$LaAlO_x/Al_2O_3$ Gate Insulator for Amorphous InGaZnO TFTs to Suppress Permittivity Scattering of Lanthanum Oxide

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ABSTRACT

Although lanthanum oxide has a high dielectric constant, it is not suitable as a gate insulator for TFTs due to its hygroscopic property. To suppress this, we propose a fabrication of a $LaAlO_x/Al_2O_3$ gate insulator by aluminum doping and adding Al_2O_3 barrier on lanthanum oxide.

1 INTRODUCTION

Amorphous indium gallium zinc oxide (a-IGZO) thin-film transistors (TFTs) have been widely used because of its high field-effect mobility, good uniformity for wide area and low processing temperature [1]. In conventional thin film transistors, SiO_2 or SiN_x have been used as gate insulators but they could not induce the high current and low threshold voltages due to their low dielectric constant [2]. Therefore, it would be a promising way that use lanthanum oxide which has high dielectric constant as gate insulator to induce the high performance of a-IGZO TFTs.

However, fabrication of lanthanum oxide film by solution process has limitation as a gate insulator because of permittivity scattering is occurred by its hygroscopic property. It has been reported that RE-based ternary oxide (e.g. HfLaO, TaLaO and $HoTiO_3$) as gate dielectric can further improve the TFT performance by suppressing the moisture absorption of the RE binary oxide [4]. In addition, nearly all metal oxides except Al_2O_3 are crystallized during deposition or thermal annealing process [5]. Therefore, Al_2O_3 is proper material to suppress hygroscopic property of lanthanum oxide film.

In this paper, two methods are proposed to use lanthanum oxide as gate insulator film for a-IGZO TFTs. The first one is suppressing crystallization of lanthanum film by properly mixing La_2O_3 solution with Al_2O_3 solution to make $LaAlO_x$ film. The second one is improving surface roughness and suppressing additional moisture absorption by capping $LaAlO_x$ film by thin Al_2O_3 film.

2 EXPERIMENT

2.1 Precursor Solution Synthesis

For the deposition of $LaAlO_x$ and Al_2O_3 gate dielectric layers by a solution process, precursor solutions for each gate dielectric were prepared by dissolving corresponding metallic precursors in a 2-methoxyethanol (2ME) solvent. For the $LaAlO_x$ solution, lanthanum nitrate hexahydrate ($La(NO_3)_3{\cdot}6H_2O$) and aluminum nitrate nonahydrate ($Al(NO_3)_3{\cdot}9H_2O$) was dissolved in 2-ME with a total concentration of 0.5 M with various concentration of 1:0, 5:1, 3:1 and 1:1. For the Al_2O_3 solution, 0.5 M of aluminum nitrate nonahydrate ($Al(NO_3)_3{\cdot}9H_2O$) was dissolved in 2ME. To prepare the 0.1 M a-IGZO solution, indium nitrate hydrate ($In(NO_3)_3{\cdot}xH_2O$), gallium nitrate hydrate ($GaN_3O_9{\cdot}xH_2O$), and zinc acetate dehydrate ($Zn(CH_3COO)_2{\cdot}2H_2O$) were dissolved in 2-ME and these components were mixed to achieve a 7:1:2 molar ratio of In:Ga:Zn. Then, each solution was stirred on hotplate at 75°C for 12 hours and filtered through 0.1 μm polytetrafluoroethylene (PTFE) syringe filters, respectively, before spin-coating.

2.2 Device Fabrication

For the metal-insulator-metal (MIM) devices, the $LaAlO_x$ precursor solution was spin-coated on ITO glass substrate at 3000 rpm for 30 s and pre-annealed at 120°C for 10 mins to remove the solvent. Spin-coating and pre-annealing process was repeated for 3 times for enough thickness of $LaAlO_x$ films. Subsequently, Al_2O_3 precursor solution was spin-coated on $LaAlO_x$ film at a speed of 5000 rpm for 30 s. After done of deposition of $LaAlO_x$ and Al_2O_3 dielectrics, post annealing was performed on a hotplate at 300°C for 1h in ambient air. Then, a 70 nm aluminum metal contact was deposited by thermal evaporation system on dielectric films for evaluate MIM structures.

