Fabrication of tunneling dielectric thin-film transistor with very thin SiN_x films onto source and drain

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Abstract: Tunneling Dielectric Thin-Film Transistor (TDTFT), which was proposed to reduce the gate-off current by utilizing a tunneling effect, was fabricated in a bottom-gate structure. For the tunneling dielectric, a 1.7-nm-thick SiN_x film was deposited onto the source and drain by a low-pressure chemical vapor deposition (LPCVD) method. The gate-off current of the TDTFT was reduced less than 1/10 in comparison with a conventional TFT. Although the subthreshold characteristics and the g_m were degraded due to the tunnel resistance, it will be compensated by further thinning of SiN_x film or using the material with the barrier height lower than SiN_x.

Keywords: TFT, tunneling effect, SiN_x, gate-off current

Classification: Electron devices

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1 Introduction

With an increase of pixel density of liquid crystal displays (LCD) or organic light emitting diode (OLED) displays, the number of thin-film transistors (TFTs) used in those displays has increased and the TFTs have also been downsized. To realize a high speed, a high brightness and a low power-consumption for those displays, a decrease in the gate-off current of the TFTs is one of the key issues [1, 2]. The origin of the gate-off current is due to the grain boundary or in-grain defects, such as the point defect or dislocations. Although the trial to decrease those defects has been performed by enlarging the grain size [3] or terminating the dangling bonds by hydrogens [4], it is difficult to remove those defects completely. To solve this problem, a new transistor named as Tunneling Dielectric TFT (TDTFT) [5, 6] was designed and proposed. The TDTFT employs nonlinear resistors connected in series to the source and drain electrodes. By using the tunneling dielectric film as a resistance, it is theoretically possible to make the gate-off current decrease without the deterioration of subthreshold swing. In this paper, we report the configuration of the actually fabricated TDTFT using SiN_x as a tunneling dielectric film and compare the electrical characteristics of the TDTFT with those of the conventional TFT (conv. TFT).

2 Experimental

Figs. 1 (a), (b) show the cross-section view of the bottom gate-type TDTFT and the optical micrograph of the actually fabricated one. The tunnel diodes are fabricated directly onto the poly-Si layer as the nonlinear resistor. In the experiment, n⁺Si wafer was used as a gate electrode. The field oxide and the gate oxide with thicknesses of 280 nm and 66 nm were formed in turn by the thermal oxidation. Poly-Si film with a thickness of 53 nm was deposited by a low-pressure chemical vapor deposition (LPCVD) method at 635°C. The source and drain (S/D) were doped using ion-implantation with arsenic at dose of 10¹⁵ cm⁻². To prevent electric field concentration at the corner of the S/D, the thermal annealing in oxygen atmosphere was carried out at 850°C. For tunneling dielectric film, a 1.7-nm-thick SiN_x film was deposited

at 750°C by the LPCVD. The thickness of the SiN_x was measured by using spectroscopic ellipsometer. The SiO₂ passivation (PV) film with a thickness of 620 nm was deposited by atmospheric-pressure CVD (APCVD). Contact holes were etched by the wet etching. Aluminum (Al) layer was formed by the sputtering method. Thicknesses of the Al layers of the front and back sides are 800 and 400 nm, respectively. Hydrogen annealing at 400°C was performed. The channel length *L* and the channel width *W* are 10 μm and 50 μm, respectively. Simultaneously with this process, conv.TFT was also fabricated.

Fig. 1. Cross-section view of fabricated bottom gate-type TDTFT (a) and the optical micrograph of it (b).

3 Results and Discussion

3.1 Evaluation of SiN_x film

To clarify whether the SiN_x film is formed successfully, the direct tunneling (DT) current was measured for the Al electrode/SiN_x film/n⁺Si structure and the structure of Al/SiN_x film/poly-Si was observed by the cross-section transmission electron microscopy (TEM) and energy dispersive X-ray fluorescence spectrometer (EDX). Figs. 2 (a) and 2 (b) show the measured data and the calculated data of the DT current using the Eq. (1) by WKB (Wentzel, Kramers, Brillouin) approximation method [7] and the photograph by the cross-section TEM.

$$j_t = \frac{e}{2\pi h(\beta S)^2} \bar{\varphi} \exp(-A\sqrt{\bar{\varphi}}) - \frac{e}{2\pi h(\beta S)^2} (\bar{\varphi} + eV) \exp(-A\sqrt{\bar{\varphi} + eV}) \quad (1)$$

