ポストHfO2技術

希土類酸化膜

PVDデポ

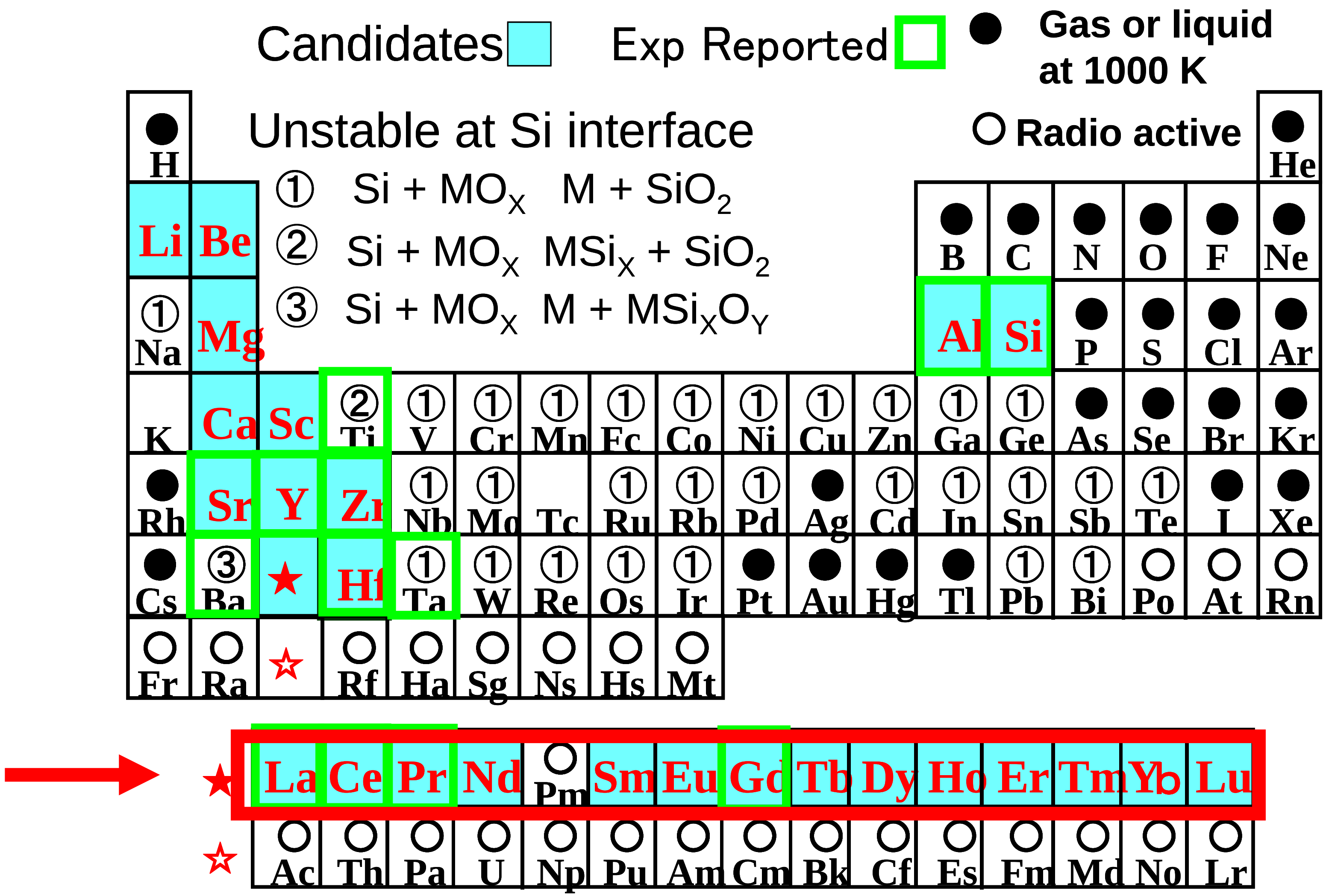
High-k Gate Dielectric Candidates

Choice of high-k

k value less than 50 is desirable for suppression of short channel effects

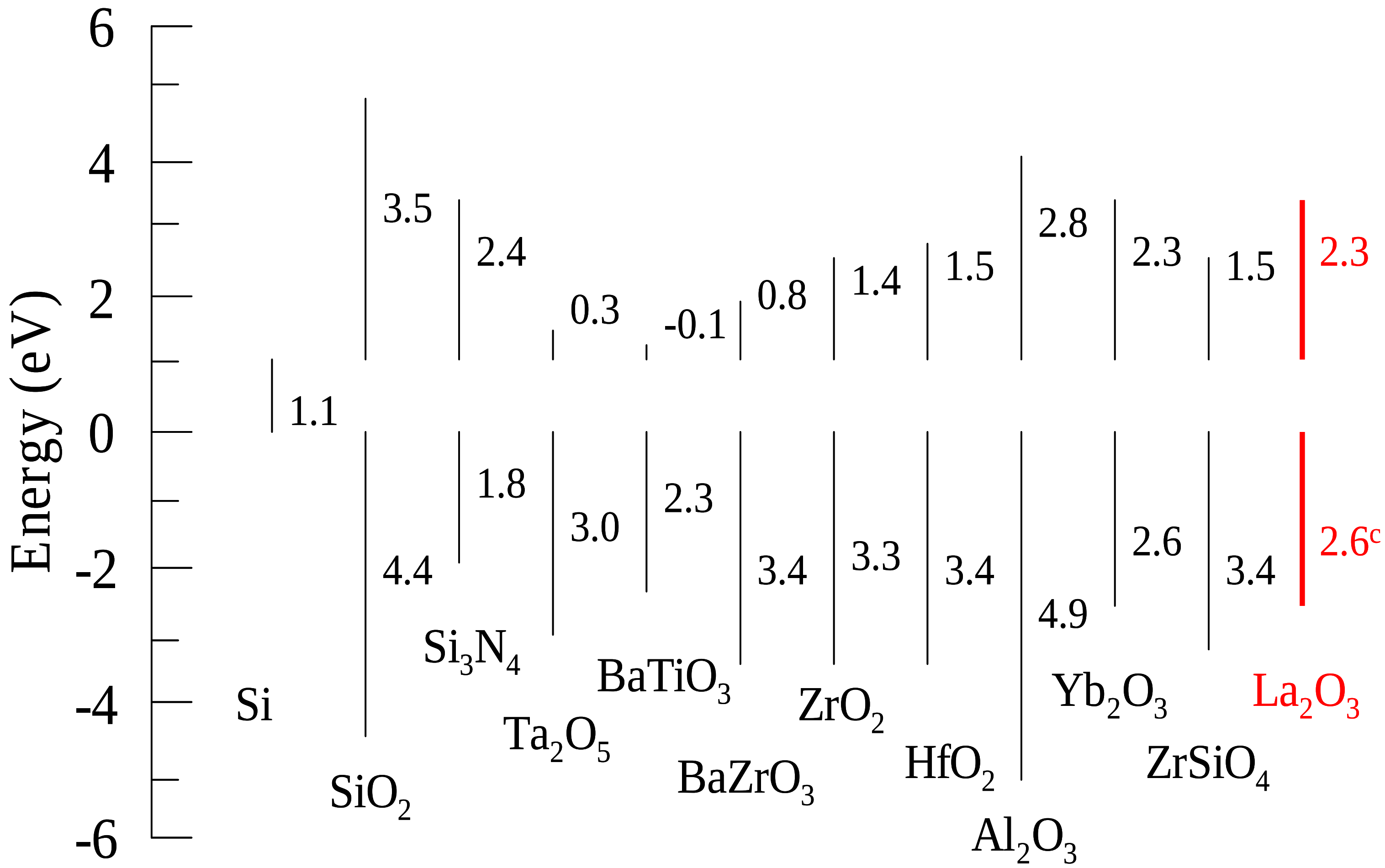
Material	k	$HfAl_xO_y$	10-15
NO stack	5-6	$HfSi_xO_yN_z$	10-15
Al_2O_3	8-9	ZrO_2, HfO_2	20-30
$HfSi_xO_y$	10-15	Lanthanide Oxides	15-30

Other options?



