Improvement of Polysilicon Oxide Characteristics by Fluorine Incorporation

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***Abstract*—The effect of fluorine on the polysilicon oxide (polyoxide) characteristics is investigated. It is found that the polyoxide leakage current and breakdown strength are improved as fluorine is incorporated into the oxide film. Experimental results show that the improvement is believed to be due to the oxide stress relaxation rather than the change of the polyoxide/polysilicon interface texture.**

I. Introduction

In order to obtain good data retention characteristics for non-volatile memory, the inter-polysilicon oxides with a low conductivity and a high breakdown field are pursued [1]. It had been reported that the breakdown strength of the polyoxide is mainly determined by the polysilicon/polyoxide interface roughness [2, 3]. Fluorine had been investigated to be applied to single crystal Si (c-Si) metal-oxide-semiconductor (MOS) device to increase the device hot-carrier immunity and irradiation hardness [4]. These reliability improvements were suspected to be due to the strain relaxation of the interface. Recently, it had been experimentally demonstrated that the c-Si oxide grown in NF_3 ambient exhibited a smaller stress than those grown in dry O_2 [5]. In this letter, we report that the introduction of fluorine into polyoxide reduces its leakage current and increases its breakdown strength.

II. Experiment

A polysilicon film of 3000 \AA thickness was deposited at625^{\circ}C by a low-pressure chemical vapor deposition (LPCVD) system on p-type silicon substrate on which a 5000} Å thick thermal oxide was grown at 1050°C in wet O_2. The polysilicon was implanted with 5×10^{15} arsenic/cm^2 at 120 keV and then annealed at 850° C for 60 min in an N_2 gas. After defining the polysilicon island, a 270 Å gate oxide was grown at 850° C in a dry O_2 ambient. Then an LPCVD amorphous silicon of 800 Å thickness was deposited *at 550°C*. After defining the top-gate pattern, a 200 Å pad oxide was grown *at 850°C in dry O_2* on the amorphous silicon and then implanted with 2×10^{15} phosphorus/cm^2 at 40 keV. The dopant was annealed at 850° C for 60 min in an N_2 gas. Fluorine ions with doses of 1×10^{13}, 1×10^{14}, 1×10^{15} and 3×10^{15} cm^{-2} were implanted at 25 keV through the pad oxide and then annealed at 850° C for 60 min in a N_2 gas. For the control samples, no fluorine was implanted, but they were also subjected to the same high temperature annealing as fluorine-implanted samples. All devices were covered with a 2000 Å plasma-enhanced chemical vapor deposition (PECVD) SiO_2 for passivation. Contact holes were opened, and Al were deposited and the pattern. Finally, all devices were sintering at 350° C for 35 min in N_2 gas. The I–V characteristics of the polyoxides were measured by HP 4145 semiconductor parameter analyzer.

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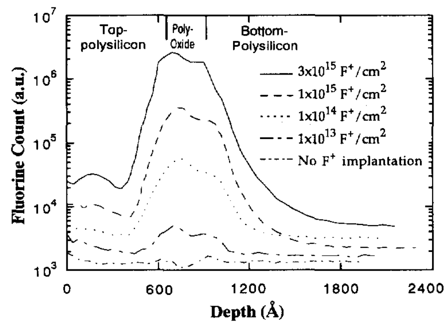

Fig. 1. The SIMS profiles of fluorine for the devices implanted with 1×10^{13} cm^{-2}, 1×10^{14} cm^{-2}, 1×10^{15} cm^{-2}, 3×10^{15} cm^{-2} and without fluorine implantation. The post-implantation annealing temperature is 850° C.

