High Mobility IGZO TFT fabricated by Solution-Based Non-Vacuum Mist Chemical Vapor Deposition

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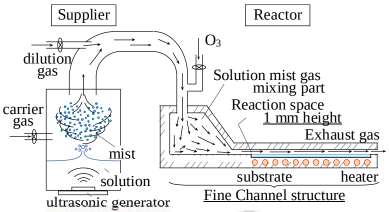
- Motivation -

Last year, an oxide thin film transistor (TFT), consisting of a channel layer (IGZO) and gate insulator (AlO_x) continuously grown by mist chemical vapour deposition (CVD), was fabricated. Mist CVD is a solution-based fabrication technology that can be performed under atmospheric pressure, using a simple and easy system configuration that is both low cost and environmentally friendly [1,2]. TFT characteristics are greatly influenced by the properties of both the gate insulator and the active layer. Fabrication of both a gate insulator film and a semiconductor film by non-vacuum processes is very important for development of the TFT fabrication process. Thus, the paper reporting the oxide TFT with an IGZO/AlO_x stack grown by mist CVD serves as an important indicator for development of the TFT fabrication process without vacuum. In previous reports, the initial oxide TFT, which consists of a 116 nm AlO_x thin film and a 47 nm IGZO thin film fabricated by mist CVD, exhibited the following characteristics: field-effect mobility (μ_{lin}) of 4.2 $cm^2/(Vs)$; on/off ratio of more than 10^8; sub-threshold slope (S) of 0.55 V/dec. and hysteresis (ΔV_H) of 1.47 V [3]. These parameters were not as good as those of the IGZO TFT fabricated by the conventional vacuum process [4,5].

Recently, we have worked towards improvement of each thin film and the interfaces of the films in order to improve the properties of the oxide TFT. The properties of the oxide TFT have been efficiently improved with the assistance of ozone (O_3) in various fabrication methods. In this paper we report an improvement of the characteristics of the each thin film, and an oxide TFT with an IGZO/AlO_x stack fabricated by mist CVD with O_3 assistance.

- Experiments -

Mist CVD system

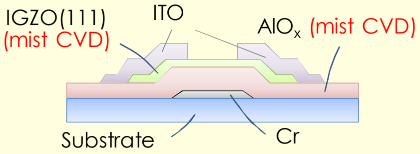


Growth conditions of AlO_x & IGZO thin films grown by mist CVD

		AlO_x	IGZO
Solute	:	Metal acetylacetonate, Me(acac)$_x$ b)	
Solvent (Mixing ratio)	:	Distilled water c), Methanol d) (10:90)	
Concentration (mol/L)	:	0.020	0.030 (1:1:1)
Thickness (nm)	:	≈ 100	≈ 50
Temperature (°C)	:	***cST***: 430, ***cO₃***:360	350
Substrate	:	Eagle_XG e)	
System	:	100 mm ver. FC system	
Carrier gas (flow rate)	:	Air, 2.5 L/min×2	
Dilution gas (flow rate)	:	Air, 10.0 L/min×2	
Assistance gas	:	***cST***: -, ***cO₃***: O_3, >8000 ppm f)	
Ultrasonic transducer a)	:	2.4 MHz, 24 V·0.6 A, 3×2	

[a] HONDA ELECTRONICS, HM-2412, (Frequency, Power, Number)
[b1] Aluminium acetylacetonate, 99%, Sigma-Aldrich, for Al source of AlO_x
[b2] Indium(III) acetylacetonate, 99.99%, Sigma-Aldrich, for In source of IGZO
[b3] Gallium(III) acetylacetonate, 99.99%, Sigma-Aldrich, for Ga source of IGZO
[b4] Zinc acetylacetonate, > 95%, nacalai tesque, for Zn source of IGZO
[c] Wako Pure Chemical Industries
[d] Methanol, 99.8%, Wako Pure Chemical Industries
[e] Corning Inc.
[f] Generated from 1.5 L/min air by an O_3 generator (Ebara Jitsugyo, OZSD-3000A)

- Process flow of oxide TFT -

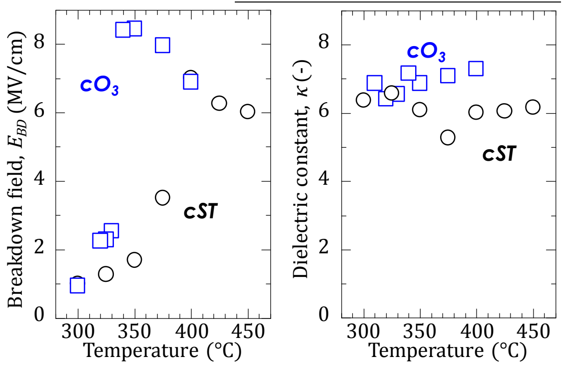


(1) Fabrication of gate electrode
Sputtering, 50 nm, 150°C
Pattering Wet etching
(2) Fabrication of gate insulator
mist CVD (1atm), ≈ 50 nm
(3) Fabrication of channel layer
mist CVD (1atm), 350°C ≈ 50 nm
Pattering Wet etching
(4) Fabrication of source & drain electrode
Sputtering, 50 nm, RT
Patterning: Wet etching (lift-off)
(5) Post annealing
H_2(5% in N_2), or N_2, 350°C, 1h

