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Common Origin of Stress-Induced Leakage Current and Electron Trap Generation

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The temperature dependence of stress-induced leakage current has been investigated to quantitatively clarify the relationship between stress-induced leakage current and electron trap generation. It has been found for the first time that the activation energy of the appearance of stress-induced leakage current agrees well with that of electron trap generation. It can be concluded quantitatively that stress-induced leakage current and electron trap generation have a common origin. Moreover, it has been clarified that stress-induced leakage current can be formulated as functions of electron energy and injected-electron fluence in the early stage of high field stress.

1 Introduction

The suppression of stress-induced leakage current is a key issue to obtain a reliable thin gate oxides in Si MOS devices. The critical energy for appearance of stress-induced leakage current [1] agrees well with that of electron trap generation [2]. A qualitative study concerning the relation between stress-induced leakage current and trapping electron in SiO_2 has already been reported [3]. In the present work, in order to quantitatively clarify the relation between stress-induced leakage current and electron trap generation, we focus on the temperature dependence of stress-induced leakage current. As a result, it has been clarified that the activation energy of stress-induced leakage current agrees well with that of trap generation rate.

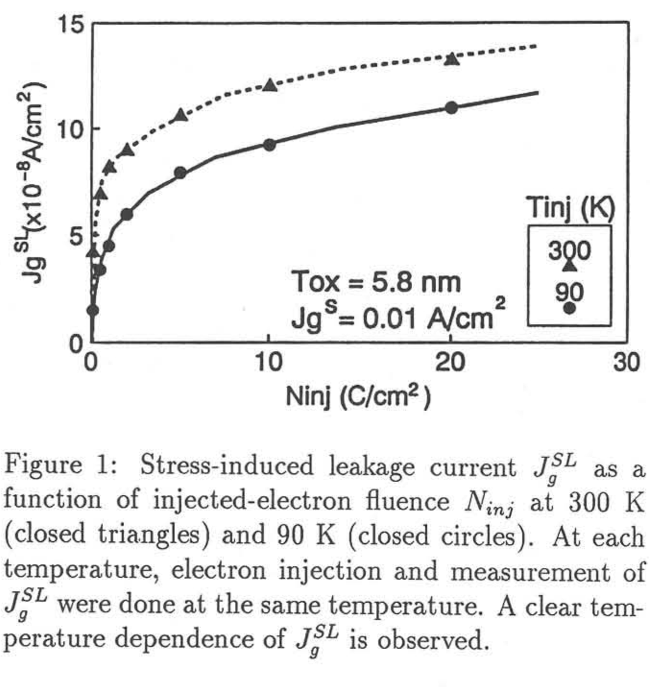

Figure 1: Stress-induced leakage current J_g^{SL} as a function of injected-electron fluence N_{inj} at 300 K (closed triangles) and 90 K (closed circles). At each temperature, electron injection and measurement of J_g^{SL} were done at the same temperature. A clear temperature dependence of J_g^{SL} is observed.

2 Results and Discussion

The devices used in this study were $100 \times 100\mu$m n-channel MOSFETs. The gate oxide thickness of 5.8 nm was chosen to eliminate oxide charge trapping. The gate oxide was grown in dry O_2 ambient at 800°C. The stress-induced leakage current density (J_g^{SL}) was defined as the increased component at the gate voltage V_g where the gate current density was 10^{-8} A/cm^{-2} in the the initial J_g - V_g characteristic from a point of view of the trap-assisted tunneling model [4]. High field stressing was performed under constant current Fowler-Nordheim electron injection from inversion layer.

Figure 1 shows stress-induced leakage current as a function of injected-electron fluence (N_{inj}) at 300 K and 90 K. As shown in Fig. 1, stress-induced leakage current has a clear temperature dependence. In

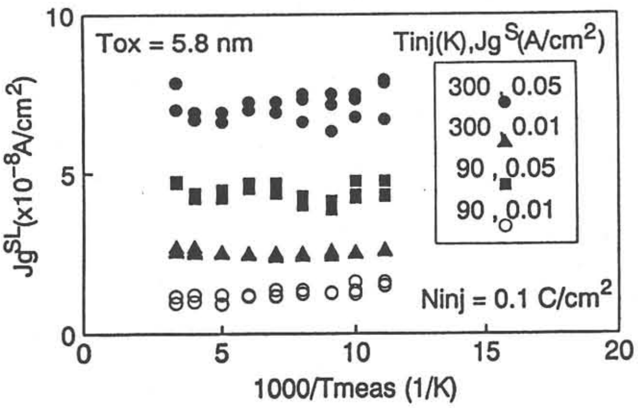

Figure 2: Measurement-temperature dependence of stress-induced leakage current J_g^{SL} for various stressing temperatures T_{inj} and stress current densities J_g^S. It is clearly shown that J_g^{SL} is independent of measurement temperature T_{meas}.