The bottom-gate structure of a-IGZO TFTs with $LaAlO_x/Al_2O_3$ gate dielectrics were fabricated using solution process as shown in fig. 1. Synthesized $LaAlO_x$ solution was spin-coated at 3000 rpm for 30 s and pre-annealed at 120°C for 10 mins to remove the solvent. Spin-coating and pre-annealing process was repeated for 3 times for enough thickness of $LaAlO_x$ films. Subsequently, Al_2O_3 precursor solution was spin-coated on $LaAlO_x$ film at a speed of 5000 rpm for 30 s.

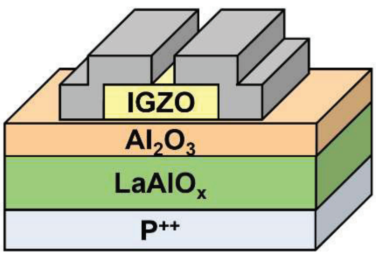

Fig. 1 Schematic of the a-IGZO TFT with $LaAlO_x/Al_2O_3$ gate insulator.

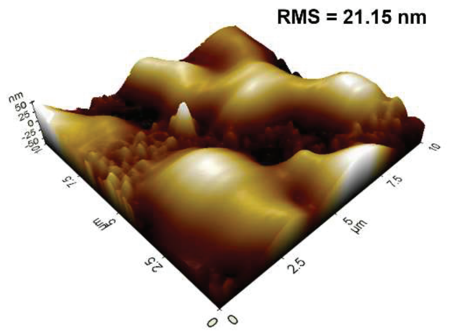

Fig. 2 AFM images of surface morphology of La_2O_3 dielectric films at annealing temperature 300°C.

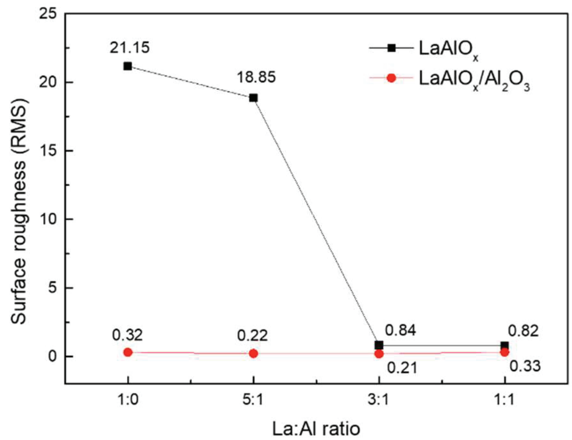

Fig. 3 Surface roughness values of $LaAlO_x$ and $LaAlO_x/Al_2O_3$ dielectric films.

After deposition of $LaAlO_x/Al_2O_3$ dielectrics, post annealing was performed on hotplate at 300°C for 1h in ambient air. Then, synthesized IGZO solution was spin-coated at 4000 rpm for 30 s. After spin-coating, UV-O_3 treatment was performed for 2 hours to improve the properties of the IGZO film and annealed at 350°C for 3 hours. Then, source/drain aluminum electrode of 70 nm were deposited by thermal evaporation system using shadow mask. The channel width (W) and length (L) were 1000 μm and 100 μm, respectively.

To investigate the properties of the dielectric films, the capacitance–voltage (C–V) measurements were carried out using an Agilent HP 4284A impedance analyzer. The surface roughness of dielectric films was measured by atomic force microscope (AFM; Park Systems, XE-100, non-contact mode). Leakage current density of $LaAlO_x/Al_2O_3$ dielectric films and electrical characteristic of a-IGZO TFT with $LaAlO_x/Al_2O_3$ gate dielectric were carried out using a semiconductor parameter analyzer Agilent 4145B, respectively.

