ON THE LEAKAGE CURRENT MECHANISM IN NON-UNIFORM FILM POLYCRYSTALLINE SILICON TFTs

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Abstract—Leakage current mechanism in polysilicon TFTs fabricated on a non-uniform film is investigated. The approach utilizes test structures which have non-uniform film thickness at the drain, source and channel regions. An order of magnitude reduction in leakage current at high drain bias is observed in the thick drain TFT structure compared to the thin drain structure. The improvement on the leakage current is due to the reduction in electric field at the thicker drain. The electric field reduction in the thick drain structure is verified using two-dimensional simulations. The influence of the electric field on the anomalous leakage current is investigated with the grain boundary trapping effects separated out.

I. INTRODUCTION

Polysilicon thin film transistors (TFTs) fabricated using a low temperature process have gained much attention in flat panel display such as AMLCDs. TFT devices made with thinner film have the advantages of lower grain boundary trap density, higher mobility, and higher on-state current compared to thicker film devices [1]. However, thinner film devices experience higher electric field due to two dimensional effect arises from the reduced junction depth compared to thicker film devices [2,3]. The anomalous leakage current in TFTs is a function of channel electric field and number of grain boundary traps in the polysilicon film. In fact, the leakage current is exponentially dependent on the electric field and just directly proportional to the grain boundary trap density [4]. In order to reduce this electric field, a lightly doped drain (LDD) structure or offset-drain structure is usually employed [5,6]. However, these structures introduce high source/drain series resistance which limits the on-state current. It was reported previously that the electric field can be reduced in thin film SOI MOSFETs by using a thick drain structure, resulting in higher breakdown voltage [3]. However, no previous work has been reported on the effect of the thick drain structure on the leakage current in TFT devices.

In this work, the source, channel and drain thicknesses of the polysilicon TFTs are varied using chemo-mechanical polishing of the active film. These structures are used to study the leakage current mechanism and its dependence on drain electric field without the influence of grain boundary trapping effects. Experimental results show that a significant reduction in leakage current in the thick drain structure is obtained compared to the thin drain structure. Furthermore, using this approach, the effect of the channel electric field on the leakage current can be studied without the influence of grain boundary trapping effects.

II. DEVICE FABRICATION

Schematic cross-section of the test structures with different source, drain and channel region thicknesses are shown in Fig. 1. The three test structures fabricated are 1) structure with the source and the channel region made on thicker film (3000Å) and drain region made on thinner film (800Å), Type-A, 2) structure with the drain and the channel region made on thicker film and the source region made on thinner film, Type-B, and 3) structure with the source and the channel region made on thinner film and the drain region made on thicker film, Type-C. The process steps for the fabrication of these structures are described as follows.

Schematic cross-section of the process steps are shown in Fig. 2. Silicon wafers with 5000Å thermally grown oxide were used as starting substrates. A 2000Å polycrystalline silicon was deposited first and patterned. Subsequently, a 1000Å LPCVD oxide was deposited. Following that, a 5000Å silicon layer was deposited at 550°C in amorphous form by LPCVD. The amorphous silicon was then recrystallized for 20 hours in nitrogen ambient at 600°C. After the island formation (Fig. 2a), a 3000Å LTO was deposited and patterned using the negative of the island mask (Fig. 2b). This oxide will be used as polish stop for achieving the various film thicknesses. The wafer was then chemo-mechanically polished up to the LTO polish stop as shown in Fig. 2c. Due to the excellent selectivity between polysilicon and LTO dur-

(A)

(B)

(C)

Fig. 1. Schematic cross-section of the test structures: (a) thick source and channel region, Type-A, (b) thick drain and channel region, Type-B, and (c) thin source and channel region, Type-C (thicknesses for the thick and thin regions are 3000Å and 800Å, respectively).

ing polishing, a very good control on the thickness of the polysilicon is achieved. After polishing, polysilicon regions with different thicknesses ($\sim 800\text{\AA}$ and $\sim 3000\text{\AA}$) are formed in the various regions of the devices. The surface topology becomes flat all over the wafer after the polishing. Furthermore, an 1000Å APCVD oxide was deposited as front gate oxide, and a 2500Å gate polysilicon was deposited and patterned. A self-aligned N+ implantation was then performed (Fig. 2d). The dopants were activated during densification of the LTO at 600°C for 10 hours in oxygen ambient. After the metallization and patterning, the devices were hydrogenated using H_2 r.f. plasma for 2 hours.