R. Hauser, IEDM Short Course, 1999

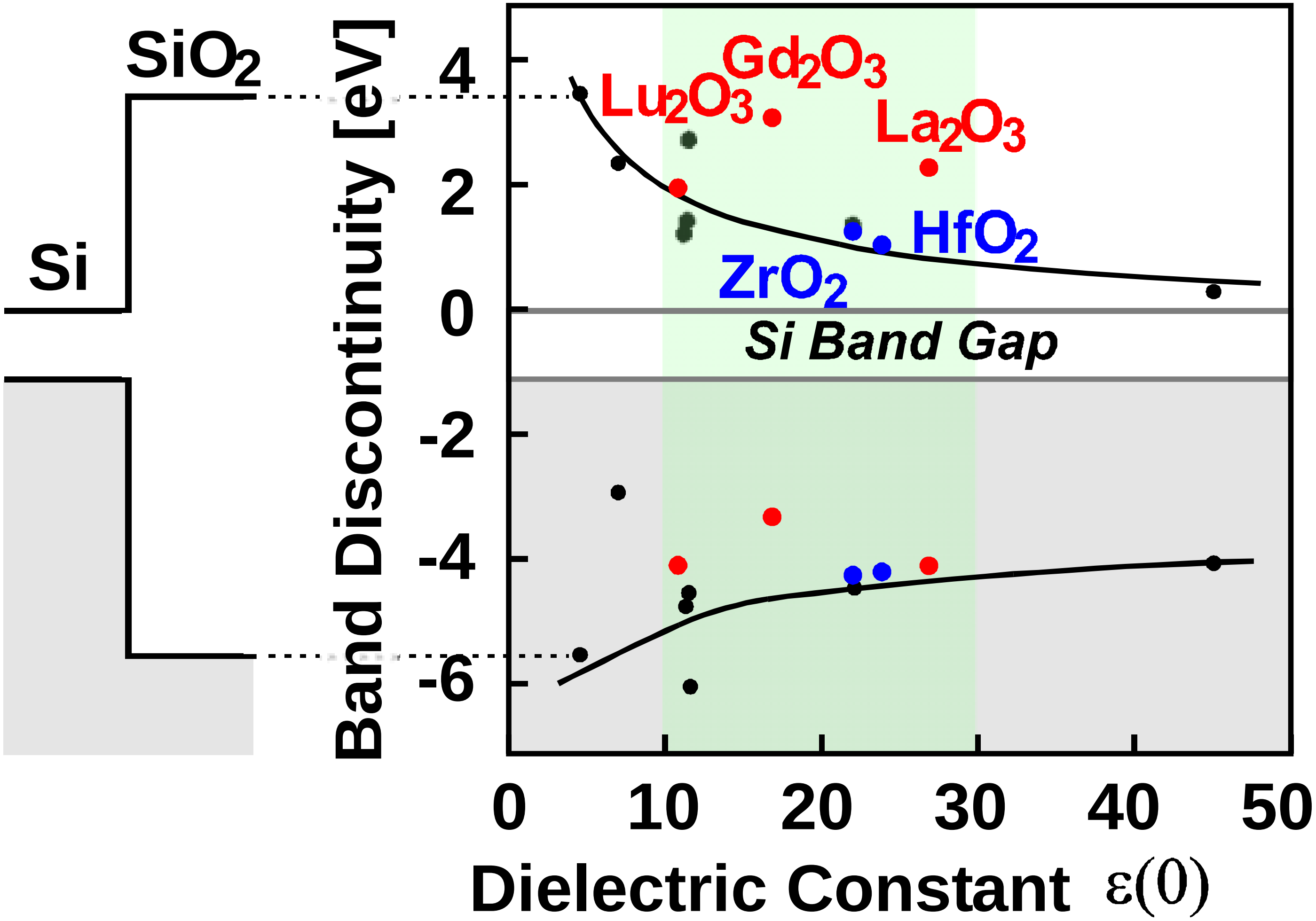
Band offsets for High-k dielectrics on Si



＊ C Estimates.

参考文献: J.Robertson Journal of Non-Crystalline Solids 303(2002) P98

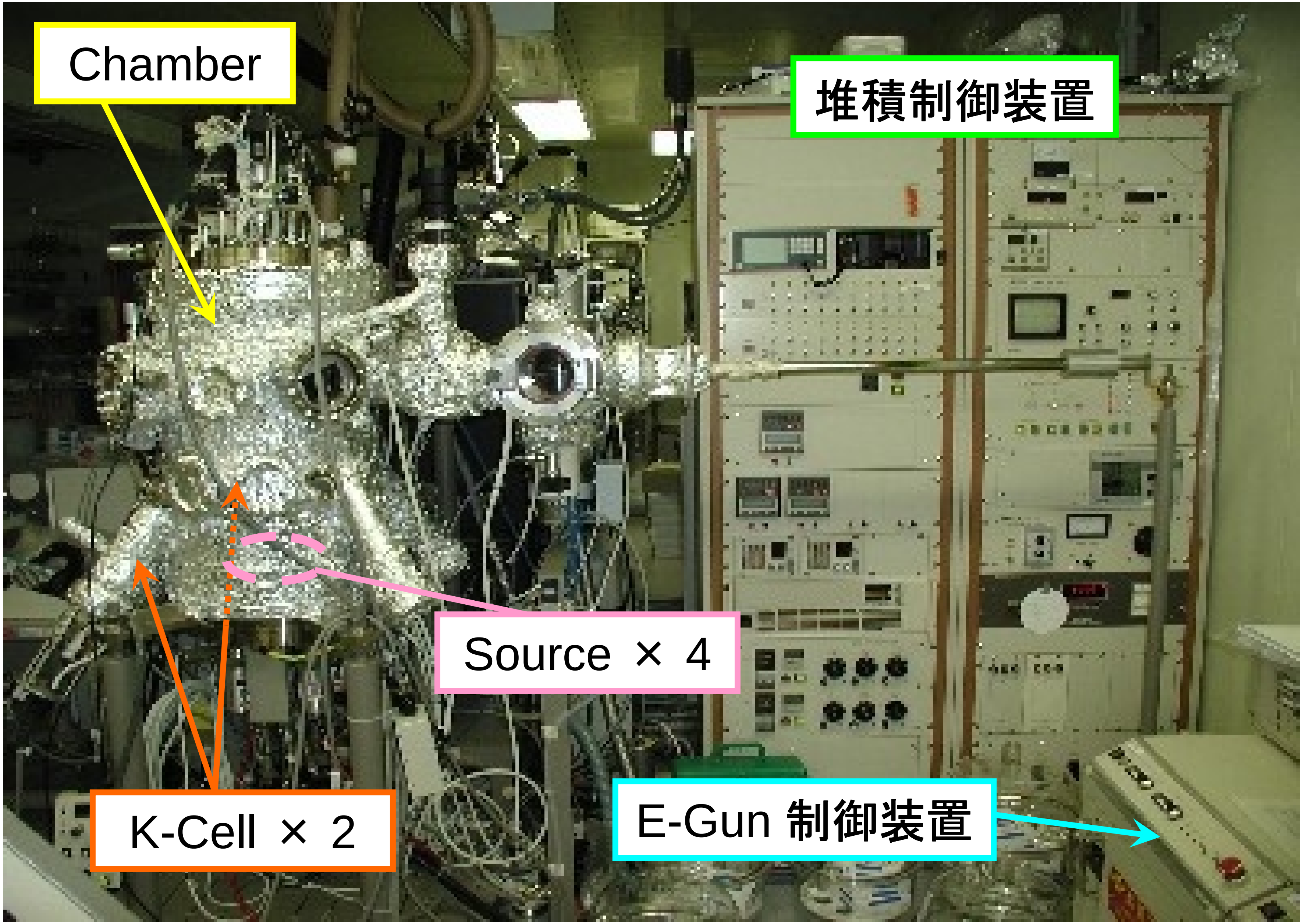
Experimental data by XPS by Prof. T. Hattori



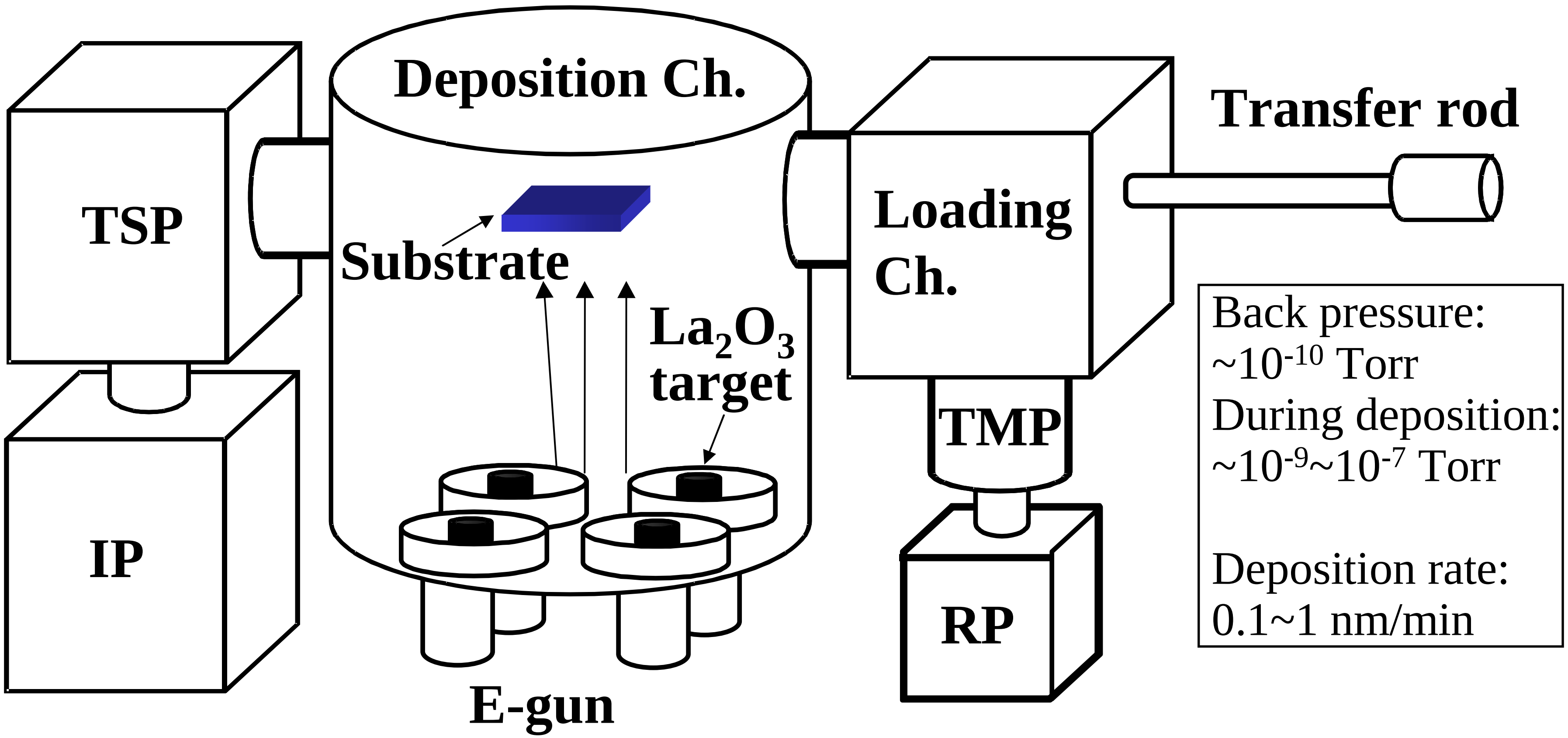
$\sqrt{\phi_B} * k$: **Figure of Merit of High-k**

