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Electrical Transport Properties in the Restricted MOS Inversion Layers

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Abstract: We have studied transport properties of very narrow inversion channel in Si-MOSFET's. Aperiodic conductance fluctuations in strongly localized regime have been found at low temperature. Peak and valley positions in σ-Vg curve are independent of temperature and of magnetic field. We have investigated the structures from a viewpoint of one particular variable range hopping in the long channel. Temperature dependence of the peak conductance provides the energy spacing between a pair of hopping sites, and the electron density of states in the strongly localized regime.

Introduction

Investigation of semiconductor nanostructures has been rapidly progressed and a number of new phenomena in mesoscopic and ballistic regime have been reported. One of the reasons for studying quantum phenomena is a possibility of the application to the future electronic devices. In Si-MOSFET's, the mobility is not so high and it is rather hard to see the ballistic motion. However, the Si-MOS inversion layer is still a good experimental stage to investigate the transport properties in two dimensional system with precisely changing the carrier density. On the other hand, the electrical transport properties in strongly localized regime has not been understood yet, though it will be accentuated in the low dimensional systems.
In this paper, we focus upon the aperiodic structures observed in σ-Vg characteristics in very narrow MOS inversion layers in strongly localized regime.

Experimental Results and Discussion

The devices studied in this work were very narrow channel MOSFET's fabricated by ion-implantation, described in detail elsewhere [1]. The channel width is difficult to be determined correctly, but it should be less than 0.1 μm in the strongly localized regime. The two-probe conductance measurements were mainly performed by using a low frequency lock-in technique. The mobility and the inelastic scattering length of a large MOSFET fabricated on the same wafer are 12000 cm^2/Vsec and 0.3 μm by low magnetic field Hall effect and magnetic negative conductance, respectively.
Figure 1 shows σ-Vg characteristics as a parameter of temperature. The gate bias region shown in Fig.1 corresponds to the very low carrier density, which is indicated in Fig.2. This relationship between Ns and Vg was determined by SdH oscillation in the strong inversion. The origin of these structure has been discussed from the points of 1D subband, universal conductance fluctuation (UCF), variable range hopping (VRH), or resonant tunneling (RT)[2,3]. The main purpose of this paper is to understand the conduction mechanism in the strongly localized regime.

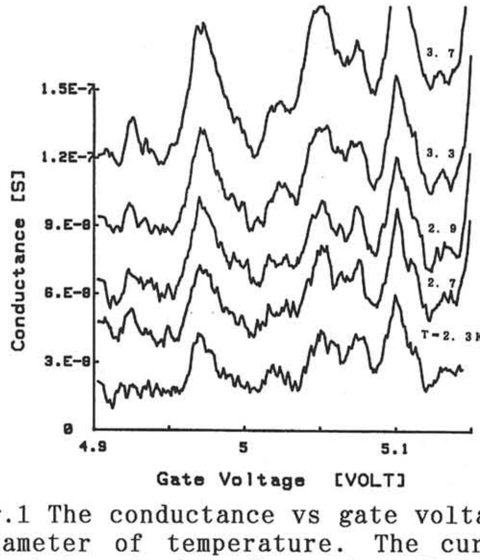


Fig.1 The conductance vs gate voltage as a parameter of temperature. The curves are offset for clarity. The peaks and valleys do not depend on the temperature.

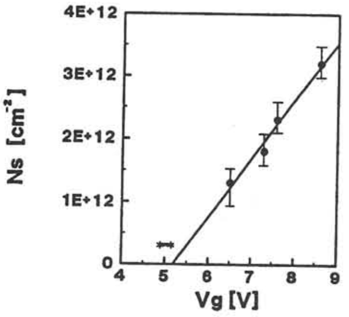
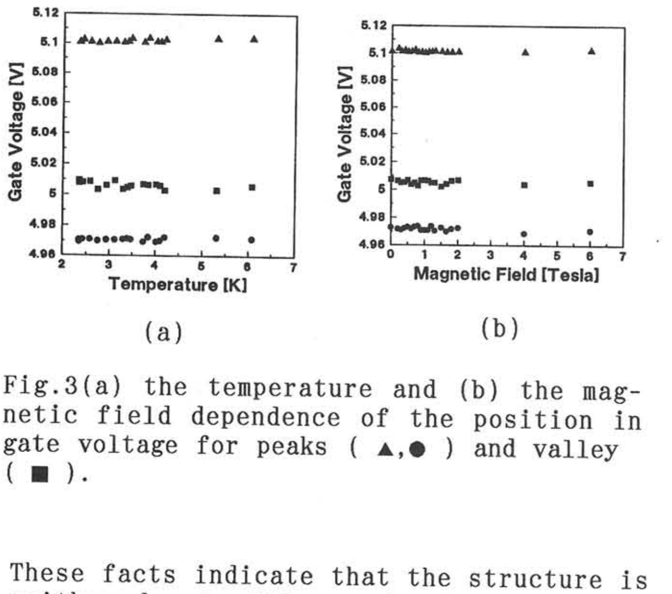


Fig.2 The relationship between electron and gate voltage, determined by Shubnikov de Haas oscillation in the strongly inverted region. The gate bias region focused on in this paper is denoted by ⟷

Both temperature and magnetic field dependences of the peak position against the gate voltage are shown in Fig.3(a),(b). We have found that the peak positions are insensitive to the temperature or the magnetic field. And, the structures were completely reproducible after the sample was once warmed up to the room temperature.



(a) (b)

Fig.3(a) the temperature and (b) the magnetic field dependence of the position in gate voltage for peaks (▲,●) and valley (■).

