Effect of Interface Roughness on Carrier Transport in Asymmetric Channel: An EMC/MD Simulation Study

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INTRODUCTION

Surrounding-gate metal-oxide-semiconductor (MOS) transistors have been attractively studied as promising devices for logic and memory LSIs [1]. In such vertical transistors, it is expected that the channel geometry tends to become asymmetric, e.g. taper shaped, due to the difficulties in the fabrication process [1].

In our previous work, it is found that mean current of an asymmetric horn-shaped channel, which widens from the source to the drain side, increases compared those of a symmetric straight channel [2]. The work, however, assumed the roughness at the sidewalls of channel is so small that the scattering is considered to be specular. This work reports on the effect of roughness at sidewalls on carrier transport in asymmetric channels, by using the ensemble Monte-Carlo/ molecular dynamics (EMC/MD) method [3,4].

SIMULATION METHOD

The carrier transport is simulated by EMC/MD method [3,4]. Carriers are treated as classical particles, and their real-space trajectories under the Coulomb point-to-point potentials are calculated by MD algorithm. The acoustic and optical phonon scatterings are taken into account as stochastic changes in the momentum of carriers according to the standard energy-dependent formulations.

We have examined three types of Si channels as illustrated in Fig. 1. One is a symmetric straight channel which corresponds to a conventional channel. The others are asymmetric horn-shaped and reserved-horn-shaped channels whose widths vary linearly from source to drain sides. These channels are characterized by a flare angle. Each device has the same volume so as to have the same resistance. Each channel is assumed to be intrinsic, containing no impurity ions. Only conduction electrons are considered as carriers. The carrier densityis the same (4.7×10^{18} cm^{-3}) for each device.

In order to reproduce the scattering at the sidewalls, the cylindrical objects are introduced as building units of the sidewall [2]. Carriers are repelled from the cylindrical objects. The interaction between carriers and the cylindrical object is described as a repulsive potential with cylindrical symmetry, whose axis is oriented perpendicular to the longitudinal direction. When a carrier approaches the interface, the carrier is elastically scattered at the sidewall. The roughness of the sidewall can be controlled by changing the radius of the cylindrical object, $\boldsymbol{r_{core}}$.

In these conditions, the current under the constant electric field of 5 kV/cm along the channel is estimated by counting the number of carriers transporting at a cross section of the channel per unit time.

RESULTS AND DISCUSSION

Fig. 2 shows the relation between mean current and flare angle for different roughness values. Although the mean current in every channel slightly decreases with the increase in the roughness, the mean current is enhanced in horn-shaped channels.

Fig. 3 shows the distribution of carrier velocity of longitudinal component along channel. For horn-shaped channels, the distribution shifts to higher velocities compared to the straight channel. Thus, the increase in the mean current in horn-shaped channels can be attributed to the enhancement in the carrier velocity.

978-3-901578-26-7

It is noted that a hump appears at high velocity side in the distribution, as indicated by the arrow in Fig. 3. This suggests the existence of carriers with quasi-ballistic transport [5], since the distribution does not obey a Gaussian. The enhancement in the hump intensity for horn-shaped channels means that carrier energy is not well relaxed due to suppression of scattering.

The hump intensity is weakened with the increase in roughness (the inset in Fig. 3), indicating the decrease in the number of carriers with ballistic transport. This is due to the increase in the probability of the back scattering towards the source side.

From above results, it is found the roughness at the sidewalls does not have a significant impact on the conductivity of horn-shaped channels. Even if the scattering becomes diffusive at the interface, the momentum of carriers in average kept collimated to the drain side by the tilted walls

CONCLUSION

The advantage of the horn-shaped channels in the conductivity is preserved even with the increase in the roughness at the sidewalls. The direction of current flow is important for device performance in the introduction of asymmetric channel geometries.

ACKNOWLEDGEMENT

This work was supported by Grant-in-Aid for Scientific Research (B) (24310082) from Japan Society for the Promotion of Sience and CREST from JST.

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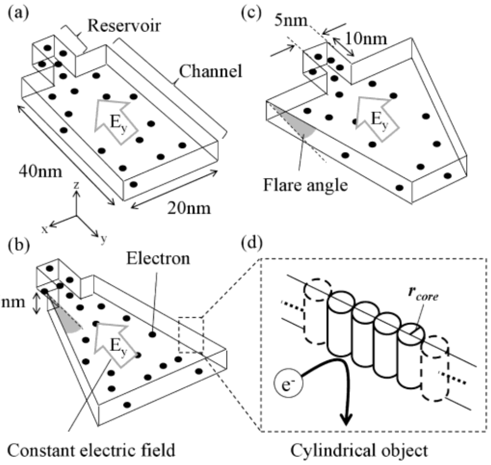

Fig. 1. Device models simulated in this study: (a) symmetric straight channel, (b) asymmetric horn-shaped channel, (c) asymmetric reserved-horn-shaped channel, and (d) cylindrical objects as building blocks of sidewalls. Carriers are injected from a reservoir connected to the channel.

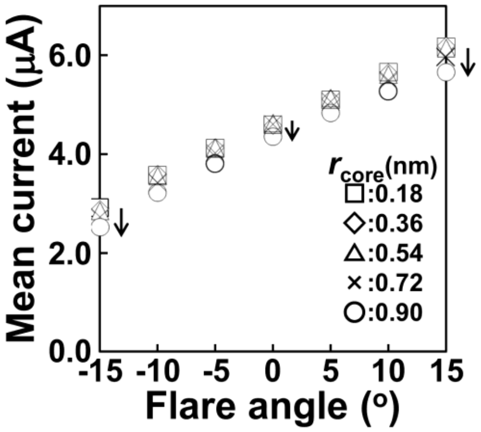

Fig. 2. Relation between mean current and flare angle for different roughness values.

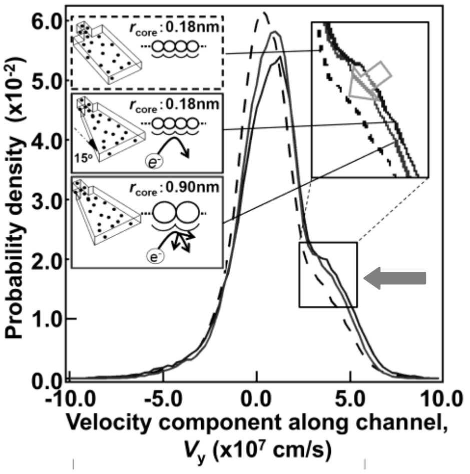

Fig. 3. Distribution of carrier velocity of longitudinal component along channel.