Performance Degradation of superlattice transistors by scattering

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INTRODUCTION

As supply voltage is scaling down with device dimension, steep subthreshold slope (SS) transistors have been studied intensively because they can operate at low supply voltage and with fast switching speed.

One approach to obtain a SS steeper than 60mV/dec is to use an energy filter to filter out high energy electrons. Tunneling FETs use band-to-band tunneling as an energy filter and have steep SS, but suffered from small I_{on} due to the limit of tunneling probability [1] .

Superlattice MOSFETs use the miniband and minigap of superlattice as energy filter, and ballistic modeling has shown SS of ~ 30 mV/dec and on current of ~ 350 uA/um [2]. However there is a doubt whether scattering will degrade the steep Subthreshold swing and ON/OFF ratio of the device.

A full self-consistent quantum transport simulation including explicit scattering process can describe the superlattice MOSFET accurately, but high computation load is required. Here we will use a simple model that is as fast as ballistic simulation but capable of describing different intensities of scattering.

MODEL

The device is based on a double-gate MOSFETs (Fig.1) with a 3.3 nm thick undoped $In_{0.53}Ga_{0.47}As$ channel, 20 nm gate length, and a 2.56 nm thick gate dielectric having ε_r=20. The superlattice has 12 monolayers(ml) thick wells and 4 ml, 6 ml, 6 ml, 4 ml barriers.

The potential is obtained by solving the Poisson Equation and Quantum transmitting boundary method equations self-consistently [3]. Given the same potential, transport results from two models are compared: one calculates ballistic quantum transport throughout the device, the other divides the device into two reservoirs with scattering and a ballistic channel. Constant Fermi levels are assumed in the reservoirs, which consists of high doping contacts and superlattice region.

To include the effect of scattering in the reservoirs, a small imaginary scattering potential is added to the diagonal elements of Hamiltonian matrix. 5meV and 10meV are used for the imaginary potential, similar to values used in the literature [4].

RESULTS

As the imaginary scattering potential increased from 0 to 10meV, the transmission probability in the minigap increased from 10^{-3} to $2x10^{-1}$ (Fig. 2). This indicates that the OFF-current will increase. The slope of decay at upper edge of 1^{st} miniband also degraded, indicating a degradation of SS. in addition the transmission in the miniband gets smoother. This indicates that the ripples in the miniband will hurt the I_{on} less than it did in the ballistic scenario.

Under ballistic assumption, there is a clear distinction between miniband and minigap in energy resolved current (Fig. 3). With the imaginary scattering potential introduced, the distinction between miniband and minigap becomes blurred, so more high energy electrons are getting into the channel.

Using 0.1 uA/um as the off current(I_{off}), the transfer characteristics is simulated at a drain bias of 0.2V. The SS degraded from 32mV/dec to 57mV/dec as imaginary scattering potential increased from 0 to 10meV. The on current degraded from ~350 uA/um to 160 uA/um. A conventional MOSFET with the identical structure but without the superlattice has 110 A/m on current (Fig. 4), so the superlattice MOSFET still

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has better SS and ON/OFF ratio even with considered scattering.

Conclusion

In this work a model that uses an imaginary scattering potential to describe the effects of scattering in the reservoirs is applied to simulate transport properties of superlattice MOSFETs and results are compared with ballistic simulations. As scattering intensities increase, the Subthreshold Swing and ON/OFF ratio both degraded, but superlattice MOSFETs can still outperform conventional MOSFETs at low supply voltage.

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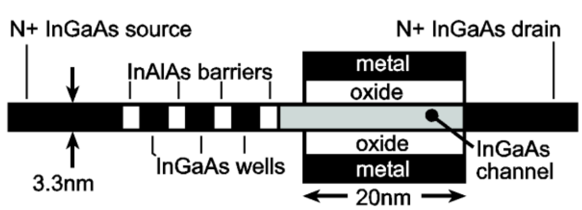

Fig. **1**. Simulation geometry: cross-section of a Double Gate MOSFET with a superlattice in the source

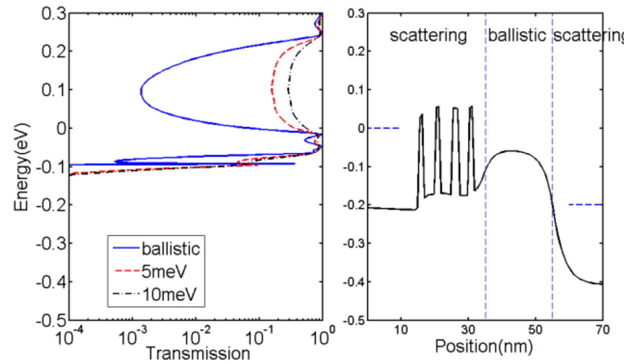

Fig. 2. Left: Transmission probability of a superlattice MOSFET under ballistic assumption, 5meV broadening and 10meV broadening. Right: corresponding band diagram indicating three regions in the device

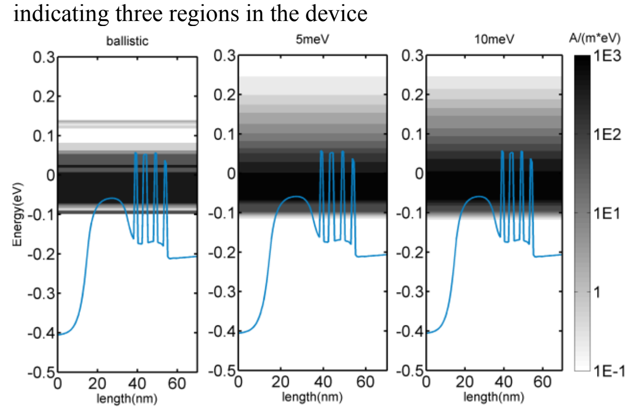

Fig. 3. energy resolved current density for ballistic simulation, 5meV imaginary scattering potential and 10meV. The figure is in log scale.

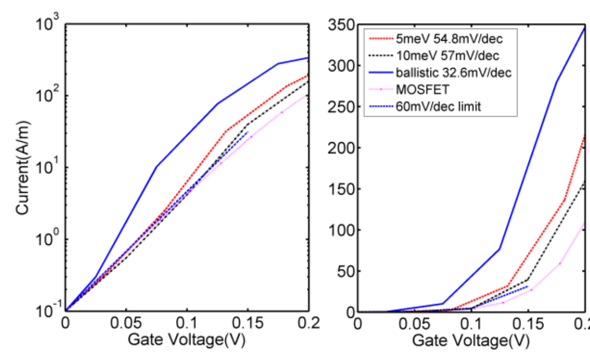

Fig. 4. Transfer characteristics calculated under ballistic assumption, with 5meV broadening and 10meV broadening compared with a MOSFET with identical structure but no superlattice in the source. The dashed line indicates the 60mV/dec limit.