Insulating Films on Semiconductors Barcelona June 18-20, 2003

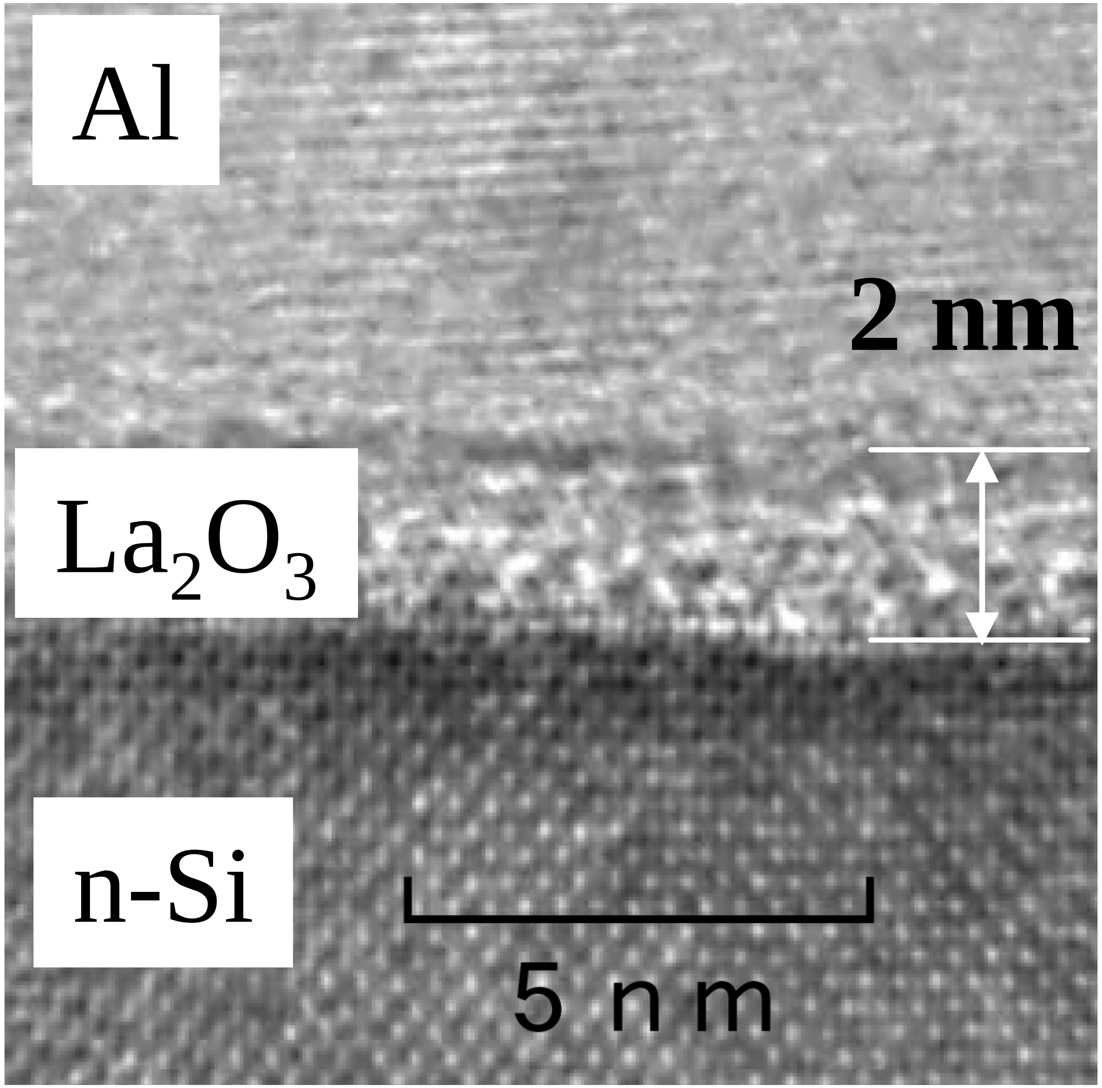
MBE装置



Our Molecular Beam Deposition System



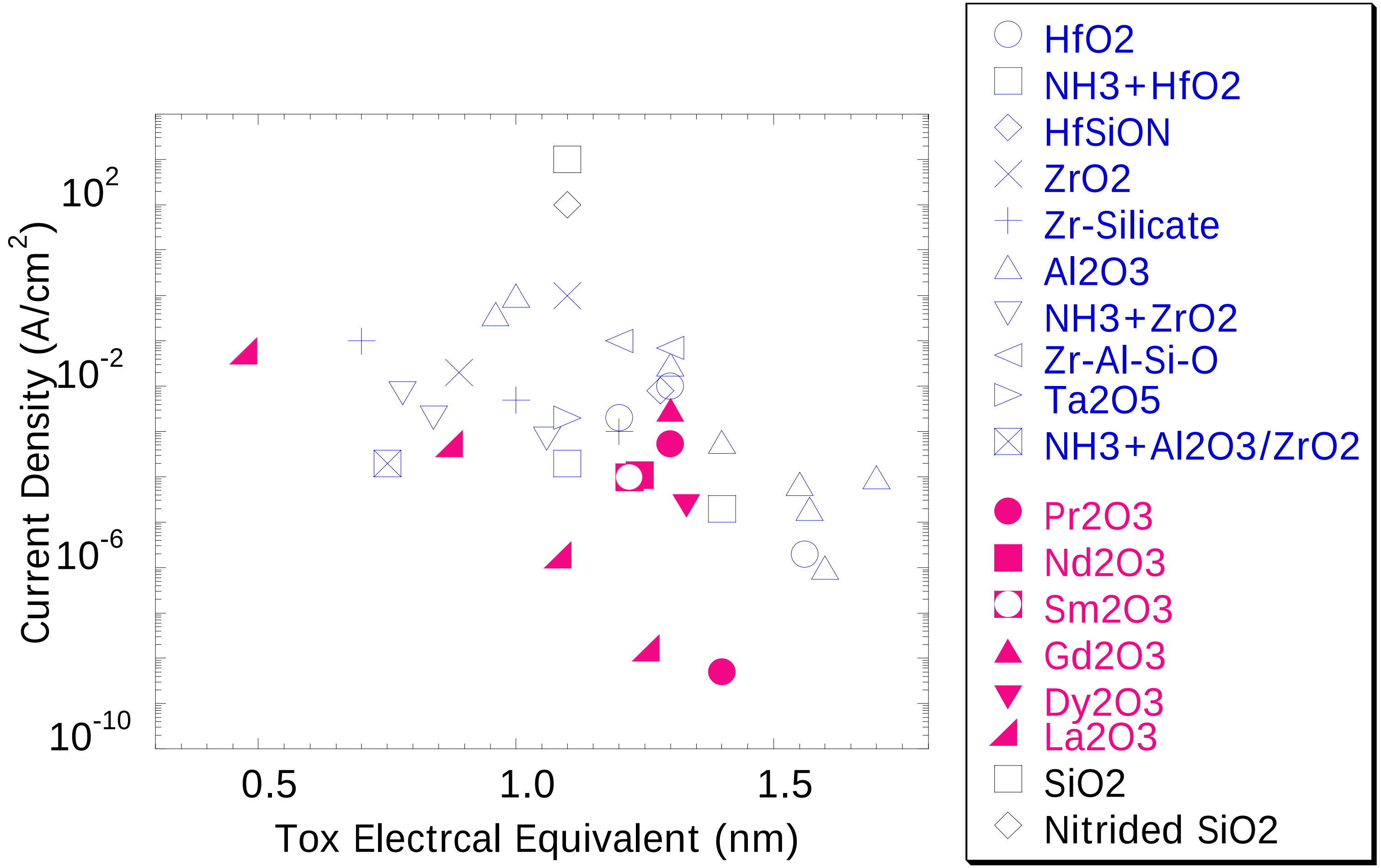
Cross sectional TEM images for Al/La_2O_3/n-Si.
400^oC depo., 400^oC RTA in N_2.