3 RESULTS AND DISCUSSION

The surface morphology image of La_2O_3 at annealing temperature 300°C is as shown in fig. 2. It shows high surface roughness RMS of 21.15 nm because of crystallization peaks of La_2O_3 films. These serious surface

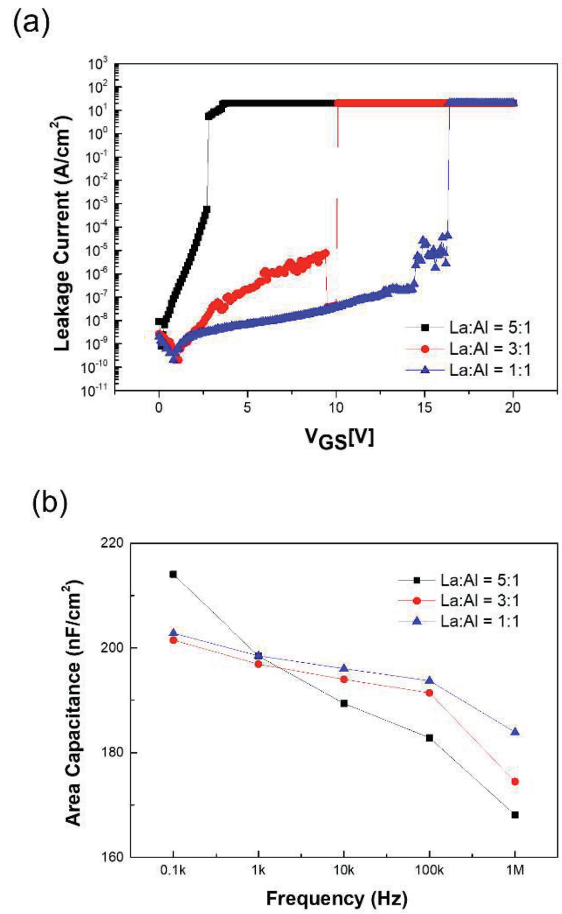

Fig. 4 (a) Leakage current and (b) frequency-dependent characteristics for $LaAlO_x/Al_2O_3$ dielectric films with various La:Al concentrations.

problems indicate that La_2O_3 film cannot be used as gate insulators due to high leakage current induced by bad surface roughness. Fig. 3 shows surface roughness values of $LaAlO_x$ and $LaAlO_x/Al_2O_3$ dielectric films with various La:Al concentration. The surface roughness of $LaAlO_x$ was greatly improved at La:Al = 3:1 and 1:1. Also, the surface roughness values of $LaAlO_x$ films with Al_2O barrier ($LaAlO_x/Al_2O_3$) shows great surface roughness under 0.33 nm regardless La:Al ratio. Fig. 4(a) shows leakage current density of $LaAlO_x/Al_2O_3$ dielectric films. The $LaAlO_x/Al_2O_3$ film with La:Al = 5:1 ratio has lowest breakdown voltage and as the ratio of Al increase, the breakdown voltage occurs at higher voltage. Fig. 4(b) shows frequency dependent capacitance characteristic of $LaAlO_x/Al_2O_3$ films. La:Al = 5:1 ratio shows highest frequency-dependent capacitance characteristic and as the ratio of Al increase, frequency dependent capacitance were reduced. These results indicated that aluminum doping at lanthanum film and adding Al_2O_3 barrier on lanthanum films are effective way to improve quality of solution processed lanthanum oxide dielectric film.

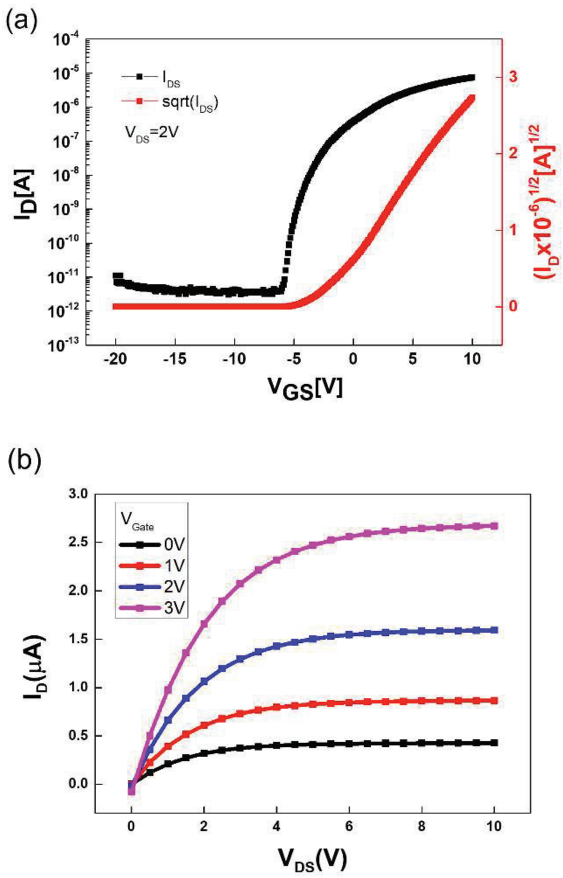

Fig. 5 (a) I-V transfer curve and (b) output characteristics of a-IGZO TFT with $LaAlO_x/Al_2O_3$ gate insulator film.