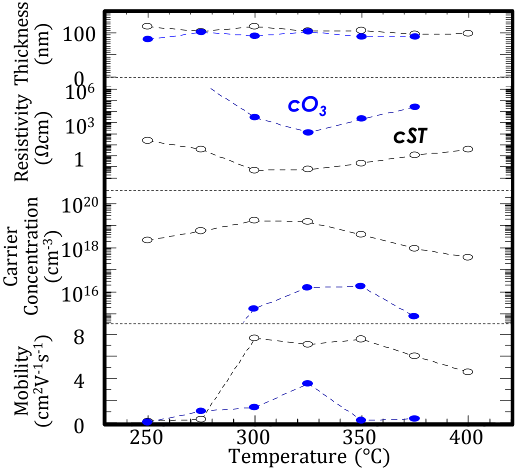
- Results -

	cST	***cO₃***
Min. Temp. (°C)	>400	>340
E_{BD} (MV/cm)	6.0	8.0
κ (-)	6	7
RMS (nm) @350°C	1.2	0.3

AlOx



IGZO



Impurity concentration

	cST	***cO₃***
H	2.0 × 10^{21}	7.9 × 10^{20}
C	2.0 × 10^{20}	1.2 × 10^{20}
N	1.4 × 10^{18}	6.6 × 10^{17}

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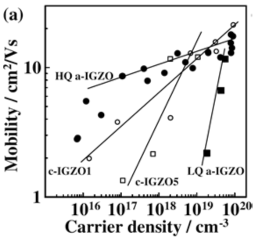
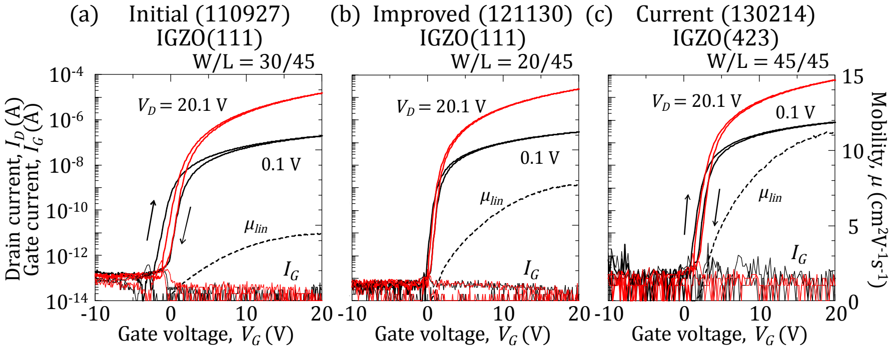
Sci. Technol. Adv. Mater., 11 (2011) 044305.



Oxide TFT with an IGZO/AlOx stack grown by mist CVD


(a) Initial (110927) IGZO(111) W/L = 30/45
(b) Improved (121130) IGZO(111) W/L = 20/45
(c) Current (130214) IGZO(423) W/L = 45/45

In:Ga:Zn ratio in the film is not necessarily correspond to that in precursor solution. For example, In:Ga:Zn ratio in the IGZO thin film grown at 350°C with O_3 assistance is around 24:40:36 when In:Ga:Zn ratio in precursor solution is 1:1:1. It is well known that the In content in an IGZO film strongly influences the mobility. Thus, composition ratio has been optimized in order to obtain the excellent oxide TFT.

			(a)	(b)	(c)
Mobility, μ ($cm^2V^{-1}s^{-1}$)	Linear	:	4.2	8.7	11.5
	Saturate	:	4.0	8.3	11.5
S (V/dec.) @ 10–100 pA		:	0.55	0.32	0.44
Hysteresis, ΔV_H (V)		:	1.47	0.47	0.72
I_{on}/I_{off} at V_{GS}=30/–10 V		:	>10^8	>10^8	>10^8
Gate leakage current @ V_G=20V		:	<10^{-12}	<10^{-12}	<10^{-12}

- Conclusion -

Each thin film and their interfaces were improved with O_3 assistance, and the previously defined properties were dramatically improved. The breakdown fields (E_{BD}) and dielectric constant (κ) of AlO_x thin films were improved from 6 to 8 and from 6 to 7, respectively. The carrier concentration of IGZO thin films was improved from 10^{19} to 10^{16} cm^{-3}. Additionally, In:Ga:Zn composition ratio in the IGZO film has been optimized.

These results show that the properties of the current oxide TFT were improved: The μ_{lin}, S and ΔV_H were 11 $cm^2/(Vs)$, around 0.4 V/dec. and around 0.5 V, respectively. These values are equivalent to those of an IGZO TFT fabricated using a vacuum process.

This result is an important first step toward an oxide TFT fabrication process under non-vacuum.