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Fabrication of Oxide TFT with an IGZO/AlOx Stack by Solution-Based Non-Vacuum Mist Chemical Vapour Deposition

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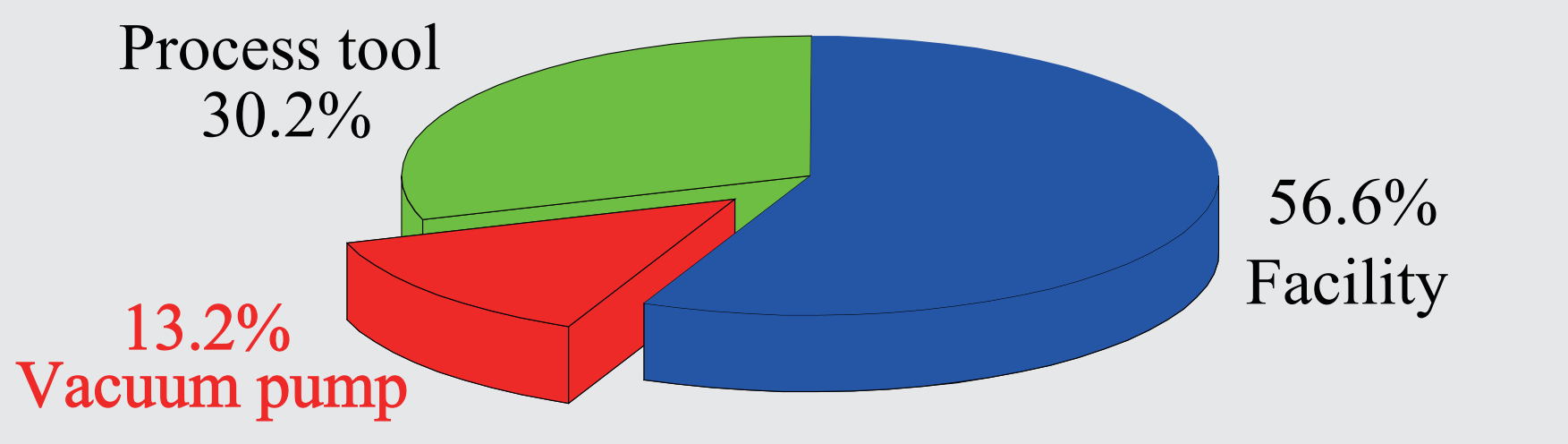
– Motivations –

The electric power ratio of semiconductor plant



2008 ISMI workshop on Equipment Energy Reduction.

A lot of electric power is needed in order to keep vacuum state. The burdens of the environment can be directly reduced by shifting vacuum process to atmospheric pressure process.

Therefore, the conversion of TFT fabrication process to a non-vacuum process is attempted for environmentally friendly. The IGZO or IZO TFTs fabricated by spin coating method or sol-gel method have been reported in Ref. 1-4.

Source materials	Insulator	Channel layer	Post annealed	TFT properties	Ref.
$ZnAc_2$, $In(NO_3)_3$ (0.2:0.2 mol), 2ME	SiN_x, 400 nm, (PECVD), 150°C	IZO, 15 nm	300°C(5 min),450°C(3 h), Air	$\mu = 6.57$, on/off = 10^9, $V_{on} = -1.5$, $V_{off} = -0.3$, $S = 0.15$	[1]
$ZnAc_2$, $In(NO_3)_3$, $Ga(NO_3)_3$, ETA in 2ME	ATO, 220 nm, (ALD), ?°C	IGZO(In:Ga:Zn), 2:1:1-3, ≈ 25 nm	(80°C(5 min) +400°C(10 min),Air)×2, 400°C(1 h), Air	In:Ga:Zn = 3:1:1, $\mu = 5.8$, on/off = 10^7, $V_t = 8.1$, $S = 0.28$	[2]
$ZnAc_2$, $SnCl_2$, $ZrCl_4$, 2ME	Th-SiO_2, (SiO_2/p^+-Si sub.)	ZrSnZnO(Zr:Sn:Zn), 0-1:7:4, ? nm,	500°C(2 h)	Zr:Sn:Zn = 0.3:7:4, $\mu = 4.02$, on/off = 3.6×10^6, $V_t = 3.1$, $S = 0.94$	[3]
$ZnAc_2$, $In(NO_3)_3$, $Ga(NO_3)_3$, EMA in 2ME (1:25)	SiN_x, (? nm)	IGZO(In:Ga:Zn), 1-5:1:2, 50 nm	400°C(3 h)	In:Ga:Zn = 5:1:2, $\mu = 1.25$, on/off = 4×10^6, $V_t = -5.09$, $S = 1.05$	[4]

