# PREMETAL PLANARIZATION USING SPIN-ON-DIELECTRIC

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## ABSTRACT

A silicate type spin-on-glass (SOG) has been used to planarize topography prior to metal deposition. Spin-on-glass was chosen for this application because of the simplicity associated with processing. The topography smoothing capability was shown to be comparable to flowed CVD oxide. It was found that curing the SOG in a dry oxygen ambient caused the film to densify poorly and to result in inferior dielectric properties. Performing the cure in a steam ambient however resulted in films with dielectric properties on par with CVD oxide films. This dielectric was used successfully in a 1.0 micron double level metal process without degrading device performance. It was shown that the film may not need to be fully densified in order to be used in this application. Temperature/humidity testing showed no anomalous effects to devices due to moisture absorption or film delamination.

## DIELECTRIC PROPERTIES

A phosphorus doped silicate SOG was used so as to getter mobile ion impurities and to be compatible with a preceding doped CVD oxide layer. The doping of the CVD oxide was chosen such that its etchrate in buffered oxide etch matched that of the SOG. The PSG/SOG dielectric layer was densified in a steam ambient. The steam ambient was found to result in superior dielectric qualities when compared to oxides densified in a dry O2 ambient. The capacitance-voltage (C-V) measurements of O2 cured SOG showed flatband voltage shifts of up to 8V when the voltage was swept first in one direction and then in the opposite direction. Polarizable material such as water is the probable cause of the shifts. The voltage shifts were not evident when steam was used in the cure cycle. Unless otherwise stated, all results presented here are for steam densified SOG.

To determine the effect of cure time on various film properties SOG was spun onto silicon substrates and cured for up to one hour at 800C. The results are shown in Figure 1. First notice that in Figure 1a the oxide thickness increases linearly with time. This indicates that the thickness of the SOG is no longer decreasing and that the additional oxide thickness is due to oxidation of the underlying silicon. Assuming a Grove-Deal oxidation model the initial densified SOG thickness is about 1050A. With an as spun thickness of 1430A, the apparent amount of SOG shrinkage is 27%. This is a typical value for silicate SOG.

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Wet etchrate data for BOE showed a decreasing etchrate with increasing cure time, Figure 1b. This data shows that the density of the SOG is increasing or that chemical bonding in the oxide is changing causing a slower etchrate. Measurements using an ellipsometer did not detect a change in densification however since the refractive index remains nearly constant regardless of length of cure, Figure 1c.

In Table 1 is shown typical film properties for silicate SOG cured at 800C for 30 minutes.

Table 1. Film properties of steam cured silicate SOG.

| Property | Value |
|---|---|
| Refractive index | 1.47 |
| Dielectric constant | 3.9 |
| Dissipation factor @ 1MHz | 0.1 |
| Stress | 1.23E9 dynes/cm2 |

INFRARED ABSORPTION

Fourier transformation infrared spectroscopy (FTIR) can be used to detect the presence of chemical bonds which can in turn indicate chemical content. The silicon-hydroxyl, or silanol bond shows up as absorption at 940 1/cm [1]. The presence of silanol results in the absorption of water which in turn causes absorption in a band from 3000 to 4000 1/cm [1]. The FTIR technique can also be used to detect silicon-oxygen bonds. Three principle peaks are associated with Si-O bond absorption. Si-O bond stretch results in absorption near 1070 1/cm. The position of the Si-O stretch absorption peak can be used to indicate film density or porosity [2]. There are bending and rocking modes associated with the O-Si-O bond which result in absorption at 800 and 450 1/cm respectively. The phosphorous-oxygen bond exhibits absorption at 1325 1/cm.

All the Si-O and P-O absorption peaks mentioned above are evident in the spectra shown in Figure 2. These spectra have had absorption due to the silicon substrate subtracted out. IR absorption spectra were taken right after SOG spin, with and elapse time from spin to measurement not exceeding 5 minutes, and again after hot plate bake. The spectrum taken right after spin, Figure 2a shows a bump around 3500 1/cm, indicating absorbed water. The peak at 940 1/cm shows the presence of silanol. The silanol absorbs polar molecules such as water very readily. Carbon, probably from residual alcohol, was detected at 3000 1/cm. The Si-O stretch peak is positioned at 1105.5 1/cm. The spectrum taken after the hot plate bake, Figure 2b, shows less silanol absorption yet still a fair amount of absorbed water. The Si-O peak has moved to 1072.7 1/cm indicating a slight densification of the film. A peak at about 600 1/cm was unidentified.

