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Research Article

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The Thin Film Phototransistor Cell with Silver Interfacial Layer

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Thin film transistor,
Phototransistor
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Abstract: In the present study, the silver (Ag) metal particle was used between two insulating layers to fabricated zinc-oxide (ZnO) thin film transistor. The Ag metal was evaporated with thermal systems. The dielectric materials such as Al_2O_3 and HfO_2 were deposited atomic layer deposition (ALD) technique. In order to have better understanding on the device operation and Ag layer, the some electrical characteristics such as I_{on}/I_{off} ratio, threshold voltage (Vth) were calculated using some different current-voltage (I-V) measurements. These values are found to be $1.1x10^3$ and 2.1 V, respectively. The I_{DS}-V_{DS} measurements were repeated 20 times to investigate the memory effect of Ag material at the interface layer. These measurements showed that the hysteresis of memory window was not decreased. In addition these measurements, the transistor's response was measured to light by taking I_{DS}-V_{DS} measurements in dark and under light. This device has been found to be photosensitive. These results shown that the ZnO thin film transistor can be used flash memory technology and photovoltaic device applications.

Gümüş Arayüzey Tabakası İle İnce Film Fototransistor Hücresi

Anahtar kelimeler
İnce film transistör,
Fototransistör,
Gümüş,
Atomik kaplama metodu

Öz: Sunulan çalışmada, çinko-oksit(ZnO) ince film transistör yapmak için iki yalıtkan tabaka arasında gümüş malzemesi kullanıldı. Gümüş metali termal buharlaştırma sistemi ile buharlaştırıldı. Al_2O_3 and HfO_2 gibi yalıtkan malzemeler atomik kaplama metodu (AKM) ile kaplandı. Şarj tuzaklama tabakasında gümüş tabakası ve aygıt yönelimini daha iyi anlamak için I_{on}/I_{off} ve eşik voltajı (Vth) gibi bazı elektriksel ölçümleri akım-gerilim ölçümlerinden hesaplandı. Bu değerler sırasıyla $1.1x10^3$ and 2.1 V bulundu. I_{DS}-V_{DS} ölçümleri arayüzey tabakasında gümüş metalinin hafıza etkisini ölçmek üzere 20 defa tekrarlandı. Bu ölçümler hafıza penceresinin genişliğinde bir azalma olmadığını gösterdi. Bu ölçümlere ek olarak, ışık ve karanlık altında I_{DS}-V_{DS} ölçümleri alınarak transistörün ışığa bağlı duyarlılığını ölçüldü. Bu aygıtın ışığa duyarlı olduğu tespit edildi. Bu sonuçlar ZnO ince film transistorünün fotovoltaik cihaz uygulamalarında ve flash hafıza teknolojisinde kullanılabileceğini gösterdi.

1. INTRODUCTION

Recently, the metal particles (MPs) were commonly used for fabrication in electronic technology due to the electric conductivity and charge trapping effect [1–3]. Especially, the silver MPs are very useful materials for solar cell [4], transistor [5] and organic light emission diode (OLED) [6]. There are many technique for metal deposition such as thermal evaporation [7], ALD [8], sputtering [9] and sol-gel process [10]. Each technique has its advantages and disadvantages. The MPs are used between transistor channel and dielectric gate for storage layer [11]. They have been improved memory and photosensitive characteristics of device. In addition to embedded MPs, the two terminal device is very important for thin film transistor and metal-oxide-semiconductor field effect transistor (MOSFET) [12]. Especially, the high dielectric materials such as Al_2O_3 and HfO_2 are commonly used in electronic devices [11,13]. The thickness and surface uniformity of these materials are critical importance for the efficient operation of the devices [14]. The Al_2O_3 and HfO_2 dielectrical materials are commonly deposited by ALD technique for micro and Nano fabrication of electronic devices [15]. The ALD technique is suitable for nanostructure. When the materials is deposited with ALD, the sample is very high homogeneous and it has very small surface RMS value. In addition these advantages it can be improved highly-thickness control and large area uniformity [5,15–17].