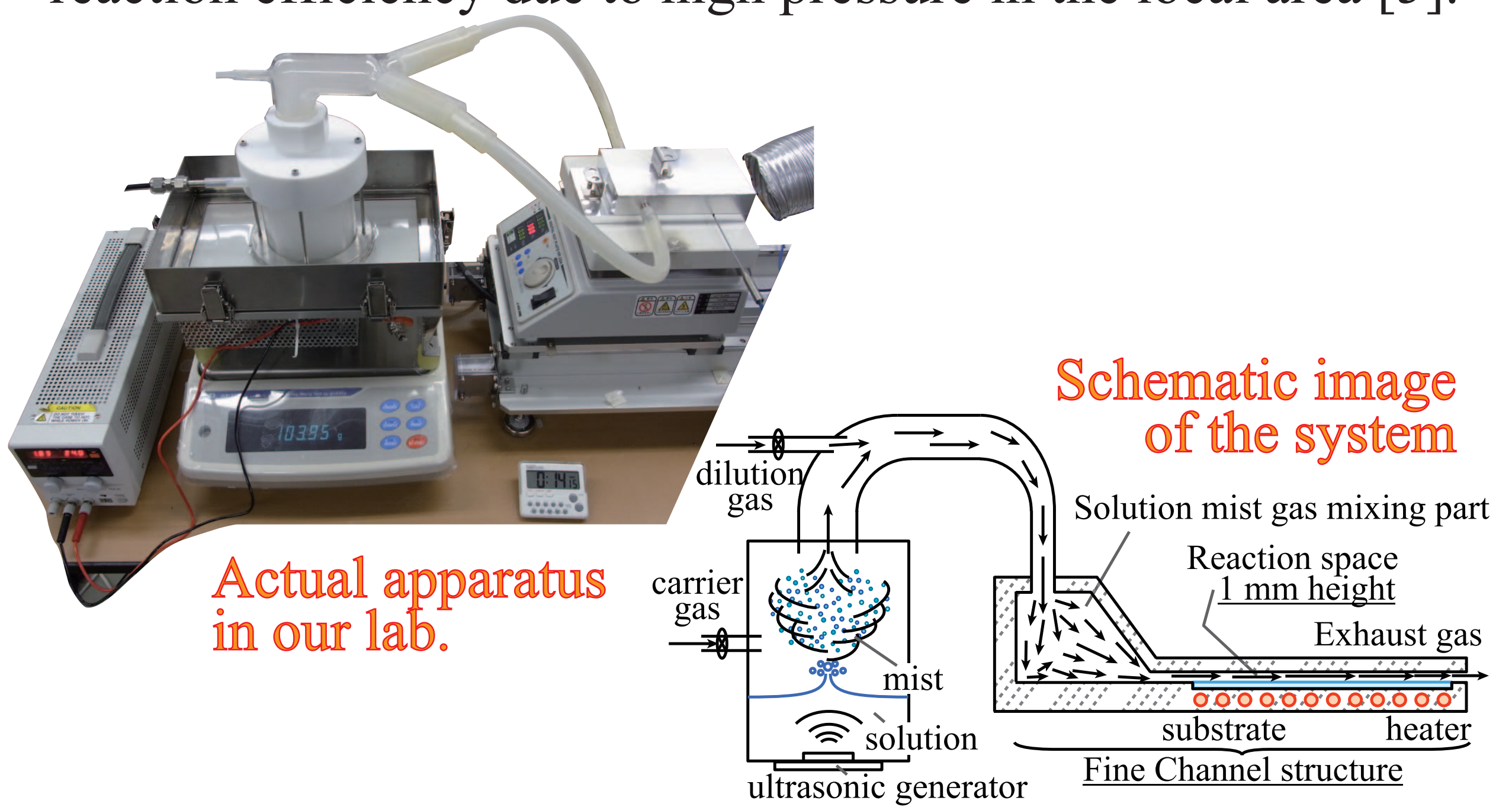
1) K-B. Park, et al., IEEE Electron Device Lett., Vol.31 (2010) pp.311. 2) P.K. Nayak, et al., Appl. Phys. Lett., Vol.97 (2010) pp.183504. 3) Y.S. Rim, et al., Appl. Phys. Lett.Vol.97 (2010) pp.233502. 4) G.H. Kim, et al., Appl. Phys. Lett., Vol.94 (2009) pp.233501.