Fig. 5(a) and (b) shows I-V transfer curve and output characteristics of a-IGZO TFT with $LaAlO_x/Al_2O_3$ gate insulator film, respectively. It shows great transfer curve and output characteristic as a TFT with a high on-off current ratio of 2.45×10^6 under a low operating voltage V_{DS} = 2V.

4 CONCLUSIONS

In this study, $LaAlO_x/Al_2O_3$ gate insulator was proposed for a-IGZO TFTs. To suppress hygroscopic property of lanthanum oxide dielectric films at a annealing temperature of 300°C, aluminum doping and adding Al_2O_3 barrier on lanthanum dielectric film were proposed. Through the AFM images, leakage current density and frequency-dependent capacitance characteristics, it was founded that proper aluminum doping and adding Al_2O_3 barrier on $LaAlO_x$ film can significantly improve dielectric film characteristics. As a result, a high-k $LaAlO_x/Al_2O_3$ gate insulator was successfully integrated into a-IGZO TFTs. The $LaAlO_x/Al_2O_3$ a-IGZO TFTs shows a great output characteristic with a high on-off current ratio of 2.45×10^6 under a low operating voltage V_{DS} = 2V.

REFERENCES

[1] T. Kamiya, K. Nomura and H. Hosono, “Present status of amorphous In–Ga–Zn–O thin-film transistors,” Science and Technology of Advanced Materials, Vol. 11, No. 4, pp. 044305 (2010)

[2] S. Y. Lee, S. Chang and J.-S. Lee, “Role of high-k gate insulators for oxide thin film transistors,” Thin Solid Films, Vol. 518, No. 11, pp. 3030-3032 (2010)

[3] X. Ding, J. Zhang, H. Zhang, H. Ding, C. Huang, J. Li, W. Shi, X. Jiang and Z. Zhang, “ZrO_2 insulator modified by a thin Al_2O_3 film to enhance the performance of InGaZnO thin-film transistor,” Microelectronics Reliability, Vol. 54, No. 11, pp. 2401-2405 (2014)

[4] X. D. Huang, Y. Ma, J. Q. Song, and P. T. Lai, “High-Performamce Amorphous InGaZnO Thin-Film Transistor With ZrLaO Gate Dielectric Fabricated at Room Temperature,” Journal of Display Technology, Vol. 12, No. 12, pp. 1522-1527 (2016)

[5] M. Esro, R. Mazzocco, G. Vourlias, O. Kolosov, A. Krier, W. I. Milne and G. Adamopoulos, “Solution processed lanthanum aluminate gate dielectrics for use in metal oxide-based thin film transistors,” Applied Physics Letters, Vol. 106, No. 20, pp. 203507 (2015)

[6] S. Y. Je, B.-G Son, H.-G Kim, M.-Y. Park, L.-M. Do, R. Choi and J. K. Jeong, “Solution-Processable $LaZrO_x/SiO_2$ Gate Dielectric at Low Temperature of 180 °C for High-Performance Metal Oxide Field-Effect Transistors,” Applied Materials & Interfaces, Vol. 6, No. 21, pp. 18693–18703 (2014)

[7] J. Kim, S. Choi, J.-W Jo, S. K. Park and Y.-H. Kim, “Solution-processed lanthanum-doped Al_2O_3 gate dielectrics for high-mobility metal-oxide thin-film transistors,” Thin Solid Films, Vol. 660, No. 30, pp. 814-818 (2018)

[8] S. Hwang, J. H. Lee, C. H. Woo, J. Y. Lee and H. K. Cho, “Effect of annealing temperature on the electrical performances of solution-processed InGaZnO thin film transistors,” Thin Solid Films, Vol. 519, No. 15, pp. 5146–5149 (2011)