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Novel Design of Electrostatic Lens Potential for Improving Bending Curvature and Transmission Probability of Drive Current for Vertical Body Channel MOSFET

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Abstract

The design guideline of electrostatic lens potential for the vertical body channel (VBC) MOSFET is investigated with focusing on the bending curvature and the transmission probability of injected electron. The new design method for boosting the body channel operation without losing the drivability is found.

1. Introduction

Vertical body channel (VBC) MOSFET is the one of the most promising candidate devices for future integrated circuit technology [see Fig.1]. The body channel operation, which the electron current flows in whole channel region, has great potential to achieve a further high current drivability and low noise characteristics[1]. In order to assist the body channel operation, in our previous studies, the implementation of electrostatic lens effect to the source-channel interface in the vertical BC-MOSFET was proposed [2]. Note that the electrostatic lens effect was demonstrated in the compound semiconductor under the low temperature in 1990 [3,4]. Our previous work reveals that this technique is suitable for the nano-scale Si transistor especially in the VBC-MOSFET. However, this technique still has the issue, which is a low transmission probability of electron. The lens shaped potential itself prevents the transmission of electron, and it makes the driving current to be lowered. In order to overcome this issue, the effects of following parameters of lens shaped potential are analyzed; the radius of curvature of lens; the shape of potential slope at the source-channel interface; and the height of the potential in the channel.

2. Model and Method

To clarify the lens effect, the electron dynamics in the VBC-MOSFET is numerically analyzed by injecting an electron wave packet from the source to the lens shaped potential. Here, the elastic scattering is only included in the calculation for obtaining the simple picture. The schema of the potential profiles is shown in Fig.2. Here, the potential profile to the radius direction in the channel is the parabolic shape, where the sufficient large positive gate bias is assumed for achieving the on state [see Fig.2 (c)]. Both the pillar radius and the channel length are set to 30nm. Under these conditions, the electrostatic lens effect is analyzed by varying the radius of curvature of the lens, the interface potential shape, and the height of the body potential as shown Fig.3.

3. Results

The dependence of radius of curvature is analyzed to vary the radius to 15, 30, 50 nm, respectively. Fig.4 shows the transmission probabilities for these conditions. Note that the interface shape of potential is smooth and the potential height is 200meV. The results indicate that the electron transmission probability does not have much difference among them. On the other hand, as shown in Fig.5, the focusing position of electron in the channel becomes near to the source side with decreasing the radius of curvature. This is due to the refraction manner of electron as shown in Fig.6. This indicates that the refraction angle becomes small with increasing the radius of curvature.

The calculated interface potential profile at the source-body in the propagating direction is investigated by varying the potential shape as shown in Fig.7, where the injected electron energy is 50meV larger than the body potential of 200meV. The transmission probabilities increase with increasing the smoothness. On the other hand, the current path is almost the same as shown in Fig.8. This result indicates that the interface shape of potential is independent from the lens parameter.

In addition, the dependence of transmission path on the body potential height is analyzed, where the height of potentials 100, 200meV are compared. Figure 9 shows the time development of electron density in the six divided regions in the Si-pillar, which enable us to analyze the path of electron wave packet quantitatively. Note that the injected wave packet energy is 250meV in this result. The result indicates that the path of electron in the channel drastically changed depends on the height of the body potential. In the case of 100 meV, electron transmitted through the center region of pillar in the channel. The case of 200meV, the electron wave packet is injected into the center region, but it shifted to the surface region with the transmitting due to the larger refraction angle at the interface (see Fig.5). On the other hand the higher potential lowers the transmission probability. From these results, the evaluation of the potential height in the channel has both good and bad effect. Therefore it should not work as controllable parameter.

4. Conclusion

The effects of lens parameters are summarized in Table 1. From this summary, the design guideline of VBC-MOSFET with the electrostatic lens potential is obtained that the Radius of curvature should be smaller for achieving the focusing the electron towards the center of the body, and the source –channel interface potential slope should be gentle for the higher transmission probability.

Acknowledgements

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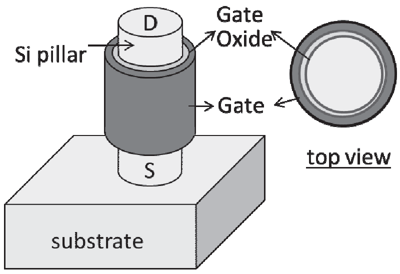


Fig.1 Schema of vertical body channel (VBC) MOSFET, where the whole body is working as the channel [5]

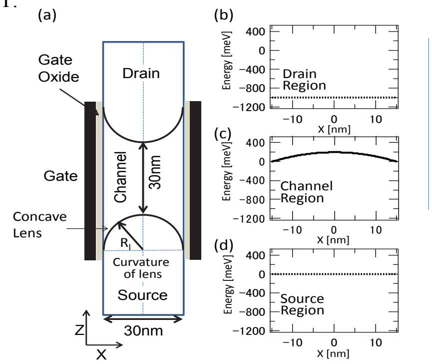


Fig.2 (a) The structure of VBC-MOSFET with lens. (b)-(d) show the potential profile of x direction in the source, the channel, and the drain, respectively.