However, in these reports, the gate insulator was prepared by vacuum process such as plasma-enhanced chemical vapour deposition (CVD). It is very important for the non-vacuum process conversion of TFT fabrication process to fabricate both a gate insulator and a semiconductor film by a non-vacuum process. Thus, we had attempted to convert TFT fabrication process to non-vacuum process with gate insulator and channel layer grown by mist CVD.

– The properties of thin films grown by mist chemical vapour deposition (Mist CVD) –

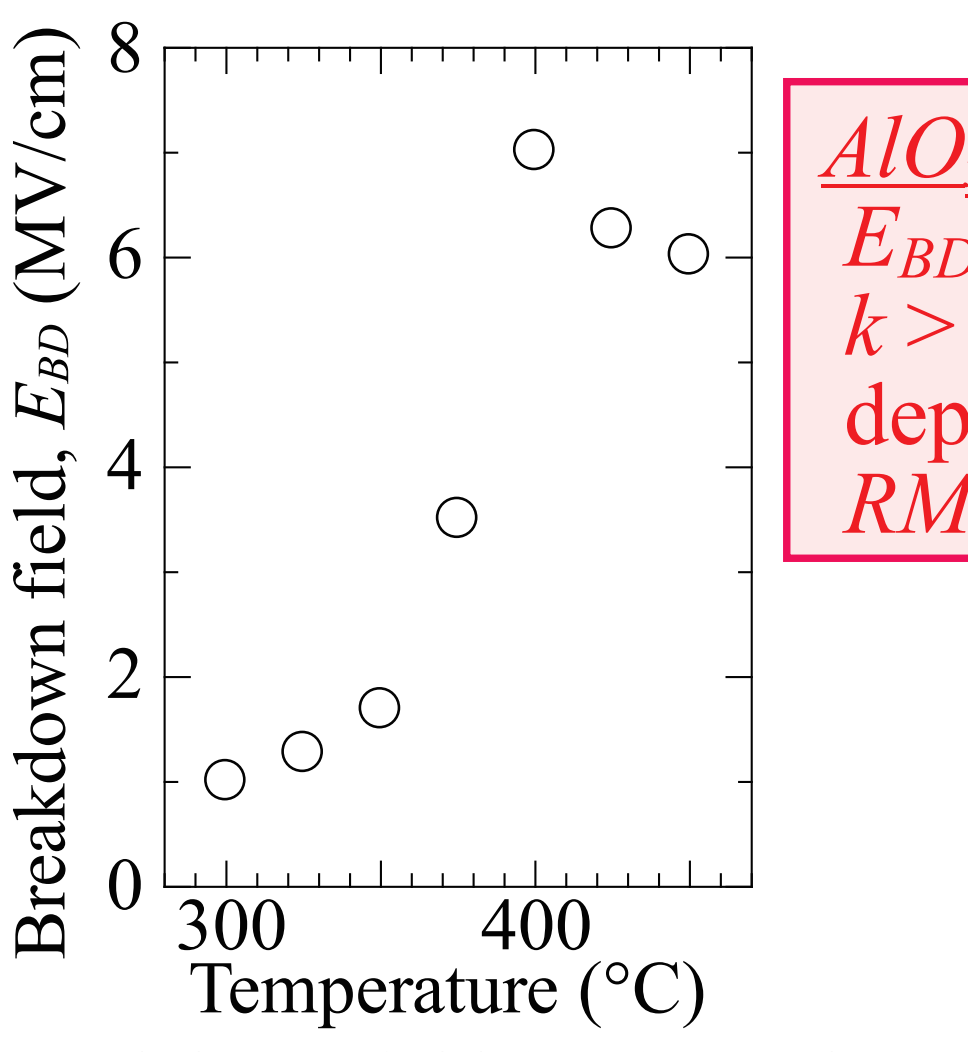
Fine channel type Mist CVD system

The FC structure, which is a depo. space of 1 mm-in-height, gives the thin films grown under a strong oxidation and high reaction efficiency due to high pressure in the local area [5].



