Fabrication of an a-IGZO Thin Film Transistor Using Selective Deposition of Cobalt by the Self-Assembly Monolayer (SAM) Process

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Interest in transparent oxide thin film transistors utilizing ZnO material has been on the rise for many years. Recently, however, IGZO has begun to draw more attention due to its higher stability and superior electric field mobility when compared to ZnO. In this work, we address an improved method for patterning an a-IGZO film using the SAM process, which employs a cost-efficient micro-contact printing method instead of the conventional lithography process. After a-IGZO film deposition on the surface of a SiO₂-layered Si wafer, the wafer was illuminated with UV light; sources and drains were then patterned using n-octadecyltrichlorosilane (OTS) molecules by a printing method. Due to the low surface energy of OTS, cobalt was selectively deposited on the OTS-free a-IGZO surface. The selective deposition of cobalt electrodes was successful, as confirmed by an optical microscope. The a-IGZO TFT fabricated using the SAM process exhibited good transistor performance: electric field mobility ($\mu_{\text{FE}}$), threshold voltage ($V_{\text{th}}$), subthreshold slope (SS) and on/off ratio were 2.1 cm²/Vs, 2.4 V, 0.35 V/dec and $2 \times 10^6$, respectively.

Keywords: Oxide TFT, Self-Assembled Monolayer Micro-Contact Printing, IGZO.

1. INTRODUCTION

Recent developments in display technologies such as liquid crystal display (LCD), plasma display panel (PDP) and organic light emission display (OLED) have resulted in fierce competition to produce affordable yet highly efficient displays. Among the next generation thin film transistors (TFTs), oxide TFTs which employ an oxide active channel are attractive because of their higher mobility when compared to amorphous silicon or organic base transistors, along with their high stability and optical transparency.¹ - ³ The use of the oxide TFTs may solve the problems of the low durability and reliability of organic transistors (OTFT) and the low mobility and optical opacity of existing amorphous silicon TFTs. Because room temperature deposition is possible, oxide TFTs can also be applied to next generation displays like OLED⁴ - ⁵ or flexible displays,⁶ which require low deposition temperature but high mobility. For many years, considerable work has focused on the use of ZnO in flexible displays because it is a crystalline phase even during room temperature deposition, theoretically providing the desired mobility. However, in practice, comparatively low mobility, instability and vulnerability to processing solvents have been hampering real-world ZnO applications. Alternatively, indium gallium zinc oxide (a-IGZO) is known to possess a high field effect mobility, greater than 10 cm²/Vs, and a good sub-threshold swing of 0.20 V/decade,⁷ - ⁸ in spite of its amorphous phase. In addition, a-IGZO is inert to solvents and shows outstanding uniformity in many properties. Therefore, a-IGZO is considered a potential candidate material for next generation TFTs.

As cost is always a concern, one approach to reduce the process cost is to employ a micro-contact printing method rather than the conventional lithography process. Since the main application of a-IGZO TFTs is the manufacture of display backplanes consisting of transistors with relatively large dimensions, a micro-stamping patterning method can be readily applied. To date, the feasibility of micro-contact printing was mainly explored with organic transistors or the SiO₂ oxide layer. There has been no report on the micro-patterning by imprinting method on an a-IGZO film. If the micro-contact printing method could be successfully...
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Fig. 1. SAM process (a) UV exposure on a-IGZO thin film for 30, 45 and 60 min (b) and (c) OTS contact printing (d) Co deposition by MOCVD and cross sectional view of a-IGZO TFT with channel (W/L = 200 μm/45 μm).

demonstrated on a-IGZO film, then the entire patterning process using a printing-only method for the fabrication of oxide transistors could be realized.

