Monte Carlo Simulation of Current Fluctuation at Actual Contact

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Abstract- **Current fluctuation at actual contact was studied by using the Monte Carlo method. The metal/semiconductor interface was treated as the Schottky contact, because the interface inevitably becomes the Schottky contact. Simulations were carried out for n^+n structures to investigate asymmetry of current fluctuation at both contacts. It was found that the current fluctuation at each contact depended on bias, impurity concentration around the contact, length of contact region, and the Schottky barrier height.**

I. INTRODUCTION

As silicon devices are scaled down, high frequency applications have been studied [1][2]. Therefore, the influence of noise should be considered in designing devices. Current fluctuation in devices has been investigated by using MC (Monte Carlo) simulations [3][4], in which the transient current has been calculated by summation of the carrier velocities in devices based on RS (Ramo-Shockley) theorem. However, terminal currents can also be calculated by counting particles crossing contacts and the relation with RS results has not been interpreted sufficiently.

In this work, the current fluctuation at each contact was investigated by applying the MC method to n^+n structures. A Schottky contact model [5] was applied as an actual boundary condition, because the metal/semiconductor interface inevitably becomes the Schottky contact, in most cases. Influences of bias, impurity concentration, length of contact region and the Schottky barrier height on the current fluctuation were studied.

II. ASYMMETRY OF CURRENT FLUCTUATION AT BOTH CONTACTS

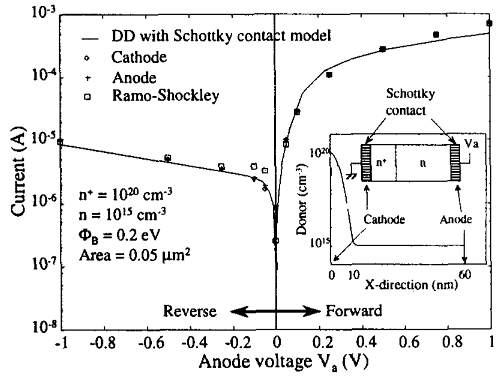

Figure 1: Current versus voltage characteristic and impurity profile of a simulated structure.

Fig. 1 shows the characteristic of current versus voltage for a simulated device and the inset shows its impurity profile. A rectifying characteristic was obtained because of low tunneling probability at the anode. The symbols are the results by MC simulations, and the line is obtained by the drift diffusion model with a similar Schottky contact model [5]. Three kinds of MC results were calculated by counting particles crossing cathode and anode contacts, and by using the RS theorem. Although all the currents are almost the same, current fluctuations are different as shown below.

Fig. 2 shows a schematic band diagram around the metal/semiconductor interface. Current crossing the interface can be calculated by using the tunneling probability, D, and a random number, r, generated for a particle reaching a turning point [5]. D is determined by the WKB approximation and the injection rate $P_{inj,l}$ from the metal at a point x_l is calculated by D and the energy distribution in the metal.

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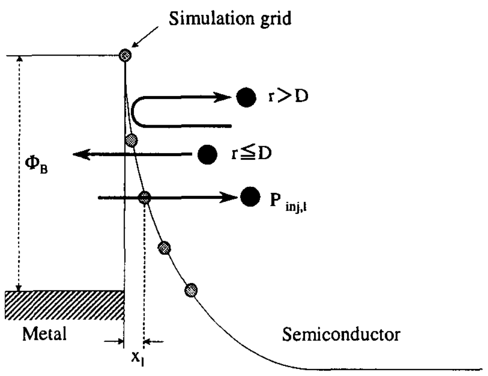

Figure 2: Schematic band diagram to show behavior of particles around the metal/semiconductor interface.

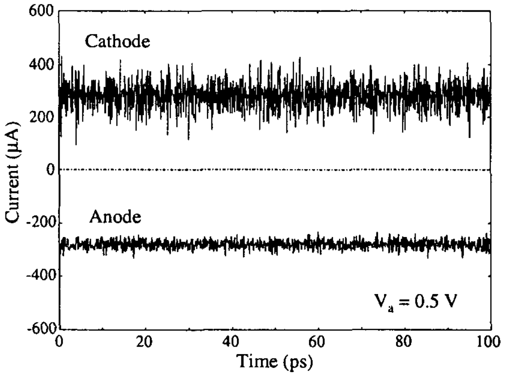

Figure 3: Current versus time at the cathode and the anode under a forward bias condition.

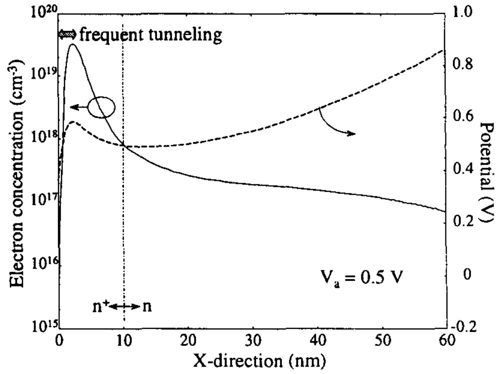

Figure 4: Electron concentration and potential distributions under the forward bias condition.

