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Improved Reliability of NO-Nitrided SiO_2 Grown on p-Type 4H-SiC

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***Abstract*—This letter demonstrates that the reliability of oxides grown on p-type 4H-SiC can be dramatically improved by NO nitridation. High-field (-8 MV/cm) room-temperature stressing and high-temperature negative-bias (250 °C, -4 MV/cm) testing were used to investigate the reliability of NO nitrided oxides. Relatively small changes in the flat-band voltage, interface-trap density and leakage current were observed after 5000 s in the case of NO nitrided oxides, while shorter stressing shifted these parameters dramatically in the case of N_2 annealed control samples.**

***Index Terms*—MOS capacitors, nitridation, oxidation, oxynitride, silicon carbide, stressing.**

I. INTRODUCTION

THE growth of high-quality SiO_2 on SiC is a crucial step for realization of SiC MOSFET's. Until now, research has mostly been concentrated on the initial electrical properties, leading to a steady progress in the improvement of the initial properties [1]–[4]. Few papers have so far discussed the long-term stability of oxides grown on SiC. Bano *et al.* carried out high-field stressing of n-type silicon carbide MOS capacitors [5]. M. M. Maranowski *et al.* investigated the long term reliability of SiO_2 thermally grown on 6H SiC at the temperature of 145 °C [6]. However, the reliability of oxides grown on SiC remains a big issue, especially in the case of high-temperature operation.

Recently, we proposed thermal nitridation of oxides grown on SiC as a method for improvement of oxide quality [7], [8]. We demonstrated favorable effects of NO nitridation on the initial electrical characteristics of the oxides grown on both n-type and p-type SiC. In this letter, we present results which show that NO nitridation dramatically improves the reliability of the oxides grown on p-type 4H-SiC at both room and high temperature.

II. EXPERIMENT

Si-faced p-type 4H-SiC wafer, purchased from Cree Research, was used in this experiment. The doping level was 1.3×10^{17} cm^{-3}. The wafer was first cleaned in a mixture of H_2SO_4 and H_2O_2, followed by an RCA clean. Immediately prior to oxidation the wafer was dipped in 1% HF for 60 s and then oxidized in a quartz furnace in ultrahigh purity oxygen at 1150 °C for 4 h. After the oxidation the wafer was cut into pieces. One set of samples was annealed in pure NO in a quartz furnace at 1130 °C for 1.5 h. The other set of samples was annealed in N_2 in the same furnace under exactly the same conditions. After the annealing, aluminum was evaporated on the top of the samples, and MOS capacitors were formed by photolithography process ($\cong$200 μm dots). Aluminum was also evaporated on the back of the sample to make a back contact. The oxide thickness, determined from the high-frequency accumulation capacitance, was 26 nm for both NO and N_2 annealed samples.

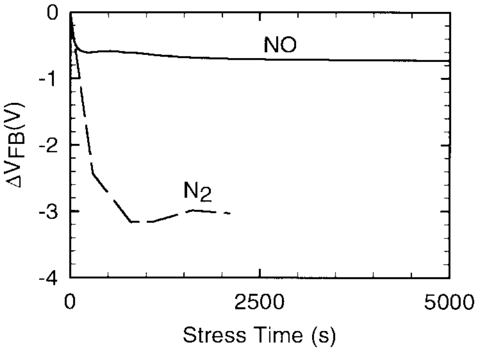

Fig. 1. Flat-band voltage shifts during high-field (-8 MV/cm) room-temperature stressing of NO and N_2 annealed samples.

Both the NO-nitrided and the control N_2-annealed samples were subjected to the following tests: (1) HF: High-field (-8 MV/cm)[1] room-temperature stressing, and (2) HT: high-temperature negative-bias (250 °C, -4 MV/cm) testing. High-frequency $C-V$ and conductance–voltage characteristics (using an HP4284A LCR meter), as well as $I-V$ characteristics (using an HP4145 Semiconductor Parameter Analyzer), were recorded before and after certain intervals of testing. The electrical field is calculated by dividing the applied voltage by the oxide thickness [4].

III. RESULTS AND DISCUSSION

The results of HF stressing are presented in the form of flat-band voltage shifts in Fig. 1. The observed maximum flat-band voltage shifts correspond to effective oxide charge increases of 6×10^{11} cm^{-2} and 2.6×10^{12} cm^{-2} for NO and N_2 annealed samples, respectively. The negative flat-band

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[1] MOS capacitors were biased in accumulation during the stressing.

