LIGHT-MODULATED SUBTHRESHOLD SWING EFFECT IN A MoS_2-Si HETERO MOSFET

Yingxin Chen[1], Jianan Deng[1], Qianqian Huang[2], Wenzhong Bao[1], and Jing Wan[1*]*

[1] State key laboratory of ASIC and System, Fudan University, Shanghai 200433, China

[2] Key Laboratory of Microelectronic Devices and Circuits (MOE), Institute of Microelectronics, Peking University, Beijing 100871, China

[*] Corresponding Author's Email: baowz@fudan.edu.cn, jingwan@fudan.edu.cn

ABSTRACT

A light-modulated subthreshold swing (SS) effect in a MoS_2-Si hetero MOSFET is discovered. The device is essentially a SOI MOSFET with MoS_2 top gate and partly gated channel. In the experiment, the SS of the device reduces from 100.2mV/dec to 70.4mV/dec under light illumination. In the TCAD simulation, the SS also shows similar light-modulated characteristic. The operation principle is mainly determined by the extra photovoltage at the top gate interface, as confirmed by the simulated results.

INTRODUCTION

Recently, the semiconductor photodetectors have attracted extensive attention, such as photodiodes [1-3], phototransistors [4] and photodetectors based on MOSFET [5, 6]. The previous researches have demonstrated that the output current or voltage of the photodetectors can be modulated by light. However, its impact on the subthreshold swing (SS) has never been reported, which is the key parameter to determine the ON/OFF ratio and supply voltage of the MOSFET.

In this work, we observed a light-modulated SS effect in a special MoS_2-Si hetero MOSFET from both experiment and simulation for the first time. The operation principle is investigated through TCAD simulation, explained by the mechanism similar to a depleted MOSFET and the interface potential variation.

LIGHT-MODULATED SS EFFECT

Fig. 1(a) schematically shows the structure of the MoS_2-Si hetero MOSFET built on SOI substrate with 12 nm top Si layer. The Cr/Au layers are deposited at each side of the P-type (1×10^{15} cm^{-3}) channel to form source/drain contacts. The N-type (2.7×10^{18} cm^{-3}) MoS_2 acts as the top gate while the P-type (1×10^{15} cm^{-3}) Si substrate is defined as the back gate, with 15 nm HfO_2 and 20 nm SiO_2 as gate oxide respectively. As the microscope image in Fig. 1(b) shows, the Si channel is partly covered by MoS_2, and its length and width are 20 µm and 10 µm. The device is essentially a MOSFET on SOI utilizing a semiconductor as the top gate, except for the uncovered channel between MoS_2 and source/drain.

By measuring the I_D-V_G curves in the dark and in the light at fixed V_D = -1V and V_{BG} = -7V, a light-modulated SS effect can be observed, see Fig. 2(a). The curves show that the device is initially in ON state at reverse-biased or slightly forward-biased V_G and turns off as the positive V_G increases. Compared to that in the dark, the SS of the device under illumination significantly reduces from 100.2mV/dec to 70.4mV/dec. Further confirmed by Fig. 2(b), the device has a lower SS at the same I_D when exposed to the light. Besides, the light-modulated SS is above but close to 60mV/dec, which is termed as the 'Boltzmann tyranny' in a standard MOSFET.

