Cost-Effective, High-k AlOx Dielectric by Spray Pyrolysis for LTPS and Oxide Thin-Film Transistors

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Abstract

We present a cost-effective spray pyrolysis method to develop high-k AlOx dielectric films for LTPS and IGO TFTs. The AlOx film shows a dielectric constant of 8.46 and a breakdown voltage of 9.25 MV/cm. Short-channel p-type LTPS and n-type IGO TFTs with AlOx exhibit field-effect mobilities of 90 and 23 cm²/V·s, respectively.

Keywords

Low-Temperature-Poly-Silicon (LTPS), Aluminum doped Indium-Gallium-Oxide (Al-IGO), Aluminum Oxide (AlOx), Thin-Film Transistor (TFT), Spray pyrolysis.

1. Introduction

Thin-film transistors (TFTs) are gaining of increasing interest for active matrix displays, flexible electronics, and emerging flexible devices. To meet the growing demands for energy-efficient, high-performance, and compact electronic devices, significant efforts have been devoted to improving both the channel materials and gate dielectric layers of TFTs. Gate dielectrics play a critical role in determining the overall performance of TFTs, as they influence key parameters such as leakage current, operating voltage, subthreshold swing, and field-effect mobility. Traditional SiO_2 dielectrics, while widely used, are limited by their relatively low dielectric constant ($k \approx 3.9$), which necessitates the use of thicker films and higher operating voltages, making them less suitable for modern low-power applications.[1-5] High-k materials, such as aluminum oxide (AlOx), have emerged as promising candidates for replacing conventional gate dielectrics due to their higher dielectric constant, excellent insulating properties, and compatibility with existing fabrication processes.[6] However, the large-scale fabrication of high-quality AlOx films remains challenging, particularly for low-cost and flexible electronics, where process scalability and cost-effectiveness are essential. In this context, spray pyrolysis has attracted increasing interest as a simple, scalable, and cost-effective deposition technique that can produce high-quality thin films over large areas, making it highly suitable for electronic products. [7-11]

In this study, we demonstrate the fabrication of high-k AlOx dielectric films using a cost-effective spray pyrolysis method, achieving excellent electrical properties and demonstrating their viability for low-power TFT application. Specifically, a 50 nm-thick AlOx dielectric film was developed, exhibiting a high dielectric constant of 8.46 and a robust breakdown voltage of 9.25 MV/cm, indicative of its excellent insulating capabilities. To validate the performance of these dielectric films, we integrated them into low-temperature polycrystalline silicon (LTPS) TFTs and Al doped indium-gallium-oxide (Al-IGO) TFTs, two promising transistor technologies for advanced CMOS electronic circuits. The p-type LTPS TFTs with AlOx gate dielectrics exhibited the high field-effect mobility of 90 cm²/V·s and a subthreshold swing of 146 mV/decade, demonstrating their suitability for applications requiring high-speed operation. Meanwhile, the Al doped IGO TFTs exhibited a field-effect mobility of 23 cm²/V·s and a low subthreshold swing of 143 mV/decade, showcasing their potential for low-power electronics. Both devices are operated effectively at reduced operating voltages, highlighting the role of the high-k AlOx dielectric.

2. Experimental details

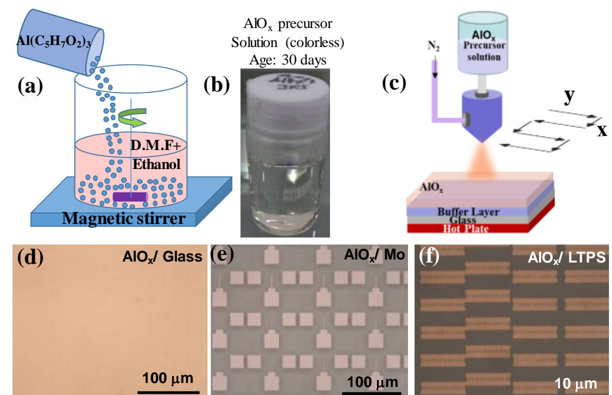

Figure 1. (a) Schematic diagram of synthesizing AlOx precursor. (b) Camera image of AlOx colorless precursor solution aged about 30 days. (c) Schematic diagram of spray pyrolysis during AlOx film deposition on preheated substrate. Microscopic optical image of the AlOx films on (d) glass, (e) Mo gate backplane for MIM structure, (f) LTPS backplane for TFT fabrication by spray pyrolysis.

