The Electrical Characteristics of Polysilicon Oxide Grown in Pure N_2O

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***Abstract*—N_2O was used to grow silicon polyoxide. It was found that the N_2O-grown polyoxide had a lower leakage current but a higher breakdown field when the top-electrode was positively biased. This is opposite to that of conventional O_2-grown polyoxide. Moreover, it had less electron trapping when stressed and a larger charge-to-breakdown.**

I. INTRODUCTION

IN order to obtain good data retention characteristics for nonvolatile memory, the inter-polysilicon oxides (polyoxides) with low conductivity and high breakdown fields have long been sought [1]–[4]. For example, textured polysilicon oxides have been widely used in nonvolatile memory [3], [4]. Recently, N_2O used as an oxidant or a post-oxidation annealing ambient for gate dielectrics has received much attention due to its endurance to Fowler–Nordheim (F–N) stress, which is thought to derive from its incorporation of nitrogen at the oxide-silicon interface [5], [8]. However, growth of polyoxides in pure N_2O has not previously been reported.

This letter reports on N_2O used as an oxidant to grow polyoxide. It was found that the grown polyoxide has very desirable qualities such as a polarity asymmetry of J-E characteristics, which has a lower leakage current but a higher breakdown field when the top electrode is positively biased; and a higher charge-to-breakdown (Q_{bd}).

II. EXPERIMENTS

The polyoxides were prepared by oxidizing polysilicon films. P-type wafers were thermally oxidized to a thickness of 100 nm. Then, a 300 nm polysilicon film (poly 1) was deposited at 625°C and doped with $POCl_3$. A one-hour drive-in process was performed in ambient N_2 at 900°C to activate the dopant; the sheet resistance of the resulting polysilicon film was 22 $\Omega/\square$. Polyoxides grown in pure N_2O at 900°C were made to a thickness of about 14 nm. For comparison, polyoxides grown in pure O_2 at 900°C were also prepared. Then, a second layer of polysilicon (poly 2) of 300 nm thick was deposited and also doped with $POCl_3$ to a sheet resistance of 22 $\Omega/\square$. After defining poly 2, all samples received a 100 nm thick oxide via wet oxidation as a passivation layer. Contact holes were opened, and Al was deposited and patterned to form capacitors. Finally, all devices were sintered at 350°C for 40 minutes in N_2 gas.

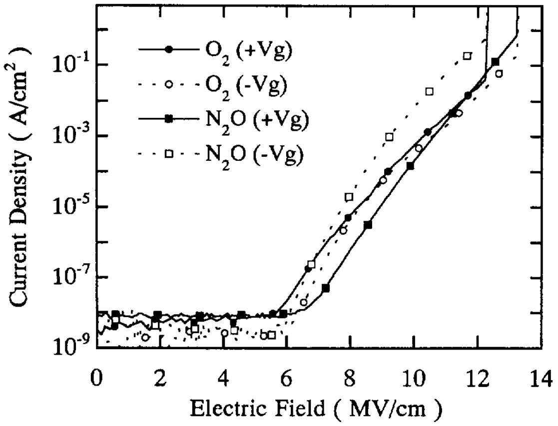

Fig. 1. The J-E characteristics of N_2O-grown and O_2-grown polyoxide devices. Both polyoxides were 14 nm thick.

III. RESULTS AND DISCUSSION

The oxidation rate of this heavily-doped polysilicon was more than three times faster than the oxidation rate of the lightly-doped Si substrate in pure N_2O and the self-limiting phenomenon, which exists for N_2O oxidation on Si [8], was not observed. The typical J-E characteristics of N_2O-grown polyoxide is shown in Fig. 1 along with those of O_2-grown control polyoxide. It can be seen that the N_2O polyoxide conducted a lower leakage current and had a higher breakdown field when the poly 2 was positively biased, whose electrons were injected from the lower polyoxide-poly 1 interface. This polarity asymmetry is opposite to that of the O_2-grown polyoxide and can be attributed to the interface roughness [4], [9]. The N_2O-grown polyoxide had a higher current density at dielectric breakdown.

