23. Electric Field Dependence of Conductivity and Magnetoconductance in Si MOSFETs in Weakly Localized Regime (Electric Field Effects, II Two Dimensional Systems)

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ELECTRIC FIELD DEPENDENCE OF CONDUCTIVITY AND MAGNETOCO nductance 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-SiO₂ interface can be determined if the ESD-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_e 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 τ_e = \( \tau_F T^{-p} \), where \( \tau_F \) is the Fermi energy and the exponent p ranges between 1 and 2 [4]. This behavior of τ_e shows that the electron-electron interaction plays a dominant role in energy relaxation mechanism for \( \tau_e \). Therefore, the temperature in \( \tau_e = \tau_F T^{-p} \) is the electron temperature \( T_e \). Thus, the inelastic scattering time is a good thermometer to measure \( T_e \) of two dimensional electron systems.

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 \( \sim \) 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 fabricated 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 cm²/Vs and the mobility at the electron concentration of \( 4.9 \times 10^{16} \) m⁻² where the measurements have been carried out is 5000 cm²/Vs.

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

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

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 Bishop 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 $\tau_c$ with increasing $E_{SD}$. In figure 4 the $E_{SD}$-dependence of inelastic scattering time $\tau_c(E_{SD})$ 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 $\tau_c(E_{SD})$ decreases with increasing $E_{SD}$. The decrease of $\tau_c(E_{SD})$ at higher $E_{SD}$ results from the heating up of electron gases by the field. Therefore, we are able to evaluate the electron temperature at each $E_{SD}$ by comparing $\tau_c(E_{SD})$ with temperature dependence of inelastic scattering time $\tau_c$ measured at low $E_{SD}$ limit.

The temperature dependence of $\tau_c$ has been measured at $E_{SD} = 1$ V/m. The inelastic scattering time decreases with increasing lattice temperature, $T_L$. The electron...
temperature is identical to the lattice temperature at the field lower than 3 V/m at 1.1 K. The $T_e$-dependence of $\tau_e$ is expressed by $\tau_e(T_e) = 100 \cdot T_e^{-1.3}$ (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 shown 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 empirical curve in Fig. 2. Therefore, the conductivity at low $T_L$'s is independent of the lattice temperature, but dependent on the electron temperature.

In stationary state at high electric field, the rate of energy gain per electron from field, $\sigma_{F} E_{sd}^2 / N_s$, is equal to the rate of energy loss to the lattice system $-\langle d\epsilon / dt \rangle$. 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 $\varepsilon_u = 12.5 \pm 3$ eV if one uses the bulk value of $\varepsilon_d / \varepsilon_u = -0.67$. The value of $\varepsilon_u$ is in good agreement with the bulk value of 12 eV [6].

References