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Conduction mechanisms for off-state leakage current of Schottky barrier thin-film transistors

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Conduction mechanisms for the off-state leakage in Schottky barrier thin-film transistor were explored. It was found that the field-emission process dominates the leakage conduction of the device with the conventional structure as the field strength in the drain junction becomes high, and results in the strong gate-induced drain leakage (GIDL) like phenomenon. In contrast, for the device with a field-induced-drain structure, the high-field region is pulled away from the silicided drain. As a result, the field-emission conduction is eliminated, so the GIDL-like leakage current is effectively suppressed. © *2001 American Institute of Physics.* [DOI: 10.1063/1.1390325]

Polycrystalline silicon (poly-Si) thin-film transistor (TFT) is an important switching element for large-area electronic applications, such as active-matrix liquid-crystal display, organic light-emitting display, etc. For these applications, simple, low-temperature processing, and a high on/off current ratio are very desirable for cost reduction and high performance. In order to meet these goals, we have recently proposed and demonstrated a Schottky barrier thin-film transistor (SBTFT) featuring co-silicided source/drain and field-induced drain (FID) extension[1,2] as is schematically shown in Fig. 1(a). The silicided source/drain scheme, which are formed using the conventional self-aligned silicidation technique, saves the ion implantation and associated annealing steps, thus greatly simplifying the fabrication processes, and could also reduce the thermal budget. Meanwhile, the FID feature induced by the subgate (i.e., field plate) enables the device for ambipolar (i.e., *p*- and *n*-channel) operation. Our experimental results showed that an on/off current ratio as high as 10^6 for both *p*- and *n*-channel operations can be achieved simultaneously on the same device. More importantly, the gate-induced drain leakage (GIDL) like off-state leakage current encountered in a conventional SBTFT [i.e., without a field plate, using sidewall spacers to isolate the source/drain and the gate during salicidation, as shown in Fig. 1(b)] could be completely suppressed.[2] In this work, we further carried out a detailed study on the off-state leakage characteristics of the devices at different temperatures. Based on these results, the conduction mechanisms for off-state leakage are discussed and identified.

Devices were characterized using a HP4156 parameter analyzer. Drain current was measured with gate voltage sweeping from 5 to −5 V. For the *p*-channel operation, the drain and subgate (i.e., field plate) voltages are −3 and −50 V, respectively. While for the *n*-channel operation, the drain and subgate voltages are 3 and 50 V, respectively. For comparison, measurements were also performed on conventional SBTFT shown in Fig. 1(b).

Figures 2(a) and 2(b) show the typical I_D–V_G characteristics under *p*-channel operation, measured at different temperatures, for the SBTFT with FID and conventional structures, respectively. As can be seen in Fig. 2, the conventional SBTFT depicts very poor performance, with intolerably high off-state leakage. In contrast, the on/off current ratio at room temperature is higher than 10^5 (and could reach 10^6 if the gate voltage is further increased), though it decreases with increasing temperature. In addition, regardless of the temperature, the SBTFT with FID is essentially free from the GIDL leakage in the off state, i.e., drain current is nearly

