AN INVESTIGATION OF CHARGE STATES IN ELECTRON IRRADIATED LOW NITRIDED SILICON DIOXIDE FILMS

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Abstract: MOS-structures with pure SiO_2 -films, with nitrided Si-SiO₂ interface region and with an insulator layer with uniform weak nitridation were irradiated with 2 MeV electron beam in steps between 10 krad (SiO₂) and 2 Mrad (SiO₂) with and without an electrical field. The electrical characterisation with CV-(Capacitance-Voltage) and DLTS-(Deep Level Transient Spectroscopy) method gives us information about the charge states in this structure. The electron irradiation generates electron-hole pairs and a positive gate field effects a hole drift to the interface, where we can find a positive oxide charge and a rising interface density. The amount of density is a function of nitridation and of the electron beam dose.

The best electrical stability under irradiation induced hole injection is to be found in an uniform nitrided SiO₂ layer.

1. Introduction

Nitrided silicon dioxide layers are further investigated for alternative gate insulator and ultrathin dielectric films. The nitrogen incorporation behaves like a good diffusion barrier /1/ for technological impurities and good radiation-hardness performance /3/. Dependent on the nitridation process SiO₂-films the nitrogen distribution into the layer varies and drifts the electrical properties /1/,/2/.

The well known characteristics of electrical properties of nitrided films in comparison with silicon dioxide are the higher amount of positive oxide charge (equivalent to the negative flat-band voltage shift) and the dependence of interface state density on nitridation time and temperature /2/,/4/,/5/.

Very important for application is the stability of electrical

parameter after charge injection. In this paper we investigate the behaviour of trapping processes before and after electron irradiation under a gate field and with different nitrogen distributions in MOS-samples.

2.Experimental

The samples were produced with the help of rapid thermal oxidation and nitridation /8/. Starting from $\langle 100 \rangle$ n-Si, 10-20 Ohm·cm substrates, a rapid thermal oxidation at 1150°C resulted an initial oxide. It was followed by a postoxidation annealing at 1050°C in pure nitrogen for 30s.

Rapid thermal nitridation in ammonia at two different temperatures T_n (1150°C for sample 19 and 1000°C for sample 22) and a reoxidation process at different T_{nox} (950°C for sample 19 and 1200°C for sample 22) should also effect a different nitrogen distribution in the silicondioxid. Afterwards Polysilicon/Al-Dots were applied on samples and the backside got an Al-metallisation, too.

The Auger Electron Spectroscopy (AES) depth profiles of nitrided samples /9/, shown in figure 1, documents the different nitrogen distribution cause to different sample preparation.

Fig. 1 AES depth profiles

The electron beam source, reported in /6/, supplies electron energy to 2 MeV. In this energy range the electrons are only slightly in interaction with SiO₂-Si-structure, but they generate electron-hole-pairs in the insulator with a rate of $8 \cdot 10^{12}$ pairs per rad (SiO₂) and per cm² /6/ (1 rad = $6.242 \cdot 10^{-7}$ MeV·g⁻¹ for SiO₂). The beam dose D, defined as beam energy per irradiated mass, was varied from 10 krad to 1 Mrad (SiO₂).

The positive gate field was 2,5 MV/cm less than the field necessary for Fowler-Nordheim-tunneling in SiO₂. After irradiation

tion we continued the field for several days.

For electrical characterisation we used the static HF-CV method and lock-in DLTS as shown in /10/ and /12/.

3. Results

Fig.2 a) CV- characteristics before and after irradiation

After irradiation of the samples under positive gate field the capacitance-voltage measurements show changes in interface state density and oxide charge (fig.2).

In many cases this statement is also true for the device resistivity. As shown by Awadelkani /13/ a great change of the device resistivity first of all is a consequence of the electron beam damage in silicon and the trapping of the electrons there.

3.1. Oxide charge

In fig. 3a is shown the change of oxide charge as a function of beam dose D with and without an electrical gate field. The SiO_2 -layer (sample 13) shows the expected behaviour. There is a small change to be noticed without the field. The change increases with the higher number of holes near the interface under the field. Though the value of the oxide charge is higher, the nitridation of the interface (sample 22) doesn't influence this behaviour.