Figure 2c shows a silicate SOG film after a 5 minute high temperature steam cure. The Si-O peaks have narrowed and the Si-O peak has moved to 1097.3 1/cm. This value is between that of the previous two spectra. A similar phenomena has been stated previously in the literature [3]. In this reference it was shown that intrinsic stress was largest when the Si-O peak position was at a minimum. In application to silicate SOG the cure cycle should be chosen to minimize the stress

since tensile stress induces SOG cracking. The spectrum in Figure 2c shows that silanol and water absorption can no longer be detected. For comparison, Figure 3 shows a spectrum of LPCVD phosphosilicate glass. The differences between the spectra in Figures 2c and 3 are slight.

## BIAS-TEMPERATURE STRESS

Capacitance-voltage tests were performed in order to determine the extent of mobile ion contamination. This test was also used to quantify fixed oxide charge. The MOS capacitors were fabricated by spinning SOG onto previously oxidized wafers. The oxide in this case was a 200A gate oxide. Aluminum C-V dots were subsequently sputtered onto the wafers. A final 400C anneal was performed in a 5% forming gas ambient. While under bias the capacitors were held at 300C for 3 minutes.

SOG cured for 30 minutes at 800C was used for these tests. The results indicate that the amount of mobile ion contamination is slight. Figure 4 shows a typical C-V plot that has a flatband voltage shift of 120mV corresponding to a mobile ion concentration of 2E10 1/cm2. This figure also shows that the initial and subsequent measured values for Vfb is 3 to 4V. This indicates that positive charge is trapped in the oxide. The origin of this positive charge is probably related to the slightly porous nature of the film cured for 30 minutes. It will be recalled that the wet etchrate of the SOG had not yet stabilized after 30 minutes of cure. In addition, preliminary results show that the amount of fixed oxide charge decreased as the length of the cure cycle was increased. In comparison, phosphosilicate CVD oxides had slightly less trapped charge.

## CONTACT ETCH

Contact cuts have been made through a PSG/SOG oxide sandwich to polysilicon and to single crystal diffusions. A single wafer type parallel plate plasma etcher was used with an etch chemistry which consisted of CHF3, CF4 and He at a pressure of 2.8Torr. This etch provided a SOG etchrate of about 5947A/min with 3.9% uniformity (1 sigma/mean). PSG etchrates were nearly identical at around 6011A/min with 4.0% uniformity. Etch chamber conditioning was found to be very important in obtaining repeatable results. Resist adhesion to the cured SOG was not found to be a problem. The planarization obtained using silicate SOG is comparable to that of flowed CVD oxide. The contact profile was satisfactory with no etchrate differences at the oxide interfaces. Work has begun investigating the possibility of anisotropically etching contacts and filling them with CVD tungsten. Initial results using CVD tungsten plugs are encouraging.

## PARAMETRIC DATA

Wafers were processed with underlying topography that was drawn to 1.0 micron design rules with step heights of approximately 5000A. Chains of 500 contacts were measured and found to be continuous in all cases. Contact resistances of metal-1 to POCl3 doped poly, n+ diffusions and p+ diffusions are shown in Table 2. These wafers were processed as described previously [3]. The only change in the process flow came at contact dielectric where the BPSG was replaced with cured silicate SOG and PSG.

Table 2. Parametric data for silicate SOG used as contact dielectric.

| | | |
|---|---|---|
| Contact Resistivities (ohm-sq um) | 20 | to N+ |
| | 130 | to P+ |
| | 7 | to poly |

Using this technology the contact resistivity from metal to p+ diffusion is typically higher than to n+ diffusions. All three contact resistivities are comparable to values obtained with BPSG in place of SOG. Contacts to device structures, using the etch described previously, were also made. Figure 5 shows typical NMOS and PMOS transistor characteristics. Temperature/humidity testing at 85C and 85% relative humidity was conducted on device wafers. The test lasted 168 hours and transistor parametric data was taken before and after the test. After the test no shift or degradation was seen in these parameters. Additionally, visual observation of the wafers revealed no cracking or delamination.

## ISSUES

One of the major concerns with using SOG prior to metal is the relatively high temperature steam cure necessary for densification. The affect of steam ambients on polycide sheet resistance is of particular concern. It was shown however that silicide sheet resistance after the cure cycle does not change as long as the silicide is capped with oxide. Clustering of Arsenic atoms in n-type polysilicon is also a concern using these temperatures. The result of the clustering is raised sheet resistance.

