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Trap Density Dependent Inelastic Tunneling in Stress-Induced Leakage Current

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1. Introduction

Most of the existing models for stress-induced leakage currents, otherwise known as SILC's, are based on the experimental observation that electrons involved in SILC are dominated by an inelastic trap-assisted tunneling mechanism accompanied by a constant energy loss, independent of the electron fluence during the stress [1-5]. However, our experiments indicate that the measured energy loss is sensitively dependent on both electron fluence and stress gate voltage, and that the SILC observed in the early stage of damage in oxides is elastic. These clarifications reveal the limit of the validity of existing models and facilitate a better modeling of SILC.

2. Samples and Experimental Techniques

The samples used in this study were p-channel MOSFET's with n^+-polycrystalline Si gate fabricated on n-type substrate with doping concentration of 5.0×10^{17} cm^{-3}, whose oxide thickness and gate area were 5.0 nm and 10^3 μm^2, respectively (Fig. 1a). The quantum yield of impact ionization was determined by the carrier separation technique for both Fowler-Nordheim current (FNC) before the stressing and SILC. The energy loss, E_{loss}, is obtained by comparing the quantum yield for electrons involved in FNC, γ_{FNC}, and that in SILC, γ_{SILC}, (Fig. 1b) [2]. Note that the energy loss is the averaged value over the electrons injected into Si substrate.

3. Results and Discussion

We have found that E_{loss} sensitively depends on both electron fluence, Q_{inj}, and stress gate voltage, $V_{g,\,stress}$. Fig. 2 shows measurements of γ_{FNC} and γ_{SILC} as a function of monitor gate voltage, $V_{g,\,monitor}$, where γ_{SILC} is smaller than γ_{FNC} because of the energy loss. Note that γ_{SILC} strongly depends on Q_{inj} in contrast to the observation reported in the literature [2]. Fig. 3 shows γ_{SILC} and E_{loss} at $V_{g,\,monitor}$ = -5.4 V as a function of Q_{inj}. Note that E_{loss} strongly depends on Q_{inj} particularly in small Q_{inj} region, otherwise E_{loss} remains almost constant. Fig. 4 shows γ_{SILC} and E_{loss} as a function of Q_{inj} for various $V_{g,\,stress}$, showing that γ_{SILC} varies linearly on a log-log scale. The measured energy loss is obviously dependent on $V_{g,\,stress}$; lower γ_{SILC} (higher E_{loss}) is observed for higher $V_{g,\,stress}$. The dependences of E_{loss} on Q_{inj} and $V_{g,\,stress}$ can be consistently explained in terms of neutral trap generation in the oxide layer. The data of Fig. 4 plotted against SILC gate leakage, $I_{g,\,SILC}$, is shown in Fig. 5, where E_{loss} surprisingly lies on a universal curve. Since $I_{g,\,SILC}$ is described as a function of neutral trap density, N_{nt}, this result indicates that the measured E_{loss} is also described as a function of N_{nt}.

Our data also revealed that the SILC is elastic in the early stage of damage in oxides. As can be seen in Fig. 4, E_{loss} for $V_{g,\,stress}$ = -6.4 V is almost zero at low Q_{inj}. This indicates an elastic conduction in the early stage of stress.

Finally, we propose a new qualitative SILC generation model, which encompasses the findings above. In the early stage of damage, dominant conduction mechanism of SILC is an elastic tunneling (Fig. 6a). One possible mechanism might be the field enhancement due to trapped positive charges [6]. As neutral traps are generated in the oxide, inelastic trap-assisted tunneling via the traps dominates the elastic conduction (Fig. 6b), which leads to the continuous increase in E_{loss} shown in Fig. 5. Therefore the dominant conduction mechanism changes from elastic to inelastic tunneling according to the damage in the oxide.

4. New Findings and Conclusions

- The average electron energy loss accompanying SILC process is dependent on both Q_{inj} and $V_{g,\,stress}$.
- The SILC observed in the early stage of damage in oxides is an elastic tunneling process.
- Our new SILC model consistently explains the findings above in terms of neutral trap generation.