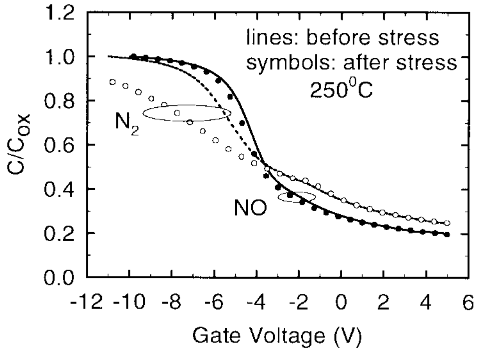

Fig. 2. $C-V$ curves measured before (lines) and after (symbols) HT testing (the test conditions: 250 °C, −4 MV/cm, 5000 s for NO, 1500 s for N_2 annealed samples).

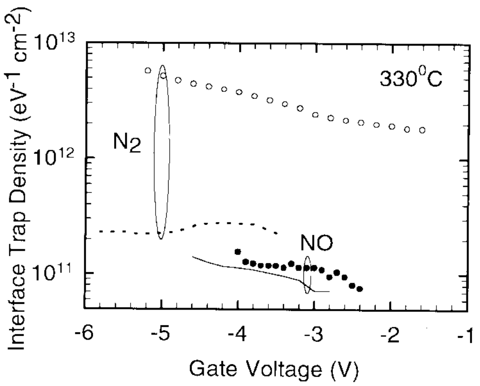

Fig. 3. Interface-trap density measured at 330 °C before (lines) and after (symbols) HT testing (the test conditions: 250 °C, −4 MV/cm, 5000 s for NO, 1500 s for N_2 annealed samples).

voltage shift indicates creation of positive oxide charge, but obviously to a much lesser extent in the case of NO nitrided samples. Also, the N_2 annealed oxides would typically break down before 2500 s of stressing, while breakdown was not observed in the case of NO-nitrided samples up to 5000 s of stressing.

The HT testing was carried at 250 °C and −4 MV/cm, for 5000 s in the case of NO, and for 1500 s in the case of N_2 annealed samples. Fig. 2 shows the $C-V$ curves measured at 250 °C before and immediately after the stressing. A slight negative shift is observed in the case of NO-nitrided samples, while the $C-V$ curves of the N_2 annealed samples are greatly distorted after the stressing. The effective oxide charge changes, calculated from the flat-band voltage shifts, are 1.6×10^{11} cm^{-2} and $>4 \times 10^{12}$ cm^{-2} for the NO and N_2 annealed samples, respectively.

The distortion of the $C-V$ curves, shown in Fig. 2, indicates that a significant amount of interface traps are created, in addition to the positive oxide charge increase, in the case of N_2 annealed samples. The interface traps measured by the conductance technique [9] at 330 °C are shown in Fig. 3. The measurements were made at surface potentials in the depletion region only. These results are in a very good correlation with the above-calculated oxide charge data, showing a slight interface trap density increase in the NO nitrided samples, and an order of magnitude higher interface-trap density increase in the case of N_2 annealed samples.

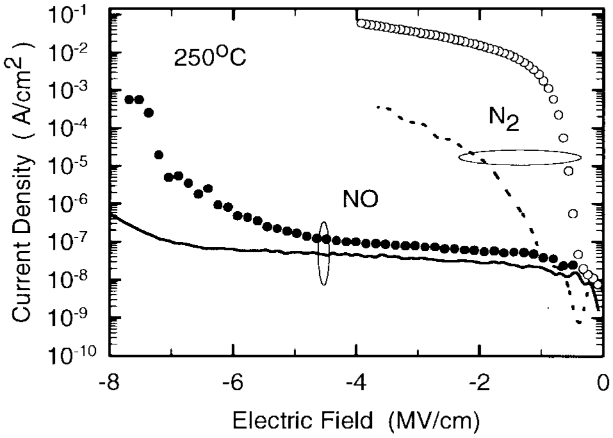

Fig. 4. J-E characteristics of NO nitrided and N_2 annealed samples measured at 250 °C before (lines) and after (symbols) high-temperature reliability stress.

Fig. 4 shows the $I-V$ characteristics of NO nitrided and N_2 annealed samples, measured at 250 °C before and after the HT testing. Much smaller leakage current density was observed in NO-nitrided samples before stressing. After the HT testing, the leakage currents increased, however, even the post-stress levels of the NO-nitrided samples are much lower when compared to pre-stress levels of the N_2 annealed samples. These results are in correlation with the above-presented results, showing that NO nitridation leads to a dramatic improvement of high-temperature endurance of oxides grown on SiC.

IV. CONCLUSIONS

In this letter we demonstrates the improvements in reliability of oxides grown on SiC by NO nitridation. Much better stability of the NO-nitrided oxides was observed under both high-field stressing and during high-temperature operation. The results obtained from the high-temperature testing are especially important, because of the fact that the high-temperature operation is perceived as one of the main advantages of SiC devices. We used limited set of samples and further detailed investigations are needed. We believe that the presented results will encourage research on optimization of the nitridation conditions and detailed reliability investigation, including comprehensive breakdown statistics.

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