Here, $A = (4\pi\beta S/h)(2m^*)^{1/2}$, and *e*, *h*, *V*, β , $\bar{\varphi}$, *S* and *m*^{*} are the electronic charge, the Planck's constant, an applied voltage, a correction factor, the average potential of the barrier ($\bar{\varphi} = \varphi_0 - eV/2$), the barrier thickness and the effective mass of electrons in the SiN_x film, respectively. φ_0 is the barrier height of the SiN_x film. $\beta = 0.99$, *S* = 1.7 nm, *m*^{*} = 0.31 *m*₀ and $\varphi_0 = 3$ eV are defined. This equation reproduces the DT current exactly except for the

early stage of the DT. In the voltage range approximately from -2.5 V to -4 V, the slope of the calculated DT current was coincided with that of the measured data. Therefore, the current flowing the SiN_x film was confirmed the DT current. Here, the hysteresis was observed in the early stage for the current-bias relation. This is thought to be due to the electron trap in the SiN_x film. Although the exact thickness of SiN_x film was not identified by the photograph shown in Fig. 2(b) because of SiN_x film being sandwiched between the polycrystalline films, it was confirmed that the SiN_x film was formed uniformly at the Al/ SiN_x /poly-Si structure. The result of the EDX measurement right to the bottom interface at the contact hole showed the existences of N and Si atoms at the Al/poly-Si interface.

Fig. 2. Measured data and calculated DT current using eq. (1) (a) and photograph of Al/ SiN_x /poly-Si by the cross section TEM (b).

3.2 Characteristics of the TDTFT

Figs. 3(a), (b) and (c) show the I_d - V_d characteristics of the conv. TFT and TDTFT, and I_d - V_g characteristics of the conv. TFT at $V_d = 0.1$ V and TDTFT at $V_d = 0.1$ and 1.0 V. The contact area is the total joint area between SiN_x film and Al layer. The drain current I_d of TDTFT was decreased compared with that of the conv. TFT. It was confirmed that SiN_x film at

the bottom of the contact hole successfully serves as a tunneling resistance. The gate-off current of the TDTFT at $V_d = 0.1$ V was decreased less than 1/10 compared with that of the conv. TFT at $V_d = 0.1$ V. It was clarified that the tunneling effect restrained the increase of the gate-off current. The I_d of the TDTFT for $V_d = 1.0$ V increases by approximately a figure as compared with that for $V_d = 0.1$ V. Although it is difficult to obtain the non-linear behavior for $V_d = 0.1$ V considering Fig. 2(a), the TFT performance for $V_d = 1.0$ V is under nonlinear regime.

Fig. 3. I_d - V_d characteristics of conv. TFT (a) and TDTFT (b) and I_d - V_g characteristics of conv. TFT at $V_d = 0.1$ V and TDTFT at $V_d = 0.1$ and $V_d = 1.0$ V (c).

For another electric characteristics, however, the preferable results were not obtained. The threshold voltages of TDTFT and conv. TFT are 16.5 and 11.3 V, and the subthreshold swings of TDTFT and conv. TFT are 2.14 and 1.15 V/dec, respectively. The maximum transconductance g_m of the

TDTFT and conv. TFT are $1.15 \times 10^{-7} \text{ S}$ and $2.27 \times 10^{-7} \text{ S}$, respectively. The subthreshold swing and g_m of the TDTFT were worse than those of the conv. TFT. The reason of these phenomena is due to the tunneling resistance at the contact area which has a close relationship with the thickness of SiN_x film. It is found from the simple calculation [5, 6] that the tunneling resistance is larger than the channel resistance in the present case. The further thinning of the SiN_x film down to 0.5 nm and the material, such as TiO_2 , with the barrier height lower than SiN_x will improve the electric characteristics of the TDTFT. The ratio of the on-current and the off-current of the TDTFT is as same as that of the conv. TFT, because the transmission coefficient of the electron through the SiN_x film is constant and independent of the value of the DT currents. To improve the on/off ratio, the lowering of the perpendicular electric field to the interface of the channel and the gate oxide with a use of the double silicon-on-insulator (SOI) structure [6] is recommended.

4 Conclusion

TDTFT having 1.7-nm-thick SiN_x film as a tunneling dielectric film onto the source and drain was fabricated for the first time. The gate-off current of the TDTFT was decreased successfully less than 1/10 compared with that of the conv. TFT. It was confirmed that SiN_x film at the bottom of the contact hole successfully serves as a tunneling resistance. TFT performance under nonlinear regime was also obtained for $V_d = 1.0 \text{ V}$. However, the subthreshold swing and the g_m were degraded. The reason of these phenomena is related to thickness of the present SiN_x film. The further thinning of it and the materials with the barrier height lower than SiN_x will improve the TDTFT performance.

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