ELECTRIC FIELD DEPENDENCE OF CONDUCTIVITY AND MAGNETOCONDUCTANCE IN Si MOSFETs IN WEAKLY LOCALIZATION REGIME

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The surfon scattering is an important mechanism in the carrier transport of two dimensional electrons in semiconductor inversion layers. The probability of surfon scattering is proportional to the square of coupling constant between electrons and surfons. Recently Shinba et al. have calculated strictly the mean energy loss per electron to lattices through surfons as a function of the electron temperature[1]. The deformation potential constant near the Si-SiO_2 interface can be determined if the E_{SD}-dependence of the electron temperature is measured.

Recent development of the theory of the Anderson localization in weak magnetic field[2,3] has made possible to explain the anisotropic magnetoconductance and to determine the inelastic scattering time τ_ε from magnetoconductance data. The inelastic scattering time in Si n-inversion layers is a function of both temperature and electron concentration. It is well expressed by $\tau_\varepsilon \propto \varepsilon_F T^{-p}$, where ε_F is the Fermi energy and the exponent p ranges between 1 and 2 [4]. This behavior of τ_ε shows that the electron-electron interaction plays a dominant role in energy relaxation mechanism for τ_ε. Therefore, the temperature in $\tau_\varepsilon \propto \varepsilon_F T^{-p}$ is the electron temperature T_e. Thus, the inelastic scattering time is a good thermometer to measure T_e of two dimensional electron systems.

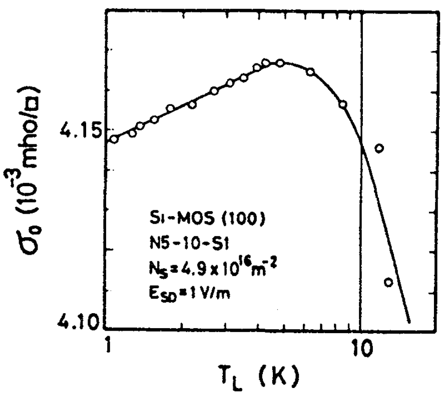

Fig. 1. Lattice temperature dependence of conductivity measured at the low E_{SD} limit of 1 V/m.

The lattice temperature (T_L) dependence of the conductivity and magnetoconductance has been measured in the temperature range from 1.1 and 13 K at the source-drain field of 1 V/m. The source-drain field dependence of the conductivity and magnetoconductance has also been measured at E_{SD} = 0.1 ∿ 1000 V/m at T_L = 1.1 and 4.2 K. Magnetoconductance measurements were carried out up to the magnetic field of 0.04 Tesla. Samples used are fablicated on (001) oriented p-type Si substrate with a gate oxide thickness of 1200 Å, channel width of 500 μm and channel length of 50 μm. The peak mobility of samples at 4.2 K is 11,000 cm^2/Vs and the mobility at the electron concentration of 4.9×10^{16} m^{-2} where the measurements have been carried out is 5000 cm^2/Vs .

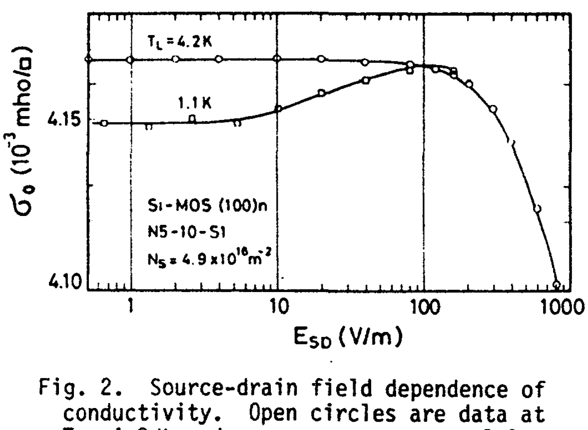

Fig. 2. Source-drain field dependence of conductivity. Open circles are data at T_L = 4.2 K and open squares are at 1.1 K.

The temperature dependence of conductivity is shown in Fig. 1. The conductivity changes logarithmically with change in temperature T_L at temperatures lower than 4 K and is well experssed by

$$\sigma_0 = 13.5 \ln T + 4147 \ (\mu\text{mho}/\ ).$$

The $\log T$ dependence of conductivity arises from the Anderson localization effect. The coefficient of $\log T$ term is in good agreement with the results of Bishiop et al.[5].

