Extended Abstracts of the 1997 International Conference on Solid State Devices and Materials, Hamamatsu, 1997, pp. 144-145

Evaluation of Electron Trap Levels in SIMOX Buried Oxide by Transient Photocurrent Spectroscopy

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1. Introduction

Separation by implanted oxygen (SIMOX) is a superior technique for fabricating low-cost uniform Si-on-insulator (SOI) substrates, which are expected to be used in future ultralarge scale integration devices. Recently, a low-dose implantation (~4×10^{17}cm^{-2}) and subsequent high temperature oxidation process, which is called internal thermal oxidation (ITOX), has been reported to improve the SOI quality[1,2]. This technique is also greatly desirable from the standpoint of productivity. For device applications, the buried oxide quality also need to be evaluated by an electrically sensitive method.

In SIMOX wafers fabricated by both high- and low-dose implantation, fixed oxide charges and electron traps detected by C-V measurements have been reported to affect the SOI device operation by changing the threshold voltages[3,4]. In this study, we investigated the electron traps in the buried oxides of low dose ITOX/SIMOX wafers by transient photocurrent spectroscopy[5,6]. Electron traps density of ~10^{15}cm^{-3} were detected without any artificial defect generation pretreatments. The trap nature was characterized from the trap level distribution and electron capture cross section.

2. Experiment

The samples used in this study were taken from commercially available ITOX/SIMOX p-type substrates, which were formed by low-dose oxygen implantation (3.75×10^{17}cm^{-2}) at an energy of 180 keV. For the optical measurement, the surface SOI layers were selectively removed by dipping into boiling hydrazyne (N_2H_4). The thickness of the buried oxide was measured to be 110 nm by ellipsometry. For comparison, a thermal oxide with the same thickness was prepared (wet, 950°C). After chemical cleaning of the SiO_2 surfaces, MOS diodes with Al gates were fabricated by Al deposition through a mask put on the SiO_2 surface. In the transient photocurrent spectroscopy, light from a 300 W xenon arc lamp was monochromized, and focused on a 20-nm-thick semi-transparent gate with an area of 0.0125 mm. The light irradiation was controlled with an electric shutter. The light intensity spectrum was measured with Newport 1830C optical power meter. The photocurrent was measured with a Hewlett-Packard 4140B picoammeter.

The photocurrent spectroscopy consists of a series of processes including photoinjection and two-step photodepopulation. The whole measurement is performed under a constant gate negative bias (V_g = -5V). First, the trap levels are filled by photoinjection at a fixed photon energy ($h\nu_0$ = 4.5eV), where the photoexcited gate electrons flow into the SiO_2 over the potential barrier ($h\nu_0 > q\phi_b$~3 eV) and are observed as the external circuit current. Since the photoinjection current ($J=10^{-9}$ to 10^{-8}A/cm^2) is time-independent, the number of injected electrons is proportional to the photoinjection time. In the subsequent photodepopulation process, the trapped electrons can be optically excited to the SiO_2 conduction band, if the electron trap level E_T satisfies the relation E_c-E_T < $h\nu$, where E_c is the SiO_2 conduction band edge level (Fig. 1). A transient current will be observed until the trap levels are emptied. In two-step photodepopulation with photon energies of $h\nu_1 = h\nu-\Delta h\nu$ and $h\nu_2 = h\nu+\Delta h\nu$ (1.6 eV < $h\nu$ < 3.0 eV), the second step photodepopulation current can be attributed to the

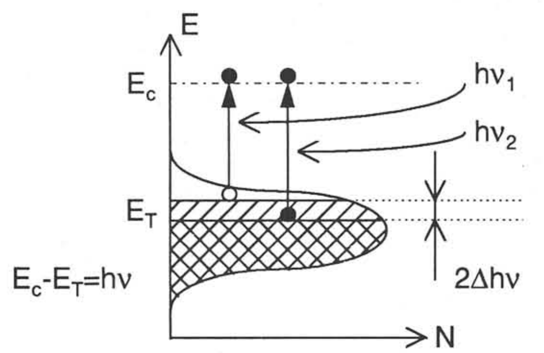

Fig. 1 Schematic picture of the two-step photodepopulation process after photoinjection for an assumed electron trap level distribution.

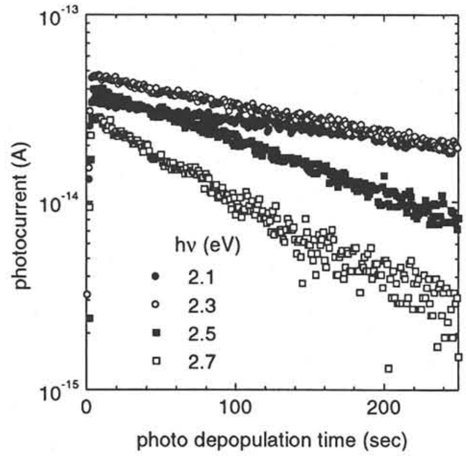

Fig. 2 The transient photocurrent in the second step photodepopulation for different photon energies.

trapped electrons around the level of $E_T = E_c - h\nu$ with an energy window of $2\Delta h\nu$, since the trapped electrons are fully emptied in the first photodepopulation.

3. Results and Discussion

We measured photodepopulation currents just after the photoinjection (T = 300s) for the SIMOX buried oxide and the thermal oxide. Only for the buried oxide diode, the photocurrent was observed to decay exponentially in the investigated photon energy range. Typical transient photocurrents in the second photodepopulation step are shown in Fig. 2, for the photon energy step of $2\Delta h\nu = 0.2$ eV.