order to clarify the origin of this temperature dependence, stress-induced leakage current was measured at various temperatures. Figure 2 indicates the measurement temperature (T_{meas}) dependence of stress-induced leakage current. Stressing temperatures (T_{inj}) were 300 K and 90 K. Stress-induced leakage current was found to be independent of measurement temperature below 300 K for all cases. Therefore, at a constant injected-electron fluence, stress-induced leakage current is determined by stressing temperature and by stressing current density.

To discuss quantitatively the dependences of stressing temperature and stressing current density on stress-induced leakage current, we measured the stress-induced leakage current at various temperatures under the condition that stressing temperature is equal to measurement temperature (Fig. 3). The strong temperature dependence of stress-induced leakage current is shown irrespective of stressing current density and of injected-electron fluence. Figure 4 shows the increased component of stress-induced leakage current J_g^{SL} - J_g^{SL0} as a function of reciprocal stressing temperature. J_g^{SL0} means the temperature-independent component in stress-induced leakage current. The activation energy E_a of temperature dependent component in stress-induced leakage current is a constant (about 0.13 eV) irrespective of either stressing current density or injected-electron fluence. The activation energy of 0.13 eV seems to be in good agreement with the activation energy of electron trap generation [2]. These experimental results demonstrate that stress-induced leakage current and electron trap generation have a common origin.

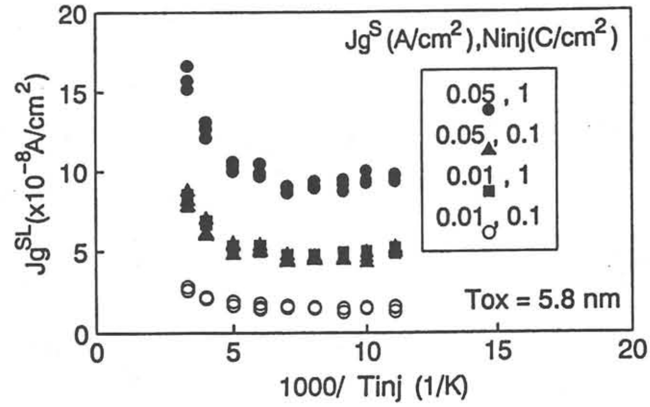

Figure 3: Stressing-temperature dependence of stress-induced leakage current J_g^{SL} for various stress current densities J_g^S and injected-electron fluences N_{inj}. Stressing was performed at each measurement temperature T_{meas}. For all cases, J_g^{SL} drastically increases at higher than around 150 K with increasing temperature.

In order to quantitatively discuss the mechanism of electron trap generation which acts as tunneling sites for stress-induced leakage current, we measured stress-induced leakage current as functions of stress current density and of injected-electron fluence. Figure 5 shows stress-induced leakage current as a function of injected-electron fluence at 90 K. A single power of 0.4 was obtained irrespective of stressing current density.

In order to obtain the stressing current density dependence of stress-induced leakage current, J_g^{SL} was plotted as a function of stressing current density (Fig. 6). As shown in Fig. 6, stress-induced leakage current increases rapidly at high stressing current density. This is because there is a threshold energy for the tunneling-sites generation which contributes to stress-induced leakage current [1]. It has been clarified that stress-induced leakage current in the early stage of high field stress can be formulated as follows.

$$J_g^{SL} = C_0 \varepsilon(J_g^S) N_{inj}^{0.4} \left(1 + \gamma \exp\left(-\frac{0.13(\mathrm{eV})}{kT}\right)\right), \tag{1}$$

where ε (J_g^S) is a function of electron energy which depends on the stressing current density. By utilizing Eq.(1) and a relationship of $N_{inj} = J_g^S \cdot t$, where t means injection time, stress-induced leakage current can be expressed as functions of stressing current density and injection time.