Physical thickness = 2 nm

EOT = 0.6 nm

T_{ox} Electrical Equivalent vs. Current Density



From IEDM 2000, IEDM 2001, SSDM 2001 and VLSI Symp. 2001(Advanced Program)

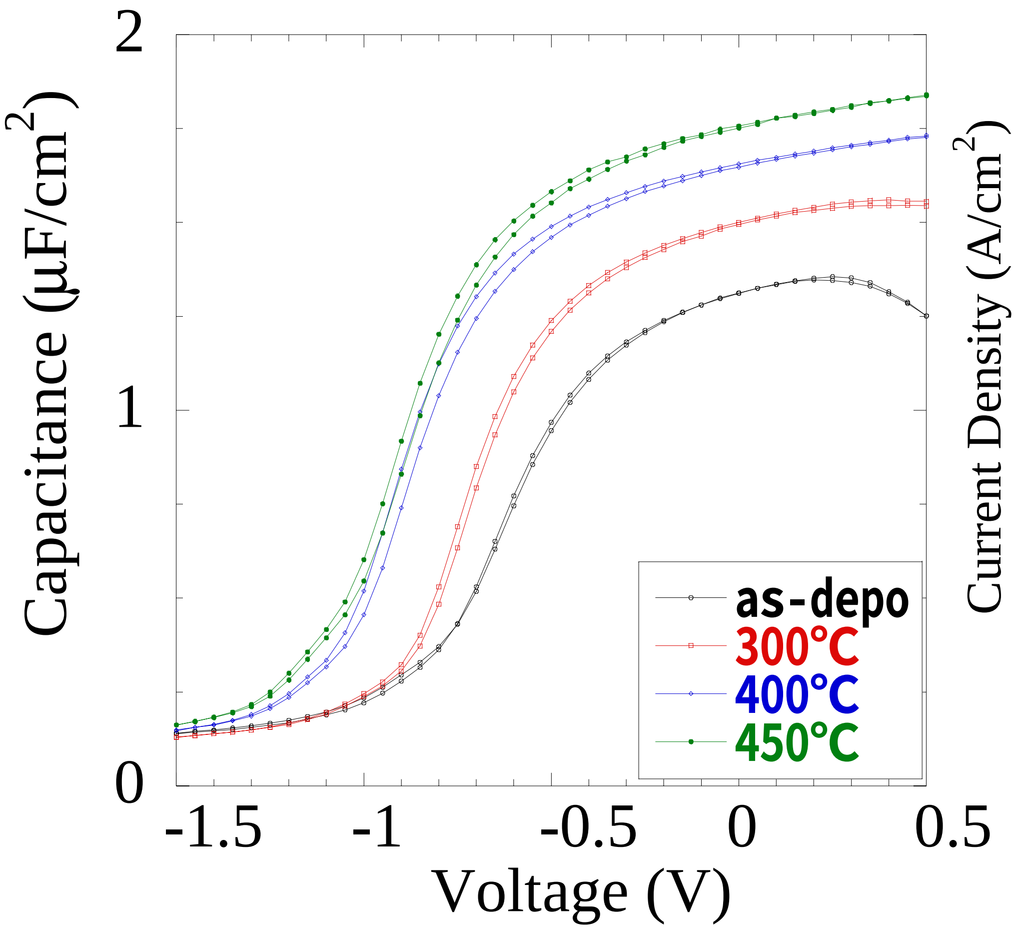
Annealing (5min)		EOT [nm]	Vfb [V]	ΔVfb [V]	Relative Dielectric Constant	Leakage [A] @1V
without		1.760	0.806	0.123	17.0	1.06e-2
O_2	200^0C	1.762	0.823	0.165	15.6	3.09e-6
	300^0C	1.617	0.870	0.257	16.9	9.51e-7
	400^0C	3.103	0.391	-0.700	9.62	1.37e-5
N_2	200^0C	1.106	0.784	0.083	**27.0**	3.04e-7
	300^0C	1.443	0.785	0.081	26.1	7.27e-6
	400^0C	1.280	0.808	0.123	23.3	2.77e-6

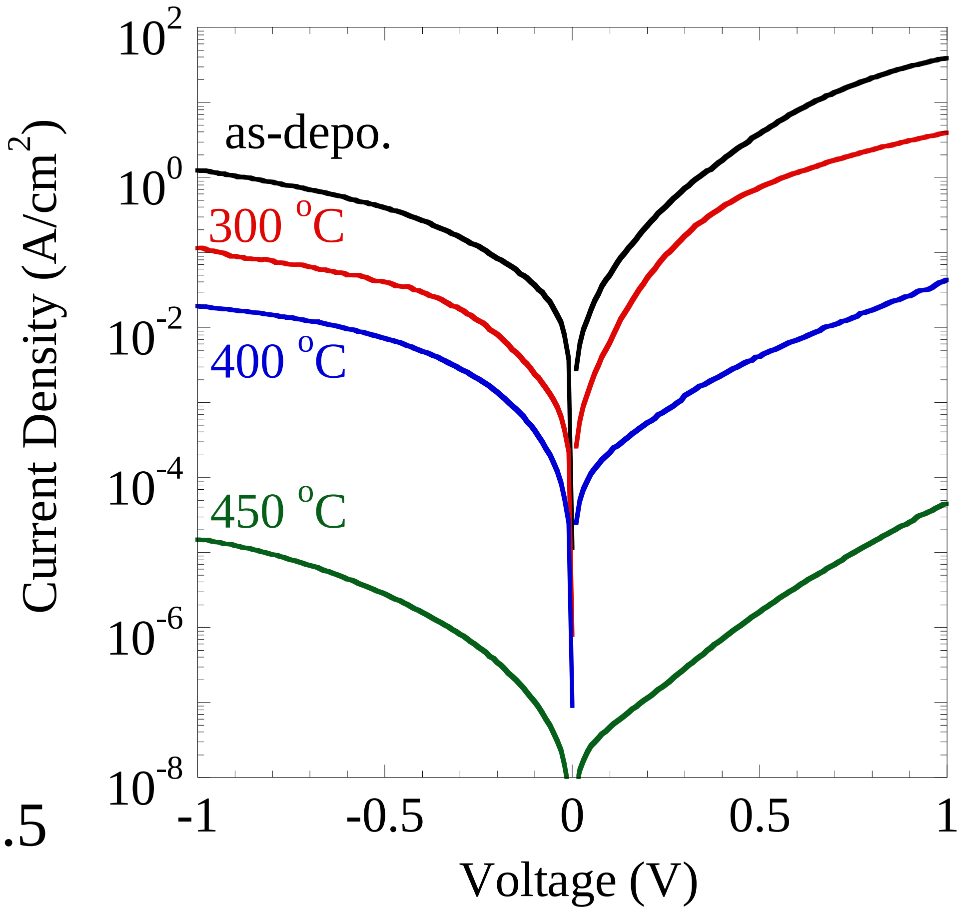
$$V_{fb,\,fitted} = \Delta W_{func} + \Delta V_{fb,Calc} = W_{gate} - W_{silicon} + V_{fb,Calc}$$

Preliminary results

Dry N2 annealing

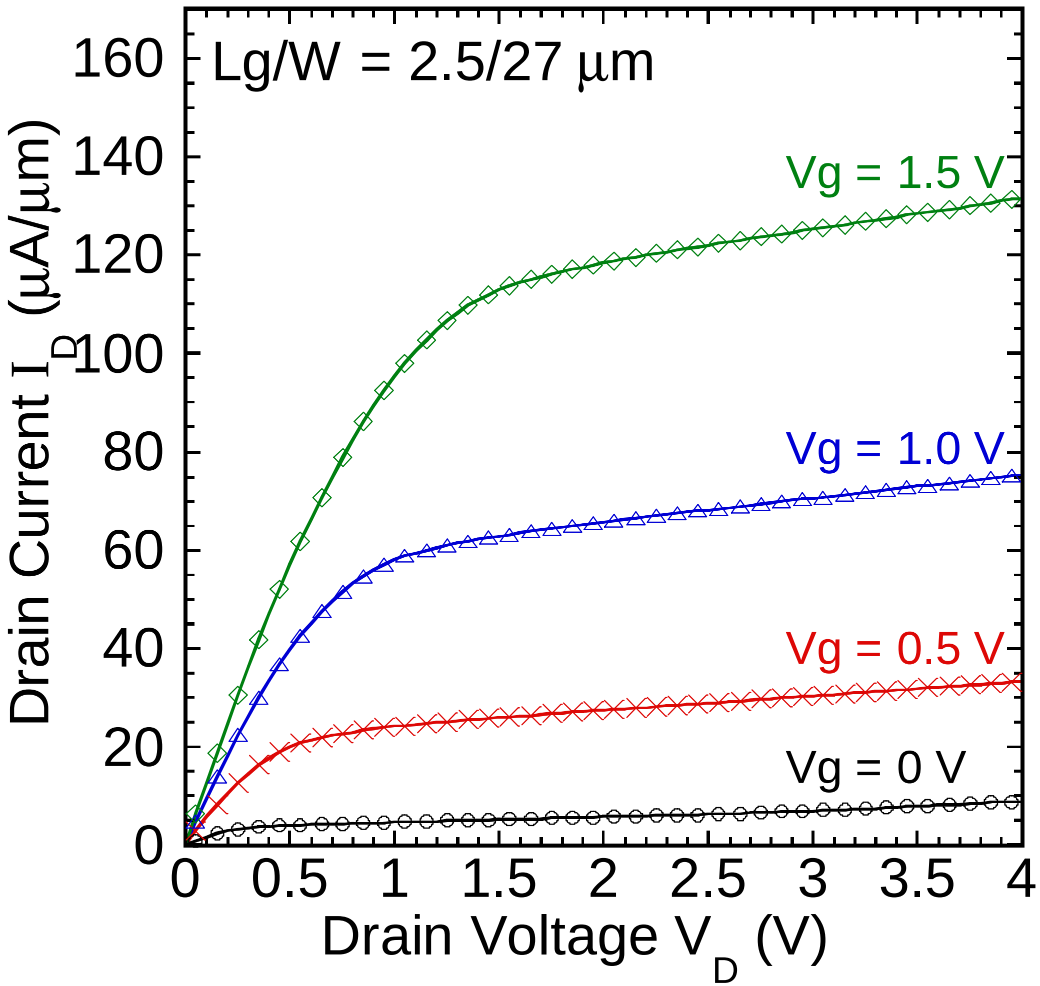
Densification: good
Vfb shift: problem
Being solved by PM anneal

