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ORGINAL ARTICLE

The Effect of Gate Length and Temperature on ZnO MOSFETs Operation

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ABSTRACT

The effect of gate length on the operation of ZnO MOSFETs have been simulated. Three transistors with gate lengths of 100, 200 and 500 nm are simulated. Simulations show that with a fixed channel length, when the gate length is decreased, the output drain current is increased, and therefore the transistor transconductance increases. Moreover, with increasing temperature the drain current is reduced, which results in the reduced drain barrier lowering. The simulated device geometries and doping are matched to the nominal parameters described for the experimental structures as closely as possible, and the predicted drain current and other electrical characteristics for the simulated device show much closer agreement with the available experimental data.

***KEYWORDS*:** Transistor, channel length, transconductance, drain voltage.

INTRODUCTION

In recent years, there has been an increasing interest in using the wide band gap semiconductor ZnO for microwave power amplification. The MOSFET transistor is one of the most favored devices in the construction of large scale integrated circuits because of its simplicity of construction, the comparative lack of dopant diffusion problems and the resultant high packing densities possible [1-5]. Whilst the preferred semiconductor is still silicon, industry is now tooling up for wide band gap semiconductor like ZnO production, which offers high electron mobility and hence the prospect of greater frequency operating rates. Its direct bandgap furthermore allows easier integration with optical devices. For this reason ZnO MESFETs have received much attention in the literature, particularly with respect to their simulation in an attempt to understand the basic principles of their operation. ZnO offers the prospect of mobility comparable to other group III-V materials and is increasingly being developed for the construction of optical switches. Other authors have also pointed out the potential importance of ZnO and a few simple devices have been simulated. The MOSFET transistors have been found to be more effective than ordinary transistors made from the semiconductor materials [6-8]. In MOSFETs the forming layer of the transistor channel is very thin and the sub-base current is also zero because of their insulation. Hence, carriers are closer to the gate, so the gate will have a greater control over the channel current. In this transistor, the effect of drain voltage on threshold voltage is less than in comparison with other devices [9-10].

To investigate the operation of ZnO based MOSFET transistors, analytical and simulation methods were studied [11-13]. However, their operations have not been fully identified, and further research is needed.

In this study, a few thin transistors were investigated. The channel length was held constant, but the gate length covers part or all of the channel length. Then by holding the channel length constant, the effect of the change of the gate length on the characteristics of the transistor was studied. It has been indicated that in nano transistors made with carbonic nano pipes if the gate connection does not cover a part of the channel, some characteristics of the transistor will improve [14]. In this study, a nano transistor made of silicon was used. Stimulation for three transistors with gate lengths of 100, 200, 500 nm were carried out.

This article is organized as follows. Details of the simulation methods are presented in section 2, and the results of the change in gate length on the gate current-voltage curve with regard to different drain voltages, and the comparison of threshold voltage are presented in section 3. In section 4 the results of the stimulation for the comparison of the drain current-voltage curve with regard to the different gate voltages are proposed.

THEORY OF ATOM DISPLACEMENT

We have supposed three ZnO MOSFETs with 500, 200 and 100 nm gate lengths in the simulation. The impurity concentration of drain and source are 10^{17} cm^{-3} and the channel has 10^{16} cm^{-3}. The channel thickness is about 50 nm and the gate oxide layer has 20 nm thickness.

The balance equations is carried out to simulate Electron transport properties in the device.

To calculate mobility, we have to solve the Boltzmann equation to get the modified probability distribution function under the action of a steady electric field. Under the action of a steady field, the Boltzmann equation for the distribution function can be written as [10-11]

$$\frac{\partial f}{\partial t} + v.\nabla_r f + \frac{eF}{\eta}.\nabla_k f = \left(\frac{\partial f}{\partial t}\right)_{coll} \qquad (1)$$

where $(\partial f/\partial t)_{coll}$ represents the change of distribution function due to the electron scattering. In the steady-state and under application of a uniform electric field the Boltzmann equation can be written as

$$\frac{eF}{\eta}.\nabla_k f = \left(\frac{\partial f}{\partial t}\right)_{coll} \qquad (2)$$

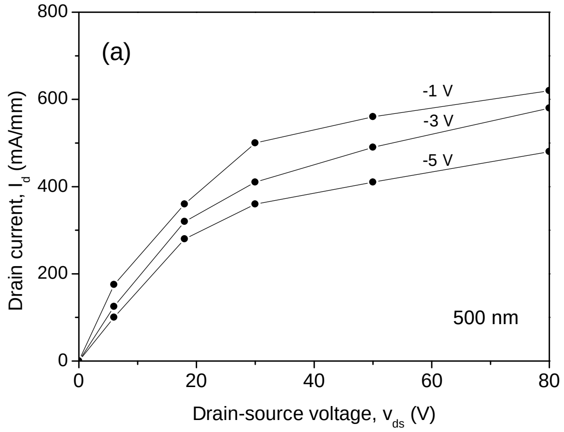
Consider electrons in an isotropic, non-parabolic conduction band whose equilibrium Fermi distribution function is $f_0(k)$ in the absence of electric field. Note the equilibrium distribution $f_0(k)$ is isotropic in k space but is perturbed when an electric field is applied. If the electric field is small, we can treat the change from the equilibrium distribution function as a perturbation which is first order in the electric field. The distribution in the presence of a sufficiently small field can be written quite generally as

$$f(k) = f_0(k) + f_1(k)\cos\theta \qquad (3)$$

where θ is the angle between k and F and $f_1(k)$ is an isotropic function of k, which is proportional to the magnitude of the electric field. $f(k)$ satisfies the Boltzmann equation 2.