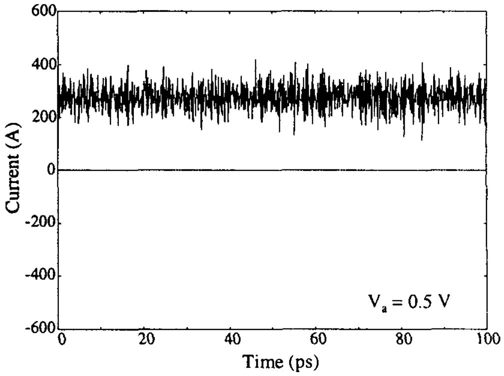

Figure 5: Current versus time calculated by Ramo-Shockley theorem under the forward bias condition.

Fig. 3 shows that current fluctuation at the cathode is larger than that at the anode under a forward bias condition. This is because the tunneling probability and electron concentration around the cathode are higher than those around the anode. Fig. 4 shows distributions of electron concentration and potential under the forward bias condition. The potential bending around the cathode is due to the Schottky barrier and the electron concentration around the cathode is depleted by the barrier. Frequent tunneling events take place between the cathode and an electron concentration peak near the cathode, whereas the tunneling around the anode occurs less frequently because of the lower tunneling probability and the low electron concentration around the anode.

Fig. 5 shows current versus time calculated by the RS theorem under the same forward bias condition. Dispersion of the current fluctuation seems to be close to that of the cathode in Fig. 3, but slightly smaller. This is because the fluctuation calculated by the RS theorem reflects fluctuation of average flux in the whole region of the device, whereas the fluctuation calculated by counting particles at each contact reflects the fluctuation of flux in the local region around the contact.

III. HOT ELECTRONS AROUND N$^+$ REGION

Fig. 6 shows the dependence of dispersion of current fluctuation normalized by the average current on the anode voltage. The normalized dispersion at the cathode is always larger than that at the anode. Normalized dispersion calculated by the RS theorem is also plotted, which is almost the same as that at the cathode under low forward bias conditions. This is because the velocity fluctuation in the high electron concentration region around the cathode is mostly reflected in the RS theorem [3]. The fluctuation at the cathode becomes larger than the RS results as the

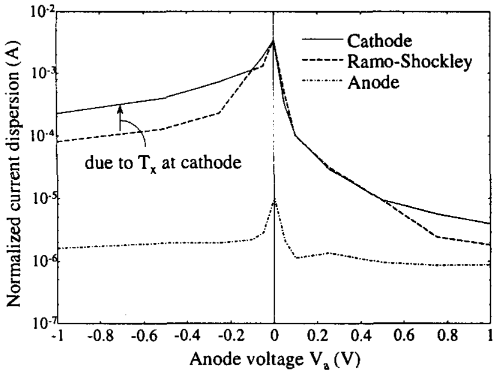

Figure 6: Normalized current dispersion versus anode voltage.

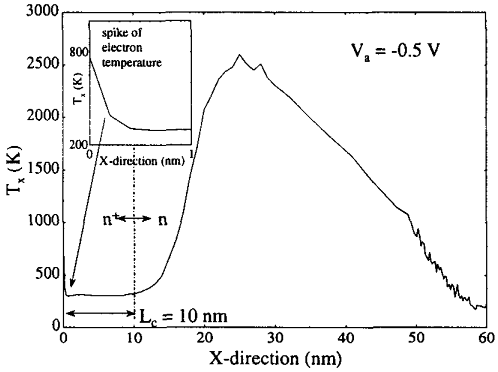

Figure 7: Distribution of electron temperature for parallel direction under a reverse bias.

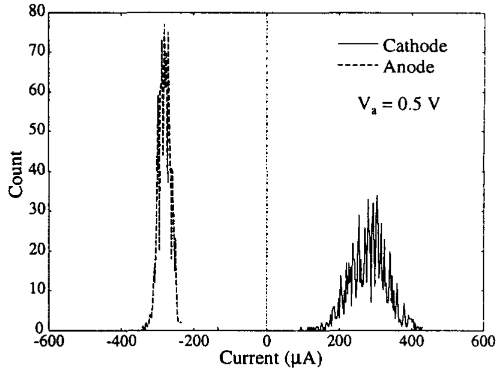

Figure 8: Statistic of current fluctuation under the forward bias condition.

