Suppression of the Floating-Body Effect in Poly-Si Thin-Film Transistors With Self-Aligned Schottky Barrier Source and Ohmic Body Contact Structure

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Abstract—In this letter, we developed a new self-aligned *S*chottky barrier *s*ource and *o*hmic *b*ody contact (SSOB) method that can effectively suppress the floating-body effect in poly-Si thin-film transistors (TFTs). Experimental results show that the SSOB-TFTs give higher output resistance, less threshold voltage variation, improved subthreshold characteristics, and larger breakdown voltage compared with conventional TFTs. The characteristics of the SSOB-TFTs are suitable for high-performance driving TFTs with a high output resistance and large breakdown voltage.

Index Terms—Floating-body effect, kink effect, ohmic body contact, poly-Si TFTs, Schottky barrier source.

I. INTRODUCTION

POLYCRYSTALLINE silicon thin-film transistors (poly-Si TFTs) are key devices in active-matrix liquid crystal displays (AMCLDs). Due to the relatively-large field-effect mobilities in both n- and p-channel devices, poly-Si TFTs can be used to incorporate the integrated driving circuits in AMLCDs [1]. Recently, poly-Si TFTs are suitable for the pixel driving elements of active matrix organic light-emitting diode (AM-OLED) [2], and the driving TFTs with a high output resistance are desirable. However, the output characteristics exhibit an anomalous current increase in the saturation regime, often called a "kink" effect [3], [4] due to an analogy with silicon-on-insulator (SOI) devices [5]. This phenomenon can be attributed to the floating-body effect [6] and the avalanche multiplication enhanced by grain boundary-traps [7]. The avalanche multiplication is caused by the high drain electric field and the presence of grain boundaries and traps enhances the kink effect in poly-Si TFTs [7]. The added drain current enhances impact ionization which leads to a premature breakdown in return [6]. Several structures, such as lateral body terminal (LBT) [8], low-barrier body-contact (LBBC) [9], and Schottky body contact [10] have been reported in order to reduce the kink current. However, LBT needs an additional terminal for the body bias; LBBC needs additional implantation
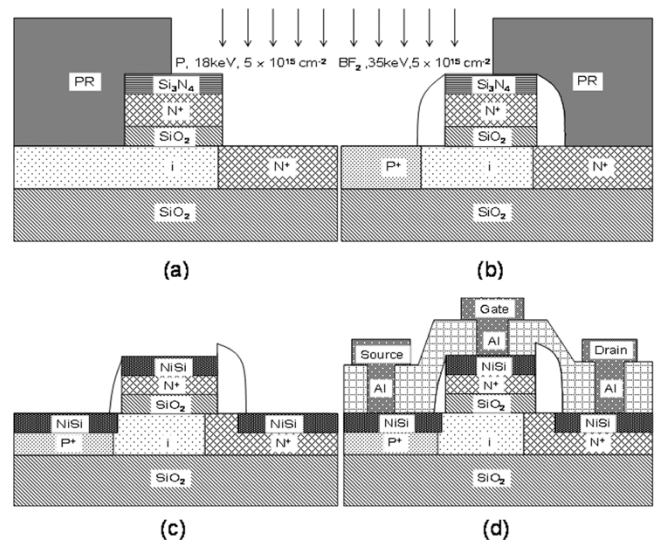
Fig. 1. Key processes of the SSOB-TFTs: (a) n^+ drain-side implantation; (b) p^+ body-contact implantation; (c) Ni-salicidation and Schottky barrier source formation; and (d) poly-Si TFTs with SSOB after contact and metallization processes.

processes and thicker channel thickness for the body contact; and the high-forward-bias turn-on voltage of the Schottky diode was reported using Schottky body contact. Among these structures, Schottky barrier MOSFETs (SB-MOSFETs) are thought to have some advantages over conventional MOSFETs, such as the reduction of parasitic resistance and capacitance, and the immunity to the short channel [11], latch-up, or SOI floating-body effects [12].

In this letter, we have developed a self-aligned *S*chottky barrier *s*ource and *o*hmic *b*ody contact (SSOB) method for contacting the body terminal of poly-Si TFTs and forming the silicided source applicable to technologies that incorporate self-aligned silicide cladded junctions. The new structure provides a very effective body contact to suppress all undesirable floating-body effects. Various device parameters, such as subthreshold characteristics, output characteristics, and breakdown voltage, are compared with conventional poly-Si TFTs.