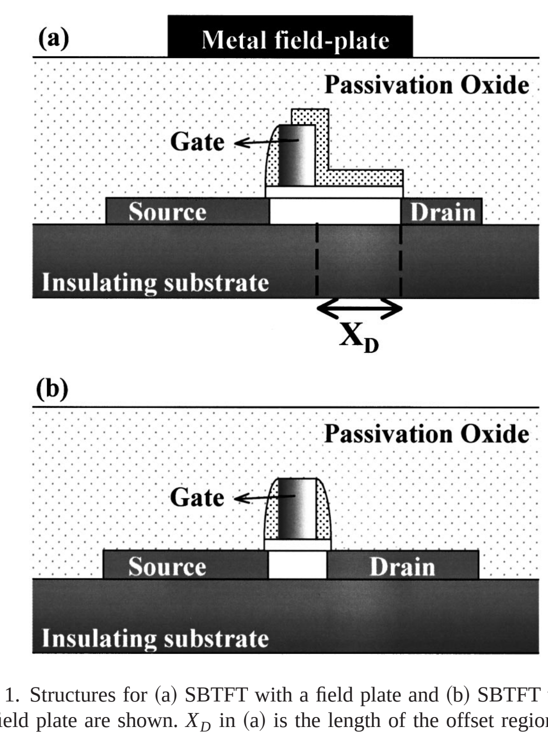

FIG. 1. Structures for (a) SBTFT with a field plate and (b) SBTFT without the field plate are shown. X_D in (a) is the length of the offset region in the channel.

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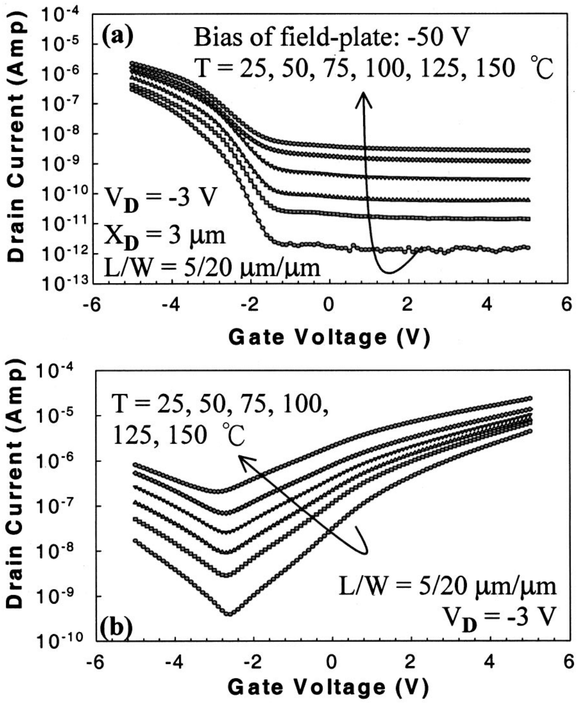

FIG. 2. $I_D - V_G$ characteristics for *p*-channel operation of SBTFT with (a) FID and (b) conventional structures characterized at different temperatures are shown. In (a) and (b), the current at a fixed V_G increases with increasing temperature.

independent of the applied gate voltage. This is in strong contrast with the results of the conventional SBTFT shown in Fig. 2(b).

The corresponding Arrhenius plots for FID and conventional SBTFTs, measured at $V_G = 0$ and 4.5 V, are depicted in Fig. 3. The extracted activation energy clearly shows two trends. First, E_A for conventional SBTFT is lower than that of the SBTFT with FID for a given V_G. Second, for conventional SBTFT, E_A is very sensitive to the gate bias and decreases as V_G becomes more positive in the off state. In contrast E_A for SBTFT with FID shows only very minor dependence on V_G in the off state. Though the results for *n*-channel operation are not shown, similar trends were observed. For example, E_A values for *n*-channel operation of conventional SBTFT are 0.492 and 0.210 eV at $V_G = 0$ and -4.5 V, respectively. In contrast, the E_A values for FID devices fall in the range of 0.56–0.57 eV in the off state that is nonsensitive to V_G.

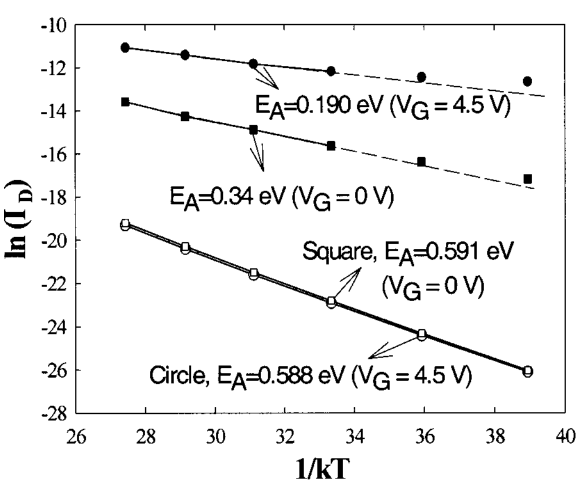

FIG. 3. Arrhenius plots for *p*-channel operation of SBTFTs are shown. (Empty symbols: FID; filled symbols: conventional structure).

