PHYSICS NOTE

PN-102

Spin-On-Glass (SOG) Charge Physics

Introduction

Spin-on-glass used in planarization can be a factor in creating inversion layers beneath thermally grown field oxide [1, 2]. Such layers provide conduction between transistors which are supposed to be isolated. They can also cause excessive loading on a dynamic node leading to operational circuit failures at low frequencies [3]. Inversion related to SOG tends to cause yield problems and can become a reliability problem if it manifests itself slowly.

There are two widely divergent opinions on the cause of charge generation in oxide stacks containing SOG.

- Turner [4] comments on slow SOG curing at use conditions which gradually creates charge. There are no references cited in this write-up, and discussions with numerous device, process, and reliability engineers have failed to substantiate his comments. A supplier of SOG rejected these comments out-of-hand while providing information on SOG related oxide charge referenced in the next paragraph [3].
- Others [1 - 3] describe creation, movement, and fixing of hydrogen ions as being the cause of SOG charge generation. There is no mention of slow curing in the three referenced articles.

In the absence of information to corroborate the Turner comments, this note essentially summarizes information consistent with references 1 to 3.

Water as a Source of SOG Charging

Moisture due either to incomplete SOG curing or to absorption after curing is a source for hydrogen ions, i.e. protons, within insulator stacks containing SOG. Protons are more mobile than sodium or potassium ions, and once liberated, are readily swept to the Si-SiO_2 interface under positive bias on the metal layer above the stack.

While measurements of sodium and potassium ion densities are generally repeatable and symmetric, measurement of proton density has proven difficult for several reasons:

1) Heat and electric fields used to assess ionic contamination are sufficient to liberate protons which might otherwise remain bound within the SOG [1]. Thus, testing for protons can actually indicate a problem when none exists.

2) Capture of protons at the metal gate appears to occur [1]. That is, while protons can be swept to and from a silicon surface, they can only be swept to a metal gate. Once there, reversing the field does not result in charge movement. As a result, test results cannot be confirmed by repeating the test.

3) Heat has two opposite effects. It can liberate protons, thereby permitting charge movement [1]. It can also drive moisture out, thereby eliminating the source of hydrogen leading to charge generation [3].

Moisture Absorption is the SOG Issue

Even if hydrogen ions can be eliminated through selection of appropriate sandwich materials [3], SOG will absorb moisture unless it is densified at temperatures approaching 900°C [1]. There is always the potential for creation of hydrogen ions without a hermetic seal above the SOG layer. Circuit layout, isolation techniques, and limiting product application [2] are some techniques used to address the problem.

Testing with a Heated Structure

A metal gate transistor with SOG in the gate dielectric can be used to determine likelihood of field inversion from mobile hydrogen ions. However, the very conditions, i.e., high voltage and high temperature, used for detection can liberate hydrogen ions, so careful attention must be paid to test conditions, correlation with other indicators, and interpretation of results.

There are several considerations in using a test structure with a polysilicon heater, as in Figure 1.

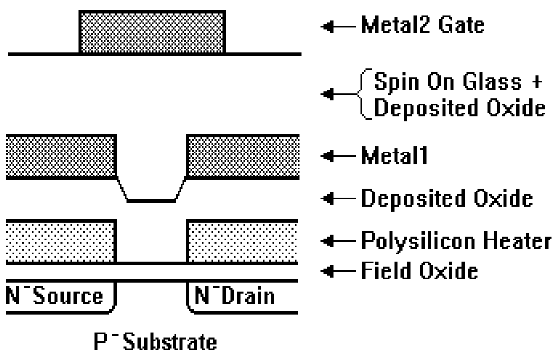

Figure 1 - Field Transistor with Poly Heater

Native Charging

Threshold voltage of an unstressed transistor is measured to provide a baseline. Since threshold of a transistor with such a thick oxide is high, the measurement voltage itself can liberate protons. Thus, the measurement needs to be made quickly.

Pushing Protons to the Silicon Interface

To accelerate effects of protons being in the oxide, a positive bias at relatively low temperature is applied to the metal gate. This moves the protons as close as possible to the Si-SiO_2 interface given the thermal profile produced by the polysilicon heater. Another quick threshold measurement indicates the worst-case shift for the sample under test. Threshold should decrease for P-type substrate if ions move.