II. EXPERIMENT

The key processes to fabricate the SSOB-TFTs are shown in Fig. 1. First, a 50-nm amorphous silicon (a-Si) layer was deposited by low-pressure chemical vapor deposition (LPCVD) at 550 °C on oxidized silicon wafers. Next, the a-Si layer was then recrystallized by solid-phase crystallization (SPC) at 600 °C
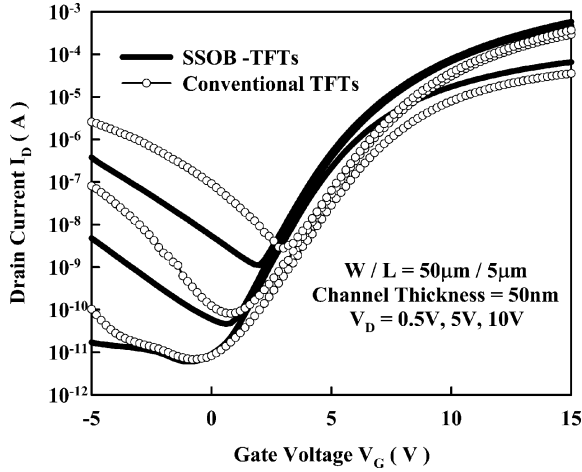
Fig. 2. Transfer characteristics of the conventional and the SSOB-TFTs with $W/L = 50~\mu\text{m}/5~\mu\text{m}$.

Fig. 3. Transfer characteristics of the Schottky drain and the SSOB-TFTs with $W/L = 50~\mu\text{m}/5~\mu\text{m}$.

for 24 h. After the active region patterning, a 50-nm gate oxide layer was deposited by high-density plasma chemical vapor deposition at 350 °C. Subsequently, a 150-nm *in situ* n^+ doped a-Si layer and a 150-nm Si_3N_4 hard mask layer were deposited by LPCVD. After defining gate electrode, the remaining oxide on source/drain regions was removed by diluted HF. A mask was used to perform the n^+ drain-side implantation with P^+ to dose 5×10^{15} cm^{-2} and energy 18 keV [Fig. 1(a)]. A 250-nm oxide sidewall spacer was formed by deposition and etching of TEOS oxide. A similar mask was used to perform the p^+ doped body-contact BF_2 implantation with dose 5×10^{15} cm^{-2} and moderate energy 35 keV. This implantation serves to form a p^+ junction below the Schottky barrier source for ohmic body contact and also improves the conductivity at the bottom of the source for better body current collection simultaneously [Fig. 1(b)]. Meanwhile, only source- side oxide spacer was removed by buffered oxide etch (BOE). After removing the pho- toresist of body-contact mask, the Si_3N_4 hard mask layer was then selectively etched in a hot phosphoric acid bath. A second 25-nm oxide sidewall spacer was again formed by deposition and etching of TEOS oxide. Dopants were activated by rapid thermal annealing (RTA) at 750 °C for 20 s. A Ni film of about 10 nm was deposited by sputtering after a dilute HF-dip and then Ni-salicidation was carried out at 500 °C for 30 s by one-step RTA in the N_2 ambient. Unreacted Ni was removed in H_2SO_4 : H_2O_2 solution. The Schottky barrier source was formed by the Ni-salicidation [Fig. 1(c)]. After contact and the metal- lization processes, the resultant poly-Si TFT with SSOB was shown in Fig. 1(d). Conventional devices with self-aligned n^+ source/drain and without Ni-salicidation were also fabricated to serve as control ones. No further hydrogenation procedures were implemented after sintering at 400 °C for 30 min.

III. RESULTS AND DISCUSSION

The measured transfer characteristics of the conventional and the SSOB-TFTs with $W/L = 50~\mu\text{m}/5~\mu\text{m}$ are shown in Fig. 2. The off-state leakage currents in the conventional TFTs are slightly higher than that in the SSOB-TFTs. Fig. 2 also displays that the threshold voltage V_{TH} (defined as