Fig. 2 shows the trapping behavior of N_2O-grown polyoxide. The capacitor area was 5×10^{-4} cm^2 and the stress condition was 1 mA/cm^2 constant current injection for both positive and negative bias. It can be seen that the N_2O-grown polyoxide had smaller voltage shifts, with both the positive and negative bias stress. This means that the N_2O-grown polyoxide trapped fewer electrons. The O_2-grown polyoxide Vg shifts were almost the same for both polarity stressing, but for the N_2O-grown polyoxide, positive stress Vg shift

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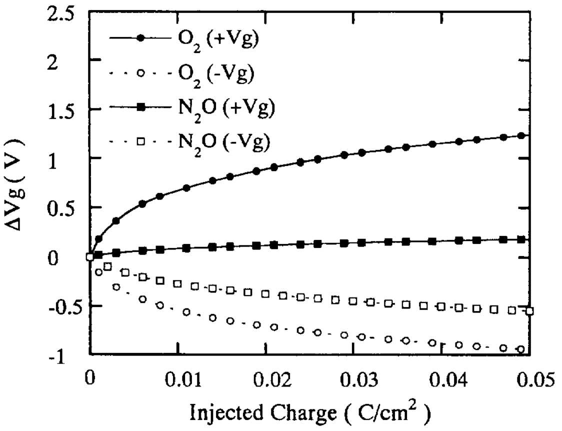

Fig. 2. The voltage shifts of the N_2O-grown polyoxide and the O_2-grown polyoxide devices under positive and negative constant current stress of 1 mA/cm^2. The gate area was 5×10^{-4} cm^2.

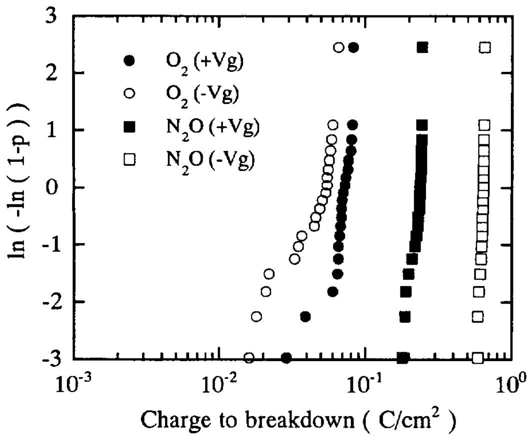

Fig. 3. The Weibull charge-to-breakdown plots for N_2O-grown and O_2-grown polyoxide devices under positive and negative stress. The stress condition was 1 mA/cm^2 and the gate area was 5×10^{-4} cm^2.

was significantly lower than its negative stress Vg shift. This difference was due to nitrogen pile-up at the N_2O-grown polyoxide/poly 1 interface.

Fig. 3 shows the Weibull charge-to-breakdown plot for 40 N_2O-grown and O_2-grown polyoxide capacitors under 1 mA/cm^2 stress. The N_2O-grown polyoxide had larger Q_{bd} and narrower Q_{bd} distribution than did the O_2-grown polyoxide. This improved Q_{bd} of the N_2O-grown polyoxide was due to the reduced electron trapping which is shown in Fig. 2. Moreover, the Q_{bd} improvement of N_2O-grown polyoxide is the most apparent for negative bias stress. The O_2-grown polyoxides had more defect-related breakdowns in the lower Q_{bd} region, but the N_2O-grown polyoxides had more intrinsic breakdowns. From Figs. 2 and 3, Q_{bd} is greater when top-electrode of polyoxide is biased such that injection occurs at the "leakier" interface. For N_2O-grown polyoxide, it is negative bias; for O_2-grown polyoxide it is positive bias. This is in agreement with the hole-trapping breakdown model, which predicts that Q_{bd} increases as the anode field decreases [9], [10].

IV. CONCLUSION

In conclusion, the above results show that the polyoxide grown in N_2O has improved integrity over conventional O_2-grown polyoxides. It has desirable J-E polarity asymmetry of J-E characteristic, i.e., lower leakage current and higher E_{bd}, when the top electrode is positively biased, reduced electron trapping and a larger Q_{bd} than the conventional O_2-grown polyoxides.

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