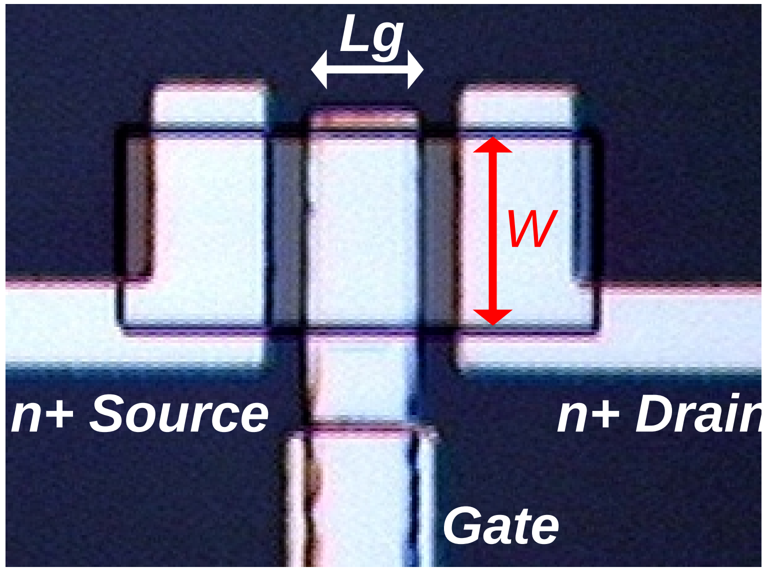




I_D - V_D Characteristics (Lg = 2.5 µm)

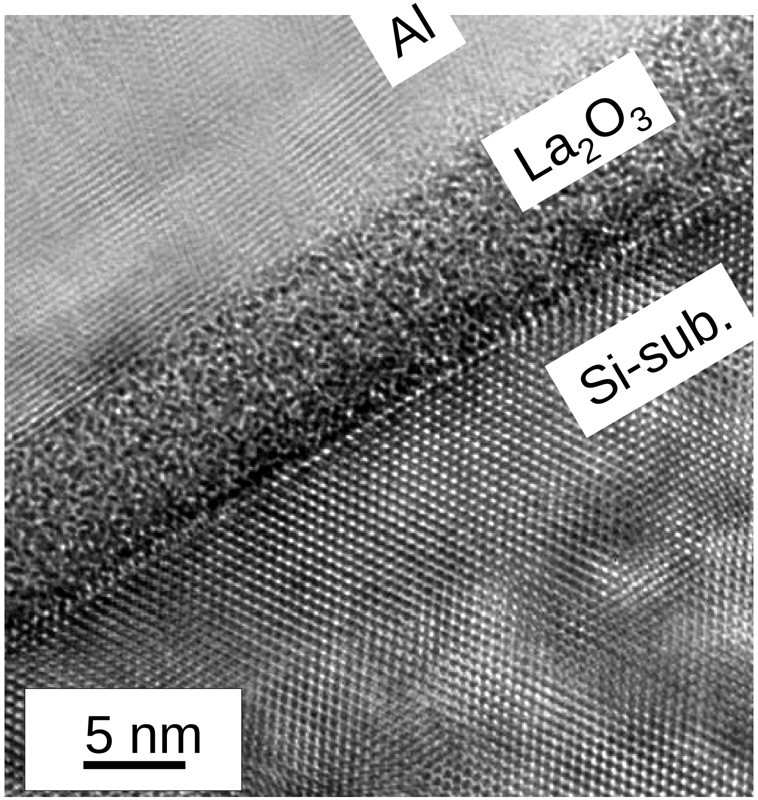
Chemical Oxide, Deposition Temp. = 250°C,
Lg = 2.5 µm, W = 27 µm, EOT = 3.0 nm