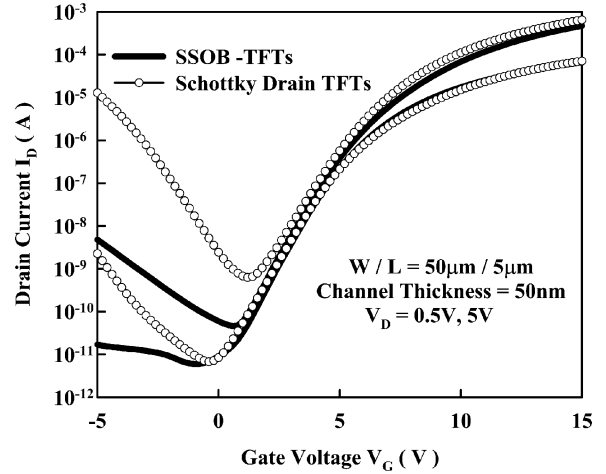$I_D = W/L \times 100$ nA) is 6.9 V and 6.1 V for the conventional TFTs at $V_{DS} = 0.5$ V and $V_{DS} = 10$ V, respectively. However, V_{TH} is 5.4 V and 5.2 V in the SSOB-TFTs at $V_{DS} = 0.5$ V and $V_{DS} = 10$ V, respectively. Since the hole accumulation at the channel increases the body potential and lowers the junction barrier at the source region, a large number of hole carriers may be collected by the source. The leakage current is the sum of the electron current by field-emission at the drain region and the hole current caused by p-n forward bias at source [8]. With this ohmic body contact, the hole accumulation in the body and parasitic bipolar effects can be eliminated, resulting in a stable V_{TH} [9], [13] and lower off-state leakage current in the SSOB-TFTs [14]. The benefit of the SSOB-TFTs also can be found on subthreshold swing (S.S.). The S.S. of the conventional and the SSOB-TFTs are about 1230 mV/dB and 1100 mV/dB, respectively. We believe that it may be due to the shallow silicided source junction and p^+ junction in the SSOB-TFTs.

To prove asymmetric S/D embedded in our SSOB struc- ture, devices were measured again with interchanged S/D, i.e., Schottky drain TFTs with Schottky barrier drain and n^+ source. Fig. 3 shows the transfer characteristics of the Schottky drain and the SSOB-TFTs with $W/L = 50~\mu\text{m}/5~\mu\text{m}$. No- tably, the subthreshlod and on-state transfer characteristics for both devices are almost the same, except for gate-in- duced-drain-leakage (GIDL)-like currents when V_G was at negative bias. Normally, GIDL-like currents were often found for Schottky drain TFTs due to holes tunneling to the channel from drain metal silicide [15]. The GIDL-like currents become significant at the stronger accumulation region and higher drain voltage in the Schottky drain TFTs. This GIDL-like current can be three orders of magnitude reduced by the n^+ drain in the SSOB-TFTs.

The measured output characteristics of the conventional, the Schottky drain and the SSOB-TFTs are shown in Fig. 4. The kink effect of the SSOB-TFTs is considerably reduced com- pared with the conventional and the Schottky drain TFTs. Under high drain voltage, excessive holes are accumulated at the body region and the drain breakdown is reduced by the floating-body
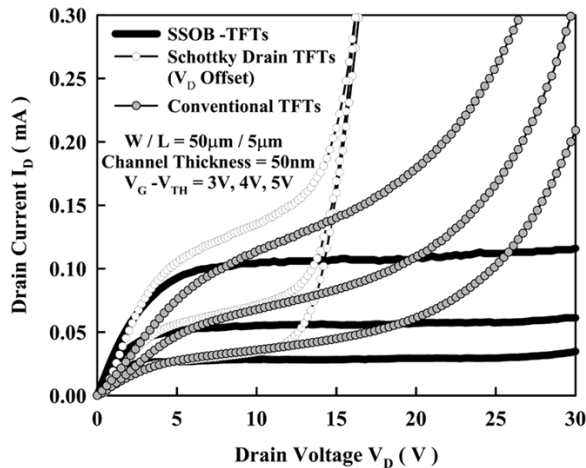
Fig. 4. Output characteristics of the conventional, the Schottky drain, and the SSOB- TFTs with $W/L = 50\,\mu m/5\,\mu m$.

effect in the conventional TFTs [16], [17]. This hole accumulation causes a profound kink effect, which in turn deteriorates the output characteristics and induces parasitic bipolar transistor action [18], [19]. Since the SSOB-TFTs effectively collect the hole current generated by impact ionization, the floating-body effect is significantly suppressed and breakdown voltage is increased. Fig. 4 also indicates that the output characteristics of the Schottky drain TFTs have a finite drain voltage offset which is considered to arise from the Schottky barrier formed between the Schottky barrier drain and n^+ inversion layer [20]. The low breakdown voltage ($V_D \sim 15$ V) and kink-like current for Schottky drain TFTs may result from the inherent p-i-n diode forward biased at $V_D > 0$ V.

IV. CONCLUSION

We have developed a self-aligned SSOB structure for poly-Si TFTs to provide an effective body contact and suppress the floating-body effect. The GIDL-like currents occurred in the Schottky drain TFTs are reduced by the SSOB-TFTs. These SSOB-TFTs show a reduced kink effect and increased breakdown voltage and are suitable for driving circuit applications for high-voltage gain.

ACKNOWLEDGMENT

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