One problem associated with doped silicate SOG is occasional poor adhesion to oxide. This can result in delamination of the SOG or possibly voids along cusps in the underlying CVD oxide. As the doping of the SOG is increased adhesion problems worsen. Along with adhesion, moisture absorption is a problem with doped silicate SOG. If the SOG is not cured soon after spinning the film onto the wafer large bumps will form uniformly over the film surface. A hot plate bake will drive off the absorbed water with out apparent degradation to the film.

## REFERENCES


[1] M. Nakamura, et al., J. Elec. Soc., vol. 133, 1167 (1986).
[2] W.A. Pliskin, J. Vac. Sci. Tech., vol 14, 1064 (1977).
[3] B. Bastani, et al., Proceedings of Symp. on VLSI Technol., 41 (1987)

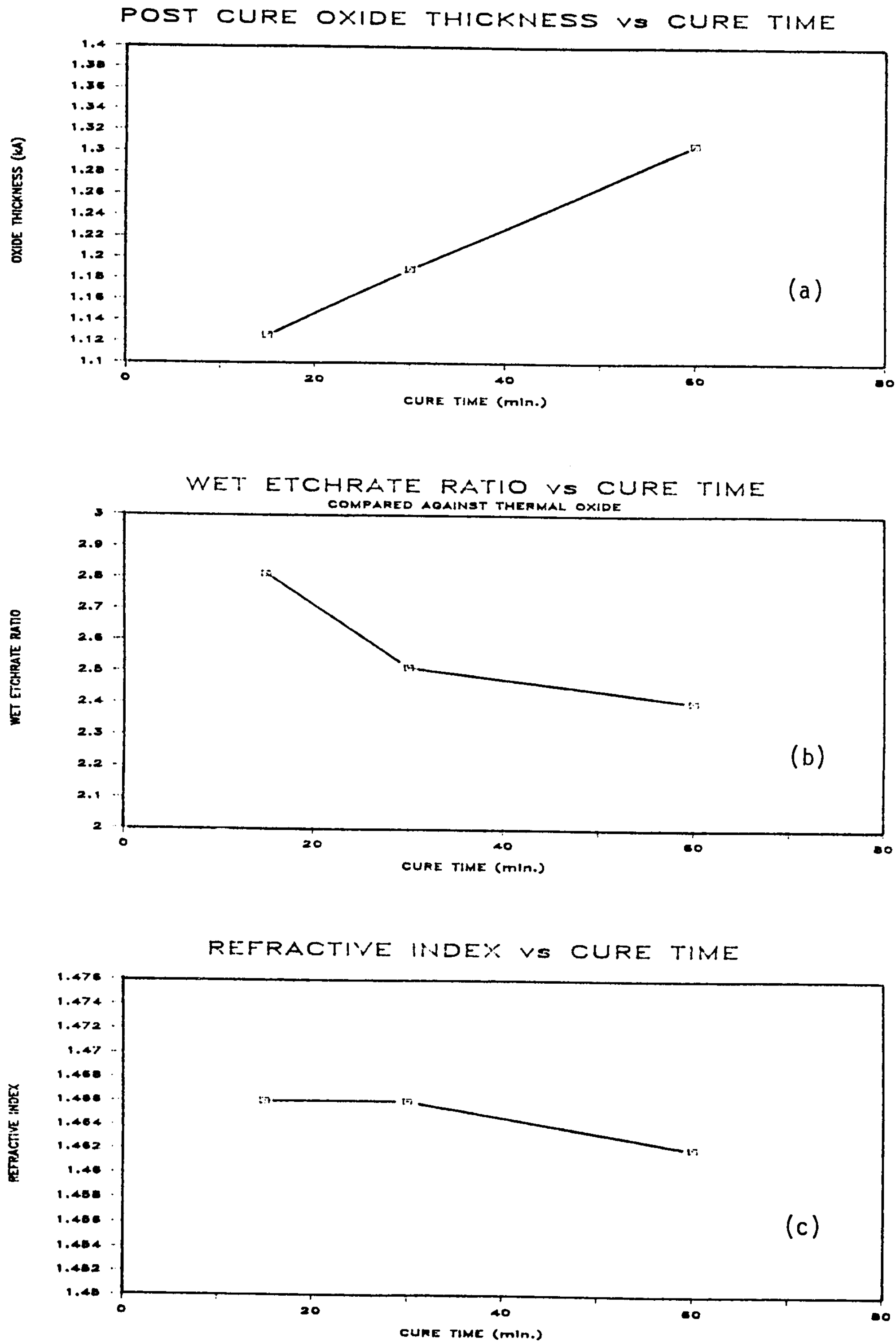


Figure 1. Film properties of cured silicate SOG versus cure time.