Please refer [5]
"Study on mist CVD and its application to the growth of ZnO thin films"
T. Kawaharamura,, Ph.D. Thesis, Faculty of Engineering, Kyoto-Univ., 2008 [in Japanese]
http://repository.kulib.kyoto-u.ac.jp/dspace/bitstream/2433/57270/1/26041.pdf

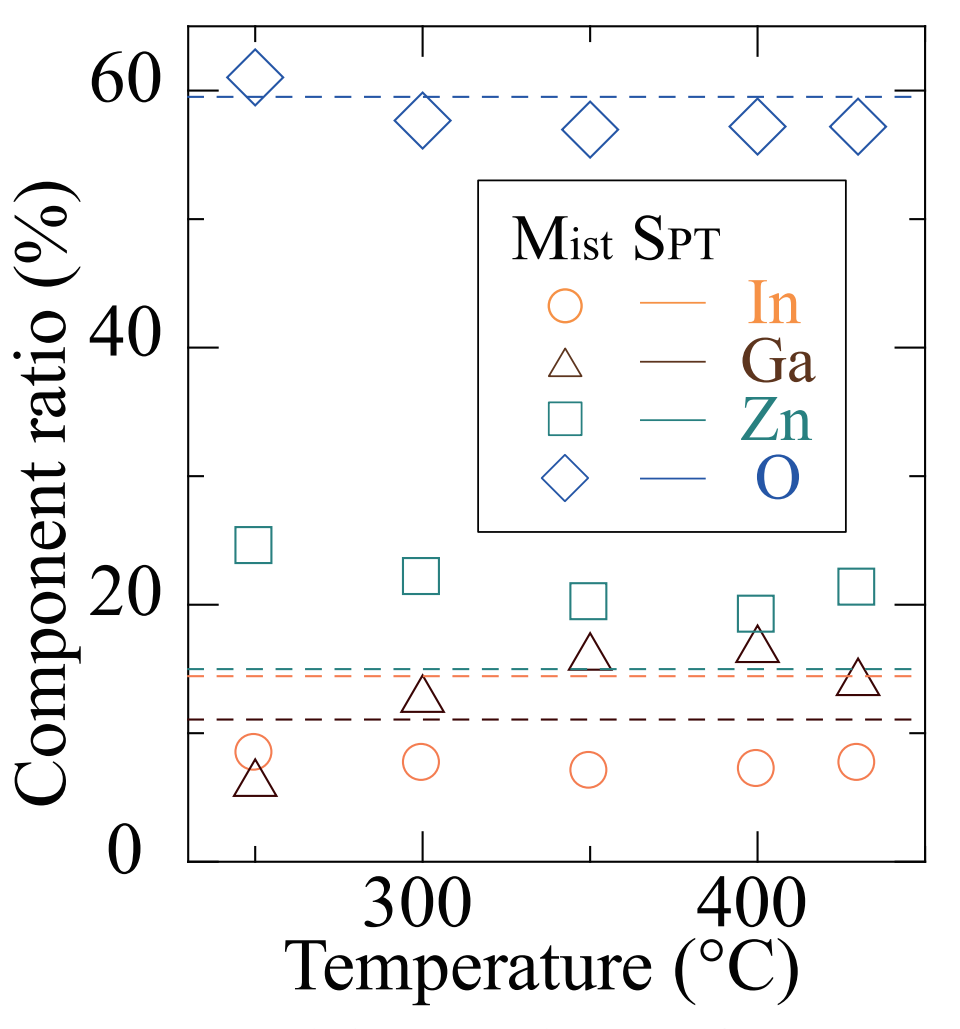
Aluminium oxide (AlO_x) thin film was grown using aluminium acetylacetonate ($Al(acac)_3$) as a source solute by the mist CVD. The AlO_x thin film grown at temperature above 400°C exhibited the breakdown field (E_{BD}) over 6 MV/cm and the dielectric constant (k) over 6, respectively. The E_{BD} of AlO_x thin film grown at temperatures below 350°C was dramatically declined due to a residual of OH bonding in the AlO_x thin films.



Breakdown field (E_{BD}) of AlO_x thin films grown by mist CVD.

AlO_x ($T > 400$°C)
$E_{BD} > 6$ MV/cm
$k > 6$
depo. rate = 23 nm/min
RMS =1.6 nm

