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B5-1 Ferroelectric Field Effect Memory Device Using Bismuth Titanate Film

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For the purpose of electrically reprogrammable nonvolatile semiconductor memory charge storage in the gate dielectric of IGFET such as MNOS and MAOS has been utilized. In these most cases rather high write-in voltages are required. Another approach for this purpose is the utilization of ferroelectric field effect. Since it is very difficult to prepare thin film ferroelectric on semiconductor, previous studies on ferroelectric field effect devices have been exclusively limited to the structures of thin-film semiconductors on bulk ferroelectrics[1-4)]. In the present work IGFET with ferroelectric bismuth titanate film was investigated. The purpose of the present work is twofold : first, to prepare ferroelectric bismuth titanate film on n^+-Si substrate and, second, to examine the characteristics of the memory transistor.

Bismuth titanate films ($\sim$1μm thick) were deposited onto n^+-Si substrates by rf diode sputtering from a 0.8 $Bi_4Ti_3O_{12}$+0.2$Bi_{12}TiO_{20}$ ceramic target, then heat-treated in the atmosphere including oxygen. The x-ray diffraction patterns of the films heat-treated at temperatures above 550°C for 30 min show the polycrystalline monoclinic structure characteristic of $Bi_4Ti_3O_{12}$. The ferroelectric hysteresis loop of the film heat-treated at 700°C for 30 min indicates a remanent polarization P_r about 5.5μC/cm^2 and coercive field about 250 kV/cm, as shown in Fig.1. Polar state in either direction is very stable at room temperature. The small signal dielectric constant is about 90 at 1MHz at room temperature. The electrical resistivity is about 7×10^{12}Ω-cm.

P-channel IGFET with the film 1μm thick was fabricated 10Ω-cm (100) n type Si (Z/L=30). The IGFET is turned on by applying a negative pulse to the gate, and vice versa. The I_D-V_G characteristics is shown in Fig.2. The polarity of threshold shift is consistent with that expected from polarization reversal. Switching time is dependent upon applied field (typically 10msec at 20V, and 500 nsec at 35V). Fig.3 shows the I_D-V_D characteristics of the "ON" and "OFF" states. In the "OFF" state drain current is determined by reverse current of drain junction. In the "ON" state drain current is given by

$$I_D \approx \frac{Z}{L}\mu(P_r^* + C_i(V_G - V_T))V_D,$$

where P_r^* is effective polarization per unit area

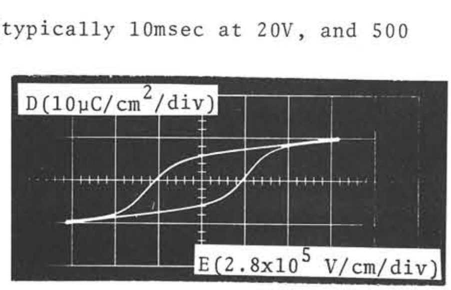

Fig.1. D-E hysteresis loop at 10kHz in a bismuth titanate film 7200Å thick on an n^+-Si.

and V_T is the threshold voltage except the effect of the polarization of the film. Typically channel conductance is about 1.0∿1.5 m℧ in the absence of the gate bias. The transconductance is found to be very small (∿0.7μ℧). The drain current does not level off up to V_D=-50V. These are reasonable taking into consideration the fact that the dielectric constant of the film has much smaller value in polar state than that in non-polar state. At present the reduction of the dielectric constant is not well understood. The "OFF"-state is very stable. The slight decrease of the "ON"-state conductance is observed for a few days. The polar state of the gate film is experimentally found to be very stable, consistent with the fact that the film has very large activation field (∿10^6V/cm). The slight decay of the "ON"-state conductance appears to be ascribed to the charge transfer to the interface states.

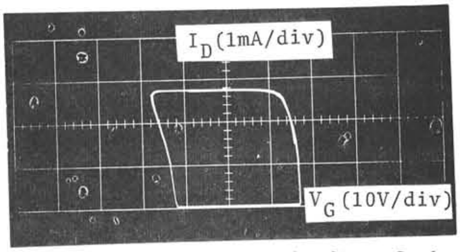

Fig.2. I_D-V_G characteristics of the p-channel transistor at 1Hz at V_D=-2V.

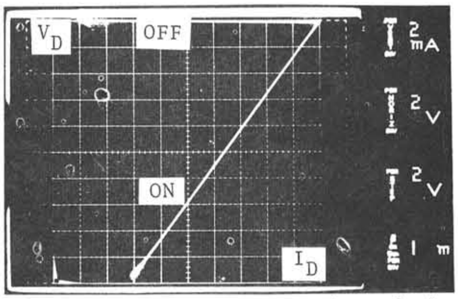

Fig.3. I_D-V_D characteristics of the p-channel transistor at V_G=0V.

The ferroelectric IGFET with bismuth titanate film will offer possibilities in many applications because of its low write-in voltage and structural properties compatible with integrated circuitry.

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1) J. L. Moll and Y. Tarui, 1963 Solid State Device Research Conference, Michigan, June, 14, (1963).

2) P. M. Hyman and G. H. Heilmeier, Proc. IEEE, vol.54, 842(1966)

3) R. Zuleeg and H. H. Wieder, Solid-State Electronics, vol.9, 657(1966)

4) S. S. Perlman and K. H. Ludewig,IEEE, ED-14, 816(1967)