RESULTS

The effect of gate length on electron transport in ZnO based MOSFETs with 500, 200 and 100 nm gate lengths has been illustrated in figure 1a to 1c. This figure shows drain current versus drain-source voltage for different gate lengths. It is apparent from this figure that higher velocities are reached as the gate length is reduced as a result of the increase in longitudinal electric field and velocity overshoot effects. It follows that the electron transit time under the gate is reduced in two ways; there is a reduction in the transit length and also the electron velocity is larger. The high value of the field at the source-end of the gate is responsible for the almost ballistic acceleration of the electrons as soon as they enter the channel region under the gate.



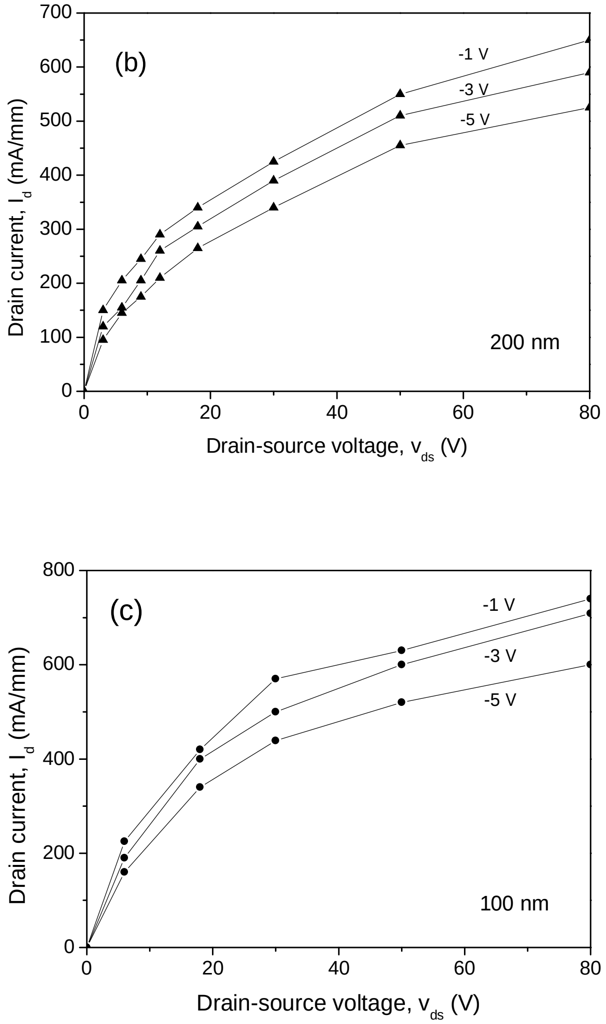


Figure 1: The effect of gate length on the electrical characteristics of ZnO MOSFET. *I-V* characteristics for gate lengths of 500, 200 and 100 nm has been illustrated in figure 1a to 1c, respectively.

Figures 2 show the calculated drain current versus drain-source voltage at different gate biases for temperatures of 300 K and 420 K when the gate length is 500 nm. The simulated characteristics at 300 K show good saturation behavior with a knee voltage around 20-30 V and a saturation drain current of about 2200 mA/mm for Vgs=-1 V. The high drain current density is encouraging for the use of ZnO for high-power applications. From figure 2a it is clear that the device is not completely pinched-off even at large negative gate bias Vgs=-9 V which is due to strong electron injection into the buffer layer at high electric fields. An increasing fraction of the drain current flows through the buffer as the drain voltage increases.

At V_{ds}=80 V essentially the whole drain current flows entirely through the buffer. To obtain some idea of the effect of high temperature on ZnO MOSFETs, simulations were carried out at T=420 K, keeping the other device parameters unchanged. The *I-V* curves obtained are shown in figure 2b. Comparing the *I-V* curves at T=300 and 420 K, it can be seen that the drain current is somewhat lower at the higher temperature, due to increased phonon scattering, but the effect is not major. The transconductance of the simulated MOSFETs is about 140 mS/mm at 18 V drain bias and -1 V gate voltage for room temperature. When the drain bias is increased to 50 V at the same gate voltage, the transconductance increases approximately to 200 mS/mm. The higher value of transconductance in simulated ZnO MOSFET is related to a higher drain current.

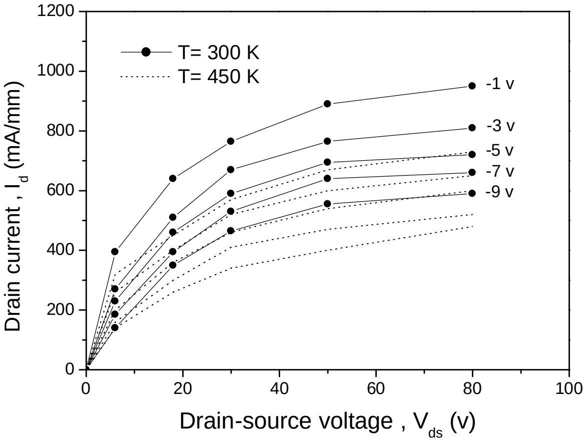


Figure 2: Electrical characteristics for ZnO MOSFET at 300 K and 420 K when the gate length is 500 nm.

CONCLUSION

The effect of gate length on electron transport in ZnO MOSFETs has been studied. The *I-V* characteristics show that higher velocities are reached as the gate length is reduced as a result of the increase in longitudinal electric field and velocity overshoot effects. Our results show that as the temperature is increased the collapsed drain current is also increased due to higher electron scattering rates

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