The uniform weak nitrided SiO_2 -layer irradiated without the field is dependent on irradiation in the same way. However, the dependence of the oxide charge on beam dose decreases when irradiated under a positive gate field.

3.2 Interface state density

The change of interface state density N_{it} pre- and postirra-

diation is proportional to the difference between change of flatband voltage ΔV_{fb} and change of midgap voltage ΔV_{mg} . In figure 3b and c this difference is presented as a function of the electron beam dose. The irradiation of the pure SiO_2 -layer demonstrated the expected increase in N_{it} . The difference was higher under irradiation with field than without. However, the nitrided samples didn't show any dependence of the interface state density on irradiation without field, which means a higher radiation hardness.

By way of switching on the external field the behaviour of the sample with nitrided interface (sample 22) only became identical with the behaviour of pure SiO_2 -film. This fact is a good argument for the model conception of the hole interaction that plays a central role in generation of interface states. The interface state density of sample 19 didn't change while increasing beam dose under a field.

The termspectra, found with the help of DLTS-measurements, are documented in figure 4 ($N_{it} = f(E)_D$ with positive field). The virgin oxide (sample 13*) had $N_{it} < 2 \cdot 10^9 \text{ eV}^{-1} \text{ cm}^{-2}$. N_{it} increases greater near midgap with rising beam dose. The interface

Fig.3 a) oxide charge of all samples as function of beam dose D
b) interface state density as function of beam dose

state density of nitrided samples is higher than density of SiO_2 before irradiation, but doesn't increase greatly after irradiation.

At the energy level of $(E_C - 0.4) \text{ eV}$ the interface state density, was presented as a function of the injected charge Q_{inj} in fig. 5. For calculation purposes the injected charge was supposed at a gain of 90%. For the pure silicon dioxide layer there was found a N_{it} -generation rate one hundred times higher than the rate calculated for uniform nitrided films. We can deduct that

nitridation changes the generation mechanism for interface states fundamentally. The following model considers this fact and the forementioned observations .

4. Conclusion

As shown by M.Schmidt /7/ the hole generation under positive gate field effects in Si-SiO₂-structures the breaking of Si-Si-bonding (O-vacancy), Si-H-bonding, Si-O-H-bonding and of Si-O-tight bonding near interface. The breaking of those bondings generates E'-centres that work as an increased positive oxide charge: $O_3 \equiv Si^+ \cdot Si \equiv O_3$

The released single positive charged (H⁺), atomic (H) or molecular (H₂) hydrogen diffuses to the interface and causes, as shown by Grunthaner /14/, the creation of silicon dangling bonds of the form: $\cdot Si \equiv Si_3$ (P_b-centres) and $\cdot Si \equiv Si_2O$

The nitridation of silicondioxide presumably causes on the one hand a substitution of oxygen by nitrogen or by nitrogen-hydrogen configurations and on the other hand also the reduction of the Si-H-bondings. In this case the originating Si-NH₂-, Si₂=NH- or Si₃≡N-bondings are energetically more stable, as with saturation with hydrogen. Therefore it can be expected that after irradiation and hole generation in nitrided SiO₂ a lower oxide charge can be found./16/

Fig.4 DLTS-terminalspectra after different irradiation doses

Fig.5 interface state as function of injected charge

The interface state density will be less influenced by the lower portion of free hydrogen. At the same time the integration of nitrogen to interface effects as described by Severi /4/, a relaxation of the Si-O-Si-bonds.

This counteracts the breaking of the bonds by hydrogen /14/.

The results shown above are in accord with the described model:

- The sample with nitrided interface only shows in comparison with pure SiO₂, a higher generation of oxide charges. This is certainly due to a higher portion of hydrogen and the conditions of nitridation and reoxidation. The interface state density has clearly improved in this sample after charge injection in comparison with SiO₂.
- The equalized nitridation (sample 19) points to a more stabilized behaviour of the oxide charge against hole injection, which obviously causes a more decreased generation of interface states. This result corresponds with that described in /3/.

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