Therefore, we studied the patterning of source/drain on a-IGZO film using a self-assembly monolayer (SAM) process9–12 to test the feasibility of replacing conventional lithography. The source/drain area was defined by applying the SAM process to the a-IGZO thin film after the surface was treated with UV light. In order to see the effects of UV exposure time on the device properties, we fabricated the bottom-gate structure transistors and evaluated their characteristics.13

2. EXPERIMENTAL DETAILS

Prior to the SAM patterning process, it is essential to investigate the surface property changes of a-IGZO film caused by various UV treatment conditions. A 50-nm a-IGZO layer was deposited on a glass substrate using a radio frequency (RF) sputtering system under the following conditions: plasma power of 40 W, Ar:O2 gas ratio of 9:1 and chamber working pressure at 5 mtorr. The a-IGZO film was exposed to UV light at both 184 nm and 254 nm for 0, 30 and 60 minutes. To characterize the changes in the a-IGZO thin film surface energy during UV exposure, the water contact angle was measured after each UV treatment.

For the fabrication of a bottom common gate structure TFT with a-IGZO, a 1.5 cm × 1.5 cm Si wafer was prepared as a gate. A 150 nm thick SiO2 dielectric layer was deposited by plasma enhanced chemical vapor deposition (PECVD) at 250 °C, followed by a-IGZO film deposition which was applied as stated above. The edges of the a-IGZO thin film were wet etched in buffered oxide etching (BOE) to avoid the possible creation of a conducting path between the bottom gate and active layer, leaving only a 1 cm × 1 cm square island pattern. The a-IGZO thin films were then exposed to UV light for 30, 45 or 60 minutes. For the selective deposition of Co by the SAM process, a stamp with S/D patterns was produced on the wafer using poly dimethyl siloxane (PDMS). After a spin coating of n-octadecyltrichlorosilane (OTS) was applied over the PDMS stamp, contact printing was applied to the UV-treated a-IGZO thin film. Co was selectively deposited on the S/D area by metal organic chemical vapor deposition (MOCVD) at a 200 mtorr working pressure and 70 °C. Figure 1 presents a schematic of the SAM process flow, and Figure 1(d) illustrates the final configuration of the TFT. The electric characteristics of the a-IGZO TFT were measured using an Agilent 5270 B semiconductor parameter analyzer.

3. RESULTS AND DISCUSSION

Figure 2(a) shows the water contact angle on a bare a-IGZO film after UV exposure for 60 min; Figures 2(b), (c) and (d) show contact angles on the OTS layer covered a-IGZO thin film after UV exposure for 0, 30 and 60 min, respectively. Both the 184 nm and 254 nm wavelengths increase the O molecules in the air through the reactions O2 + O2 = O3 + O and O3 = O2 + O. The O molecules clean the contaminants from the IGZO film surface. Furthermore, UV light generates OH− groups from H2O molecules in the air and replaces the O atom on the IGZO surface with OH− groups. Thus the surface becomes strongly hydrophilic as a result of incomplete bonding of the OH− groups. Since OTS [CH(CH3)2]n-SiClx molecules have −CH3 on one end and −SiClx on the opposite end, when OTS is printed onto an a-IGZO thin film, the OH− and SiClx chemically react and form SiO2. During this process, gaseous HCl is released and...
a SiO$_2$ bond is created. The OTS molecules are lined up vertically on the a-IGZO surface as shown in Figure 1(c).
Therefore, the OTS-printed area terminates with a $-\text{CH}_3$ and renders the surface hydrophobic, while the OTS-free area remains hydrophilic. Figure 2 clearly demonstrates the progressive increase in the water contact angle as the a-IGZO thin film becomes more hydrophilic with longer exposure time to UV light.

In order to check the possibility of UV light effects on the intrinsic properties of the a-IGZO, the optical band gap was measured from specimens with and without UV exposure. No noticeable difference in the optical band gap energy (3.2 eV) was observed between the two types of specimen (see Fig. 3).