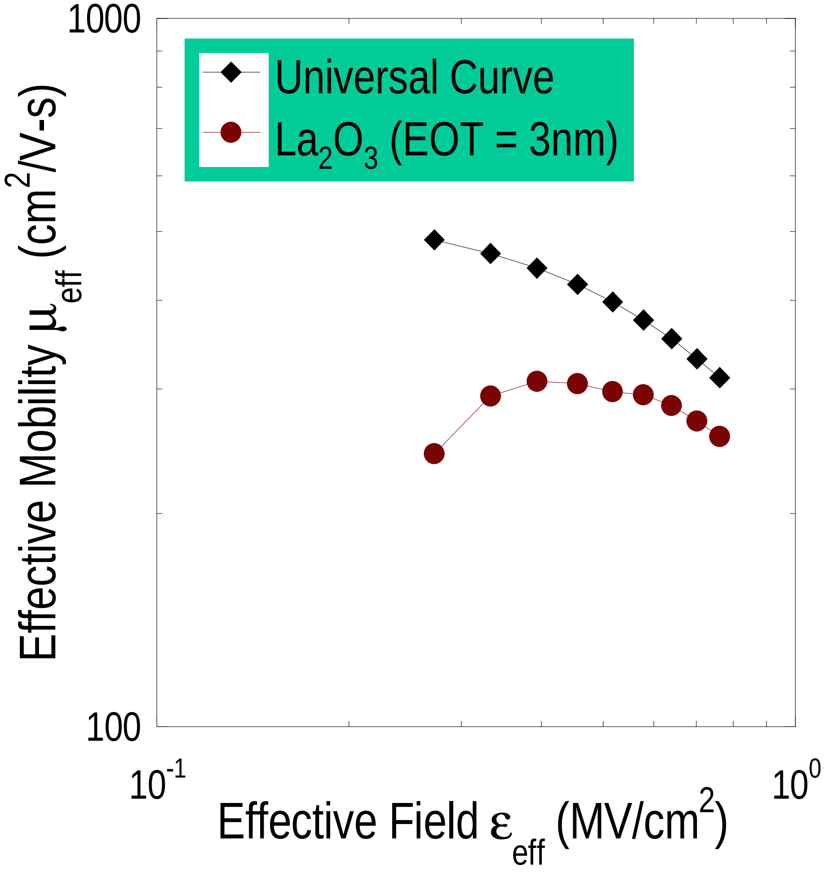


Deposition Temp. = 250^{o}C, Tphy = 10 nm, Annealed

in O_2 400^{o}C 5min

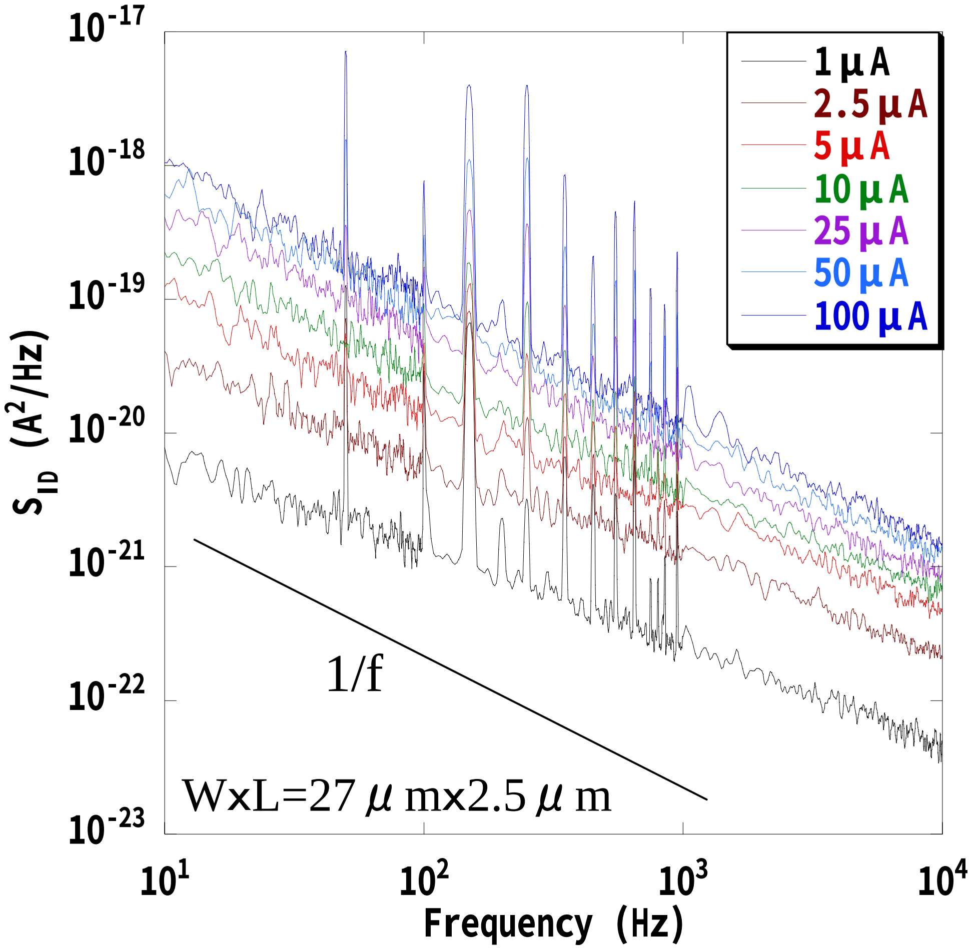


Electrical Characteristics – Mobility μ_{eff}



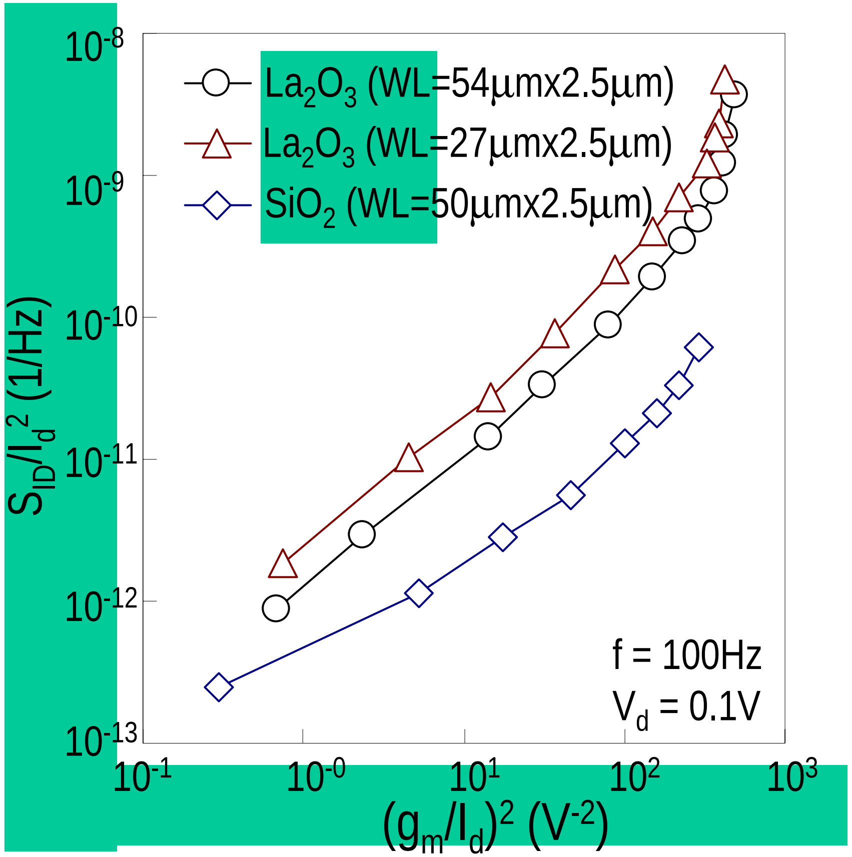
High effective mobility of nearly the same to the universal curve was obtained with EOT = 3nm La_2O_3 gate dielectrics.

Flicker noise at V_{ds}=100mV



Results and Discussion (6)

LF Noise – Comparation with SiO_2

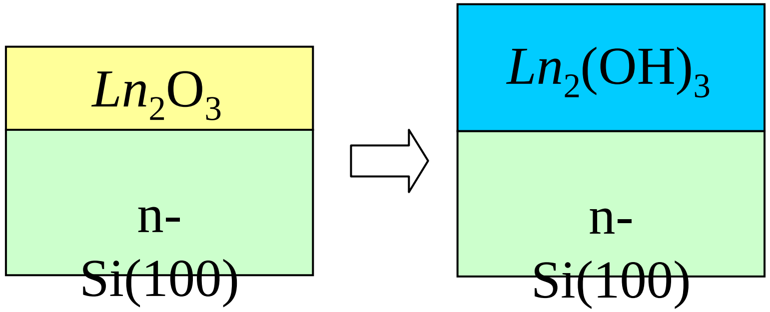


The normalized noise spectrum of n-type MISFET's with La_2O_3 gate dielectrics is about one order in magnitude higher than that of SiO_2 obtained from thermal oxidation.

Absorption of moisture and CO_2

The oxides become hydroxide and carbonate in H_2O and CO_2 ambient.