The conductivity changes against source-drain field at lattice temperatures, T_L of 1.1 and 4.2 K as shown in Fig. 2. At the lattice temperature of 1.1 K the conductivity increases with increasing E_{SD} and reaches the value of the conductivity at $T_L = 4.2$ K at field of 100 V/m. On the other hand the conductivity decreases with increasing E_{SD} at 4.2 K.

The E_{SD}-dependence of magnetoconductance at $T_L = 4.2$ K is shown in Fig. 3. The magnetoconductance is independent of E_{SD} up to 3 V/m at 1.1 K and 50 V/m at 4.2 K. When the source-drain field exceeds these fields the magnetoconductance decreases with increasing E_{SD}. The magnetoconductance is well reproduced by Hikami, Larkin and Nagaoka's formula[2] at all source drain field we investigated.

The decrease of magnetoconductance arises from the deduction of τ_ε with increasing E_{SD}. In figure 4 the E_{SD}-dependence of inelastic scattering time $\tau_\varepsilon(E_{SD})$ at 1.1 and 4.2 K are shown. The inelastic time independent of E_{SD} at low field limit up to $E_{SD} = 3$ V/m at 1.1 K and $E_{SD} = 40$ V/m at 4.2 K. When E_{SD} exceeds the critical field $\tau_\varepsilon(E_{SD})$ decreases with increasing E_{SD}. The decrease of $\tau_\varepsilon(E_{SD})$ at higher E_{SD} results from the heating up of electron gas by the field. Therefore, we are able to evaluate the electron temperature at each E_{SD} by comparing $\tau_\varepsilon(E_{SD})$ with temperature dependence of inelastic scattering time τ_ε measured at low E_{SD} limit.

The temperature dependence of τ_ε has been measured at $E_{SD} = 1$ V/m. The inelastic scattering time decreases with increasing lattice temperature, T_L. The electron

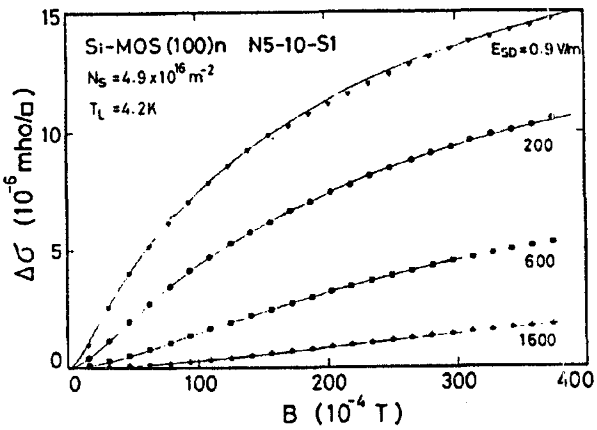

Fig. 3. Magnetic field dependence of magnetoconductivity. Solid lines are calculated by Hikami, Larkin and Nagaoka's formula with α and τ_ε which give the best fit to experiments.

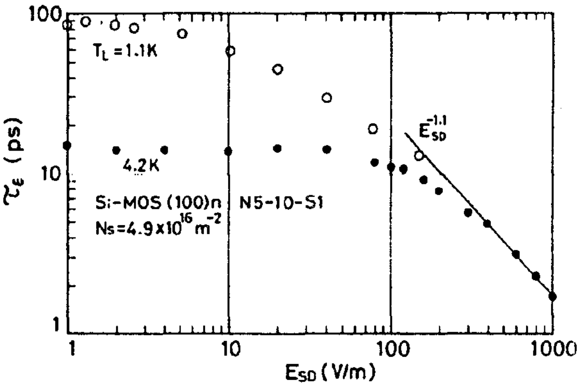

Fig. 4. Source-drain field dependence of inelastic scattering time $\tau_\varepsilon(E_{SD})$.