To analyze this transient photocurrent, we assumed a simple model considering the photoexcitation of the trapped electrons and the capture of conduction band electrons at the trap levels. The first order kinetic rate equation for the trapped electron charge q(t) (cm^{-2}) is

$$dq(t)/dt = J\sigma_e (eN - q(t))/e - S\sigma_p q(t), \quad (1)$$

where N (cm^{-2}) is the trap level density, J (A/cm^2) is the current density during photoinjection, S ($cm^{-2}s^{-1}$) is the photon flux, σ_e (cm^2) is the electron capture cross section, and σ_p (cm^2) is the photoionization cross section. During the photodepopulation, the first term can be ignored in Eq. (1). Then, by assuming q(t=0) = eN, the photocurrent can be shown to decay exponentially: $I(t) = dq(t)/dt = I_0 \exp(-t/\tau)$, where $I_0 = -eNS\sigma_p$ and $\tau = (S\sigma_p)^{-1}$. For the first step photodepopulation ($h\nu$ = 2.6 eV), the initial photocurrent I_0 and the time constant τ give the parameters of $N = 2.2\times10^{10} cm^{-2}$ and $\sigma_p = 2\times10^{-18} cm^2$. An analysis of the second step photodepopulation currents enabled us to obtain the trap parameters for each trap level corresponding to the incident photon energy. As shown in Fig. 3, the trap density distribution has a broad peak at around $E_c - E_T$ = 2.3 eV.

To investigate the trap filling process, we measured the number of trapped electrons as a function of the photoinjection time, for the photodepopulation with a photon energy of 2.6 eV. Here, most of the trap levels can be emptied at this photon energy, judging from the trap density distribution shown in Fig. 3. The number of trapped

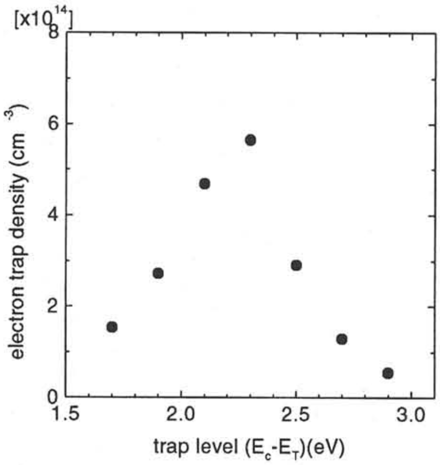

Fig. 3 Electron trap density distribution in buried oxide.

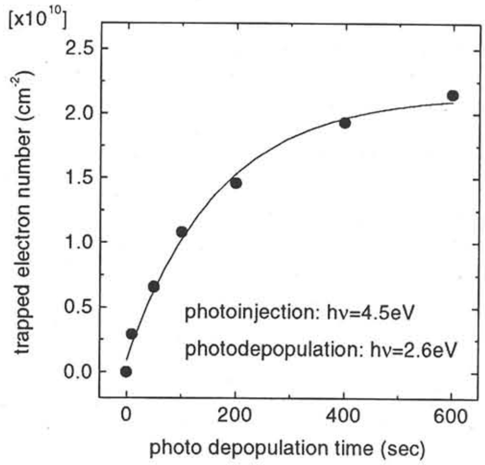

Fig. 4 Trapped electron number dependence on the photoinjection time.

electrons increased with the increasing photoinjection time and then saturated (Fig. 4). This result can be analyzed by using the above model as the photoinjection process. The second term in Eq. (1) can be ignored during the photoinjection. By assuming q(t=0) = 0, q(t) is given as $q(t) = Q\{1-\exp(-t/\tau)\}$, where Q = eN and $\tau = e/J\sigma_e$. From the best fitted parameters, we determined the number of trap levels and the electron capture cross section; $N = 2.3\times10^{10} cm^{-2}$ and $\sigma_e = 8.8\times10^{-14} cm^2$. Considering the buried oxide thickness and the diode area, the average trap density is estimated to be $2\times10^{15} cm^{-3}$. The obtained capture cross section is high enough to be regarded as that of a Coulomb attractive center, which is almost two orders higher than that of the neutral point defects ($\sim10^{-15} cm^2$). Therefore, we can conclude that the electron traps observed by the transient photocurrent spectroscopy are positively charged centers. We can also infer that such electron traps existing in the as-received SIMOX wafers may be a kind of isolated oxygen deficient defects.

4. Summary

Electron traps with a density of $2\times10^{15} cm^{-3}$ were detected in a low dose ITOX/SIMOX buried oxide by transient photocurrent spectroscopy. The capture cross section of $8.8\times10^{-14} cm^2$ shows that the electron traps are positively charged centers. By the two-step photodepopulation method, the electron trap level distribution was shown to have a peak at around $E_c - E_T$ = 2.3 eV.

References

1) S. Nakamura, T. Katayama, Y. Miyamura, A. Matsuzaki, M. Imai, K. Izumi, and N. Ohwada, Proc. IEEE Int. SOI conf. (1994) 71.

2) A. Ogura, T. Tatsumi, T. Hamajima, and H. Kikuchi, Appl. Phys. Lett. **69** (1996) 1367.

3) S. Masui, T. Nakajima, K. Kawamura, T. Yano, I. Hamaguchi, K. Kajiyama, and M. Tachimori, Proc. IEEE Int. SOI conf. (1994) 83.

4) V. Afanas'ev, B. Aspar, A. A.-Herve, G. Brown, W. Jenkins, H. Hughes, and A. Revesz, Proc. IEEE. Int. SOI Conf. (1996) 56.

5) D. J. DiMaria and F. J. Feigl, Phys. Rev. B **11** (1975) 5023.

6) Y. Miura and S. Fujieda, Proc. Mat. Res. Soc. Symp. **428** (1996) 343.