III. RESULTS AND DISCUSSION

For an LPCVD polysilicon TFT, according to the trap-assisted field-emission model, the leakage current can be expressed as [4]

$$I_L \approx qZx_e N_T \left(\frac{1}{\tau_{TC} + \tau_{TV}} \right) \left(\frac{|V_D|}{E_y} \right)$$

The time constants τ_{TC} and τ_{TV} represent the probability per unit time that a trapped carrier will tunnel through a triangular barrier at the channel/drain junction. They can be expressed as

$$\tau_{TV} \approx \tau_{OV} \exp \left(\frac{4(2m_p^*)^{1/2} (E_T - E_V)^{3/2}}{3qhE_y} \right)$$

$$\tau_{TC} \approx \tau_{OC} \exp \left(\frac{4(2m_n^*)^{1/2} (E_C - E_T)^{3/2}}{3qhE_y} \right)$$

where m_p^* and m_n^* are the effective mass for holes and electrons, τ_{OV} and τ_{OC} are the effective carrier transit time in the valence and conduction bands, E_y is the lateral component of the electric field into the channel from the drain, x_e is the effective depth of the junction region, E_T is the triangular barrier height at the channel/drain junction, N_T is the trap density which is equal to $2N_{ST}/d_G$ where N_{ST} is the grain boundary areal trap density and d_G is the average columnar grain size. It is seen from the above equation that the leakage current is exponentially dependent on the strength of the electric field. Therefore, the leakage current can be reduced by decreasing the electric field at the channel/drain junction.

Fig. 3 illustrates the gate characteristics of Type-A and Type-B devices with identical device dimensions and drain voltage. It is seen that the leakage current of Type-B devices at the zero gate bias and in the negative gate bias regime is remarkably lower than that of Type-A devices. This reduction in the leakage current is due to the reduction of the electric field in Type-B devices since its drain junction depth is increased compared to that of Type-A devices. It is

Fig. 2. Schematic cross-section of the process steps for the fabrication of the test structures: a) after mesa etch, b) after polish stop oxide patterning, c) after chemo-mechanical polishing, d) after gate patterning and source/drain implantation

also seen from Fig. 3 that the on-state current of Type-A devices is slightly higher than that of Type-B devices. This is because hot carriers are generated due to the high electric field in Type-A devices. The minimum leakage current is decreased more than an order of magnitude in Type-B devices in comparison to Type-A devices. This reduction in leakage current improves the on/off current ratio of Type-B devices.

Fig. 4 shows the simulated lateral electric field profile at the channel/drain junction of Type-A and Type-B (thin and thick drain) devices when the devices were biased at $V_{DS}=5V$ and $V_{GS}=-5V$. A 15% reduction in lateral electric field is obtained in thick drain (Type-B) devices.

Fig. 5 shows the gate transfer characteristics of Type-B and Type-C devices. Type-B and Type-C devices are the same except that the channel region in Type-C devices is thinner. Both structures are main-

Fig. 3. Gate transfer characteristics of Type-A and Type-B devices.

tained with a thick drain region. In doing so, the number of grain boundary traps in the channel region of Type-C devices is reduced compared to that of Type-B devices while still maintaining the same electric field. From Fig. 5, it is shown that the zero bias leakage current is not dependent on the number of grain boundary traps. However, the anomalous leakage current in the negative gate bias regime is strongly dependent on the number of grain boundary traps. Comparing Fig. 3 and Fig. 5, one can see that the zero bias leakage current is more strongly dependent on the strength of the electric field at the channel/drain region than on the number of grain boundary traps.

It is also important to note that in thinner film devices, the higher electric field will generate more hot carriers which eventually causes kink effect to occur. Therefore, a thin channel region with a thick source and drain regions can give a higher on/off current ratio and at the same time provide reduced kink effect. In addition, for sub-micron devices, it provides lower source/drain series resistance due to the thick source/drain region.

IV. CONCLUSION

Unique test structures were fabricated to analyze the dependence of the leakage current on the electric field. Using these structures, it was experimentally demonstrated that the anomalous leakage current was increased with increasing electric field. It was found that by thickening the drain region, the strength of the electric field at the drain/channel region is reduced, and thereby reducing the leakage current. Simulation results have also verified that the electric field at the

Fig. 4. Simulated electric field profile near the channel/drain junction region of thin and thick drain devices at $V_{DS} = 5V$ and $V_{GS} = -5V$.

channel/drain junction region is indeed reduced. We have also investigated the effect of the electric field on the leakage current without the influence of the grain boundary trap charges in the channel region.

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Fig. 5. Gate transfer characteristics Type-B and Type C devices.

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