A Band-to-Band Tunneling MOSFET Using a Thin Film Transistor

H. S. Momose, S. Kambayashi, H. Kawaguchi, I. Mizushima, S. Onga, and J. Matsunaga

ULSI Research Center, Toshiba Corporation
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki, 210, Japan, Fax: 44-549-2267

The band-to-band tunneling phenomenon was utilized in a thin poly Si film transistor operation. It was found that the band-to-band thin poly Si film transistor has advantages over the normal operation thin poly Si film transistor, regarding gate length dependence and operating temperature dependence.

INTRODUCTION

As MOSFETs have become smaller, the band-to-band tunneling phenomenon, caused by gate-to-drain electric field, has become significant, and many studies on this phenomenon have been reported [1-4]. A new transistor mode has been proposed, which makes use of this effect, in which the drain-to-substrate band-to-band tunneling current is controlled by the gate bias [5,6]. In the experiment, a poly Si film, crystalized from an amorphous silicon film, was used as the thin film. In this paper, band-to-band tunneling is utilized in a thin film transistor and (BT)²TFT (Band-To-Band Tunneling Thin Film Transistor) operation is reported for the first time.

EXPERIMENTS AND RESULTS

Figure 1 (a) shows a cross-section through the (BT)²TFT used in this experiment and the bias conditions adopted. The cross-sections and the bias conditions for a band-to-band tunneling bulk transistor ((BT)³) and normal operation TFT are also shown in Figs.1 (b) and (c), respectively. Device parameters for the transistors are listed in Table 1. In the experiment, a poly Si film, crystalized from an amorphous silicon film, was used as the thin film. First, the amorphous silicon film was deposited by SiH₄ LPCVD at 550°C. Then, the film was crystalized by 10 hour annealing in a nitrogen atmosphere at 600°C. The crystal size was around 0.5 μm.

Figures 2(a) and 2(b) show the Iₚ₋Vₚ characteristics for (BT)²TFT and (BT)³, respectively. Figures 3(a) and 3(b) show subthreshold Iₚ₋Vₕ characteristics for (BT)²TFT and the (BT)³, respectively. Almost identical characteristics were obtained, although the current magnitudes differed between the (BT)²TFT and the (BT)³ cases, because the gate oxide thicknesses were different. Leakage current at high drain and low gate biases for (BT)²TFT are normal channel current between the source and drain. This leakage current is turned-on by the higher gate voltage, with respect to the p thin-film-substrate potential, which is determined by the drain bias via the forward drain-substrate junction. In this
In this experiment, the gate oxide thickness for (BT)²TFT was much thicker than that for (BT)³. The (BT)³ current drive I_D and S factor dependences on the gate oxide thickness were measured. The results are shown in Fig.4. The figures show that the (BT)²TFT I_D and S factor are on the gate oxide thickness dependence lines for (BT)³. Thus, if the (BT)²TFT gate oxide thickness is reduced to that for (BT)², characteristics similar to those for (BT)³, as shown in Figs. 4(a) and 4(b), will be obtained.

Figure 5 shows the I_D-V_G characteristic short channel effects for the (BT)²TFT and the normal operation TFT. The short channel effect for the (BT)²TFT is very small, because the tunneling phenomenon occurs locally, and thus I_D for the (BT)²TFT is inherently independent from the channel length.

Figure 6 shows I_D dependence on operating temperature. The (BT)²TFT temperature dependence was smaller than that for the normal operation TFT. Basically, the tunnel current has very small temperature dependence. Probably, the (BT)²TFT temperature dependence is caused by indirect tunneling via some intermediate states [3].

Figure 7 (a) shows the (BT)²TFT cross-section view. The (BT)²TFT size is smaller than the normal operation TFT (Fig.7 (b)), because p thin-film-substrate can be used as the drain. In addition, a (BT)²TFT current dependence on the gate length and the operation temperature are better than those for a normal operation TFT. This is because that the (BT)²TFT structure requires only one n-p reverse biased junction and controlled gate on it.

CONCLUSION

Band-to-band tunneling transistor operation was observed in a thin film transistor structure. It was found that the band-to-band thin film transistor (BT)²TFT has advantages over the normal operation thin film transistor, regarding gate length and operating temperature dependences, as well as in regard to its small size. Thus, it has a potential to built very small and low current device.

ACKNOWLEDGEMENT

The authors would like to thank M. Kashiwagi and K. Natori for their continuous encouragement during the work.

REFERENCES

Table 1. Transistor device parameters.

<table>
<thead>
<tr>
<th>Thin Film Transistor</th>
<th>Bulk Transistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{ox}=40\text{nm}$</td>
<td>$T_{ox}=6-25\text{nm}$</td>
</tr>
<tr>
<td>$T_{ox}=41\text{nm}$</td>
<td>$W/L=10\mu\text{m}/10\mu\text{m}$</td>
</tr>
<tr>
<td>$W/L=0.8\mu\text{m}/4.0\mu\text{m}$</td>
<td>$C_d=1x10^{17}\text{cm}^{-3}$</td>
</tr>
</tbody>
</table>

Fig 1. Transistor cross-section and bias conditions.
(a) Band-to-band thin film transistor: (BT)$^2$TFT
(b) Band-to-band bulk transistor: (BT)$^3$
(c) Normal operation thin film transistor

Fig 2. I - V characteristics for transistors
(a) $I_D - V_D$ for (BT)$^2$TFT
(b) $I_D - V_D$ for (BT)$^3$

Fig 3. I - V characteristics for transistors
(a) $I_D - V_G$ for (BT)$^2$TFT
(b) $I_D - V_G$ for (BT)$^3$
Fig 4. Gate oxide thickness dependence of (BT)²TFT and (BT)³ on
(a) Current drive $I_D$
(b) Subthreshold slope $S$ factor

Fig 5. $I_D$ - $V_G$ dependence on gate length.
(a) (BT)²TFT
(b) Normal operation TFT

Fig 6. $I_D$ dependence on operating temperature

Fig 7. Transistor cross-sections
(a) (BT)²TFT cross-section view
(b) Normal operation TFT cross-section view