hydroxide



$$Ln_2O_3 + H_2O \rightarrow Ln_2O_3 \cdot H_2O$$

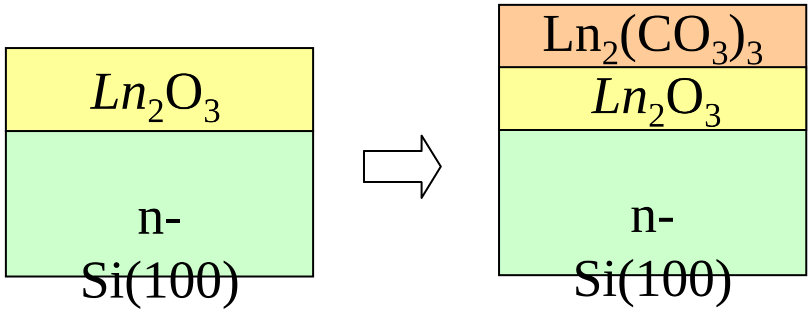
↓

$$Ln_2O_3 + H_2O \rightarrow 2(LnOOH)$$

↓

$$2Ln(OH) + H_2O \rightarrow 3Ln_2(OH)_3$$

carbonate

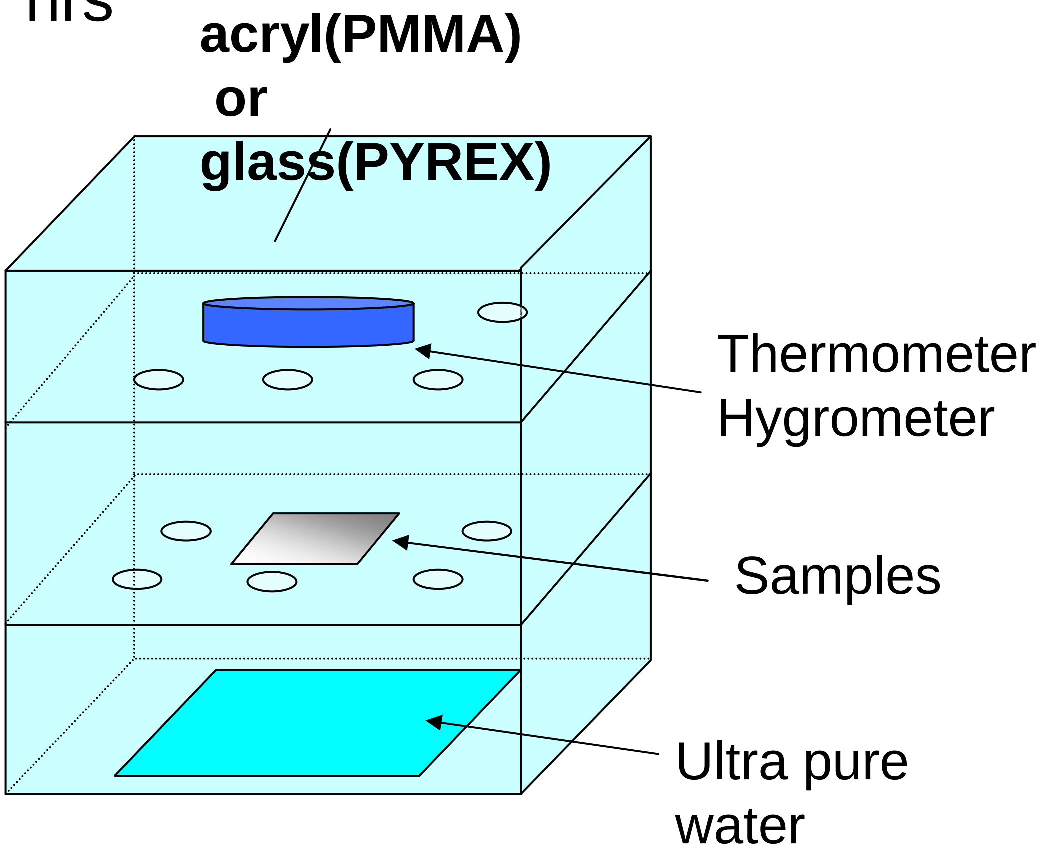


$$Ln_2O_3 + 2CO_2 \rightarrow Ln_2(CO_3)_3$$

※*Ln*: Lanthanide

Experimental apparatus

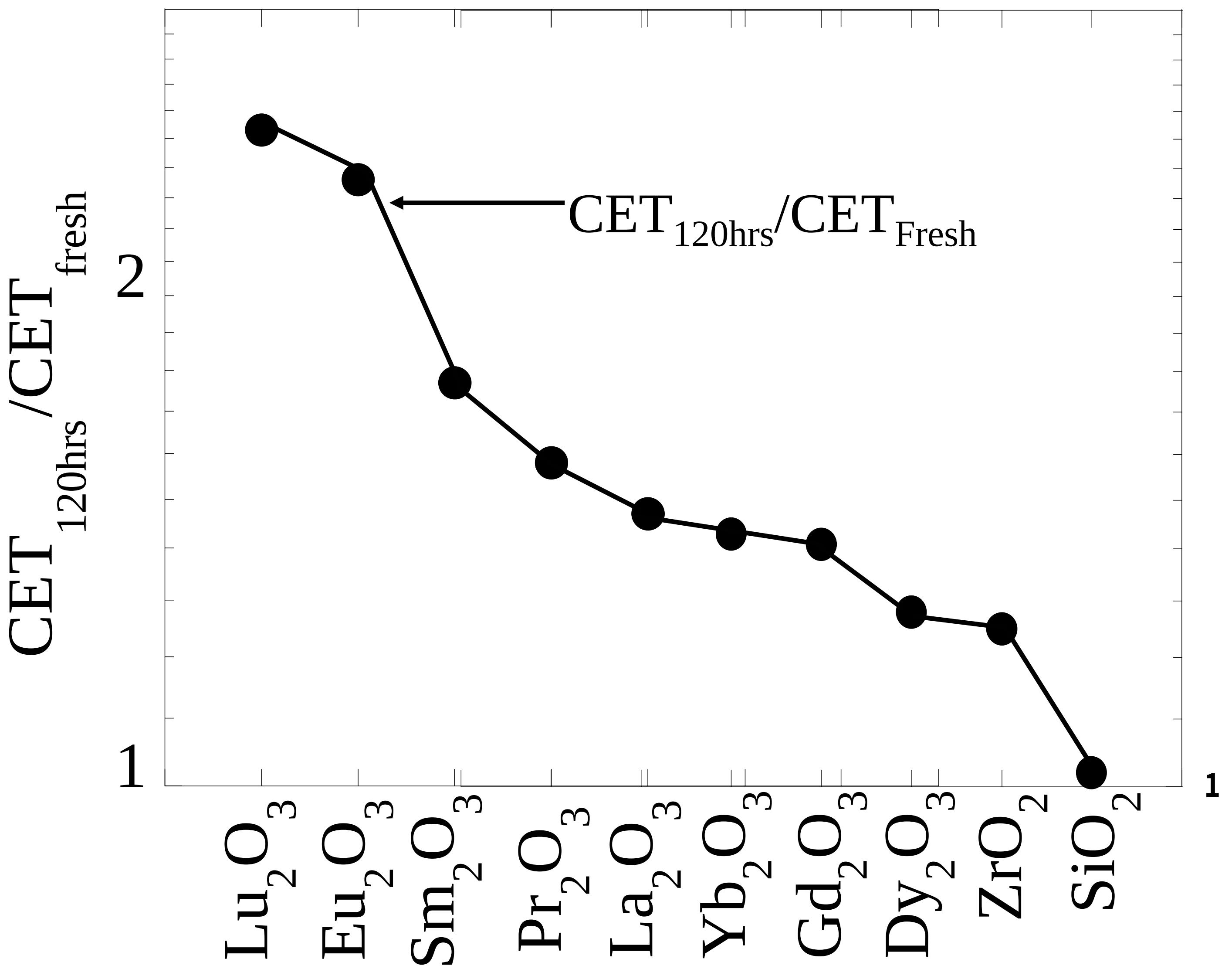
Temperature: ~20^{o}C
Humidity: 80%
Humidification time:
0 ~120 hrs



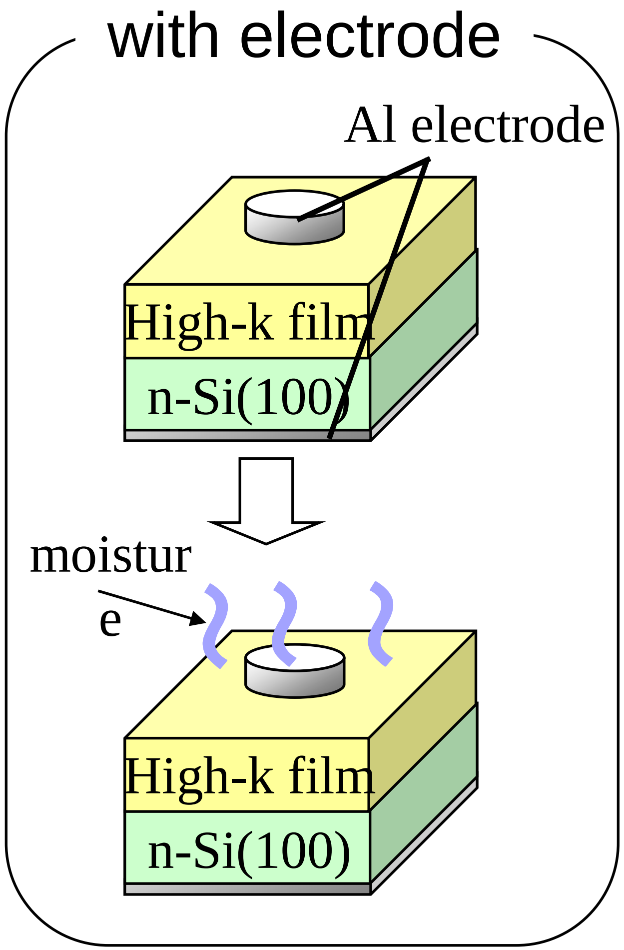
glass (PYREX) acryl (PMMA)