We consider that the tunneling sites for stress-

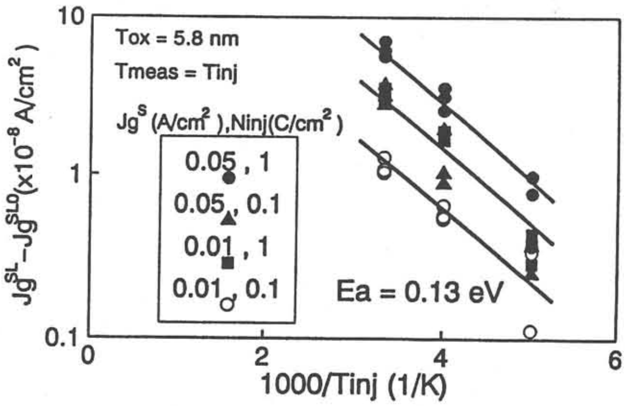

Figure 4: Increased component of stress-induced leakage current J_g^{SL} - J_g^{SLO} as a function of reciprocal temperature. J_g^{SLO} means the temperature independent component for various stress-induced leakage current J_g^{SL}. Activation energy E_a of 0.13 eV is constant for all cases.

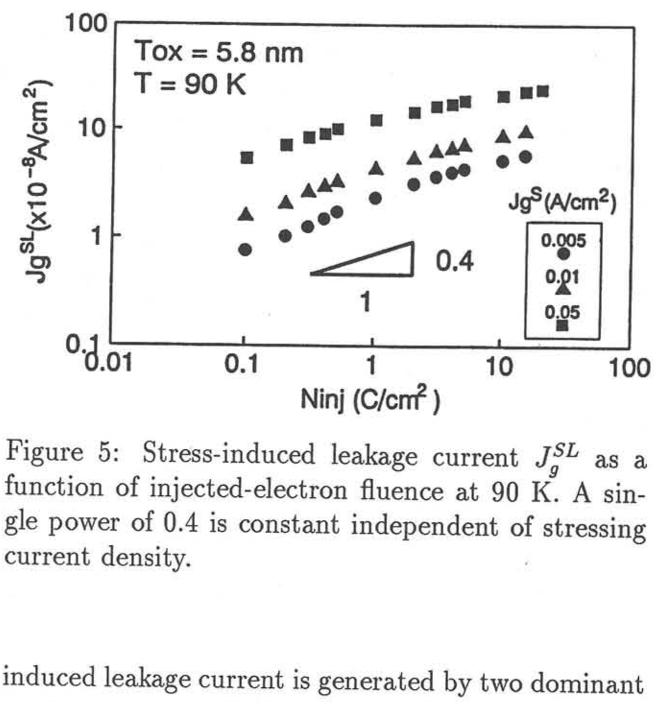

Figure 5: Stress-induced leakage current J_g^{SL} as a function of injected-electron fluence at 90 K. A single power of 0.4 is constant independent of stressing current density.

induced leakage current is generated by two dominant mechanisms; one is temperature-dependent mechanism and the other is temperature-independent mechanism. For the temperature-dependent component in Eq.(1), we think that the diffusion of hydrogen released from Si-H bonds is responsible for the creation of tunneling sites. On the other hand, for the temperature-independent component of stress-induced leakage current in Eq.(1), it is inferred that the injected hot electrons with much higher energy than kT break bonds in the SiO_2 network and broken bonds act as tunneling sites.

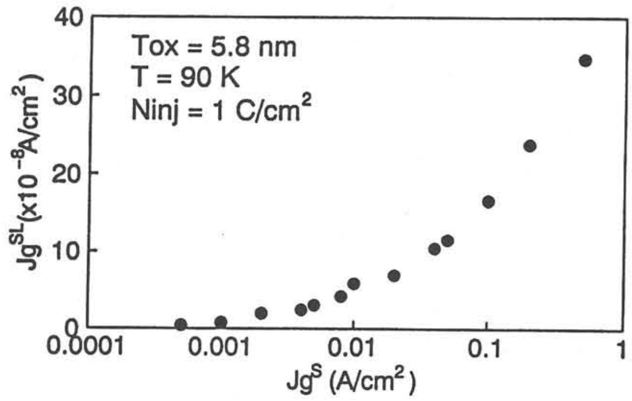

Figure 6: Stress-induced leakage current J_g^{SL} as a function of stressing current density at 90 K.

3 Conclusions

In order to quantitatively clarify the relationship between stress-induced leakage current and electron trap generation, we investigated the temperature dependence of stress-induced leakage current. As a result, it was found that the activation energy of the appearance of stress-induced leakage current agrees well with that of electron trap generation. Therefore, it can be concluded quantitatively that stress-induced leakage current and electron trap generation have a common origin. Moreover, it was confirmed that stress-induced leakage current can be formulated as functions of electron energy and injected electron fluence for the early stage of stress.

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