These facts indicate that the structure is neither due to UCF nor due to 1D effect. Figure 4 shows the temperature dependence of the conductance for several peaks and valleys. The results can be roughly fitted to the 1D variable range hopping scheme for the peaks in σ-Vg and the peak width (FWHM) increases with temperature, which cannot be explained by simple RT. Therefore, we can safely assign these structures to the VRH mechanism. A question is, here, that a number of hops should be required to the current conduction, and that the averaging over the channel length may smear out the fine structure, because our sample length is too long compared with the hopping length.

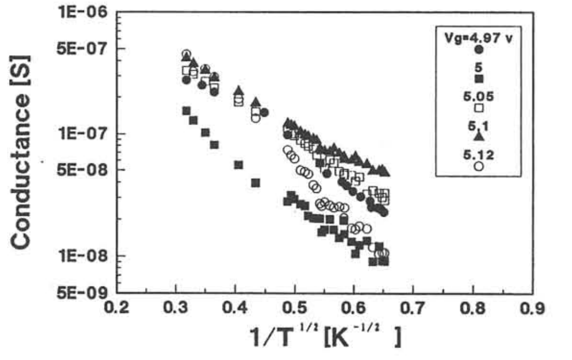


Fig.4 The temperature dependence of conductance for several peaks and valleys.

However, it can be easily understood, when a few critical hops essentially dominate the total electrical conduction[4]. In our case, no temperature dependence of the peak position implies that one critical hop is involved in the conductance, especially for first one or two peaks in Fig.1. Although we have pointed out that the peak conductances are shown by the 1D VRH scheme, 1D hopping system with only a few hops is not self averaging and it will be better to use the following equation by P.A.Lee [4].

$$\ln(G/G_{ij}) = -2X_{ij}\xi^{-1} - (1/2kT)(|E_i - \mu| + |E_j - \mu| + |E_i - E_j|) \quad (1)$$

Here, ξ and μ are the localization length and the chemical potential, respectively. We suppose that μ is located between E_i and E_j from the fact of the temperature insensitiveness of the peak position as shown in Fig.3(a)[3], though we cannot say where is the chemical potential in a gate bias condition. Figure 5 shows the 1/T dependence of the peak conductance at Vg=4.97 V. From the linear dependence in Fig.5, we can obtain the energy difference between the two hopping sites involved in this conduction

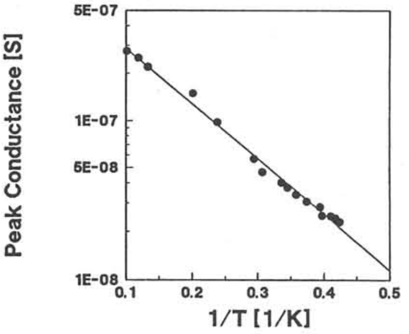


Fig.5 The linear relationship between the peak conductance at Vg=4.97 and the inverse of temperature.

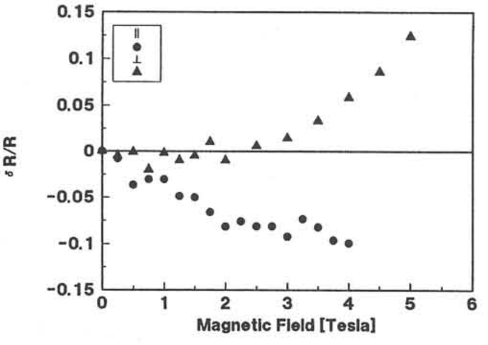


Fig.6 Relative magnetoresistance as a parameter of the magnetic field. The magnetic field is applied perpendicular● and parallel▲ to the sample.

process. Concerning this pair of hopping sites, ΔE_{ij}=0.7meV by using Eq.(1). This value corresponds to the density of states $D(E)=2x1.4x10^3$ eV^{-1} (2 is a spin degeneracy). This event should take place within the range of localization length, ξ. On the other hand, the density of states in 2DEG is $1.6x10^{14}$ $cm^{-2}eV^{-1}$. Therefore, if ξ is about 0.04μm, the result is quite consistent. Furthermore, this is weakly equal to the value evaluated by the 1D VRH scheme, assuming the effective channel width for this critical hopping is comparable to the localization length, 0.04 μm. We think that the above assumption of the channel width may be quite reasonable, because we observed large negative magneto-resistance in the same gate voltage, as shown in Fig.6, and it is due to the narrow effect of the channel width comparable to ξ[1].

Finally, we also investigated the temperature dependence of peak width (FWHM) against the gate voltage. In typical Mott hopping, the chemical potential spacing between peaks and valleys is proportional to $T^{0.5}$[4]. It is found in this particular hopping peak, Vg=4.97, that the peak width increases with temperature, as shown in Fig.7.

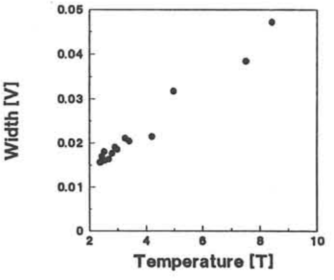


Fig.7 Peak width (FWHM) at Vg=4.97 vs temperature

Conclusion

We investigated the electrical transport properties in the strongly localized regime in the very narrow Si MOS inversion layer. The aperiodic structures in σ-Vg curve is attributed to a critical variable range hopping even in long channel devices. The temperature dependence of the peak conductance provides the energy difference between hopping sites, which is about 0.7 meV in this sample. The density of states derived from this energy is in the same order with that in 2DEG, when assuming the localization length is comparable to the channel width.

References

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