For LTPS TFTs, fabrication began with a 100 nm SiO_2 buffer layer deposited via PECVD at 420 °C, followed by a 50 nm a-Si film at 360 °C. Dehydrogenation was performed at 450 °C for 2 h in an N_2 furnace, and crystallization of the a-Si layer was

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achieved using conventional ELA. A 50 nm AlOx gate insulator (GI) was deposited by spray pyrolysis at 400 °C, followed by a 100 nm Mo gate metal layer. The gate and GI were patterned using self-aligned process, and p^+ doping with boron ions was performed in the source/drain regions. The 50 nm SiO_2 interlayer was deposited, followed by 450 °C activation for 2 h. Then, 300 nm SiNx interlayer was deposited by PECVD at 360 °C. Source/drain contact holes were patterned, and a 200 nm Mo layer was deposited to form the source/drain electrodes.

For Al doped IGO TFTs, a bottom-gate structure was fabricated starting with a 100 nm Mo gate electrode deposited on glass via DC sputtering and patterned. A 50 nm AlOx gate insulator was prepared via spray pyrolysis at 400 °C through multiple scans, including intermediate curing (3 min at 400 °C), UV treatment, and Ar/O_2 plasma refinement. Annealing followed at 400 °C for 2 h in air. A ~5 nm Al-IGO channel layer was deposited via spray pyrolysis at 400 °C, patterned, and wet-etched to form the active island. Contact holes in the AlOx layer were patterned, and a 100 nm Mo layer for the source/drain electrodes was sputtered at 150 °C, patterned, and dry-etched using NF_3/O_2 plasma.[9] A 50 nm AlOx passivation layer was deposited by spray pyrolysis at 300 °C, and the device underwent a final vacuum anneal at 250 °C for 6 h. Electrical properties were measured using an Agilent 4156C semiconductor parameter analyzer.

3. Results and Discussion

The AlOx precursor solution was synthesized, followed by stirring for 2 h to obtain a transparent, colorless solution suitable for spray deposition, as shown in Fig.1(a). To assess the aging effect on the homogeneity, the solution was kept in an ambient environment for 30 days, with no visible change observed (Fig.1 (b)). Fig.1(c) presents the schematic of spray system, where the solution was uniformly sprayed in the x-y dimensions onto a 6-inch square substrate. Fig.1 (d-f) displays the optical images of AlOx film deposited at 400 ^{0}C on preheated glass, Mo backplane, and patterned LTPS substrate. The films appear uniform, free from particles and coffee-ring effects—critical qualities for smart display backplanes. Schematic of Mo/AlOx/Mo capacitor with a metal-insulator-metal (MIM) structure was fabricated to study the electrical properties of the AlOx film shown in Fig. 2(a). Optical image of capacitor used for measurement at three different positions marked as p1, p2, and p3 shown in Fig. 2(b). The areal capacitance of the capacitor was measured as 122 nF/cm² and remained stable across a frequency range of 20 Hz to 2 MHz, as shown in Fig. 2(c). The dielectric constant (k) of the AlOx film was calculated to be 8.46 at 1 kHz and remained constant up to 2 MHz, as illustrated in Fig. 2(d). Leakage current density as a function of the electric field for the AlOx films was also examined, with results shown in Fig. 2(e). The AlOx films deposited at 400 °C exhibited a breakdown voltage of 9.25 MV/cm and a low leakage current

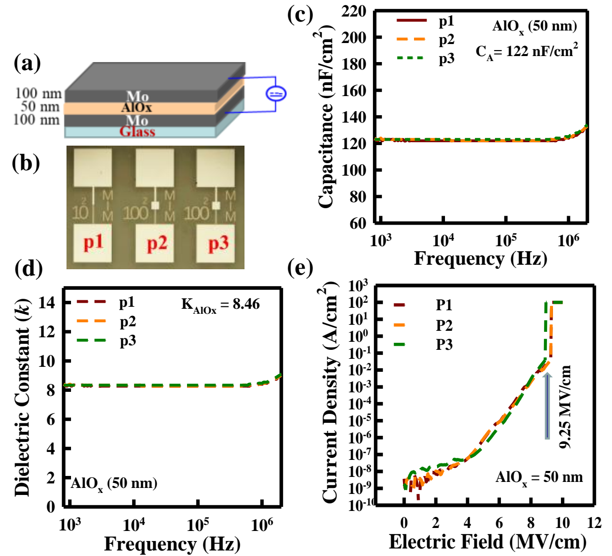

Figure 2. (a) Schematic of MIM structure of Mo/AlOx/Mo used for characterization. (b) Optical image of fabricated capacitor in three different positions. (c) Areal capacitance, and (d) dielectric constant as a function of frequency for MIM capacitors with spray coated AlOx deposited at 400 ^{0}C. Leakage current density versus electric field for AlOx dielectrics for capacitor in three different point, indicating high breakdown voltage of approximately 9.25 MV/cm and very low leakage current.

density of ~3.64 × 10⁻⁸ A/cm². Overall, the AlOx films deposited at 400 ^{0}C demonstrated excellent dielectric properties, including stable capacitance over a wide frequency range, a high dielectric constant, and low leakage current density, making them highly promising for gate dielectric for TFTs.

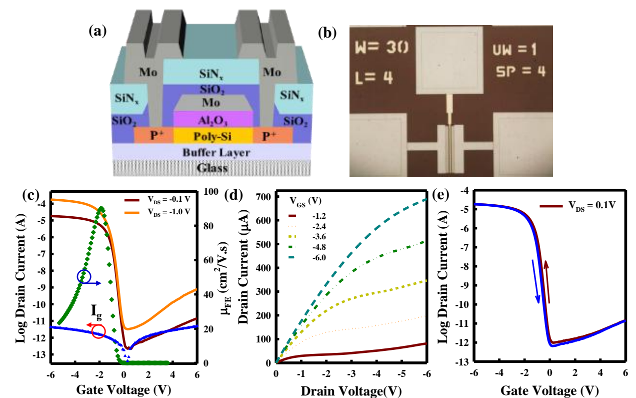

Figure 3. (a) Schematic of self-aligned coplanar p-type LTPS TFT. (b) Optical image of TFT with width (W) of 26.7 μm and length (L) of 4.16 μm. (c) The transfer curves, field-effect mobility (μ_{FE}), and gate leakage current (I_G) for p-type LTPS TFT with high-k AlOx gate dielectric. Transfer characteristics are measured using a V_{GS} sweep of 6 to −6 V at V_{DS} of −0.1 and −1.0 V. (d) Output curves of the LTPS TFT at V_{GS} ranged from -1.2 to -6 V.

Fig. 3(a) shows the schematic cross-sectional view of the self-aligned, coplanar structured LTPS TFT with AlOx dielectric, while Fig. 3(b) shows the optical image of the fabricated TFT featuring a channel width of 26.7 μm and a length of 4.16 μm. Fig. 3(c) illustrates the evolution of the transfer curve of the LTPS TFT, including gate leakage current (I_G) and field-effect mobility (μ_{FE}).

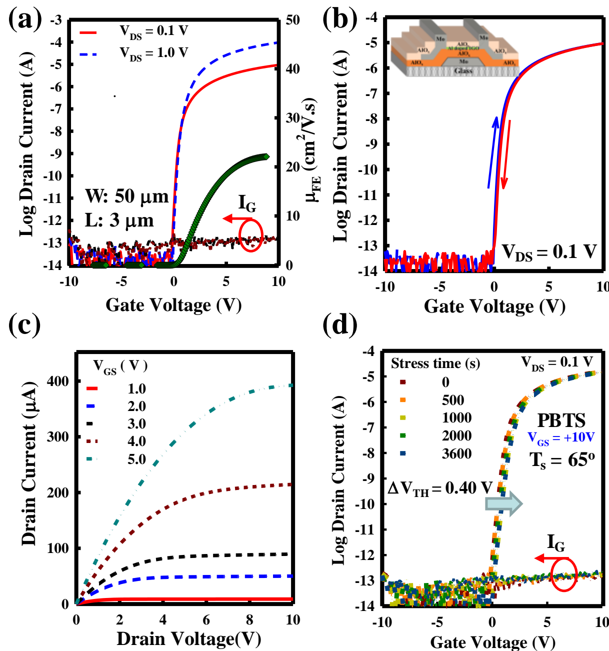

Figure 4. (a) Transfer curves, gate leakage current (IG), and field-effect mobility (μ_{FE}), for Al doped IGO TFTs with AlOx dielectric deposited at 400 °C including AlOx passivation by spray pyrolysis deposited at 300 °C. (b)Transfer curves with hysteresis loop for VDS of 0.1 V and found almost negligible hysteresis. (c) Output curves for the TFT, demonstrating clear pinch-off and saturation behavior with no current crowding in the linear region, indicating good ohmic contact between the channel and the S/D contacts. (d) Positive temperature bias stress (PBTS) test at 65 °C for a constant V_{GS} of +10V for 1 h, showing negligible V_{TH} shift and negligible charge trapping at the Al-IGO/AlOx interface.

The device demonstrates the μ_{FE} of 90 $cm^2V^{-1}s^{-1}$, a threshold voltage (V_{TH}) of -0.4 V, and a low subthreshold swing (SS) of 146 mV/dec under low operating voltage. Additionally, the on/off drain current ratio (I_{on}/I_{off}) is measured to be 10^8. The output characteristics in Fig. 3(d) depict the LTPS TFT behavior with AlOx deposited at 400 °C. The observed clear pinch-off and saturation regions, with no current crowding at low V_{DS}, confirm good ohmic contact. [4] Fig. 3(e) presents the transfer curve for LTPS TFT at V_{DS} of -0.1 V, exhibiting minimal hysteresis. This minimal hysteresis indicates a high-quality interface between LTPS and AlOx. [4] Literature summary on high-k gate dielectrics for LTPS TFTs are shown in **Table 1.**

Additionally, we fabricated inverted staggered Al doped IGO TFTs using an AlOx gate dielectric deposited at 400 °C and an AlOx passivation layer deposited at 300 °C. Fig. 4(a) presents the transfer curves, including I_G and μ_{FE}, for Al doped IGO TFTs with a channel width of 50 μm and length of 3 μm. The devices were characterized by sweeping V_{GS} from -10 V to +10 V at V_{DS} values of 0.1–1.0 V, showing the μ_{FE} of 23 cm²/V·s, V_{TH} of 0.2 V, and SS of 143 mV/dec. Fig. 4(b) displays the transfer curve with a hysteresis loop measured at V_{DS} = 0.1 V, where negligible hysteresis is observed. The absence of hysteresis and the low SS suggest a high-quality interface between the AlOx gate insulator and the Al-IGO channel. [10-11] Fig. 4(c) shows the output characteristics of the Al doped IGO TFTs, highlighting clear pinch-off and saturation behavior without current crowding in the linear region, which confirms good Ohmic contact between the channel and the source/drain electrodes.[12-14] To assess the electrical stability of the TFTs, positive bias temperature stress (PBTS) tests were conducted at a constant V_{GS} of +10 V at 65 °C for 1 h. As shown in Fig. 4(d), the transfer curves exhibit negligible shift in V_{TH}, indicating minimal charge trapping at the IGO/AlOx interface. [15]

4. Conclusion

The AlOx films deposited via spray pyrolysis at 400 °C exhibited excellent dielectric properties, including high dielectric constant (8.46), low leakage current (10^{-8} A/cm²), breakdown voltage of 9.25 MV/cm and good uniformity. P-type LTPS TFTs with a 4.16 μm channel length with AlOx dielectric achieved high mobility (90 cm²/V·s), low subthreshold swing (146 mV/dec), and high I_{on}/I_{off} ratio of 10^8. Al doped IGO TFTs with AlOx gate dielectric and passivation layers demonstrated the μ_{FE} of 23 cm²/V·s, low SS (143 mV/dec), negligible hysteresis, and stable operation under positive bias temperature stress, confirming high-quality interfaces and device reliability. These findings highlight the potential of AlOx films for large area, low-cost manufacturing of TFT backplanes for display applications.

Table 1. Literature summary on high-k gate dielectrics for LTPS TFTs

GI	Crystallization method	GI process	*W/L* (*μm/μm*)	V_{TH} [V]	μ_{FE} [$cm^2 V^{-1} s^{-1}$]	SS [$V dec^{-1}$]	I_{on}/I_{off}	*k*	Driving voltage [V]	Ref.
HfO_2	SPC	Electron-beam evaporation	100/10	-0.8	64.1	0.12	10^6	N/A	4	[1]
Y_2O_3	SPC	E-gun evaporation	10/5	1.76	32.7	0.27	10^7	13.6	4	[2]
Pr_2O_3	SPC	E-gun evaporation	2/2	1.27	40.0	0.22	10^6	26.2	8	[3]
Eu_2O_3	SPC	E-beam evaporation	10/10	0.16	44	0.14	10^7	19	2	[4]
HfO_2	SPC	MOCVD	1/1	0.3	39	0.28	10^6	20.4	6	[5]
AlO_x	MIC	Sputtering	10/10	-2.3	25.9	0.46	10^7	N/A	15	[6]
AlO_x	**ELA**	**Spray pyrolysis**	**27/4**	**-0.4**	**90.3**	**0.16**	**10^8**	**8.46**	**6**	**This Work**

5. Acknowledgements

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