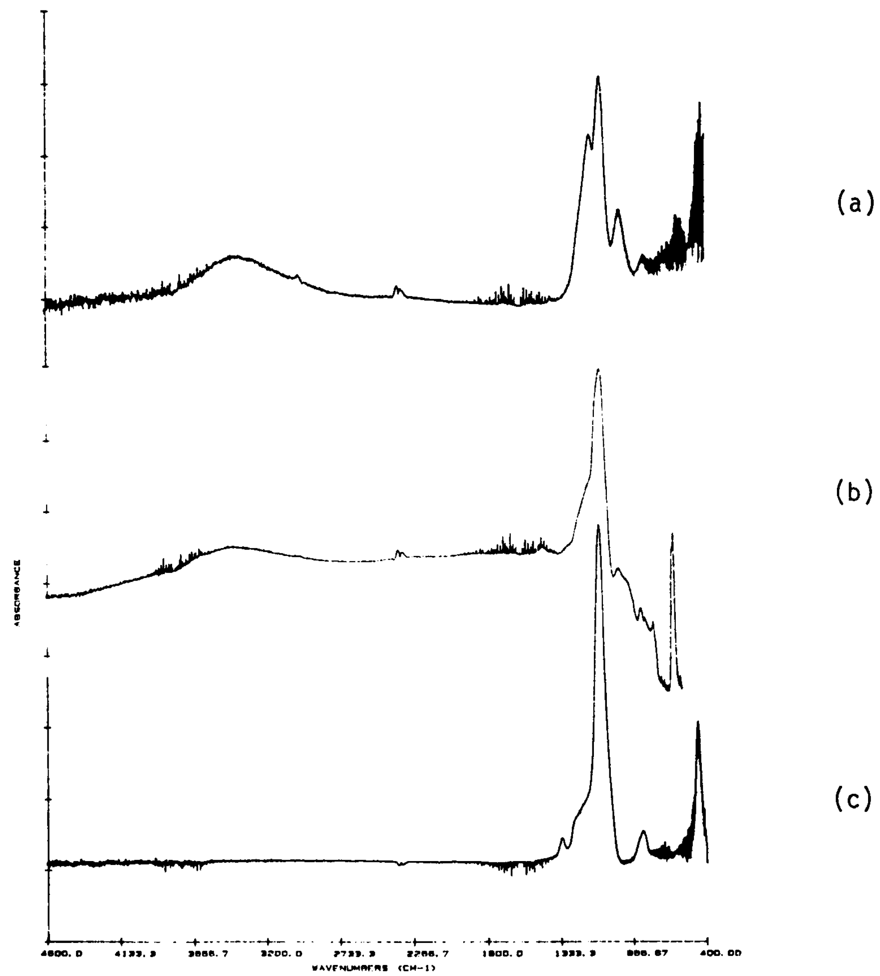


Figure 2. FTIR spectra of silicate SOG at various stages of cure.
a) as spun b) after hot plate bake c) after steam cure.

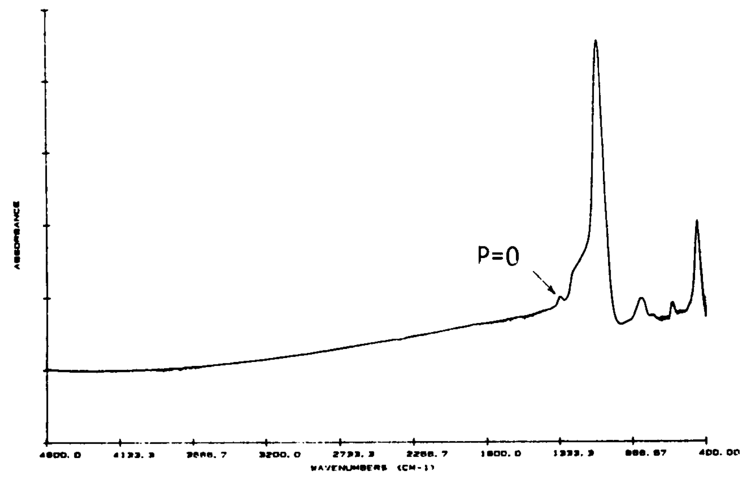


Figure 3. FTIR spectrum of densified LPCVD phosphosilicate glass.

