Introduction of a Reset MOSFET to Mitigate the Influence of Ionic Movement in Perovskite MOSFET Photodetector Measurements

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***Abstract*— A Reset MOSFET is added to a perovskite MOSFET-based photodetector to serve as a current source to mitigate the influence of ionic movement on the performance of the photodetector. With the added MOSFET, the hysteresis is significantly reduced, and the dark current is controllable. The on/off ratio resumes to 10^6 and an ultrasensitive responsivity (over 80, 000 A/W) is achieved under only 13 nW/cm^2 red (665 nm) light intensity.**

Keywords—perovskites, photodetector, ultrasensitive, ionic movement, MOSFET

I. Introduction

The halide organic-inorganic perovskites are excellent candidates of optoelectronic materials due to the direct band gap and large optical absorption coefficient [1-4] . The combination of a perovskite thin film and a MOSFET can provide an ultrasensitive photodetector with large responsivity. However, the perovskite film can have ionic movement due to an applied electric field [5, 6] thereby causing a large hysteresis in the transfer curve of the photodetector. This ionic movement deteriorates the responsivity and stability of the photodetector since the dark current is greatly increased by these moveable ions. This manuscript is comprised of three parts: a) How do we verify there is ionic movement in the perovskite by I-V measurement; b) how does the ionic movement change the performance of the perovskite MOSFET-based photodetector; and c) show how we mitigate the ionic movement influence on our photodetector to effectively evaluation the intrinsic properties of the perovskite.

II. Results and Discussion

A. Detecting Ionic Movement in Perovskite

A simple I-V measurement can be done to verify the existence of ionic movement. The test setup is shown in Fig. 1. The two 50µm gap interdigitated array (IDA) electrodes (W/L ratio: 1368) were patterned by photolithography and 100 nm of gold was deposited by cryogenic evaporation. The perovskite ($MAPbI_3$) was deposited on top of the electrodes patterned by a two-step, spin-coating process [7]. The constant voltage applied to the electrodes in this measurement was 0.1V. During the applied constant bias, the light was turned on and off. The measured current is greatly increased when the light is on since there were more generated electron-hole pair carriers in perovskite. If the quality of the perovskite is good, there is only electron and hole movement with reduced ionic movement in the perovskite. The result of current-time (I-t) measurement demonstrates that the current increased when the light is on and stays the same before the light turns off (Fig. 2a). Ideally, the

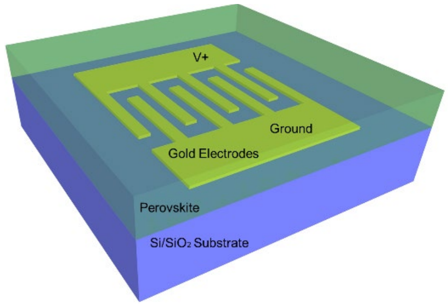

Fig. 1. I-V Test setup of perovskite ionic movement. The constant voltage was biased at V+ and current was measured versus time.

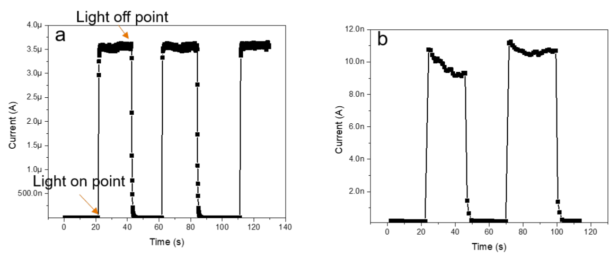

Fig. 2. Test results of ionic movement in perovskite. a). Result of perovskite without ionic movement. b). Result of perovskite with ionic movement.

electrons and holes responded very fast [8] with the light, and the mobility is high [9]. Therefore, the current increases very fast while the light was on. Once electron-hole pair generation saturates, the number of electrons and holes are stable as well, thereby stabilizing the current before the light is turned off. However, the current is not stable when the light is kept on because there is ionic movement (Fig. 2b).