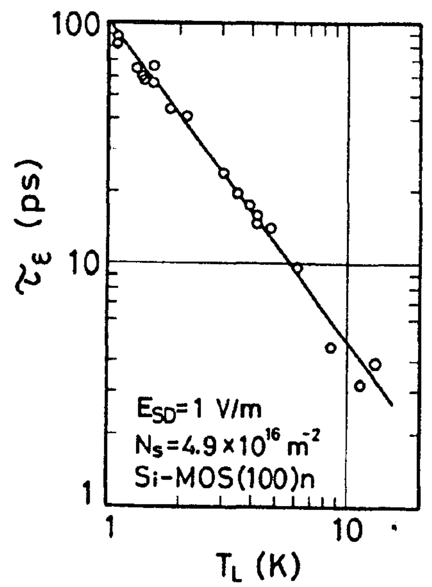

Fig. 5. Lattice temperature dependence of inelastic scattering time $\tau_\varepsilon(T_L)$.

temperature is identical to the lattice temperature at the field lower than 3 V/m at 1.1 K. The T_e-dependence of τ_ε is expressed by $\tau_\varepsilon(T_e) = 100 \cdot T_e^{-1.3}$ (ps) at temperatures between 1.1 and 13 K as shown in Fig. 5. The electron temperature is plotted as a function of E_{sd} in Fig. 6.

We are able to re-plot the E_{sd}-dependence data of conductivity in Fig.2 into T_e-dependence of conductivity as shoen in Fig. 7. In Fig. 7, the E_{sd}-dependent conductivity at $T_L = 1.1$ and 4.2 K are lying on a single solid line which is the empilical curve in Fig. 2. Therefore, the conductivity at low T_L's is independent of the lattice temperature, but dependent on the electron temperature.

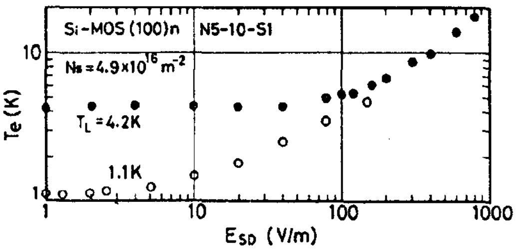

Fig. 6. Source-drain field dependence of electron temperature T_e.

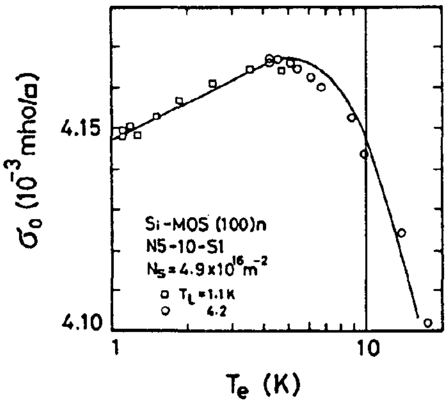

Fig. 7. Electron temperature dependence of conductivity.

In stationary state at high electric field, the rate of energy gain per electron from field, $\sigma_0 E_{SD}^2/N_S$, is equal to the rate of energy loss to the lattice system $-\langle d\varepsilon/dt \rangle$. Shinba et al. have calculated the rate of energy loss per electron based on the surfon scattering using the deformation potential constant of Si bulk [1]. In Fig. 8. both rates of the energy gain per electron (open and solid circles) and the calculated energy loss per electron (solid lines) are plotted as a function of $(T_e - T_L)$. All energy gain data at 4.2 K (solid circles) except one at $(t_e - T_L) = 0.16$ K are less than the value of the calculated energy loss rate. On the other hand at 1.1 K all data (open circles) exceed the calculated values. From these data and calculations it is estimated that the uniaxial deformation potential constant near the surface is $\Xi_u = 12.5 \pm 3$ eV if one uses the bulk value of $\Xi_d / \Xi_u = -0.67$. The value of Ξ_u is in good agreement with the bulk value of 12 eV [6].

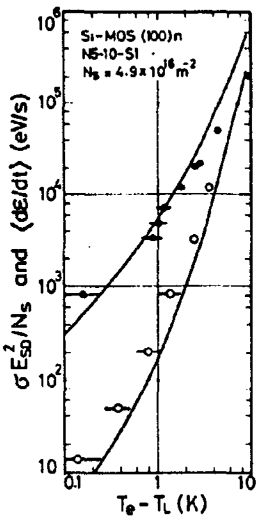

Fig. 8. $(T_L - T_e)$ dependence of energy gain per electron $(\sigma E_{SD}^2/N_S)$ from the field (solid circles at 4.2 K and open circles at 1.1 K) and energy loss per electron calculated by Shinba and Nakamura

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