The Effect of Isotropic and Anisotropic Scattering in Drain Region of Ballistic Channel Diode

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Abstract

The effect of isotropic and anisotropic scattering within the drain region of diode with ballistic channel is investigated using the semiclassical Monte Carlo simulation, and the results are discussed. The results show that the isotropic scattering can severely degrade the steady-state current, the electrons mean velocity, and increase the electrons concentration in channel because some hot electrons can back into the channel from drain, and even return to the source. On the contrary, anisotropic scattering can suppresses the backward flow of hot electrons. We conclude that the isotropic scattering in the drain region seriously influences the carrier transport relative to anisotropic scattering.

1. Introduction

Recently, advanced semiconductor device have been scaled down to the nanoscale size, the devices size will be continuously shrinking. When the channel length is further shortened less than or comparable to a carrier's mean free path, the frequency of scattering events in these nanoscale devices is diminished, so that the near ballistic transport is expected at the room temperature operation [1]. In the theory of ballistic channel devices, because carriers do not suffer any scattering in the channel region, the carriers injected from the source flow into the drain become hot carriers [2]. The understanding of these hot electrons affect on characteristics of devices with ballistic channel is regards as quite important to future novel semiconductor devices. Svizhenko and Anantram pointed out that the rebound of hot electrons in the drain region degrades the steady-state current in nanoscale MOSFETs [3]. Kurusu and Natori pointed out that the elastic scattering in the drain region significantly increase the backward flow of hot electrons and degrades the steady-state current relative to inelastic scattering [4]. Figure 1 schematically shows the rebound of hot electrons in the drain. However, the role of isotropic and anisotropic scattering is not distinguished there.

In this paper we have investigated effect of

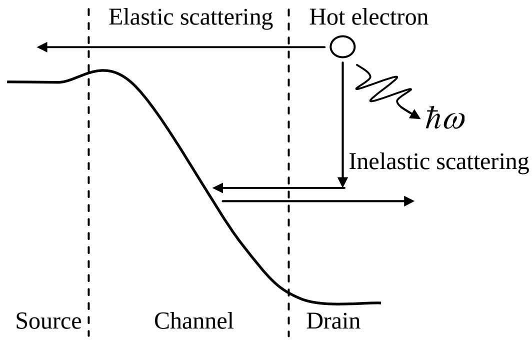

Fig. 1. Schematic diagram showing the rebound of hot electrons. Some hot electrons can flow back the channel and even reach the source if the scattering is elastic. If scattering is inelastic, rebounded electrons are unable to reach the source.

isotropic and anisotropic scattering inside drain region of ballistic channel diode using the semiclassical Monte Carlo method. Our results show that the isotropic scattering inside drain region enhance a backward flow of hot electrons from the drain toward the source and degrades the electrons mean velocity, steady-state current, and increase the electrons concentration in channel. On the contrary, the anisotropic scattering increase the peak of mean velocity, stead-state current, and decrease the electrons concentration in channel because it can suppresses the backward flow of hot electrons from the drain toward the source. We conclude that the isotropic scattering in drain region seriously influences carrier transport and decrease the ballisticity, contrary to it anisotropic scattering has the possibility to increase ballisticity of devices.

2. Simulation Method

The 2D diode model used in this research is shown in Fig. 2. The channel region is assumed to be intrinsic and perfectly uniform. We denote the n^+ doped regions as the source and the drain, respectively, and the doping concentration is 10^{18} cm^{-3}, impurity concentration is 10^{14} cm^{-3} in the source/drain region. The length of the source and drain is 40nm, and channel length is 20nm. The Diode width is 40nm. As for the scattering mechanism, isotropic acoustic phonon scattering and anisotropic ionized impurity scattering is taken into account in the investigation. Other scattering mechanisms are ignored to avoid complexity. We assumed that channel is ballistic and ignore all scatterings. We treat source and drain contacts is ideal Ohmic contacts. The lattice temperature is assumed to be 300K. We employ an analytical non-parabolicity band model for the band structure of silicon. We used the *cloud-in-cell method* to calculate the electrons concentration profile and used the *finite difference method* scheme of the Poisson equation to calculate the potential profile. The steady-state current is computed using the *Ramo-Shockley* formula [5]-[6] throughout the investigation.