IGZO
T =350°C
amorphous
depo. rate > 25 nm /min
In:Ga:Zn = 16:37:47

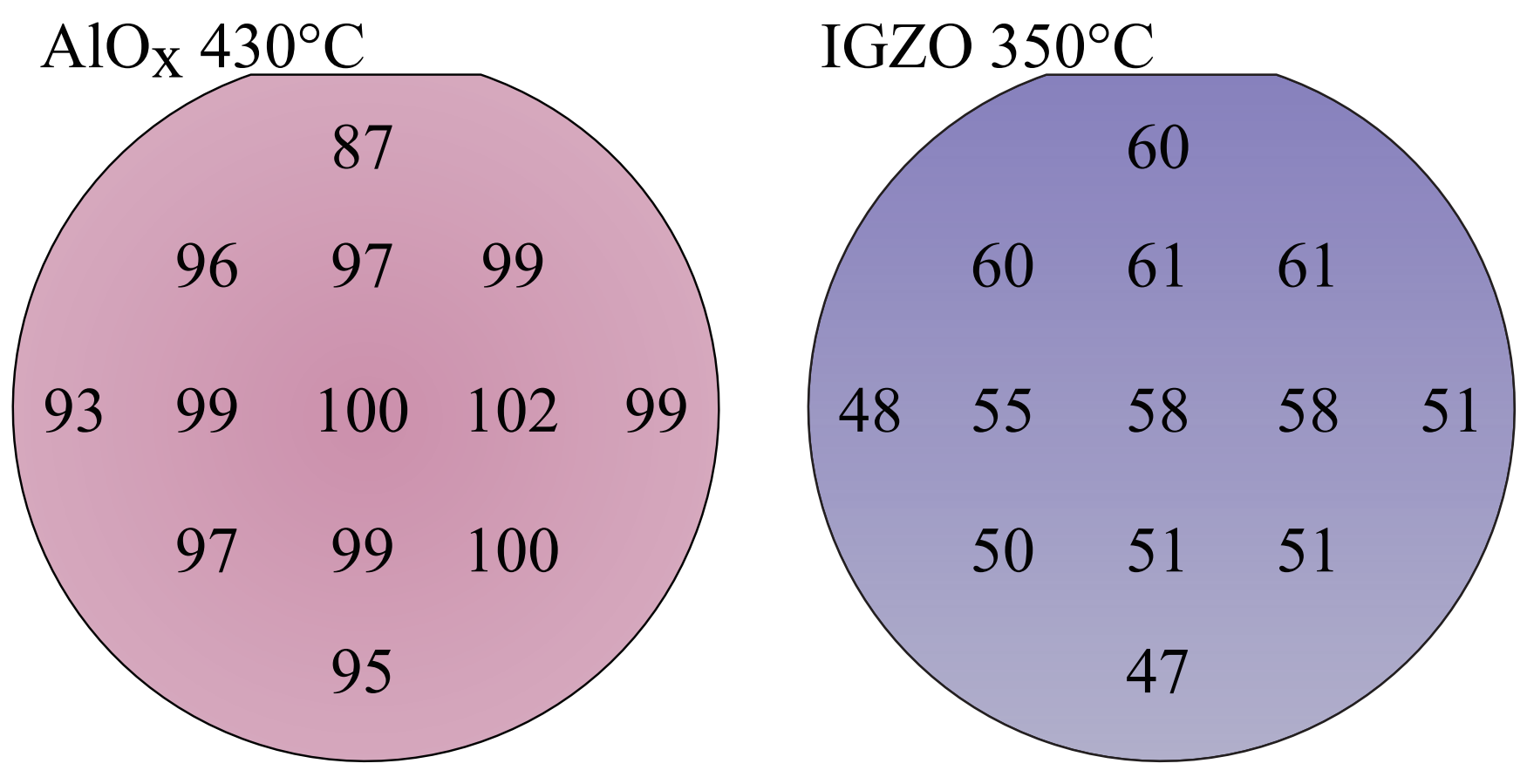


Composition ratio of the IGZO thin films grown by the mist CVD

From RBS measurement, the composition ratio of IGZO thin films grown by the mist CVD was so different from ideal elemental ratio. Composition ratio of films depends on growth temperature and mixture ratio of source materials at preparation in the mist CVD. Hence, each metal composition ratio of the IGZO thin film grown at 350°C was 16:37:47 (In:Ga:Zn).