Acknowledgments

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References

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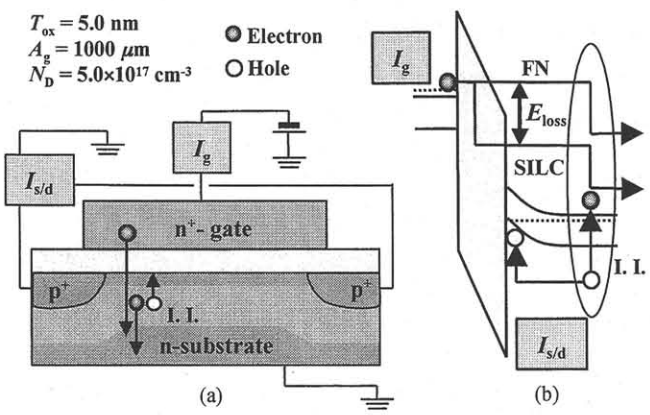

Fig. 1 (a) Schematic illustration of the measurement set-up for quantum yield measurement. Quantum yield is defined as $I_{s/d}/I_g$. (b) Band diagram in the carrier separation technique. The energy loss, E_{loss}, in SILC process is obtained by comparing the quantum yield of impact ionization (I. I.) for Fowler-Nordheim current and SILC.

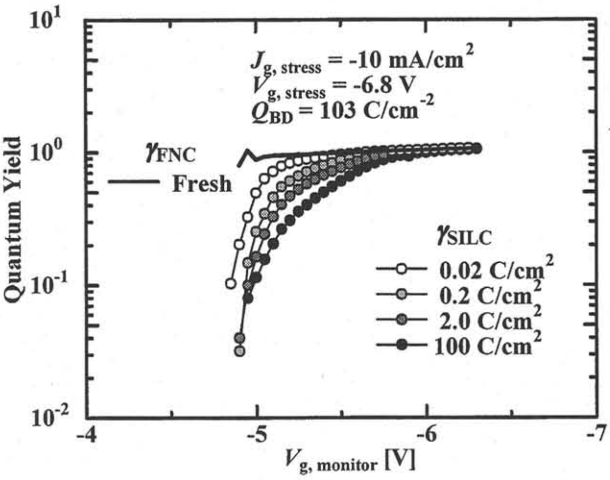

Fig. 2 Quantum yields for electrons involved in Fowler-Nordheim current, γ_{FNC}, and that in SILC, γ_{SILC}, as a function of monitor gate voltage, $V_{g,\,monitor}$. During the stressing, both $J_{g,\,stress}$ and $V_{g,\,stress}$ were almost constant.

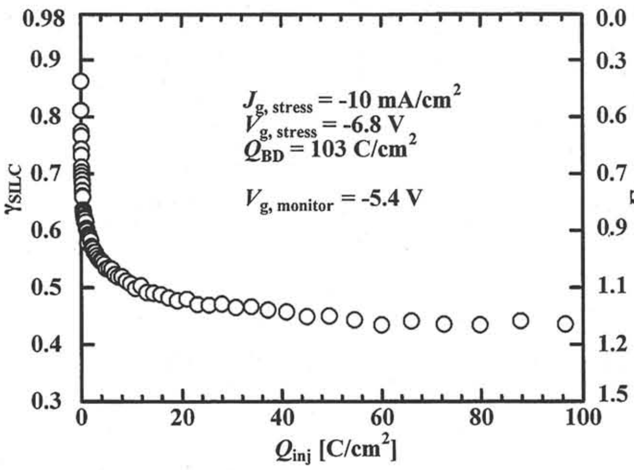

Fig. 3 The quantum yield of electrons involved in SILC and the measured energy loss monitored at $V_{g,\,monitor}$ = -5.4V as a function of electron fluence.