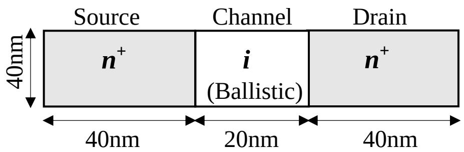

Fig. 2. Schematic structure of n^{+}-i-n^{+} diode. We assuming the channel region is ballistic in all investigation.

To distinguish the influence of isotropic scattering and anisotropic scattering inside the drain region, we will choose three different cases to perform the investigation. In A case, only the isotropic acoustic phonon scattering is considered inside the drain region. In B case, only the anisotropic ionized impurity scattering is considered inside the drain region, In C case, the drain region is

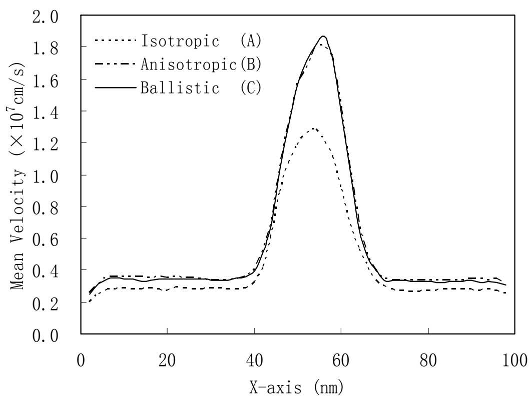

Fig. 3. Distribution of electrons mean velocity inside diode at V_D=0.1V. Dotted line (A), dashed line (B) and solid line (C) respectively show results for cases in which only isotropic scattering is considered, only anisotropic scattering is considered in the drain region and the drain region is ballistic.

assumed to be ballistic and electrons do not suffer any scattering.

Results

Distributions of the electrons mean velocity along X-axis is shown in Fig. 3. Dotted line (A), dashed line (B) and Solid line (C) is respectively show the case only isotropic acoustic phonon scattering is considered, the case only anisotropic ionized impurity scattering is considered, and the case the drain region is ideal

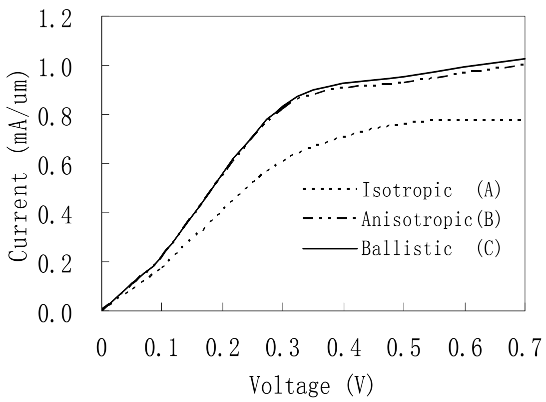

Fig. 4. *I-V* characteristics of ballistic channel diode. Dotted line (A), dashed line (B) and solid line (C) respectively show results for cases in which only isotropic scattering is considered, only anisotropic scattering is considered in the drain region and the drain region is ballistic.

ballistics.

The C case and B case have almost same distribution of the electrons mean velocity along X-axis. In both case C and B, the peaks of the electrons mean velocity in the channel are close to the drain edge. On the other hand, when isotropic acoustic phonon scattering is considered in the drain region (case A), the peak of the mean velocity is located at the center of the channel and the value is less than in case B and in case C. Figure 4 shows the current-voltage characteristics of the ballistic channel diode in each of the cases. Dotted line (A), dashed line (B) and solid line (C) respectively expresses the same cases as in Fig. 3. The case C and case B have almost the same current value in all applied biases. The case A shows a lower current compared to case B and case C in all applied biases. Figure 4 show that the steady-state current has same tendency as the electrons mean velocity as shown in Fig 3.