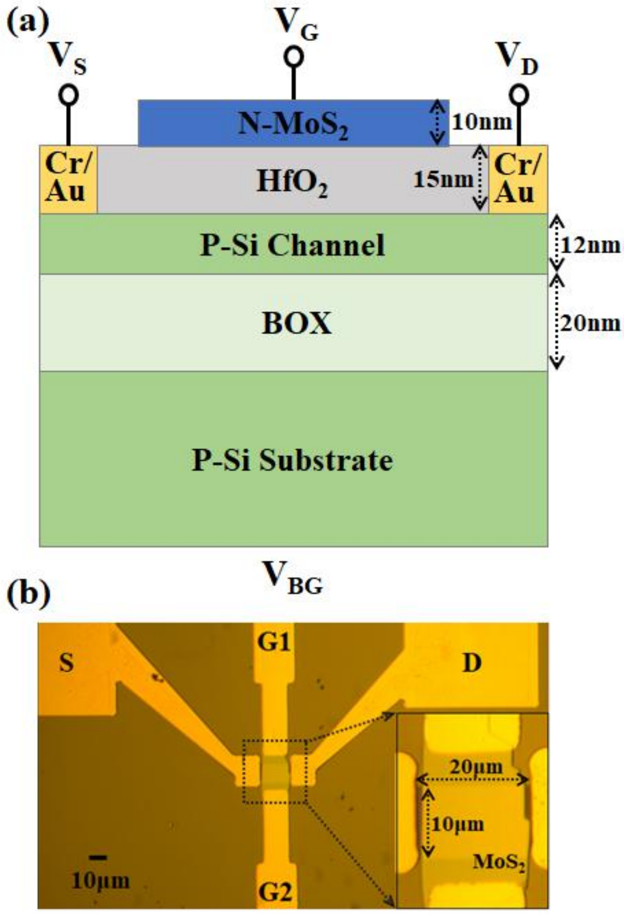

Figure 1: (a) Schematic view and (b) microscope image of the device

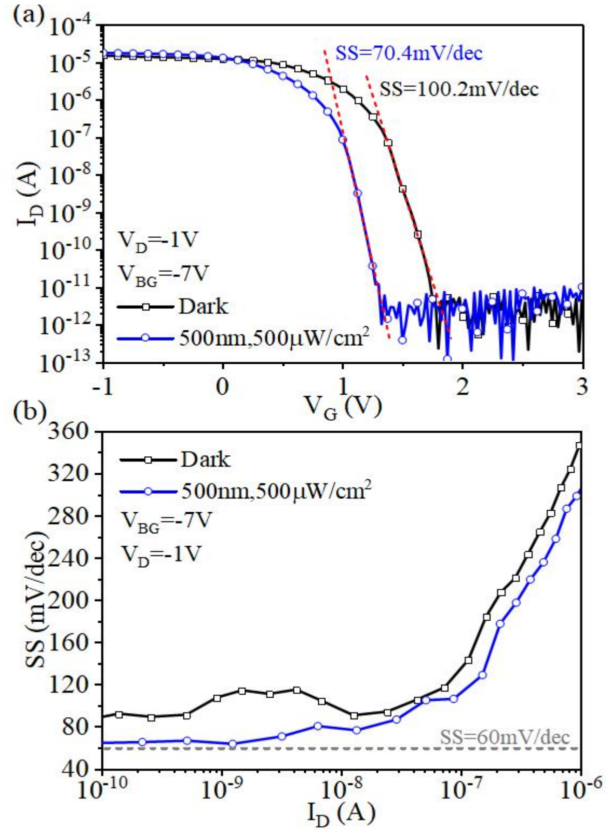

Figure 2: (a) Experimental I_D-V_G curves in the dark and under illumination at V_D = -1V and V_{BG} = -7V; (b) extracted SS versus I_D

OPERATION PRINCIPLE BY TCAD SIMULATION

TCAD simulation was conducted in Synopsys Sentaurus to understand the operation principle. As shown in Fig. 3, the light-modulated SS effect can also be observed in simulated results, which agrees well with the experiments in Fig.2.

The device in the dark behaves like a conventional depleted MOSFET. Holes are accumulated at the channel/BOX interface by the negative V_{BG}, leading to a high I_D at V_D < 0V. The negative V_G induces an incomplete hole layer at HfO_2/Si interface due to the ungated region, which contributes little to I_D. With the increasing positive V_G, the channel covered by the top gate becomes depleted or even inverted. This cuts off the conductive path at the bottom interface and hence the device turns off.