In this study, a thin film transistor was presented with a silver storage layer also shows memory and phototransistor behavior, when operated as a two dielectric terminal device at room temperature. The thin film transistor demonstrated that the mechanism is a well structure due to the significance of transistor and memristor characteristics. To better understand photosensitive characteristics of device, the some different current-voltage measurements were taken under in dark and light condition. The thin film device demonstrated that it has a potential to be used in next-generation memory cells and photovoltaic applications.

2. EXPERIMANTAL DETAILS

The device was fabricated on a doped (1-10 Ohm.cm) p-type Si(100) wafer. The device has seven experimental steps. The experimental steps were given details in published previous article [5]. The difference in this article is material used in the storage layer. Platinum metal was used on storage layer in the previous article. In this article Ag materials was used on storage layer. The thickness of metal layer was controlled with thickness monitor. It was evaporated with thermal systems not ALD. After fabrication process, the metal contact was evaporated on ZnO thin film. The current-voltage measurements were performed with Keithley 4200 and solar simulator.

3. RESULTS AND DISCUSSION

To be better understand effect of Ag particle, the thin film transistor were fabricated with ALD and thermal system. As can be seen in figure 1 shows, the film structure has three metal contact such as source, drain and gate. The green area is thin film transistor channel. The channel layers are from bottom to top Al_2O_3, Ag, HfO_2, ZnO, respectively. Thickness values of these materials are 15 nm, 10nm, 5nm and 10 nm, respectively. The thickness values were optimized at previous article [5]. The storage layer such as Ag material was evaporated with thermal evaporation technique and its thickness was controlled with thickness monitor.

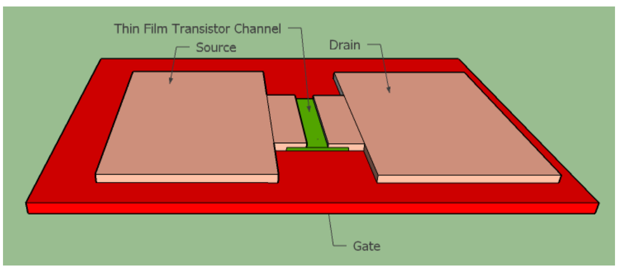

Figure 1. 2D schematic description of the thin film transistor

In order to better understand transistor characteristics, the I-V measurements were taken under different gate and drain sweep voltage. The I-V relation of thin film transistor can be described by constitutive equtions as;

$$
\begin{cases}
\mu_{eff} C_{ox} \frac{w}{L}\left[(V_{GS}-V_{TH})V_{DS}-\frac{1}{2}{V_{DS}}^{2}\right](1+\lambda V_{DS}), & if V_{GS}-V_{TH}>V_{DS}>0 \\
\frac{1}{2}\mu_{eff} C_{ox} \frac{w}{L}(V_{GS}-V_{TH})^{2}(1+\lambda V_{DS}), if V_{DS}>V_{GS}-V_{TH}>0 & \\
0, \quad if V_{DS}>0>V_{GS}-V_{TH} & \\
-\mu_{eff} C_{ox} \frac{w}{L}\left[(V_{GS}+|V_{DS}|-V_{TH})|V_{DS}|-\frac{1}{2}{V_{DS}}^{2}\right](1+\lambda|V_{DS}|), & if V_{GS}-V_{TH}>0>V_{DS} \\
-\frac{1}{2}\mu_{eff} C_{ox} \frac{w}{L}(V_{GS}+|V_{DS}|-V_{TH})^{2}(1+\lambda|V_{DS}|), & if\ 0>V_{GS}-V_{TH}>V_{DS} \\
0, \quad if\ 0>V_{DS}>V_{GS}-V_{TH} &
\end{cases} \tag{1}
$$

Where V_{GS} is the gate-source voltage, V_{DS} is the source-drain voltage, μ_{eff} is the effective channel mobility, V_{TH} is the threshold voltage, C_{ox} is the areal capacitance of the gate stack, w and L are the width and length of the channel, and λ is the early parameter.

