Ultrathin textured polycrystalline oxide with a high electron conduction efficiency prepared by thermal oxidation of thin polycrystalline silicon film on $n^+$ polycrystalline silicon

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This letter presents an ultrathin textured polycrystalline oxide (polyoxide) (~100 Å) prepared by thermal oxidation of thin polycrystalline silicon (polysilicon) film on $n^+$ polysilicon. The presented textured polyoxide exhibits a much higher electron injection efficiency, a much smaller electron trapping rate, and a much larger charge to breakdown than the normal polyoxide. The value of $Q_{bd}$ of the textured polyoxide could be more than 3000 C/cm$^2$ even under 100 mA/cm$^2$ stressing.

Polycrystalline oxides (polyoxides) are widely used as the tunneling element in floating-gate electrically erasable programmable read-only memories (EEPROMs) due to the high conductivity at the polycrystalline silicon (polysilicon)-oxide interface.$^{1-4}$ However, it has been reported that the field enhancement factor reduces as the decrease of the thickness of the polyoxide.$^5$ Thus, the reduction of the polyoxide thickness does not give a proportionally lower programing voltage.$^5$ Moreover, polyoxide exhibits a very high electron trapping rate and a very low intrinsic charge to breakdown ($Q_{bd}$)$^{3-4}$ which determines the maximum number of write-erase cycles that an EEPROM can sustain.$^7$

This letter proposes a simple method to grow an ultrathin textured polyoxide (~100 Å) with a very high electron injection efficiency, a very low electron trapping rate, and a very large charge to breakdown.

Thin textured polyoxide capacitors were fabricated on a 4000 Å polysilicon film (poly1) deposited on a substrate which was thermally oxidized to the oxide thickness of about 1000 Å. The poly1 was deposited in a low pressure chemical vapor deposition (LPCVD) system at 625 °C and then doped by POCl$_3$ at 925 or 950 °C. A 1000 °C, N$_2$+$O_2$, 30 min drive-in process was performed to activate the dopant. After the annealing process, the sheet resistance of the poly1 was measured to be about 70 Ω/□ for the 925 °C! predeposition sample (referred as median-doped polysilicon) and 28 Ω/□ for the 950 °C! predeposition sample (referred as heavily-doped polysilicon). Before oxidation, a thin amorphous silicon (a-Si) of 50 Å was deposited at 550 °C on the polysilicon films. The wafers were loaded into a furnace at low temperature (e.g., 600 °C) to reduce the thermal stress and to minimize the native oxide growth. The temperature was gradually raised to 1000 °C in a N$_2$ ambient. During the temperature ramping up step, the a-Si film was crystallized into polysilicon. Then, ultrathin polyoxide (≈100 Å) was grown by oxidizing the thin polysilicon film at 1000 °C in a dry O$_2$ ambient. Due to the rapid diffusion of oxygen through the grain boundaries of the thin polysilicon into silicon and the enhanced oxidation rate at the grain boundaries, a textured poly1/polyoxide interface is obtained. The presented polyoxide was then referred to as a textured polyoxide. The textured interface results in the localized high fields and enhances electron injection into the oxide. To characterize the grown textured polyoxide, a second layer of polysilicon (poly2) of 4000 Å was deposited and then doped with a POCl$_3$ source to the sheet resistance of about 20 Ω/□. To make a comparison, the normal polyoxide was also made at the same oxidation condition.

Figure 1 shows the Fowler–Nordheim (FN) tunneling current density versus the applied electric field ($J_e$–$E_{ox}$) characteristics of the thin textured and normal polyoxides for poly2 under a positive bias. It is seen that the textured polyoxides conduct a much higher FN tunneling current than that of the normal polyoxides in spite of the doping level of poly1. For example, the FN tunneling current density at 5 MV/cm of the textured polyoxides is more than five orders in magnitude larger than that of the normal polyoxides. The high electron conduction efficiency is important for the programming operation of the EEPROMs with a textured polycell.$^{1-4}$ The enhanced electron injec-
FIG. 2. The transmission electron micrograph of the textured polyoxide. The localized thinning regions are indicated by arrows.

FIG. 3. The gate voltage shift ($\Delta V_g$) versus time for the textured and normal polyoxides with a median-doped and heavily-doped poly1, respectively, under a constant current of 1 mA/cm$^2$ stressing. Both polyoxides exhibit an electron trapping behavior, however, the textured polyoxides show a much less electron trapping rate, especially for the case of electron injection from the poly1/polyoxide interface. This may be due to the localized thinning effect of the textured polyoxides, resulting in a smaller effective injection area and a lower bulk electric field. The smaller effective injection area could also reduce the susceptibility of the textured polyoxide to defects, which increases the intrinsic $Q_{bd}$. Figure 4 shows the $V_g$–$t$ curve of the median-doped textured polyoxide under a constant current of 100 mA/cm$^2$ stressing for poly2 under a positive bias. The effective oxide thickness is only about 98 Å. It is seen that the value of $Q_{bd}$ is more than 3000 C/cm$^2$, which is about four orders in magnitude larger than that of the normal polyoxide, as shown in Fig. 3(b).

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References: