Passivation Effects of Aluminum on Polycrystalline Silicon Thin-Film Transistor With Metal-Replaced Junctions

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Abstract—Aluminum was detected in the channel of a thin-film transistor after its replacement of the polycrystalline silicon source and drain junctions. The resulting transistor exhibits enhanced field-effect mobility, steeper slope of the pseudosubthreshold region, reduced turn-on voltage extrapolated from the linear regime of operation, higher ON-state current, and improved immunity against short-channel effects. These improvements are consistent with a measured reduction in the density of trap states. The reduction can be attributed to the presence of aluminum in the channel.

Index Terms—Aluminum, passivation, polycrystalline silicon, thin-film transistor (TFT).

I. INTRODUCTION

EXHIBITING higher field-effect mobility than the amorphous silicon thin-film transistors (TFTs), the polycrystalline silicon (poly-Si) TFTs are being applied to realizing systems-on-glass [1], such as the self-scanned active-matrix flat-panel displays [2]. Replacement of poly-Si with aluminum (Al) has been applied to the formation of TFTs with metal-replaced junctions (MERJs) [3], [4]. Although the poly-Si active islands of such TFTs are initially undoped, the channel regions immediately beyond the replacement fronts are subsequently doped with Al, which is an acceptor in Si [5]. Consequently, the detrimental effects of parasitic resistance are largely eliminated by the low resistance of the resulting metallic junctions and the ohmic contacts. However, little is known if there is diffusion of Al farther beyond the replacement fronts; and if there is, what effects Al would have on the characteristics of the TFTs.

A comparison was made of the intrinsic characteristics of TFTs with and without MERJs. The MERJ TFT was found to exhibit an enhanced field-effect mobility, steeper slope S_p of the pseudosubthreshold region [6], reduced turn-on voltage V_{on} [7] extrapolated from the linear regime of operation, higher ON-state current, and improved immunity against short-channel effects. Consistent with the improvements, a reduced density of trap states in the channel region of a MERJ TFT was extracted.

This reduction is attributed to the passivation of the traps by Al; a small amount of which is detected using time-of-flight secondary ion-mass spectrometry (TOF-SIMS) in the channel region far beyond the replacement fronts.

II. DEVICE FABRICATION

100-mm diameter, (100)-oriented n-type silicon wafers covered with 500-nm thermally grown silicon dioxide were used as the starting substrates. Conventional nickel-based metal-induced crystallization [8] at 550 °C was performed to obtain 35-nm thick poly-Si active islands. Following the sequential low-pressure chemical vapor depositions of 90-nm low-temperature oxide (LTO) at 450 °C as the gate dielectric and 220-nm poly-Si at 620 °C, the latter was patterned to form the gate electrodes. Self-aligned gate, source, and drain doping was accomplished by $4 \times 10^{15} \text{ cm}^{-2}$ boron implantation at an energy of 45 keV. The implanted dopant was activated at 620 °C for 3 h in atmospheric pressure nitrogen.

Subsequently, 200-nm LTO isolation layer was deposited, and through which, the replacement windows were opened before 2- μm Al-1%Si alloy, and 300-nm titanium (Ti) was sequentially deposited by sputtering. The Ti was selectively removed in concentrated hydrofluoric acid from some of the active islands. On those islands with the top Ti retained, the boron-doped poly-Si at the source and drain regions was completely replaced by Al after a heat treatment at 400 °C for 2 h in atmospheric pressure nitrogen. No replacement was observed on the islands with the Ti removed. On these islands were built the “conventional” TFTs. All remaining Ti was subsequently removed in hydrofluoric acid before the Al layer was patterned to form the interconnections.

After the removal of the covering poly-Si gate and gate oxide, TOF-SIMS using 25-keV Ga^+ ion was applied to detect Al in the channel regions of the MERJ and the conventional TFTs. HP 4156 Semiconductor Parameter Analyzer was used to obtain the current–voltage characteristics.

III. RESULTS AND DISCUSSION

Typical drain-current (I_d) versus terminal gate-to-source voltage (V_{gs}) transfer characteristics of the MERJ and conventional TFTs with channel width W of 10 μm and length L of 25 μm are shown in Fig. 1. The leakage current (I_{off}) is defined to be the minimum I_d at a terminal drain-to-source voltage

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Fig. 1. I_d - V_{gs} characteristics for p-type MERJ and conventional TFTs at $V_{gs} = -0.1$ V and -5 V. Shown in the inset is the dependence of V_{on} on L for both the MERJ and conventional TFTs. W is $10\ \mu\text{m}$ for all of the TFTs.

Fig. 2. Measured $R_m \equiv (V_{ds}/I_d)$ versus L of a series of conventional TFTs at different values of the gate drive ($V_{gs}-V_{on}$). The dependence of the slopes of the lines on $V_{gs}-V_{on}$, together with similar data derived from the MERJ TFTs, is shown in the inset. W is $10\ \mu\text{m}$ for all of the TFTs.

$V_{ds} = -5$ V, and the ON-state current (I_{on}) is I_d at $V_{ds} = -5$ V and $V_{gs} = -25$ V.