The right side of Figure 2 shows an expanded view of the field oxide beneath the polysilicon heater. The graph on the left side of the figure is a simple model of the temperature beneath the heater. During a short test, the high thermal conductivity of Si relative to SiO_2 (100:1) permits an assumption of insignificant temperature rise above ambient in the silicon substrate. Also, since structure area dimensions are large relative to vertical distances, temperature above the structure should be the same as that of the polysilicon heater.

A limitation of using a polysilicon heater is that temperature near the substrate is close to ambient, thereby reducing proton mobility in the very region where inversion is most strongly affected. However, the limitation is not overwhelming since use of threshold measurement to detect mobile ions is sensitive to charge throughout the oxide.

Acceleration Factor

If an activation energy of 1eV is used for surface charge accumulation [2, 5], and if acceleration due to voltage is proportional, a temperature of 250°C at 20V would provide an acceleration of 4.5×10^5. Thus, stressing for one minute would be equivalent to approximately one year at 5V and 70°C.

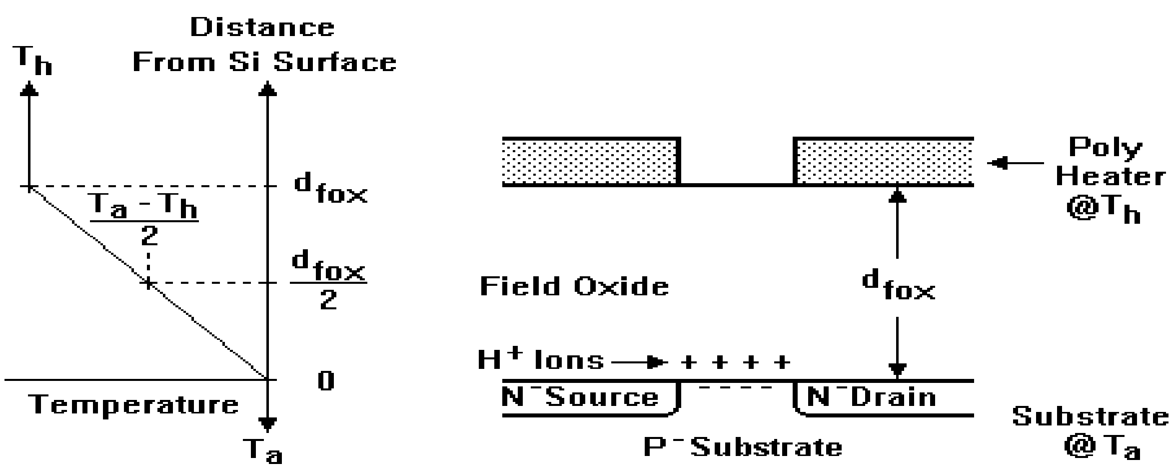

Figure 2 - Temperatures Below Poly Heater

Pushing Protons to the Metal Interface

A negative gate bias at temperature should pull the protons away from the silicon interface toward the metal gate and result in a threshold increase. However, the same effect occurs with mobile ion contamination from sodium and potassium, so an additional test is needed to isolate proton charge.

Checking for Other Ions

Since sodium and potassium ions are not captured at the metal gate like protons, repeating the positive gate stress permits separation of proton charging by simple examination of threshold shift. If the threshold does not recover, protons are the likely source of charge. If it does recover, other mobile ions are responsible.

References

[1] N. Lifshitz, G. Smolinshy, and J.M. Andrews, “Mobile Charge in a Novel Spin-On Oxide (SOX): Detection of Hydrogen in Dielectrics”, *J. Electrochem. Soc.,* Vol. 136, No. 5, pp 1440 - 1446

[2] M. Grams, W. Gladden, E. Achee, G. Goeloe, G. Gilfeather, L. Jordan, and B. Dawson, “Impact of Field Inversion on the Performance of 29K and PhoX Devices”, *Internal AMD Report,* 1995

[3] S. Hsu, L. Liu, C. Fang, S. Ying, T. Chen, M. Lin, and C. Chang, “Field Inversion in the CMOS Double-Metal Process Due to PETEOS and SOG Interactions”, *IEEE Transactions on Electron Devices*, Vol. 40, No. 1, pp 49 - 53, 1993

[4] T. Turner, “Spin-On-Glass Test”, *privately published Turner Engineering Technology manual*, pp 37 - 39, 1994

[5] H. Dicken and J. Fordemwalt, *Physics of Semiconductor Failures, Fourth Edition*, DM Data Inc., pp 171, 1996