B. Ionic Movement Degrading the Photodetector

The measurement setup is illustrated in Fig. 3, in which the W/L ratio of electrodes of the perovskite capacitor is 20. The first I_d-V_g measurement was conducted under different light intensities (Fig. 4). The V_+ was swept from 0 V to 3 V. The first measurement was in the dark which should have had a very low drain current with a W/L ratio of 20, theoretically. However, the current increased with V_+ and there is a large hysteresis when swept back from 3 V to 0 V. The current was higher when swept from 3 V to 0 V. This result demonstrates that the ionic movement happened even without illumination. Thus, the large drain current increase in the dark is attributed to ion buildup at the electrode surfaces when V_+ was swept from 0 V to 3 V. The relatively slow ions did not recover when V_+ was first swept from 3 V to 0 V, so there was a large hysteresis in drain current. Next, the I_d-time measurement was applied to investigate the changes of the drain current over time. The V_+ was fixed at 3 V and the drain current of the MOSFET was measured versus time (Fig. 5). The drain current was very small at the beginning and continued to increase until the MOSFET drain current was saturated.

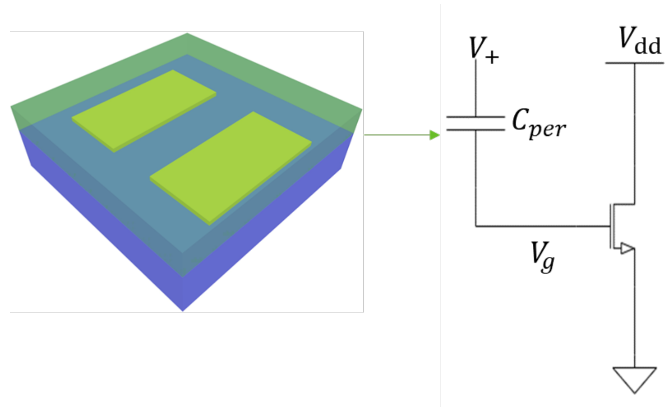

Fig. 3. Circuit schematic of test setup for ionic movement of perovskite MOSFET based photodetector with commercial MOSFET.

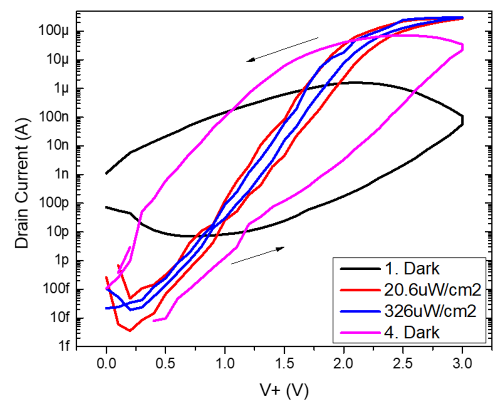

Fig. 4. Transfer characteristics of the photodetector shows the large hysteresis in the dark demonstrating ion movement.

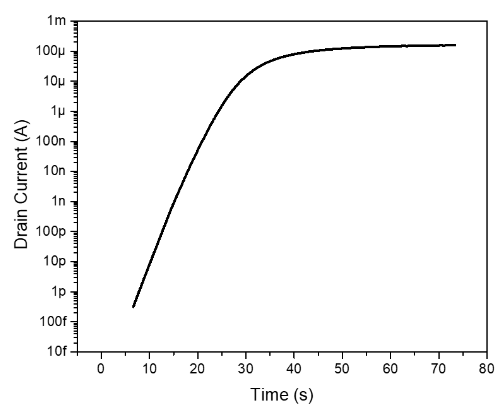

Fig. 5. I_d-time result with fixed V+ (3 V) in the dark shows the drain current changes with time.

C. Recovering Photodetector Performance by Add-on MOSFET

Another MOSFET was added in this design to mitigate the ionic movement influence on the device performance. The new circuit is shown in Fig. 6. This "reset MOSFET" could be treated as a constant current source in this setup. The V_g was set up by the resistance of perovskite using Equation 1:

$$V_g = V_+ - I_{res}R \quad (1)$$

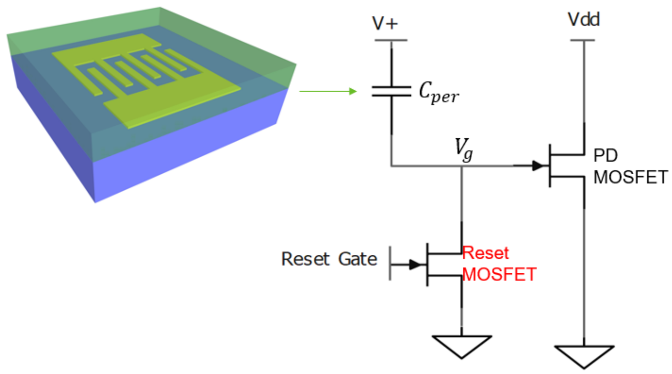

Fig. 6. Circuit schematic of adding another MOSFET at the gate of the detection MOSFET to mitigate the influence of ionic movement.