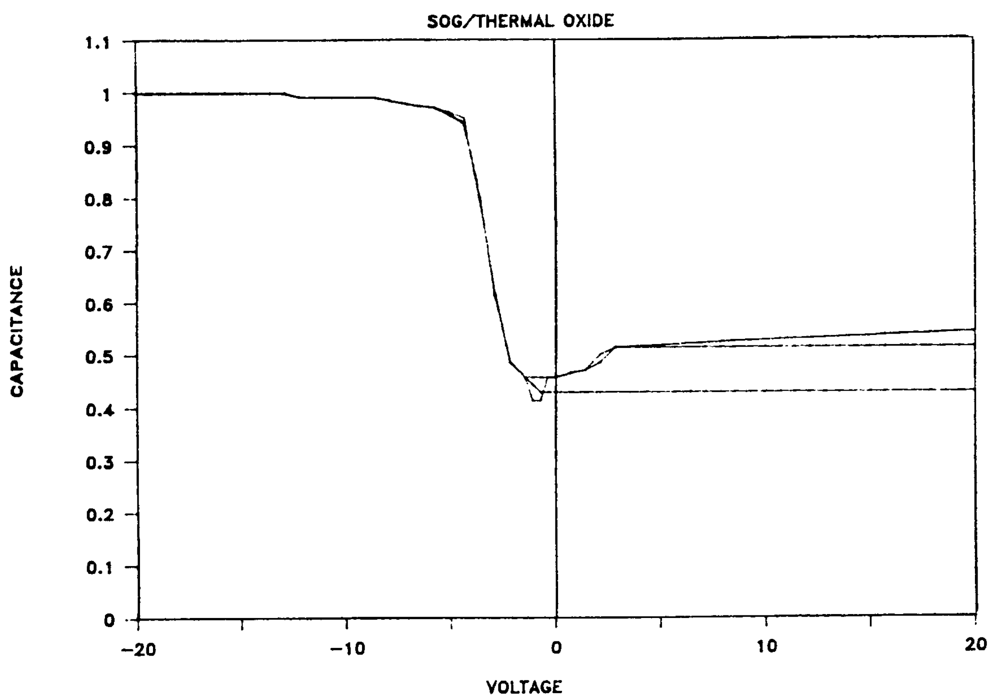


Figure 4. Capacitance-voltage plot for 1300A of cured silicate SOG on 200A of thermal oxide. Flatband voltage shift measured 120mV.

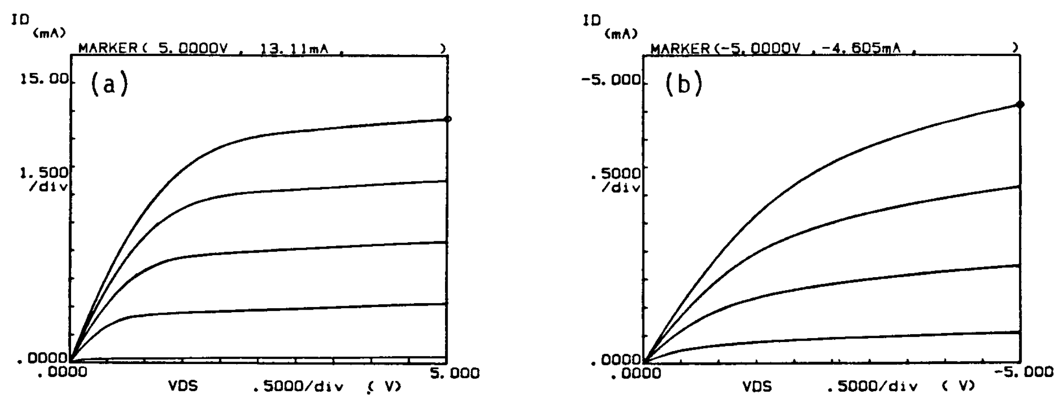


Figure 5. MOS transistor curves with spin-on-glass used as contact dielectric, (a) NMOS (b) PMOS