III. Results and Discussions

The SIMS profiles of fluorine for the devices implanted with 0, 1×10^{13}, 1×10^{14}, 1×10^{15}, and 3×10^{15} F^+/cm^2 followed by annealing at 850° C in an N_2 ambient are shown in Fig. 1. It is seen that fluorine accumulated within the polyoxide and the higher the fluorine dose, the higher the fluorine peak value. There are also some amount of fluorine existing within the polysilicons. Fig. 2(a) and (b) shows the *J-E* characteristics of the polyoxides implanted with different doses of fluorine for the positive top-gate bias (electron injection from the bottom-gate) and the negative top-gate bias (electron injection from the top-gate), respectively. It is seen that all the fluorine-implanted polyoxides exhibit a smaller leakage current and a higher breakdown strength than the non-implanted polyoxide. This result is in contrast to that of previous reports on the c-Si SiO_{2}, i.e., fluorine did not affect or even degrade the oxide breakdown strength and its leakage current [6], [7]. In this experiment, it is found that the optimum dose of fluorine to improve the polyoxide *J-E* characteristics is 1×10^{15} cm^{-2}. Too much fluorine seems to cause degradation to polyoxide

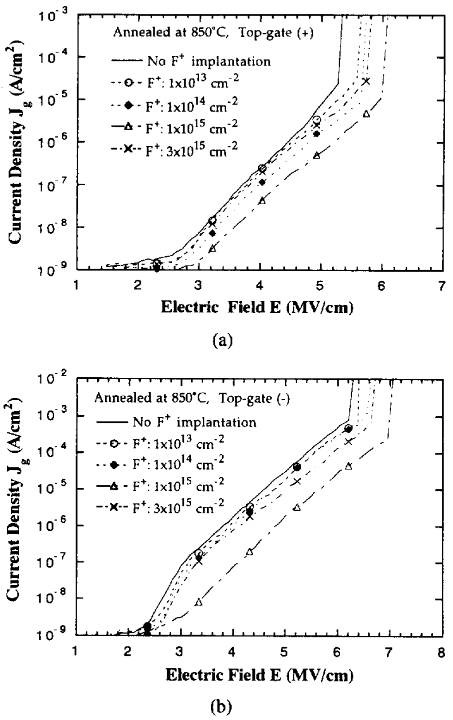

Fig. 2. The *J-E* characteristics of the polyoxides implanted with different doses of fluorine for (a) positive top-gate bias (electron injection from the bottom gate), and (b) negative top-gate bias (electron injection from top gate).

characteristics. In Fig. 2, the less tunneling leakage current when top-gate is positively biased is attribute that the bottom-polysilicon/polyoxide interface has a smoother morphology [2]. Fig. 3 shows the effective barrier height extracted from Fowler-Nordheim plots of these samples at positive top-gate bias. It is seen that the effective barrier heights were almost the same for these samples. Since the barrier height value is very sensitive to the interface texture structure [8], this implied that the fluorine-induced improvement of polyoxide characteristics was not caused by the change of the polysilicon/polyoxide interface texture. We would then suspected that the improvement of the polyoxide property is caused by the oxide stress relaxation due to the incorporation of fluorine. When fluorine was implanted into the top polysilicon and then driven in, it diffused into the polyoxide as revealed in Fig. 1. Originally, due to the high stress in the polyoxide [9], there are many strained bonds within the oxide, especially at regions nearby grain boundaries. These strained bonds are easy to be broken by high energy electrons to cause breakdown when a field is applied to the oxide. After the fluorination, the fluorine in the

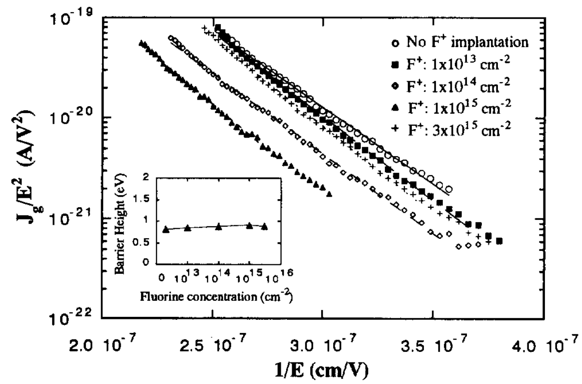

Fig. 3. Fowler-Nordheim plots for the polyoxide leakage currents at positive top-gate bias. The insert shows the effective barrier heights for the polyoxide implanted with different fluorine doses.

oxide tends to break the strained bonds and releases the oxide film stress. Hence, the oxide breakdown strength is improved.

IV. Summary

In summary, it is found that the incorporation of fluorine in the polyoxide reduced the oxide leakage current and increased the breakdown strength. This improvement is believed to be due to the oxide stress relaxation rather than the change of the polysilicon/polyoxide interface texture.

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