New Drain Conductance Method to Evaluate Impact Ionization Phenomenon in SOI MOSFET

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A new drain conductance method to evaluate the kink effects in SOI MOSFET has been proposed. Three kinds of kink currents were observed by using this new method when the temperature is reduced. These kink currents are caused by the parasitic lateral bipolar action, the forward biasing effect in the source junction and the drain junction avalanche breakdown. The kink effect is mainly dominated by the parasitic lateral bipolar action at the higher temperature and by the source junction forward biasing effect at the lower temperature in the temperature range from 300K to 20K. These kink currents were described very well by a newly proposed analytical model.

1. Introduction

SOI MOSFET has several advantages such as large transconductance and less short channel effect over the bulk MOSFET. Many people have intensively investigated about SOI MOSFET aiming to achieve sub-quarter micrometer or further scaleddown devices. However, SOI MOSFET has serious problems that the device characteristics are significantly affected by holes generated due to the impact ionization. In particular, the reduction of the drain breakdown voltage which is caused by these holes is a crucial problem. Thus, it is very important to investigate the behavior of such holes in details. The substrate current is usually measured for evaluating such holes in the bulk MOSFET. However, we can not measure the substrate current in SOI MOS-FET, because SOI film is electrically floating. It is very effective to measure the hot carrier induced photon emission for investigating the impact ionization in SOI MOSFET[1]. However, the photon emission is not always related directly to the device characteristics, although it is effective for evaluating the relative change of them in the higher drain voltage region. Then, we propose to use the dif-ferential drain conductance for investigating the impact ionization phenomenon in SOI MOSFET. The drain conductance method becomes more effective if it is used in conjunction with the photon emission measurement[2].

In this paper, the kink effect in SOI MOSFET is investigated in the wide temperature range from 300K to 20K with the drain conductance method.

2. Experimental results

LDD SOI MOSFETs with the gate oxide thickness of 22.5nm and the SOI film thickness of 100nm

were used in the experiments[3]. The bottom oxide thickness was 500nm. The devices with the gate length of 1 μ m were mainly evaluated. The I_D- V_D characteristics are shown in Fig.1 where the temperature is changed as a parameter under the fixed gate voltage of $V_G = 1.5V$. The drain current is decreased as the temperature is lowered, because the threshold voltage is increased although the mobility is increased. The kink due to the parasitic bipolar action is observed in the higher drain region at 300K. Meanwhile, another kinks appear when the temperature is decreased. However, the kink point is not very clear in the ID- VD characteristics. Then, we use the differential drain conductance to determine the kink point. Figure 2 shows the drain voltage dependences of the drain







Fig.2 Drain conductance and drain current as a function of drain voltage.

conductance and the drain current at 125K. We can clearly see three local minimums in the drain conductance curve although ID-VD curve is apparently very smooth. These local minimums in the drain conductance curve correspond to the kink points. Using the minimum drain conductance, we can derive the kink current by extrapolating the drain current at the kink point to the drain voltage where the kink current is defined[4]. The kink current derived at 300K is plotted as a function of gate voltage in Fig.3 where the hot carrier light emission intensity is also shown for comparison. Both characteristics indicate considerably good agreement. Therefore, it can be considered that such kink current is exactly related to holes generated by the impact ionization. The drain conductances at three different temperatures are plotted versus the drain voltage in Fig.4 where the gate voltage is changed as a parameter. It is obvious in the figure that the kink point shifts to the higher drain voltage region as the gate voltage is increased. Furthermore, new kink points appear in the drain conductance curves at $V_G = 1.5V$ when the temperature is lowered. In order to examine in more detail the kink effect at such lower gate voltage, the kink current at $V_G = 1.5V$ is plotted as a function of temperature in Fig.5. The kink current is derived at $V_D = 5V$. As is obvi-ous in the figure, three kinds of kink currents were observed. The kink current ΔI_{K1} in the higher temperature region results from the parasitic lat-eral bipolar action. The ΔI_{K1} is initially increased and then decreased as the temperature is decreased. The increase of ΔI_{K1} results from the increased im-The increase of ΔI_{K1} results from the increased impact ionization with decreasing temperature while the decrease of it is due to the decreased current gain of the parasitic bipolar which is caused by the freeze-out effect of impurity atoms. The kink current ΔI_{K2} results from the forward biasing effect in the source junction caused by holes which are generated by the impact ionization and accumulated in the SOI film near the source junction. The threshold voltage is apparently decreased by the forward biasing effect and consequently the drain current is increased. This increased drain current is observed as ΔI_{K2} . Therefore, ΔI_{K2} is increased as the temperature is decreased. The third kink cur-



Fig.3 Gate voltage dependence of kink current and hot carrier light emission intensity.





Fig.5 Temperature dependence of measured kink current.

rent ΔI_{K3} results from the drain junction avalanche breakdown. Thus, the kink effects in SOI MOSFET can be easily evaluated by using the drain conductance method.

3. Discussions

As mentioned above, ΔI_{K1} and ΔI_{K2} result from the parasitic bipolar action and the source junction forward biasing effect, respectively. Then, we propose an analytical model to describe these kink currents. In our model, ΔI_{K1} and ΔI_{K2} are described as follows:

$$\Delta I_{K1} = \frac{(M-1)I_{ch}}{1 - (M-1)\beta},$$
(1)

$$\Delta I_{K2} = \frac{A \cdot I_{ch}}{V_{G} - V_{th}} \frac{kT}{q} \cdot \ln(\frac{(M-1)I_{ch}}{I_0} + 1), \qquad (2)$$

where I_{ch} is the channel current, M is the multiplication factor, β is the current gain, I_0 is the saturation current of the source junction and A is constant[5], [6]. The experimental data were used for I_{ch} and V_{th} . M and V_{th} are increased, and β and I_{ch} are decreased as the temperature is decreased. The kink currents calculated using Eqs.(1) and (2) are plotted as a function of temperature in Fig.6. As is obvious in the figure, ΔI_{k1} is initially increased and then decreased as the temperature is decreased. Meanwhile, ΔI_{k2} is monotonously increased with decreasing the temperature. Thus, the calculated kink currents in Fig.6 indicate a fairly good agreement with the experimental ones shown in Fig.5. Therefore, our analytical model describes very well the kink effects in SOI MOSFET.



Fig.6 Temperature dependence of calculated kink current.

4. Conclusion

We proposed a new drain conductance method to evaluate the kink effects in SOI MOSFET. It was revealed that the kink effect is caused by the parasitic lateral bipolar action at the higher temperature and by the source junction forward biasing effect at the lower temperature in the temperature range from 300K to 20K. These kink currents were described very well by our new analytical model.

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