-sputtered films only. Argon seems to affect the film trough the whole thickness while Oxygen seem to only modify a top layer.

Figure 5 shows a SIMS profile of an 8-minute Argon sputtered Ozone TEOS film. The high chromium levels at the interface Ozone TEOS-PETEOS cap (also present is aluminum not shown in the trace) shows impurity introduced by the sputtering process. These levels of contamination are considered high even though the effects on device performance are not fully known.

Figure 6 shows SEMs of PETEOS Argon-sputtered for 2, 4 and 8 minutes. The void present in the as-deposited SEM disappear as a function of increased sputter time. Furthermore, the surface topography of the film interface with the PETEOS cap layer becomes smoother.

4 CONCLUSIONS

Physical sputtering is an efficient method of profile control. The difference between Argon and Oxygen is the sputter etch rate; the profile modification is very comparable. Physical sputtering is not capable of improving the quality of an Ozone TEOS film. The film remains hygroscopic and we have found it very electrically leaky. The profile modification scheme should therefore be used with a good quality dielectric to start with. The major drawbacks of physical sputtering are low rates and introduction of contaminants. The low etch rate are a hindrance to manufacturable processes since they limit throughput. However ways can be devised to increase the sputtering rate. More importantly, contaminants (mobile ions such as sodium) and metal impurities (Aluminum and Chromium) are much more detrimental to the device operation. The sources **must be removed** for the scheme to be useful.

Acknowledgements

Many people contributed to the results presented in this paper. We would like to thank W.Cochran, C. Lawrence and L. Olmer for worthy discussions, and K. Olasupo for assisting with the experiments. Finally, F. Stevie who provided SIMS analysis and B. Snyder SEM support.

REFERENCES

/1/ M.L. Chen et al., IEDM Technical Digest, p 256-259 (1986).
/2/ G.W. Hills et al., IEEE VMIC Proceedings, p 35-42 (1988).
/3/ M.J. Thoma et al., IEEE VMIC Proceedings, p 20-26 (1987)
/4/ L.J. Olmer et al., Proc. Electrochem. Society, Philadelphia PA May 1987.
/5/ N. Lifschitz and G. Smolinsky, J. Electrochem. Soc. August 1989
/6/ M. Thoma et al., Proceedings 1989 TMS Electronic Device Material Conference, Las Vegas.

A.S. Harrus current address: NOVELLUS Systems, Inc, 3950 North First Street, San Jose, CA 95134.
G.W. Hills current address: Applied Materials, Etch Division, 2685 Augustine Drive, Santa Clara, California 95054.