Properties of Ballistic current in MOSFETs studied by RT model

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Keywords: ballistic, transport, RT model, back scattering

ABSTRACT

How to increase the Ballistic conductivity is an important issue in the nano-scaled MOSFET. In this paper, we employed R-T model to investigate the optimum conditions for higher ballistic conductivity in MOSFET. It was found that a non-doped channel and a drain with a doping concentration less than 10^{20}[cm^{-3}] are essential for obtaining higher ballistic current in the MOSFET with a gate length of 10[nm].

INTRODUCTION

With the scaling down of the metal-oxide-semiconductor field effect transistor (MOSFET) devices in modern Large Scale Integrated Circuit (LSI)technology, the physical gate length of the MOSFET devices approached nano scale region. In the MOSFETs with such a short gate length, ballistic current becomes an important part of the drain current in the MOSFET devices[1]. Characteristics of ballistic conduction in MOSFETs were studied by K. Natori et. al. using reflection and transmission model (RT model)[2]. In this paper, using the RT model simulations, we studied the preferred MOSFET structure for a higher ballistic component in the drain current.

RESULT AND DISUCUTTION

Figure1 shows the calculated channel doping concentrations dependency of the ballisticity in a MOSFET with Lg=10[nm] and tox=0.5[nm] at Vg=0.5[V] and Vd=0.6[V]. The drain doping concentration was set to be 1×10^{20}[cm^{-3}] in the calculation. Figure1 shows the ballisticity increases with channel doping concentration decreases. Higher ballisticity was obtained when the channel doping is low. The calculated ballisticity was 0.4 when channel doping concentration is 10^{18}[cm^{-3}], but with the decreasing of the channel doping concentration, ballisticity reaches higher than 0.75 when the channel doping concentrations are below 10^{16}[cm^{-3}].

Figure 2 shows the calculated drain doping concentration dependency of the ballisticity in a MOSFET with Lg=10[nm], tox=0.5[nm] and extension=5[nm] at Vg=0.5[V] and Vd=0.6[V]. The channel was set to be full ballistic in the calculation. Obtained results show that for higher ballisticity, low drain doping concentrations (lower than 10^{20}[cm^{-3}]) are preferred.

The calculated effects of extension length to the drain current and the ballisticity in a MOSFET with in Lg=10[nm] and tox=0.5[nm] are shown in Figure 3. The channel was set to be full ballistic and the drain doping concentration was set to be 1×10^{20}[cm^{-3}] in the calculation, respectively. The calculations were carried out under the conditions of Vg=0.5[V] and Vd=0.6[V]. From figure, it is clear that shorter extension length is better for higher ballisticity under the assumption of there is only negligible reflection from the electrode which is connected to the drain region.

Since the inelastic scattering mediated by optical phonons is the energy relaxation process of the electrons, it is an important factor for ballisticity because the electrons reached to the drain region may loose their energy by inelastic scattering and cannot return to the source when reflected by the drain. Using the ratio of the mean free path of inelastic scattering (μ) and the mean free path of elastic scattering (λ), we calculated ballisticity and drain current in a MOSFET with Lg=10[nm], tox=0.5[nm] and extension=5[nm] under the conditions of λ =10[nm], Vg=0.5[V], Vd=0.6[V], channel full ballistic and drain doping concentration $=1\times10^{20}$[cm^{-3}]. Calculated results are shown in the Figure 4. The drain current and the ballisticity increase with the decreasing of the mean free path of inelastic scattering, in the other words, the drain current and the ballisticity increase with the increase of inelastic scattering.

Effects of the mean free path of elastic and inelastic scattering on drain currents are shown in the Figure 5. The calculation was carried out using a MOSFET with Lg=5.6[nm], and dtox=1.5[nm] under the conditions of Vg=0.5[V], Vd=0.6[V], channel doping concentration $=1x10^{18}$[cm^{-3}] and drain doping concentration $=1x10^{20}$[cm^{-3}] by varying mean free path of elastic and inelastic scattering. Calculated drain current does not change while the mean free path of inelastic scattering changed from 1nm to 10,000nm when the mean free path of elastic scattering is long. But when the mean free path of elastic scattering become short, drain currents increase with the decreasing of the mean free path of inelastic scattering.