– The electrical properties of oxide TFT with an IGZO/AlO_x stack –

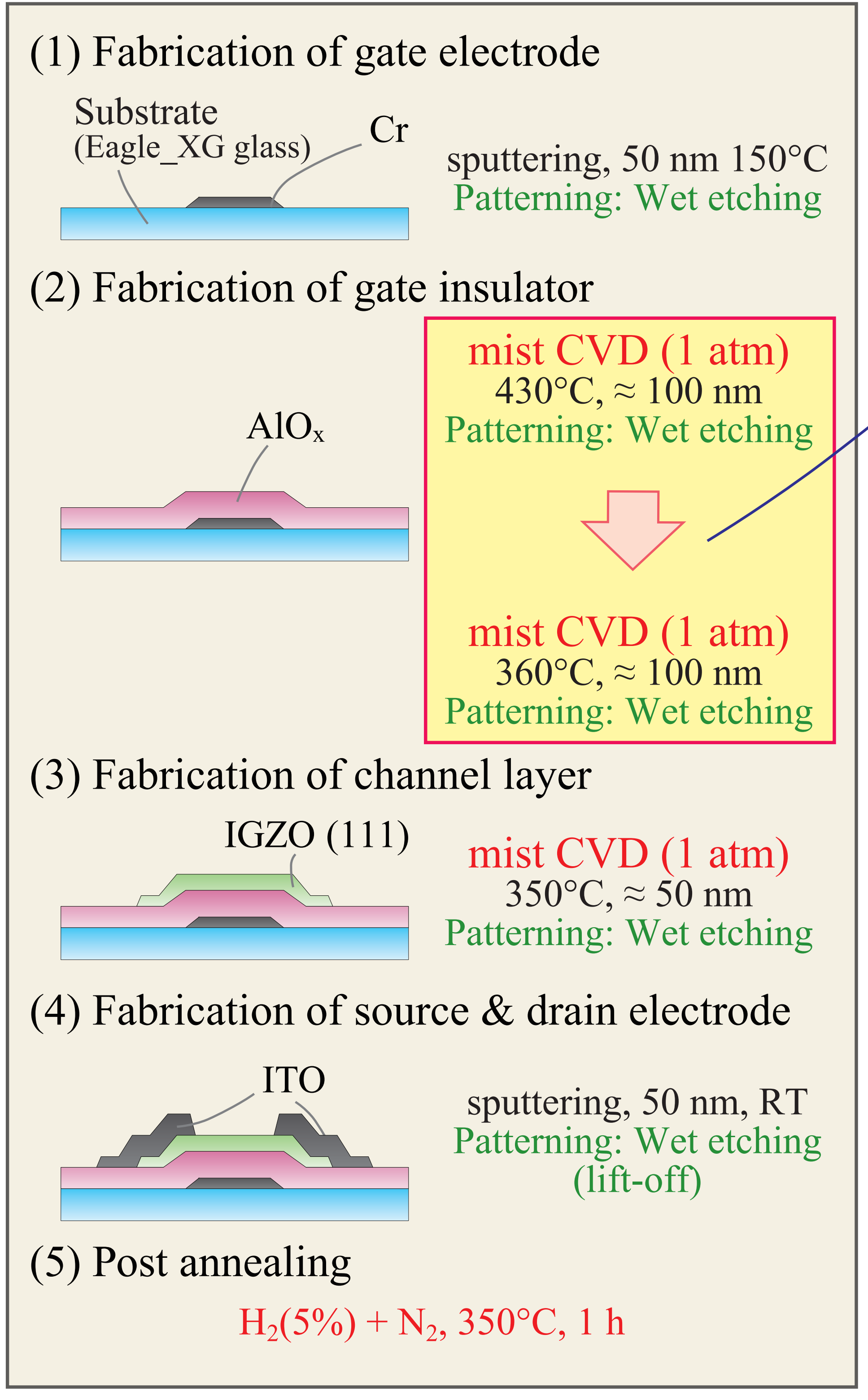
Uniformity of thin film grown by Mist CVD on ϕ 4 inch substrates.



AlO_x : Approximately-uniformity
IGZO : ±10%

In FC type mist CVD system, uniformity thin films can be gotten easily without rotating mechanism [5].