where the drain current of the "Reset MOSFET" is also an important aspect of determining the V_g. The Photodetector (PD) MOSFET would be always on if the Reset gate voltage was lower than 1 V.

The Reset gate voltage was set at 1.0 V (Fig. 7a), 1.1 V (Fig. 7b) and 1.2 V (Fig. 7c), respectively. The V+ was swept from 0 V to 3 V while the perovskite was irradiated with different light intensities. The 50 µm IDA electrodes were used for this measurement. The dark current was well controlled by adding the Reset MOSFET. The transfer curve of PD MOSFET was quite similar to the single MOSFET since the W/L ratio was larger in the 50 µm IDA electrodes. Most of the voltage was dropped on the MOSFET due to the ionic movement, even when the perovskite was in dark. The performance of the photodetector was more controllable after adding the Reset MOSFET. The dark PD MOSFET drain current could be controlled by the reset gate voltage as well. When the gate voltage was higher on the reset MOSFET, the PD MOSFET drain current was lower in the dark. The hysteresis of the PD MOSFET drain current was reduced after adding the reset MOSFET, which was a result of the resistance changing less compared with the capacitance. The drain current also increased when the light intensity increased at all three reset gate voltages.

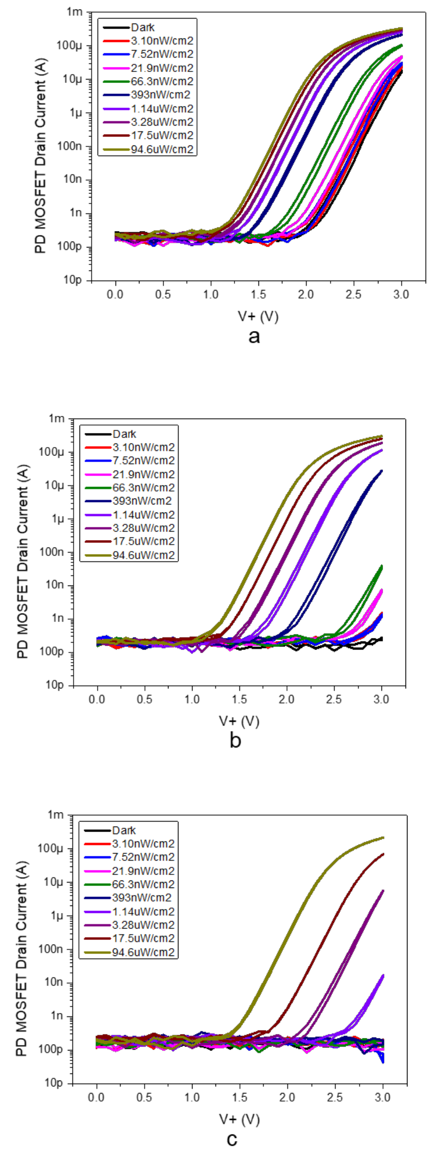

Fig. 7. Transfer curve of PD MOSFET with Reset gate voltage at a). 1.0 V. b). 1.1 V. c). 1.2 V. The dark current can be controlled by the reset gate voltage. The hysteresis in the transfer curves is significantly reduced.

III. SUMMARY

The perovskite ionic movement caused positive ion accumulation on the electrode connected to the MOSFET and thereby attracted electrons to the MOSFET channel. As a result, the measured drain current was not only modulated by the light intensity, but also generated substantial noise caused by ionic movement. To solve this problem, another MOSFET was added in the circuit. This new “reset” MOSFET worked as a constant current source. The current was manipulated by the reset gate voltage so that the original MOSFET was biased in the proper range. The perovskite in this setup was used as a resistor instead of a capacitor. The resistance only changed a little due to the ionic movement, so the influence of ionic movement was reduced and the photosensitivity was recovered.

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