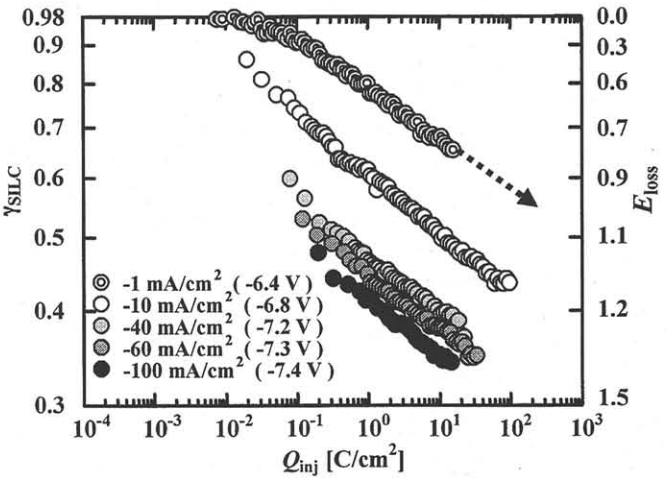

Fig. 4 The quantum yield for SILC and the energy loss at $V_{g,\,monitor}$ = -5.4 V as a function of Q_{inj} for various $V_{g,\,stress}$, showing that γ_{SILC} varies linearly on a log-log scale . The measurement for $V_{g,\,stress}$= -6.4 V was terminated prior to dielectric breakdown.

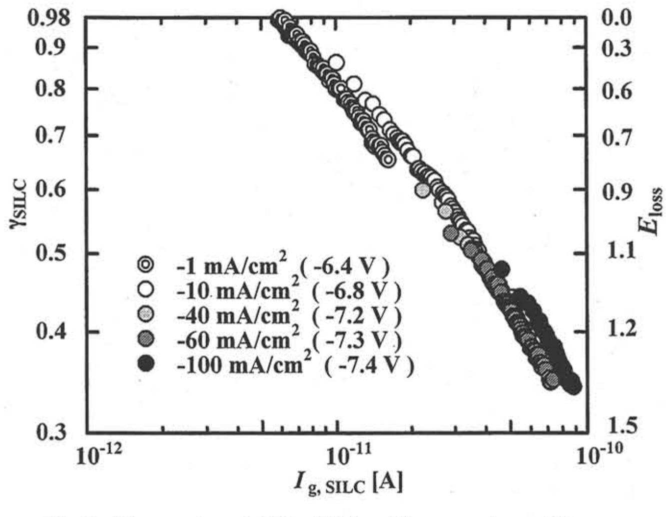

Fig. 5 The quantum yield for SILC and the energy loss at $V_{g,\,monitor}$ = -5.4 V as a function of $I_{g,\,SILC}$ for various stress gate voltages.

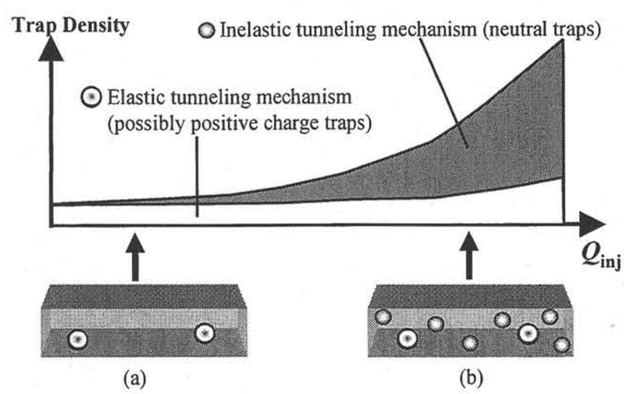

Fig. 6 Schematic illustration of our new SILC generation model. (a) In the early stage of damage, dominant conduction mechanism of SILC is elastic, which leads to zero E_{loss}. (b) As neutral traps are generated in the oxide, inelastic trap-assisted tunneling process via the neutral traps dominates the elastic conduction, which leads to the continuous increase in E_{loss} as can be seen in Fig. 5