Fabrication process



(1) Fabrication of gate electrode

sputtering, 50 nm 150°C
Patterning: Wet etching

(2) Fabrication of gate insulator

mist CVD (1 atm)
430°C, ≈ 100 nm
Patterning: Wet etching

mist CVD (1 atm)
360°C, ≈ 100 nm
Patterning: Wet etching

(3) Fabrication of channel layer

mist CVD (1 atm)
350°C, ≈ 50 nm
Patterning: Wet etching

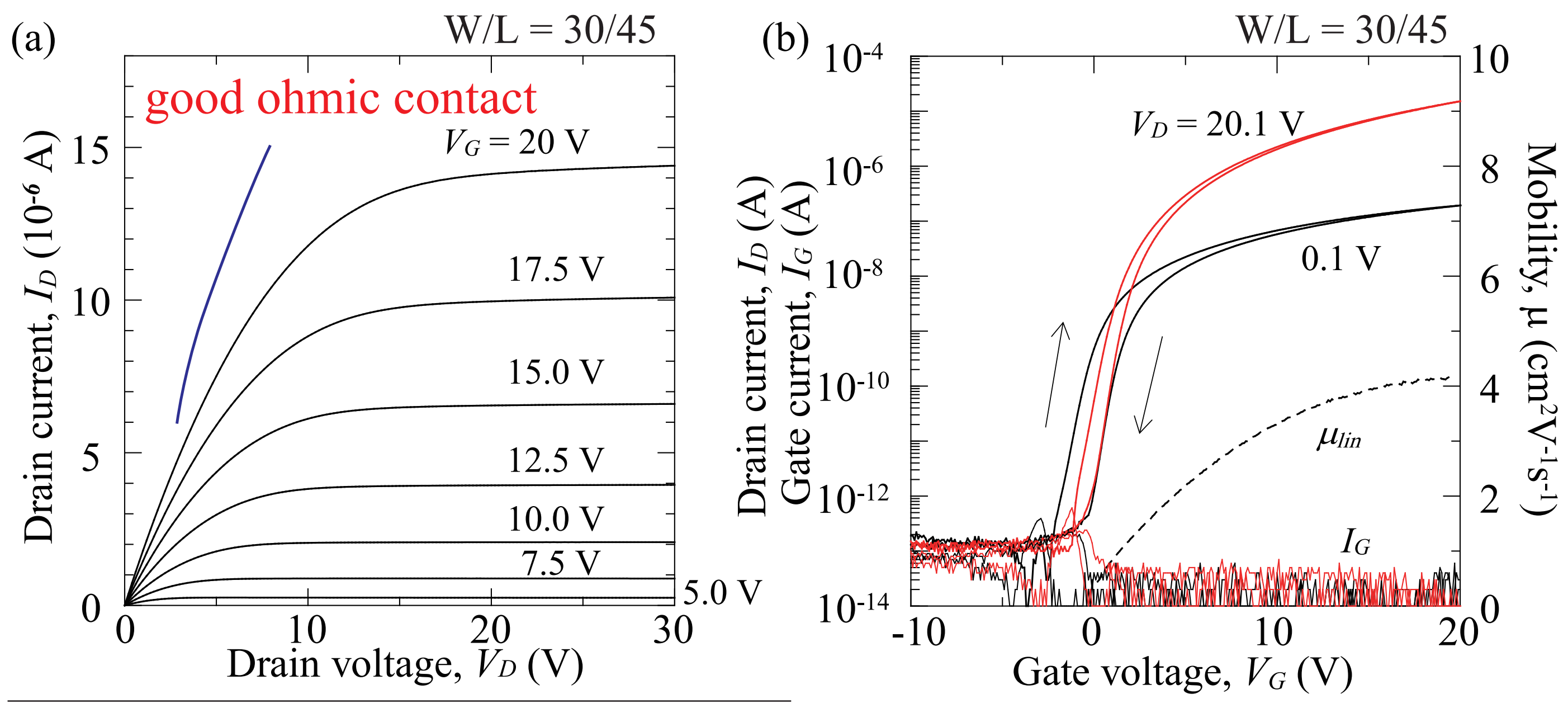
(4) Fabrication of source & drain electrode

sputtering, 50 nm, RT
Patterning: Wet etching
(lift-off)

(5) Post annealing

H_2(5%) + N_2, 350°C, 1 h

The drive of the first prototype



Mobility μ ($cm^2V^{-1}s^{-1}$)	linear	:	4.2
	saturation	:	4.0
V_{GS} at I_{DS} = 1 nA (V)		:	0.39
S (V/dec.) @ 10-100 pA		:	0.55
Hysteresis ΔV_H (V)		:	0.68
I_{on}/I_{off} at V_{GS} = 30/-10 V		:	> 10^8
Gate leakage current @ V_G = 20V		:	<10^{-12}