To investigate the effects of channel electric potential to the ballisticity, we have calculated the ballisticity of a MOSFET with Lg=10[nm] and tox=0.5[nm] under the conditions of Vg=0.5[V], Vd=0.6[V], channel doping concentration $=1x10^{18}$[cm^{-3}] and drain doping concentration $=1x10^{20}$[cm^{-3}] by varying channel electric potential from 0.1 V to -0.6V as shown in Figure 6. Calculated results are shown in Figure 7. Calculated ballisticity and also the drain current changed drastically at around the channel potential of 0.06V. Since the energy of optical phonon emission in the silicon is 0.063[V], the drastic change at around the channel potential of 0.06V indicating that probability of the energy relaxation by the optical phonon emission drastically increases at around the channel potential of 0.06V.

CONCLUSION

In summary, we have studied the preferred MOSFET structure for higher ballistic component in the drain current. Our studies on MOSFET structure with a gate length of 10[nm] show that the preferred conditions for obtaining higher ballistic current are the channel should be non-doped and the doping concentration in the drain should be less than 10^{20}[cm^{-3}]. We also studied the effects of channel electric potential to the ballistic current.

ACKNOWLEDGEMENTS

This work is supported by METI's Reserch project on Nano-electronics Materials and Structures.

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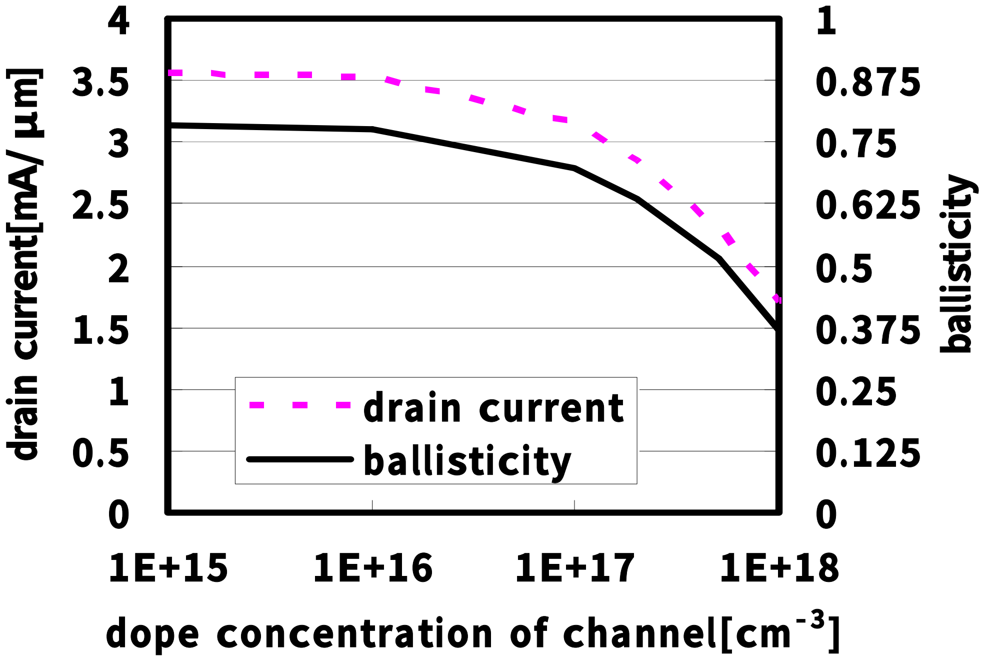

Fig.1 Channel doping concentrations dependency of the ballisticity in a MOSFET.