The modulation in SS under illumination can be explained by the change in the potential at the MoS_2/HfO_2 interface, see Fig. 4. At higher positive V_G, holes are induced at this interface, forming an electrostatically induced P-N junction with the N-type MoS_2 whereas the junction cannot be obtained at low V_G. When the device is exposed to light, photoholes flow to the MoS_2/HfO_2 interface as driven by the built-in electric field of P-N junction. This results in a photovoltage which increases the interface potential under the same V_G. The interface potential increment in the light implies that the control of V_G on the channel strengthens, causing an obviously reduced SS.

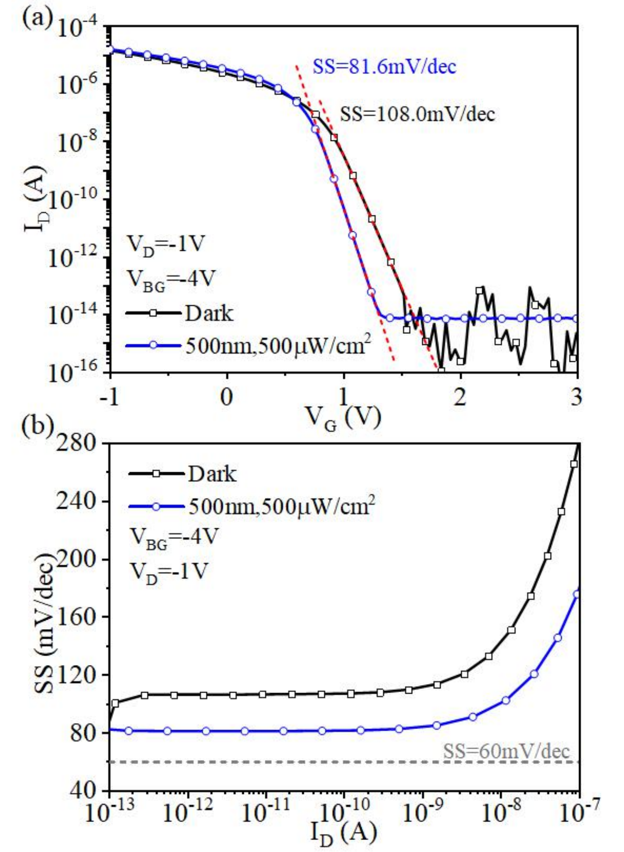

Figure 3: (a) Simulated I_D-V_G curves in the dark and under illumination at V_D = -1V and V_{BG} = -4V; (b) extracted SS versus I_D

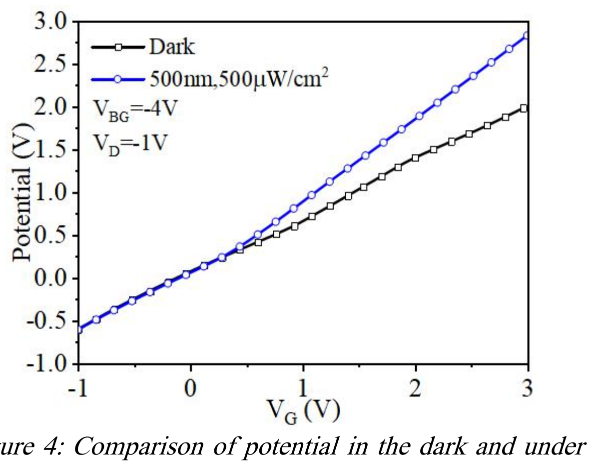

Figure 4: Comparison of potential in the dark and under illumination, extracted at the midpoint of MoS_2/HfO_2 interface

CONCLUSIONS

We found that the SS of the MoS_2-Si hetero MOSFET could be modulated by light. The experimental SS of the device under illumination is reduced to 70.4mV/dec while that is 100.2mV/dec in the dark. The simulated results are in good accordance with experiment and confirm the operation principle. When the device is exposed to light, the photovoltage provides a higher top gate controllability on the channel, resulting in a lower SS.

ACKNOWLEDGEMENTS

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