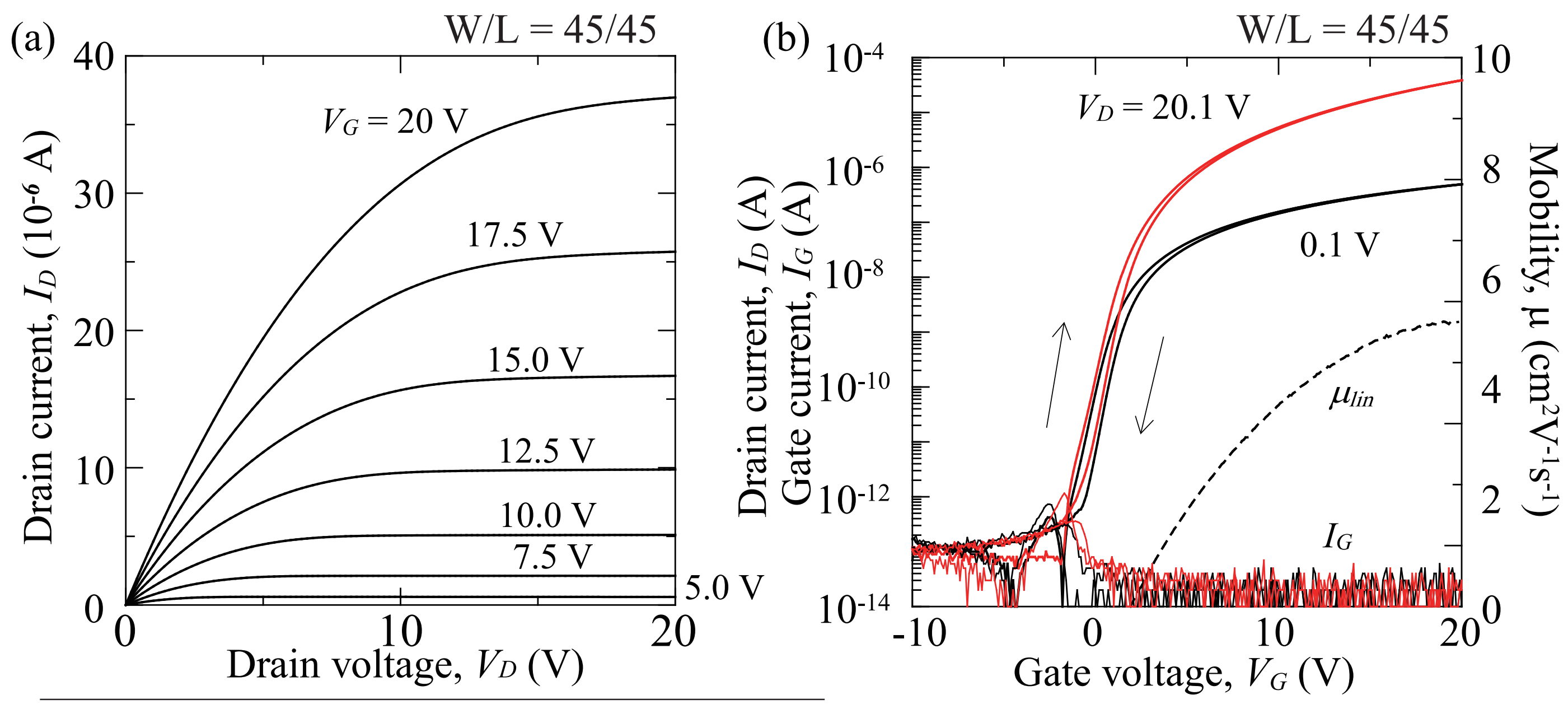
The oxide TFT was driven
with low leakage current & good on/off ratio.

S & ΔV_H are worse than previous reports

(a) Output and (b) transfer characteristics of oxide TFT with an IGZO/AlO_x stack fabricated by the mist CVD.

In order to save energy consumption or farther fabricate on flexible substrate at low temperature, growth temperature should be decreased. Therefore we developed a new process assisted with O_3 in the mist CVD. And the stable gate insulator AlO_x thin films were able to be grown by the mist CVD with assistance of O_3 at temperature around 350°C. The AlO_x thin films grown with the assistance of O_3 were employed for fabrication in oxide TFTs.

Lower temperature fabrication



Mobility μ ($cm^2V^{-1}s^{-1}$)	linear	:	5.7
	saturation	:	5.5
V_{GS} at I_{DS} = 1 nA (V)		:	0.57
S (V/dec.) @ 10-100 pA		:	0.65
Hysteresis ΔV_H (V)		:	0.51
I_{on}/I_{off} at V_{GS} = 30/-10 V		:	> 10^8
Gate leakage current @ V_G = 20V		:	<10^{-12}

The oxide TFT was driven
with low leakage current & good on/off ratio.

S & ΔV_H are worse than previous reports

Conclusion

1) Oxide TFT consisting of both channel layer (IGZO) and gate insulator (AlO_x) grown by mist CVD which is one of suitable techniques for growing thin films continuously under atmosphere was fabricated.
2) The index of non-vacuum process conversion of the TFT fabrication process was demonstrated with fabricating the oxide TFT with an IGZO/AlO_x stack grown by the mist CVD at temperature around 350°C.

Please refer
"Electrical Properties of the Thin-Film Transistor With an Indium-Gallium-Zinc Oxide Channel and an Aluminium Oxide Gate Dielectric Stack Formed by Solution-Based Atmospheric Pressure Deposition"
M. Furuta, T. Kawaharamura, D. Wang, T. Toda, and T. Hirao, IEEE Electron Device Lett. Vol.33 (2012) pp.851-853.

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