Multisubband Effects on Universal Mobility for Electrons in MOS Inversion Layer

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The universal relationship between inversion layer mobility and the effective normal field is valid for modeling the dependence of inversion layer mobility on the normal field. The effective normal field is calculated using the depletion layer charge density and the inversion layer carrier density multiplied by a parameter. The parameter depends on surface orientation and the universality is shown with parameter 1/2 for (100) and with 1/3 for (110) and (111)[1]. We analyzed the dependence of the parameter on surface orientation using a program that solves the Poisson and Schrödinger equations self-consistently.

Using depletion layer density N_{dep} and inversion layer density N_{inv}, We defined effective normal field E_{eff} as follows,

$$E_{eff} = \frac{q}{\epsilon_{Si}}(N_{dep} + \eta N_{inv}), \tag{1}$$

where η is a parameter dependent on surface orientation. We applied to a one-dimensional MOS system the Stern's method in which the anisotropy of the band structure and degeneracy of valley is considered[2] and compared the effective field with the average field calculated in quantum mechanics. We found that the parameter did not depend on surface orientation and that the normal field was approximately expressed for each surface orientation as the effective field with parameter 1/2.

Assuming that the i-th subband mobilty μ_{vi} due to lattice vibration is proportional to average distance of the i-th subband[3], total mobility μ is expressed as

$$\mu = \sum_{vi} \frac{n_{vi}}{N_{inv}} \mu_{vi} \propto \sum_{vi} \frac{n_{vi}}{N_{inv}} \frac{z_{ave}^{vi}}{m_d^{vi} m_s^{vi}}, \tag{2}$$

where v is the valley suffix, i the band suffix, m_d the density of state effective mass, m_s the conductivity effective mass, and z_{ave} the average distance of inversion layer carriers from Si/SiO_2 interface. Figure 1 shows the relationship for (100) and (111) between the mobility and effective field with parameter 1/2. Universality holds for (100) but not for (111). For (111), mobility decreases considerably as substrate impurity concentration increases. Figure 2 shows mobility μ_{vi} and carrier density n_{vi}. The normal field is 0.9 (MV/cm), and the notation of energy levels follows that of Stern[2]. The inversion layer density N_{inv} of (100) is almost same as that of (111). But total mobility of (100) is greater than that of (111) because the conductivity effective mass of (100) is lighter than that of (111). In the upper subband, the carrier density is low and mobility high. The upper subband is also needed to calculate total mobility because total mobility depends on both carrier term n_{vi}/N_{inv} and mobility term μ_{vi}. When the substrate concentration is higher, the mobility and carrier density of lower subband E_0, E_0' is relatively steady, but those of upper subbands decrease. The mobility of upper subbands for (111) decreases greater than that for (100). Thus, the mobility of (111) decreases markedly as the substrate concentration increases.

The normal field does not depend on surface orientation and is approximately equal to the effective field with parameter 1/2. The decrease in the mobility depends on the variation in the carrier population and mobility for each subband. Multisubbands need to be considered in analyzing universal mobility.

References

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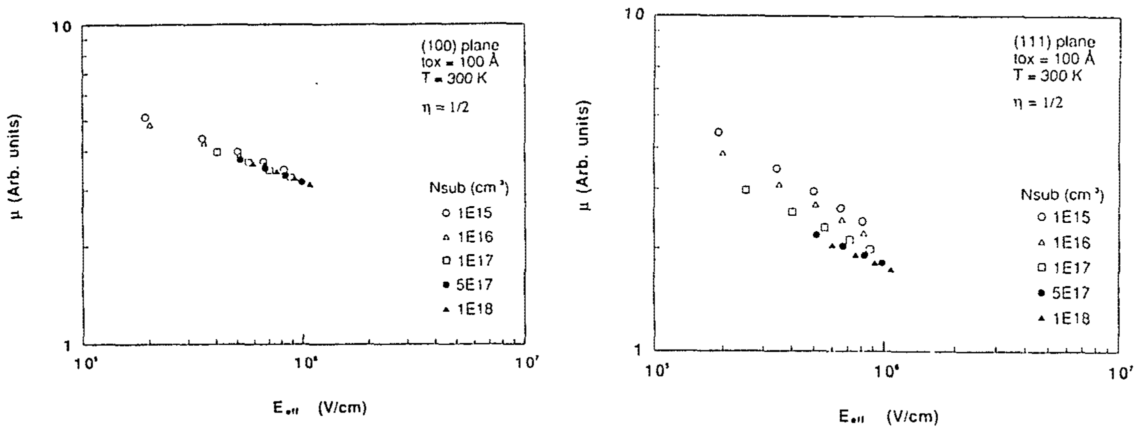
[2] Frank Stern, *Self-Consistent Results for n-type Si Inversion Layers*, Phys. Rev. B5, p. 4891, 1972

[3] H. Ezawa, T. Kuroda, and K. Nakamura, *Surfaces and the Electron Mobility in a Semiconductor Inversion Layer*, Surf. Sci. 27, p. 218, 1971



(a) (100) (b) (111)

Figure 1. Relationship between mobility and effective normal field.

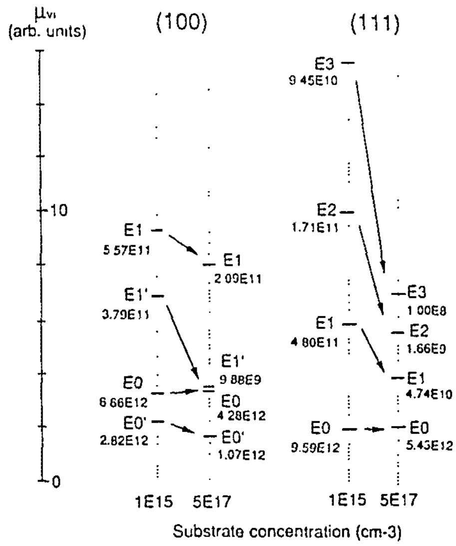


Figure 2. Dependence of mobility and carrier density on substrate concentration. The normal field is 0.9 MV/cm. Using the Stern's notation, we label the subbands E0, E1 ... .