3. Discussion

In the all cases, the channel is completely ballistic, electrons injected from the source into the drain become hot electrons because electrons do not suffer any scattering and there is not energy lost in the channel. In the case C, all hot electrons will be absorbed by the drain region because drain region is ballistic and electrons will not suffer any scattering. Therefore, the case C has high saturation steady-state current, and the peak of the electrons mean velocity is located at drain edge and the peak is also high. For the case A, hot electrons in the drain region are scattered by isotropic acoustic phonon scattering. Due to the isotropic scattering has same scattering frequency in all direction, so some hot electrons will flow from the drain back into channel, some of them have sufficient energy to return the source region because these hot electrons have not lost their kinetic energy during the elastic acoustic phonon scattering. On this account, isotropic scattering will decrease the peak of the electrons mean velocity in the channel and the steady-state current, but will increase the electrons mean concentration in the channel. Due to the velocity of rebounded hot electrons from the drain region is obviously larger than source region, so, the peak of the mean velocity shifts to the center of channel [4]. Figure 5 shows variation of scattering rate of the isotropic acoustic phonon scattering and the anisotropic impurity scattering at room temperature. The dashed line represents the isotropic acoustic phonon scattering, and solid line represents the anisotropic impurity scattering. Figure 5 shows that the scattering rate of the anisotropic impurity scattering is higher than isotropic acoustic phonon scattering when carriers have low energy. The impurity scattering is also an elastic scattering, and the electrons have not lost their energy during the scattering. However, in case B, the distribution of electrons mean velocity is the same as in case C; but the peak of velocity is lager than in case A; the value of saturation steady-state current is close to in case C, and is lager than in case A. We consider that these results are caused by the fact the impurity scattering is an anisotropic scattering. Although impurity scattering has higher

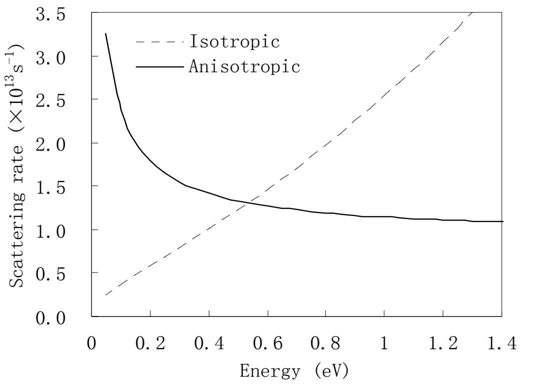

Fig. 5. Dominant scattering rate at T=300K. Dashed line and solid line represent the scattering rate of isotropic acoustic phonon scattering, and anisotropic impurity scattering, respectively.

scattering rate, but the frequency of scattering on the backward direction is much less than the frequency of forward direction due to its anisotropic characteristics, most electrons in the drain region are absorbed by the drain region after impurity scattering . When the electrons have very low frequency of the rebounding from drain region return to source, the case B has close value of electrons mean velocity and value of steady-state current with case C.

The steady-state current is degraded even if the electrons rebounding from the drain back into channel, but unable to reach the source. We will derive similar results if just some electrons have sufficient energy to return into the channel from drain. It has been pointed out that the ballisticity is the ratio of saturation current with scattering to saturation current without scattering [7]. Therefore, the anisotropic scattering can increase the ballisticity relative to isotropic scattering in the drain region because of the saturation steady-state current in case B is lager than the case A.

4. Conclusions

The effect of isotropic and anisotropic scattering in the drain region of diode with ballistic channel is investigated and results are discussed. The isotropic scattering not only degrade the mean velocity in channel and steady-state current but also seriously decrease the ballisticity of devices because isotropic scattering seriously significant the backward flow of electrons. On the contrary, the anisotropic scattering can increase mean velocity and steady-state current in channel because anisotropic scattering suppresses the backward flow of electrons, finally anisotropic scattering will increase the ballisticity of devices. We conclude that the isotropic scattering in the drain region seriously influence the carriers transport relative to anisotropic scattering.

Acknowledgement

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