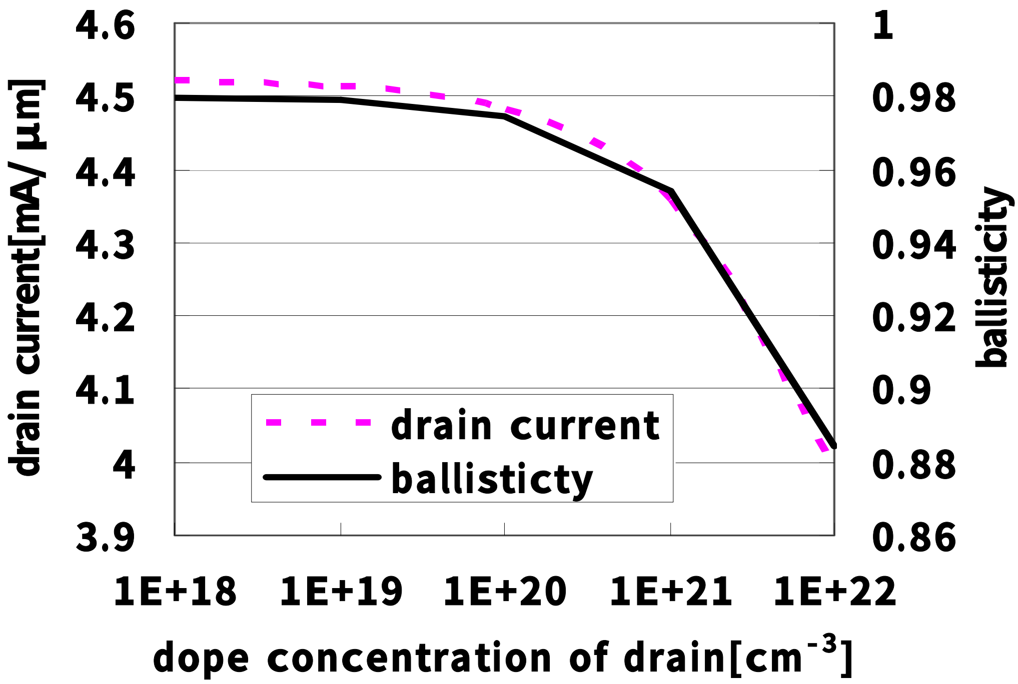

Fig.2 Drain doping concentration dependency of the ballisticity in a MOSFET.

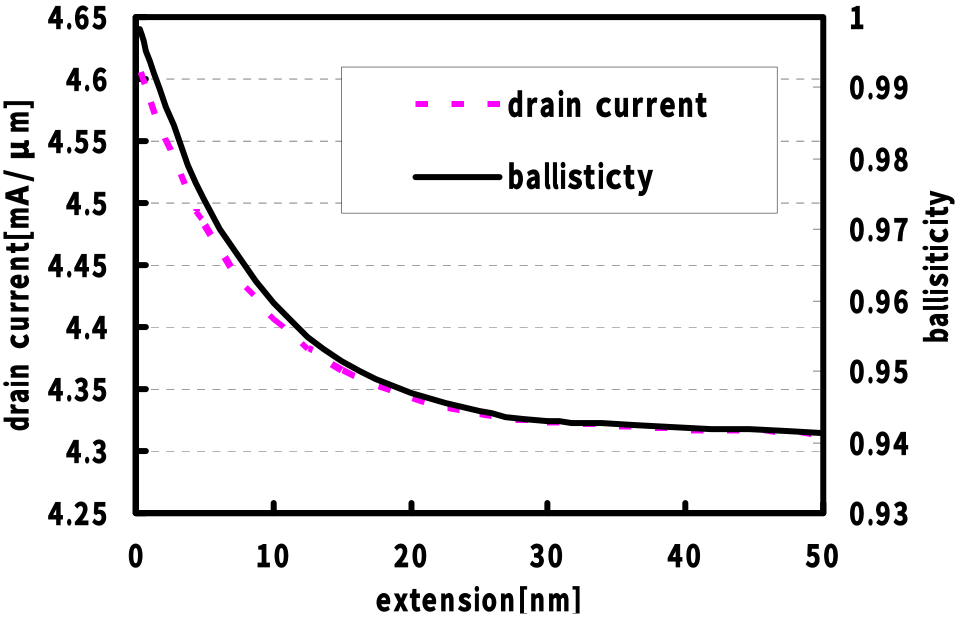

Fig.3 Ballisticity v.s. extension length (solid line) and drain current v.s. extension length (dashed line) in a MOSFET with Lg=10[nm] and tox=0.5[nm] at the conditions of Vg=0.5[V] and Vd=0.6[V].