Fig. 2 is generated from the transfer characteristics of a series of conventional TFTs at $V_{ds} = -0.05$ V. Eliminating the effects of parasitic source/drain resistance using the procedure outlined in [9], one extracts an “intrinsic” μ_{FE} of $\sim 44.6\ \text{cm}^2/\text{V}\cdot\text{s}$ for the linear regime of operation. Similarly, a μ_{FE} of $57.3\ \text{cm}^2/\text{V}\cdot\text{s}$ is extracted for the MERJ TFTs. V_{on} and S_p are extracted at $V_{ds} = -0.1$ V. These and other characteristics of the MERJ and conventional TFTs are sum-

TABLE I
COMPARISON OF THE ELECTRICAL CHARACTERISTICS OF P-TYPE MERJ AND CONVENTIONAL TFTS. THE RESPECTIVE DRAWN CHANNEL WIDTH W AND LENGTH L ARE 10 AND $25\ \mu\text{m}$

	MERJ TFT	Conventional TFT
μ_{FE} (cm^2/Vs)	55 ± 1.5	44 ± 1.2
V_{on} (V)	-6.9 ± 0.2	-12.9 ± 0.4
S_p (V/decade)	0.7 ± 0.1	1.5 ± 0.1
I_{on} ($\mu\text{A}/\mu\text{m}$)	5.9 ± 0.1	3.0 ± 0.2
I_{off} (pA/ μm)	6.2 ± 1.6	2.6 ± 1.0
R_{sd} (Ω)	1.5	641

Fig. 3. Plots of $\ln(I_d/(V_{gs}-V_{fb})V_{ds})$ versus $1/(V_{gs}-V_{fb})^2$ for the conventional and MERJ TFTs. N_t is the trap density, ϵ_{Si} is the silicon dielectric constant, ϵ_{ox} is the silicon dioxide dielectric constant, t_{ox} is the gate oxide thickness, q is the electron charge, μ_{b0} is the mobility constant, C_{ox} is the gate oxide capacitance per unit area, and V_{fb} is the flatband voltage. The circles are measured data and the solid lines are linearly fitting curves to the data.

marized in Table I, showing respective S_p of 0.7 V/dec and 1.5 V/dec, and respective V_{on} of -7 V and -13 V. The parasitic junction resistance R_{sd} of the MERJ TFT is more than two orders of magnitude smaller than that of the conventional TFT. The reduction in V_{on} , when combined with a concurrent $\sim 25\%$ increase in μ_{FE} , leads to an almost doubling of the I_{on} of a MERJ TFT.

The short-channel effects in TFTs are typically manifested by a reduction in V_{on} with decreasing L , as shown in the inset of Fig. 1. Such behavior is quite obvious for the conventional TFTs, with V_{on} dropping by ~ 5 V from $L = 15\ \mu\text{m}$ to $L = 4\ \mu\text{m}$. On the contrary, the V_{on} reduction is rather subtle for the MERJ TFTs within the range of L between 4 and $30\ \mu\text{m}$.

It is known that the characteristics of poly-Si TFT, including the short-channel effects [10], are heavily influenced by the density of trap states. Extracted from Fig. 3 using a technique proposed in [11], the respective densities for the conventional and MERJ TFTs are 4.3×10^{11} and $2.0 \times 10^{11}\ \text{cm}^{-2}$. After the removal of the covering poly-Si gate and gate oxide, Al was

Fig. 4. Positive ion TOF-SIMS spectrum taken near the middle of the channel of a MERJ TFT with $L = 25 \mu\text{m}$. Shown in the inset is the normalized transconductance $\tilde{G}_m \equiv G_m L$ versus L for the conventional and MERJ TFTs. W is $10 \mu\text{m}$ for all of the TFTs.

detected (Fig. 4) using TOF-SIMS in the channel regions of the MERJ TFTs, but not in those of the conventional TFTs. Since the two kinds of TFTs were fabricated in parallel, it is reasonable to attribute the observed reduction in the density of traps in MERJ TFTs to the presence and passivation effects of Al.

Although the characteristics of TFTs with $L = 25 \mu\text{m}$ are reported in detail, the improvements are seen for TFTs with other values of L . This is clear from the comparison of the maximum normalized transconductance $\tilde{G}_m \equiv G_m L$ given in the inset of Fig. 4, where G_m is the maximum transconductance at $V_{ds} = -0.1 \text{ V}$. Although the G_m of the conventional TFT increases with decreasing L , passivation-induced improvements are evident in all the TFTs within the range of L investigated (insets of Figs. 1 and 4). It is clear from the improvement of the TFT with $L = 30 \mu\text{m}$ that the diffusivity of Al in the polycrystalline silicon formed using metal-induced crystallization is quite high and gives rise to a diffusion length of at least $15 \mu\text{m}$ at the end of the 400°C , 2-h replacement heat treatment.

IV. CONCLUSION

A comparison was made of the characteristics of TFTs with and without MERJs. It was found that the transistors with such junctions exhibited an enhanced field-effect mobility, steeper slope of the pseudosubthreshold region, reduced turn-on voltage extrapolated from the linear regime of operation, higher ON-state current, and improved immunity against short-channel effects. Aluminum was detected in the channel of a transistor after its replacement of the polycrystalline silicon source and drain junctions. These improvements are consistent with a measured reduction in the density of trap states in the channel. The reduction is attributed to the passivation of such states by aluminum.

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