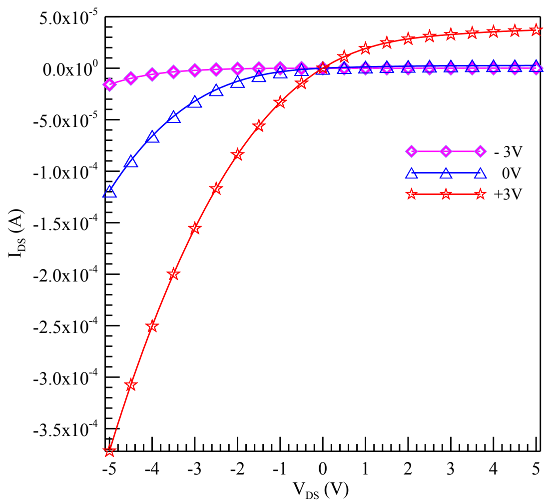

Figure 2. The I_{DS}-V_{DS} measurement of the device at a scan speed of 1 V/s for the transistor at gate voltages of V_{GS}=-3, 0, and 3V

As can be seen in figure 2, the I_{DS}-V_{DS} measurements were given to applied voltage between source and drain metal contacts and changed the gate voltages of -3 V, 0 V and 3 V. The I_{DS}-V_{DS} relation is effected to applied gate voltage. The junctionless transistor behave different characteristics due to the negative gate voltage bias regime. The thin film transistor is related with n-channel depletion type device [12]. The I_{on}/I_{off} value was calculated with I_{DS}-V_{DS} measurements at gate voltage 0 V. This value is found to be $1.1x10^3$. According to this results, fabricated thin film transistor obtained gate control. Typically more gate control leads to more I_{on}/I_{off} [18].

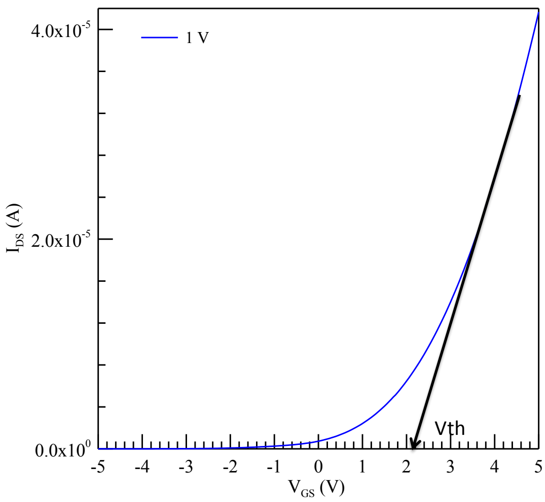

Figure 3. The I_{DS}-V_{GS} measurement of the transistor at gate voltage of V_{DS}= 1V

The other transistor charecterictics of device is threshold voltage. It can be calculated I_{DS}-V_{GS} measurements in figure 3. The threshold voltage was found to be approximately 2.1 V at V_{DS}=1V. The threshold voltage is assumed to be constant through the length of the channel. In addition these measurements, the memory characterizations of device were investigated in dark condition at room temperature. The memory window was calculated current-voltage measurement in figure 4a. It found to be approximately 0.8 V. The value is very small. But, the I_{DS}-V_{DS} measurements were repeated 20 times to investigate the memory effect of Ag material at the interface layer. As can be seen in figure 4a and b, the memory window did not changed with time. These results show that the device can be used flash memory and non-volatile memory device applications [19].

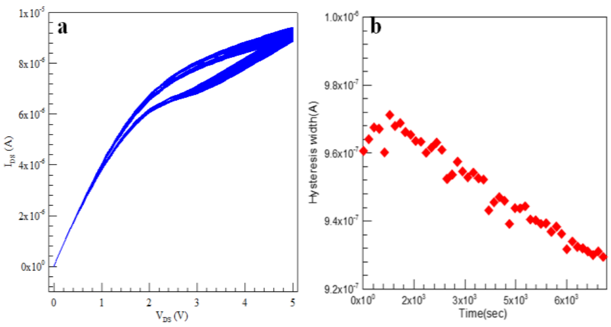

Figure 4. a) The I_{DS}-V_{GS} measurements taken 20 times at different times at gate voltage of V_{DS}= 0V **b)** Change in memory window width over the time