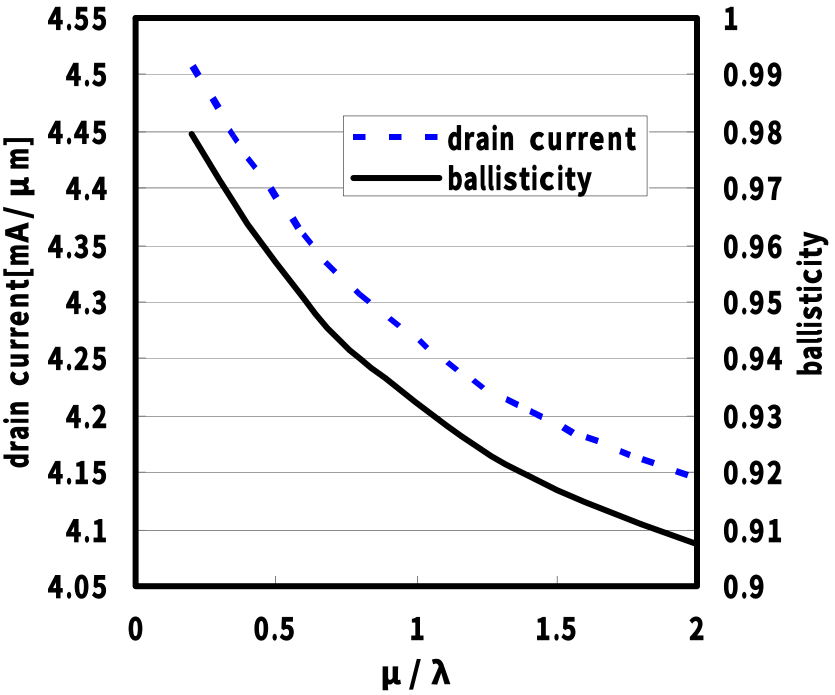

Fig.4 Relations between the ratio of μ / λ and ballisticity.

λ : mean free path of elastic scattering

μ : mean free path of inelastic scattering

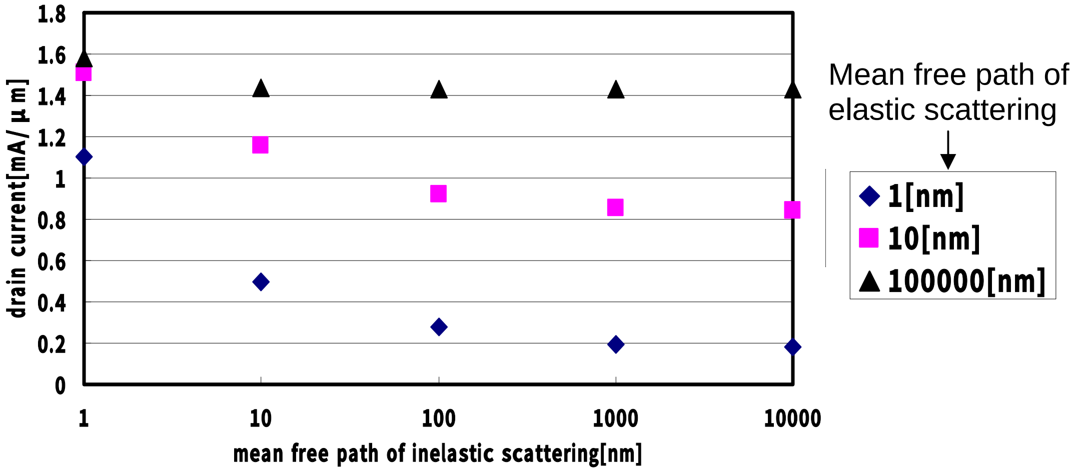

Fig.5 Calculated drain current with different the mean free path of elastic and inelastic scattering.