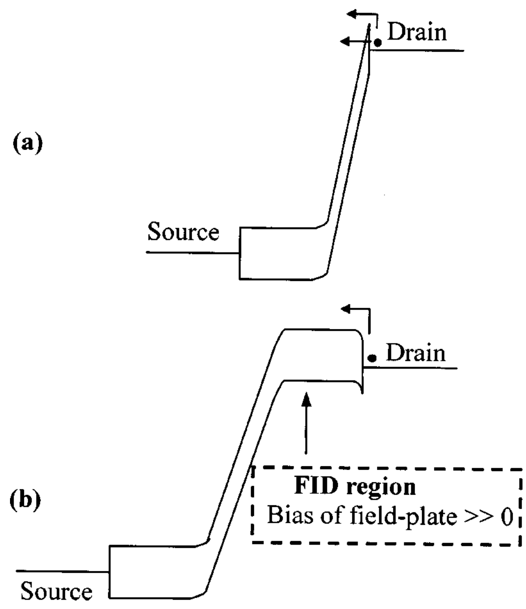

FIG. 4. Band diagrams for *p*-channel operation of SBTFTs with (a) conventional and (b) FID structures are shown ($V_G \sim 0$).

Based on the aforementioned findings, band diagrams as illustrated in Fig. 4 are proposed to explain the leakage mechanism. In Fig. 4, we concentrate only on the *p*-channel operation. Similar results could also be deduced for *n*-channel operation. For the conventional SBTFT, the field emission and thermionic emission of electrons from the drain are presumably the two primary conduction mechanisms responsible for the off-state leakage [Fig. 4(a)], and the two mechanisms are competing with each other. Under the condition when the field strength is weak, for example, $V_G = 0$, the thermionic emission dominates so the activation energy for the leakage will be close to the barrier height. As the potential difference between the gate and the drain (V_{GD}) increases, the contribution from the field emission will increase, owing to the higher field strength. This is evidenced from Figs. 2(b) and 3 that E_A for the conventional SBTFT decreases when the off state $|V_G|$ increases.

On the other hand, when FID scheme is implemented, as shown in Fig. 4(b), the existence of FID will pull the high-field region in the channel away from the drain side. As a result, thermionic emission becomes the major conduction mechanism in the off state so the leakage becomes insensitive to V_{GD} [Fig. 2(a)]. It is also worthy to note that the high bias applied on the field plate (e.g., -50 V) would shift the Fermi level in the offset channel region closer to the valence band edge, thus raises the barrier height for thermionic emission. This explains why the E_A for the device with FID shown in Figs. 2(a) and 3 is higher than that of the conventional SBTFT.

In summary, we have experimentally investigated the conduction mechanisms of the off-state leakage current for SBTFTs with FID and a conventional structure. The results show that the activation energy of the off-state leakage decreases significantly with increasing $|V_{GD}|$ for SBTFT with a conventional structure. This indicates that field-emission conduction plays a major role as the field strength in the drain junction becomes high, and results in the strong GIDL-like phenomenon. In contrast, the activation energy of the off-state leakage shows only minor dependence on V_{GD} for SBTFT with FID. This is ascribed to the fact that the high-field region could be pulled away from the silicided drain for the FID structure. As a result, the field-emission conduction will be eliminated, and thus the GIDL-like leakage current can be effectively suppressed.

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[2] H. C. Lin, K. L. Yeh, R. G. Huang, C. Y. Lin, and T. Y. Huang, IEEE Electron Device Lett. **22**, 179 (2001).