Figure 4 confirms the selective MOCVD of Co source/drain patterns of two different geometries on the OTS printing. During the deposition of Co on the SAM patterned a-IGZO thin film, Co was only deposited on the hydrophilic surface. As previously explained, the SAM patterning process cannot typically be applied to the Si film because unlike oxide or polymer films, the surface energy of Si film cannot be controlled by UV light. Therefore, in order to apply a SAM process to conventional Si base transistors, a less favorable inverted coplanar structure in which the deposition of the formation of source/drain precedes an active Si layer, is typically employed. In an inverted coplanar geometry is generally more susceptible to high contact resistance than inverted staggered geometry due to the limited area formation at the contact between S/D and the active layer. However, one can avoid such a relatively high contact resistance problem by employing an inverted staggered structure TFTs in which the process sequence of an a-IGZO active layer and S/D is switched.

Figure 5 shows the transfer characteristics of the oxide TFTs fabricated using the SAM process. With the voltage sweep from $-10$ V to $20$ V, the current was measured at $0.5$ V intervals. The width and length of the source/drain were $200$ $\mu$m and $45$ $\mu$m, respectively. The drain voltage was $6$ V because the TFT was operating in an enhancement mode region. The TFT fabricated with $60$ min UV exposure exhibited an electric field mobility of $2.1$ cm$^2$/Vs, a threshold voltage of $2.4$ V, and a substrate swing of $0.35$ V/dec. The electric field mobility ($\mu$FE) in the saturation region was deduced from the following equation:

$$I_d = \frac{W \mu_{sat} C_i}{2L} (V_g - V_{th})^2$$  \hspace{1cm} (1)
The on/off values of the drain current were $9.6 \times 10^{-7}$ A and $3.5 \times 10^{-13}$ A, respectively, with an on/off current ratio of $2.9 \times 10^6$. The a-IGZO based TFT produced utilizing the SAM process resulted in properties comparable to the TFTs processed by the conventional lithography process.\textsuperscript{17,18}

Table I lists the electrical characteristics of the TFTs fabricated with the SAM process at different UV exposure times. It is clear that the electrical properties of the TFTs improve as the UV exposure time increases. The property enhancements seem to be associated with an improvement in the deposition selectivity. As explained earlier, the selective deposition of Co is influenced by the UV exposure time. Relatively short exposure of 30 or 45 min is probably not enough to convert OTS on the a-IGZO to hydrophobic sufficiently. Therefore, the trace of Co could be deposited on the channel surface area between source and drain that may lead to high off current shown in the Figure 5.

Table I. a-IGZO device parameters from three different transistors.

<table>
<thead>
<tr>
<th>Insulator</th>
<th>On/off ratio</th>
<th>$SS$ (V/dec.)</th>
<th>$V_{th}$ (V)</th>
<th>$\mu_{FE}$ (cm$^2$/V·s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV 30</td>
<td>$5.6 \times 10^7$</td>
<td>3</td>
<td>5</td>
<td>$\sim 0.03$</td>
</tr>
<tr>
<td>UV 45</td>
<td>$9.0 \times 10^6$</td>
<td>0.5</td>
<td>1.9</td>
<td>$\sim 0.15$</td>
</tr>
<tr>
<td>UV 60</td>
<td>$2.9 \times 10^6$</td>
<td>0.35</td>
<td>2.4</td>
<td>$\sim 2.1$</td>
</tr>
</tbody>
</table>

4. CONCLUSION

This research demonstrates the ability to control the surface energy of a-IGZO film by exposure to UV light. The degree of hydrophobicity of the a-IGZO film increased with exposure time, thus the selective deposition of the Co electrode was more effective with longer exposure. Although the UV treatment seems to have no effect on the optical properties of the a-IGZO film, the electrical measurements from the devices fabricated with various exposure times illustrate that it is the UV treatment that brings about the effects on the electrical properties. Consequently, the patterning of an a-IGZO film by the SAM process can effectively replace the conventional lithography process. Since the SAM process is applicable to oxide films, the patterning of transparent electrodes, such as ITO and AZO, are also possible. Eventually, all the patterning processes involved in the fabrication of oxide transparent transistors can be realized.

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References and Notes


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