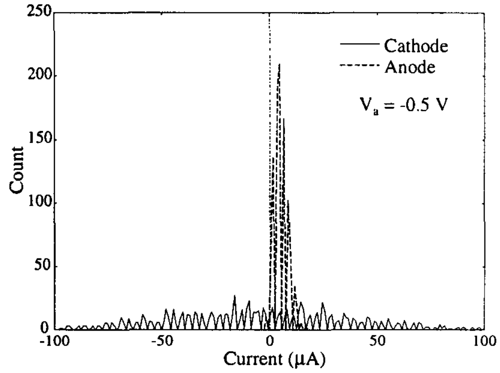

Figure 9: Statistic of current fluctuation under the reverse bias condition.

forward bias increases, since electrons launched through the Schottky barrier gain energy, and the electron temperature increases locally around the cathode, which is observed as the difference from the RS results.

Under reverse bias conditions, the fluctuations at the cathode are always larger than those by the RS theorem, which can also be explained by the electron temperature for the parallel direction, T_x. Fig. 7 shows the distribution of T_x, calculated by $T_x = \frac{m^*}{k_B}(< v_x^2 > - v_{dx}^2)$, where m^* is the effective mass, k_B the Boltzmann constant, v_x the velocity of each electron, and v_{dx} the average velocity. T_x in the n^+ region is almost the same as the ambient temperature, but a peak is observed just at the cathode. The peak is caused by hot electrons in the n^+ region and it is observed as the difference from the RS results. The hot electrons in the n^+ region are caused by the phenomenon that energetic electrons accelerated in the n region are insufficiently relaxed in the n^+ region, and the hot electrons surmount the Schottky barrier.

T_x is reflected in the statistic of the current fluctuation at each contact. Fig. 8 and Fig. 9 show the statistics of current fluctuation under forward and reverse bias conditions. In Fig. 8, the width of the statistic for the anode is narrower than that for the cathode. This is because electrons are ballistically drifted in the n region, and the injection rate from the metal at the anode is lower than that at the cathode. Therefore, the dispersion of electron velocities around the anode is smaller than that around the cathode. On the other hand, in Fig. 9, the width of the statistic for the cathode is much wider than that for the anode. This is caused by the higher electron temperature as shown in the inset of Fig. 7.

Fig. 10 shows dependences of T_x around the cathode on the n^+ region length L_c and the Schottky barrier height ϕ_B under the reverse bias condition. T_x decreases as L_c increases, because the electron energies are relaxed

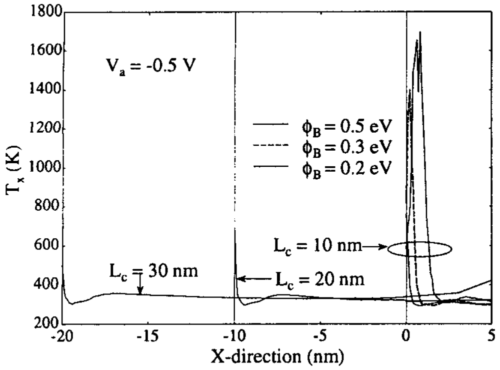

Figure 10: Distribution of electron temperature for parallel direction around the cathode under the reverse bias.

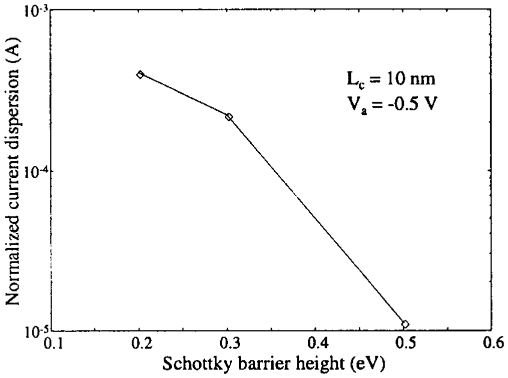

Figure 11: Normalized current fluctuation versus Schottky barrier height under the reverse bias condition.

by scattering. Consequently, there must be a trade-off between the diffusion region resistance and the hot electron noise. On the other hand, T_x increases as the Schottky barrier ϕ_B at the cathode becomes higher, which indicates that the higher energy electrons surmount the higher barrier. However, the total fluctuation is a decreasing function of the Schottky barrier height as shown in Fig. 11. This is because the electron concentration is depleted more as the barrier becomes higher. Therefore, the hot electron noise should be considered as another tradeoff with the contact resistance.

IV. CONCLUSIONS

The current fluctuation at the actual contact was calculated by the Monte Carlo method using the Schottky contact model as a boundary condition. It was shown that the current fluctuation depends on the electron concentration and the tunneling probability around the contact. Moreover, it was found that the current fluctuation by hot electrons at the contact, attached to the n^+ region, depends on the length of the n^+ region and the Schottky barrier height.

ACKNOWLEDGMENT

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