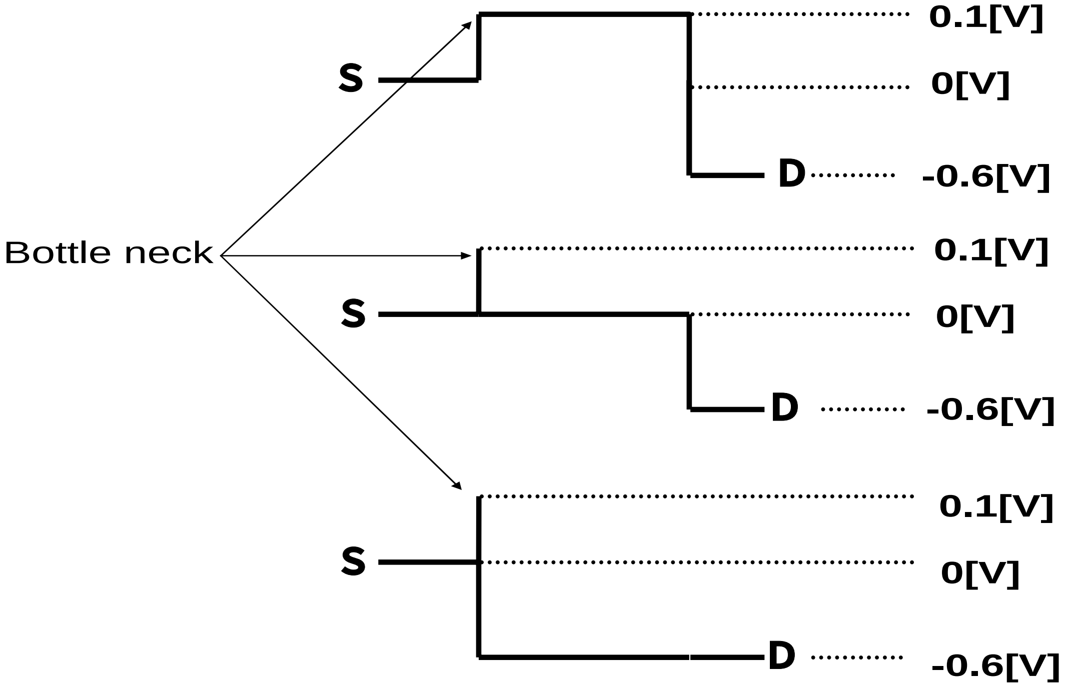

Fig.6 Channel electric potentials in the calculation. S source, D drain. Potential at the bottle neck, source and drain are 0.1[V], p 0[V] and -0.6[V], respectively.

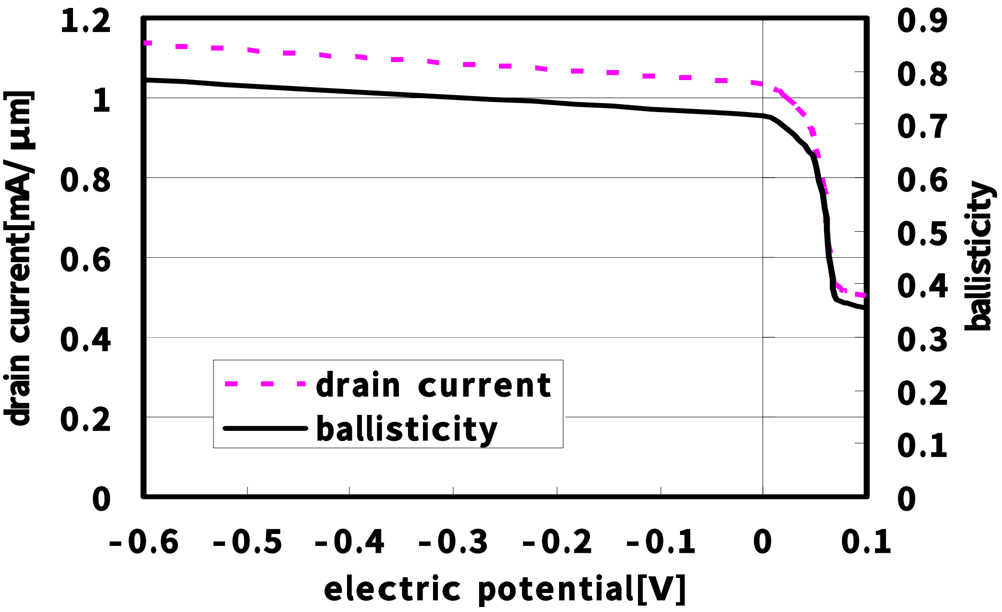

Fig.7 Effect of the channel electric potential on ballisticity . Calculated using the channel electric potentials shown in Figure 6.