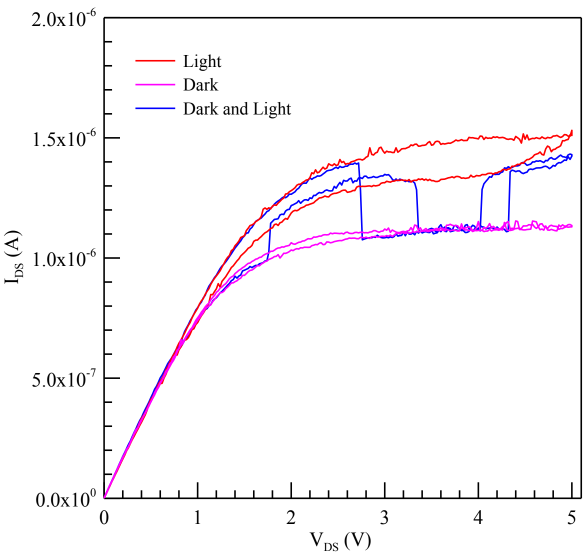

Figure 5. The I_{DS}-V_{DS} measurements at dark and light condition taken 20 times at different times at gate voltage of V_{GS}= 0V

In order to understand the device operation with Ag as a storage layer, the photovoltaic characterizations were investigated under illumination condition as can be seen in figure 5. The I_{DS}-V_{DS} measurements were taken and compared in dark and light conditions at positive voltage. The thin film transistor was effected photon energy in figure 5 at V_{GS}= 0V. The I_{DS}-V_{DS} measurements performance was different between dark and illumination condition.

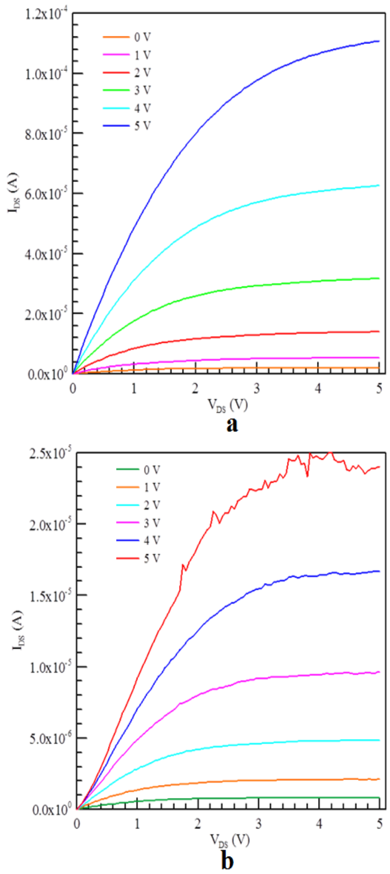

Figure 6. The I_{DS}-V_{DS} measurement of the device, **a)** Light condition and **b)** Dark condition at a scan speed of 1 V/s for the transistor at gate voltages of V_{GS}= 0, 1, 2, 3, 4, 5V

In addition to, the I_{DS}-V_{DS} measurement were performed to characterize its photovoltaic properties at different gate voltage in figure 6. As can be seen in figure 6a and b, the device has different current measurements at different gate voltage under illumination and in dark condition. The device can be said to be about 10 times better under light condition. Therefore, the responsivity of the device was reasonable from the photogating effect [20]. According to these results, the device can be used both thin film transistor and memory technology due to the memory hysteresis and phototransistor applications.

4. CONCLUSION

In this study, the thin film ZnO transistor was fabricated with ALD and thermal evaporation systems. Some transistor and memory parameters such as I_{on}/I_{off} ratio, threshold voltage and memory window width were calculated with current-voltage characteristics. The Ag metal particles were used in storage layer and the photovoltaic properties of Ag metal particles were investigated in dark and illumination conditions. It is clearly that the device has memory characteristics and photoresponsed structure. The obtained device can be used on memory structure and phototransistor applications.

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