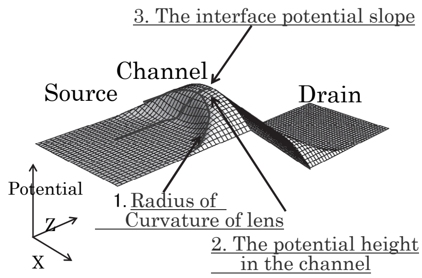


Fig.3 Lens Potential Parameters

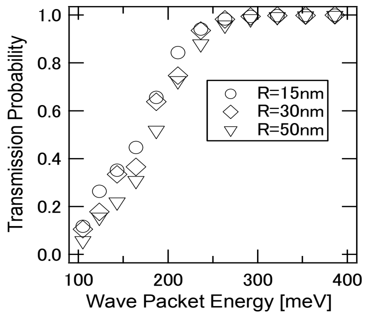


Fig.3 The reflection manner of electron at the potential interface.

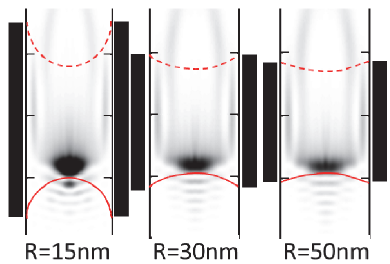
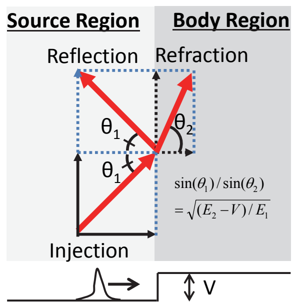


Fig.4 Snapshot of electron density at 0.1ps for various radius of curvature.



$\sin(\theta_1)/\sin(\theta_2) = \sqrt{(E_2 - V)/E_1}$

Fig.5 The reflection manner of electron at the potential interface.

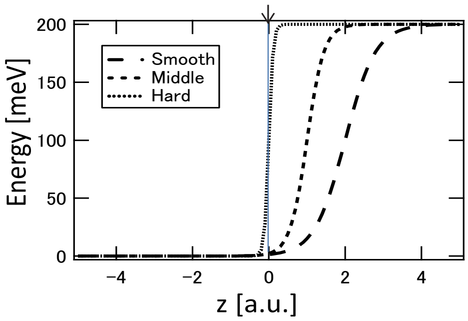


Fig.6 The potential profiles for the source-channel direction

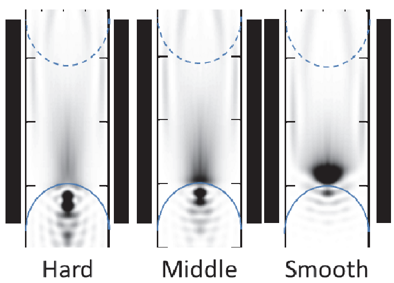


Fig.7 Snapshot of electron density at 0.1ps for various interface shape

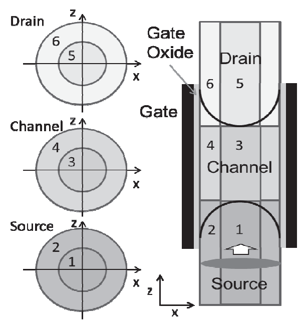


Fig.8 The pillar is divided into six regions for evaluating the path of electron in the channel

Table 1 Summary of the effect of lens parameters on the device operation

	Radius of Curvature	Interface Potential Slope	Height of Body Potential
Bending Curvature	↑	→	→
Transmission Probability	→	↑	→

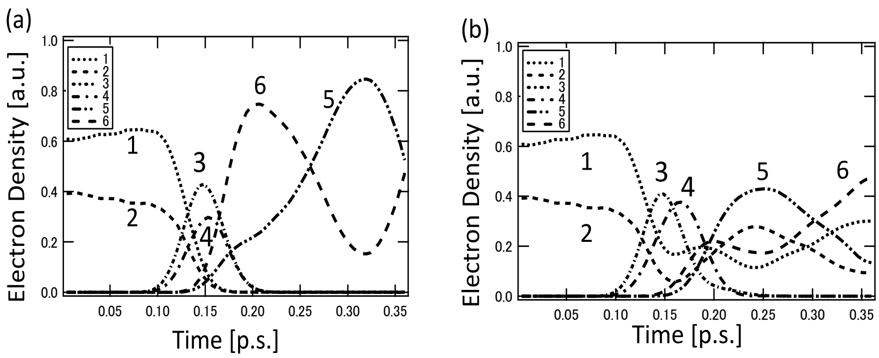


Fig.9 Time dependence of electron density in each pillar region (see Fig.8). The height in the channel is (a) 100meV, (b) 200meV.