*PMMA :
$CH_2C(CH)_3COOCH_3$

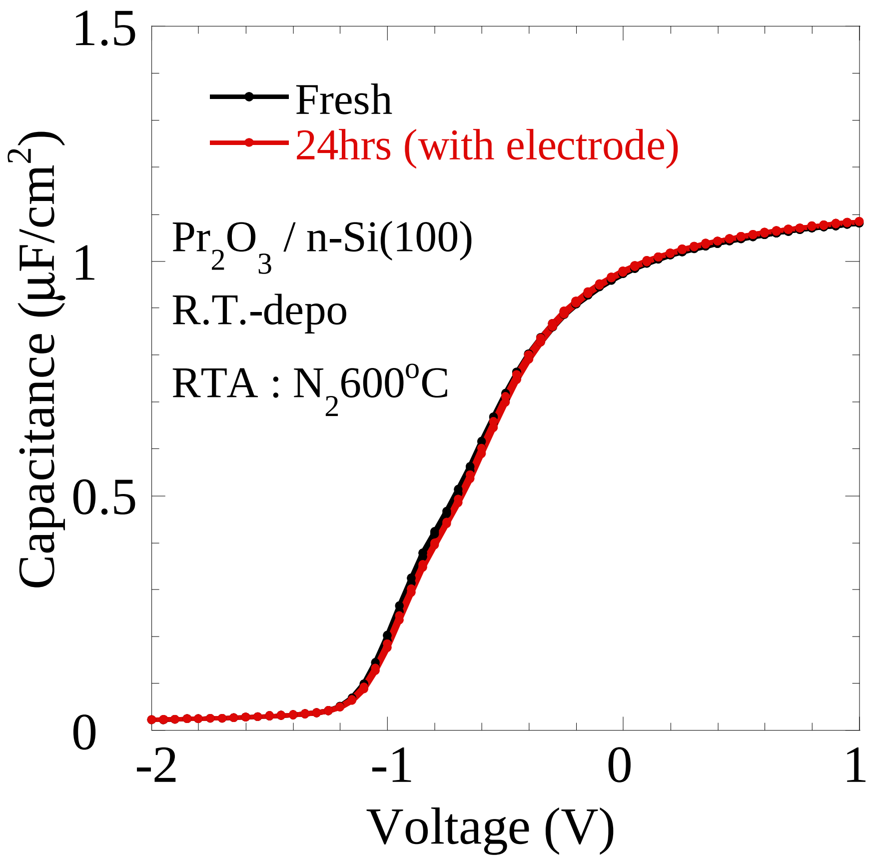
Change of CET for all studied



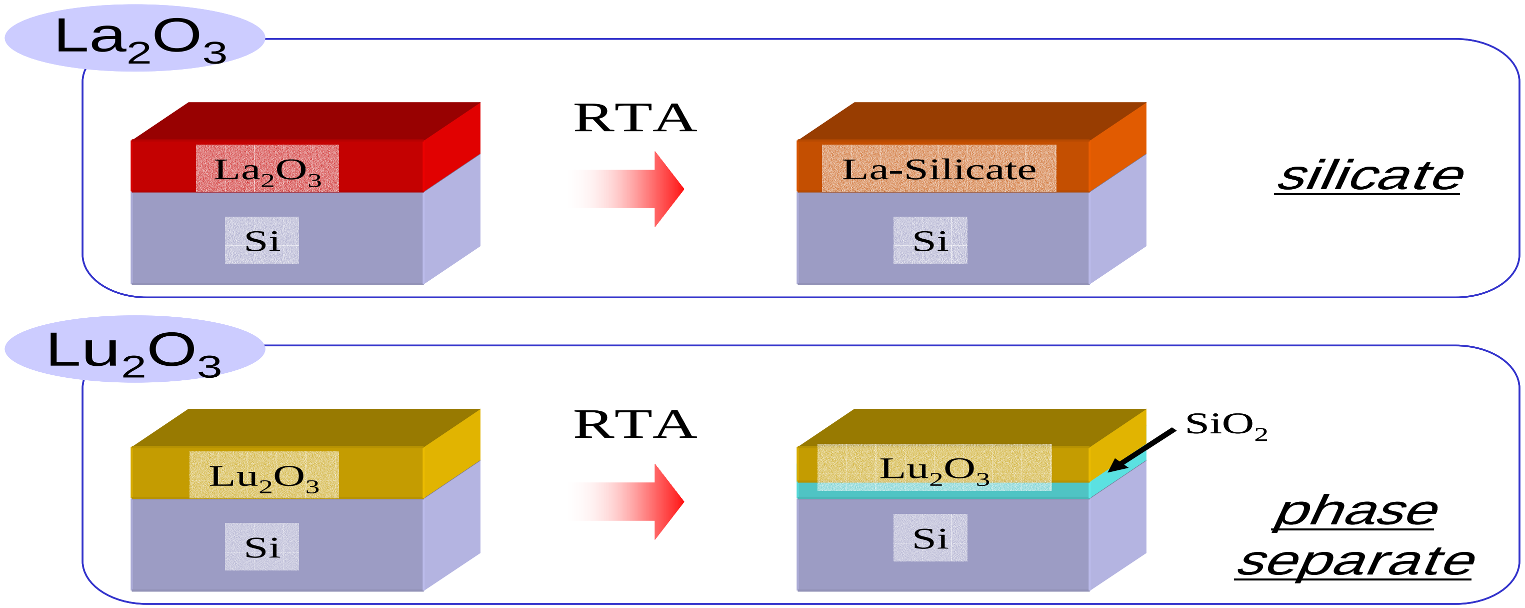
Absorption test in case of acryl apparatus after the Al electrode formation for Pr_2O_3.



C-V

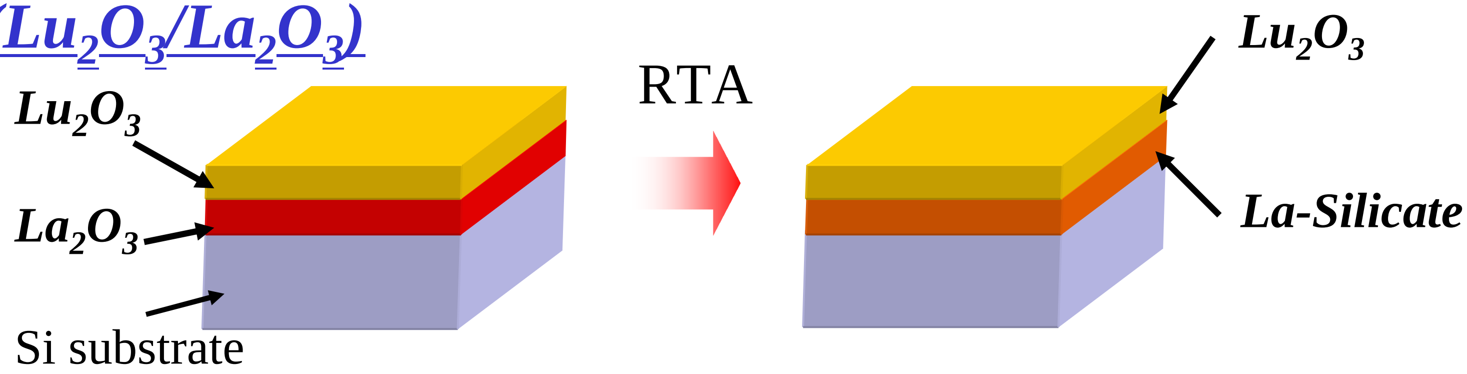


研究目的



Ref. S.Ohmi, et al., *J. Electrochem. Soc.*, 150, F134(2003)
H.Nohira et al., *J. Appl. Surf. Sci.*, *216*(2003)

Stack(Lu_2O_3/La_2O_3)



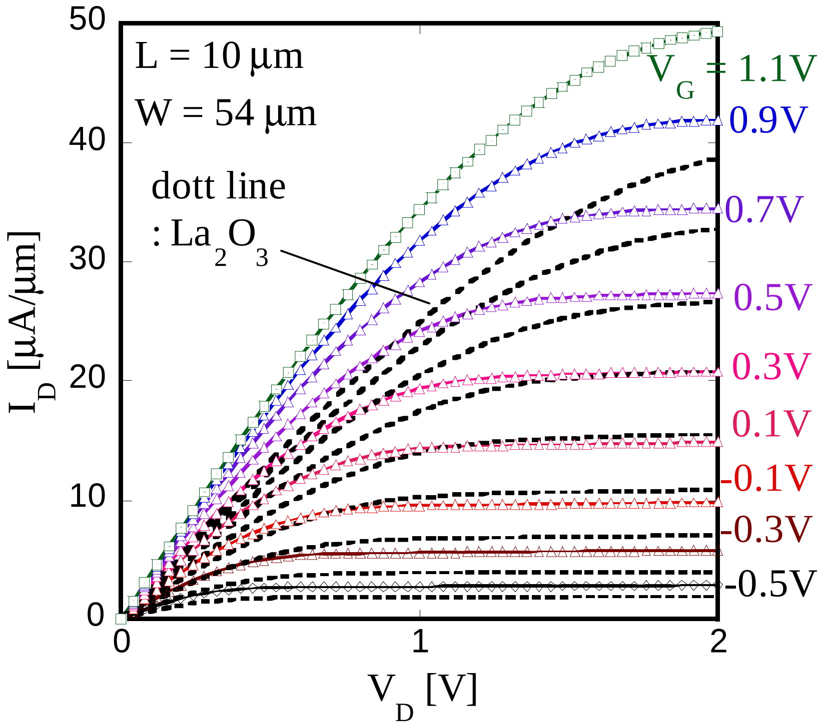
La_2O_3で界面層成長と微結晶化を抑える
Lu_2O_3で膜全体silicateを抑え、耐湿性を向上

誘電率を保ちつつリーク電流を抑制

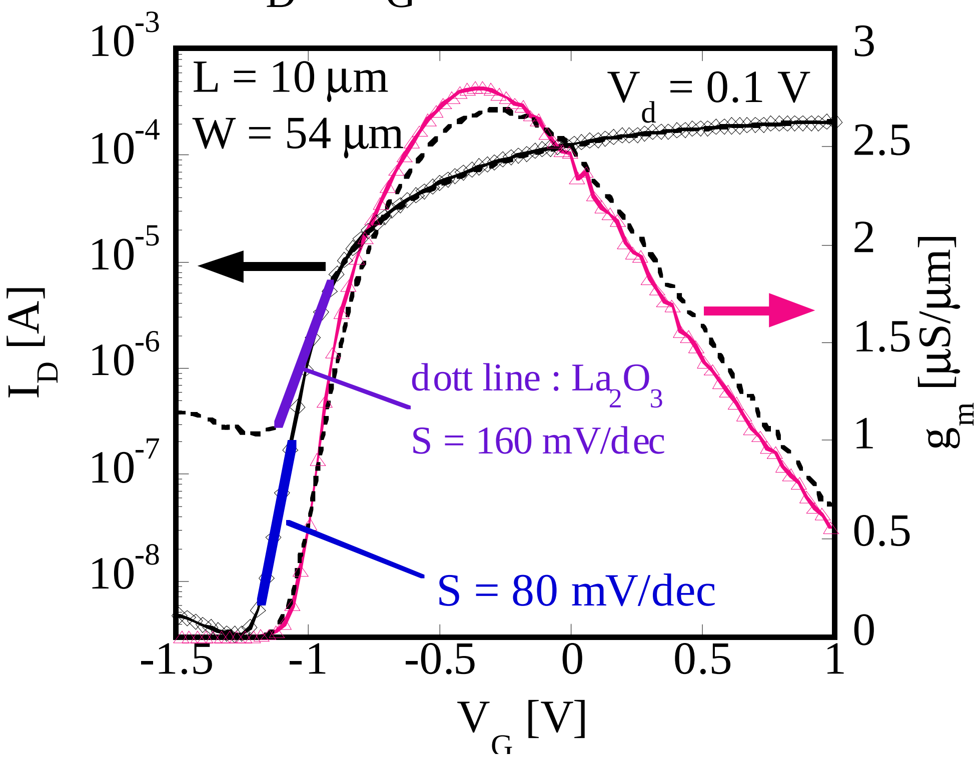
積層構造(Lu_2O_3/La_2O_3/n-Tr)の作製

nMIS 250^{o}C堆積, annealed at 400^{o}C, Al電極を使用

I_D-V_D Characteristics



I_D - V_G Characteristics



μ_{eff} = 163 [$cm^2V^{-1}s^{-1}$]
(EOT = 2.05 nm)

$O_2$300→$O_2$400でより改善がみられ、
同条件のLa_2O_3と比較して、良好な特性が得られた

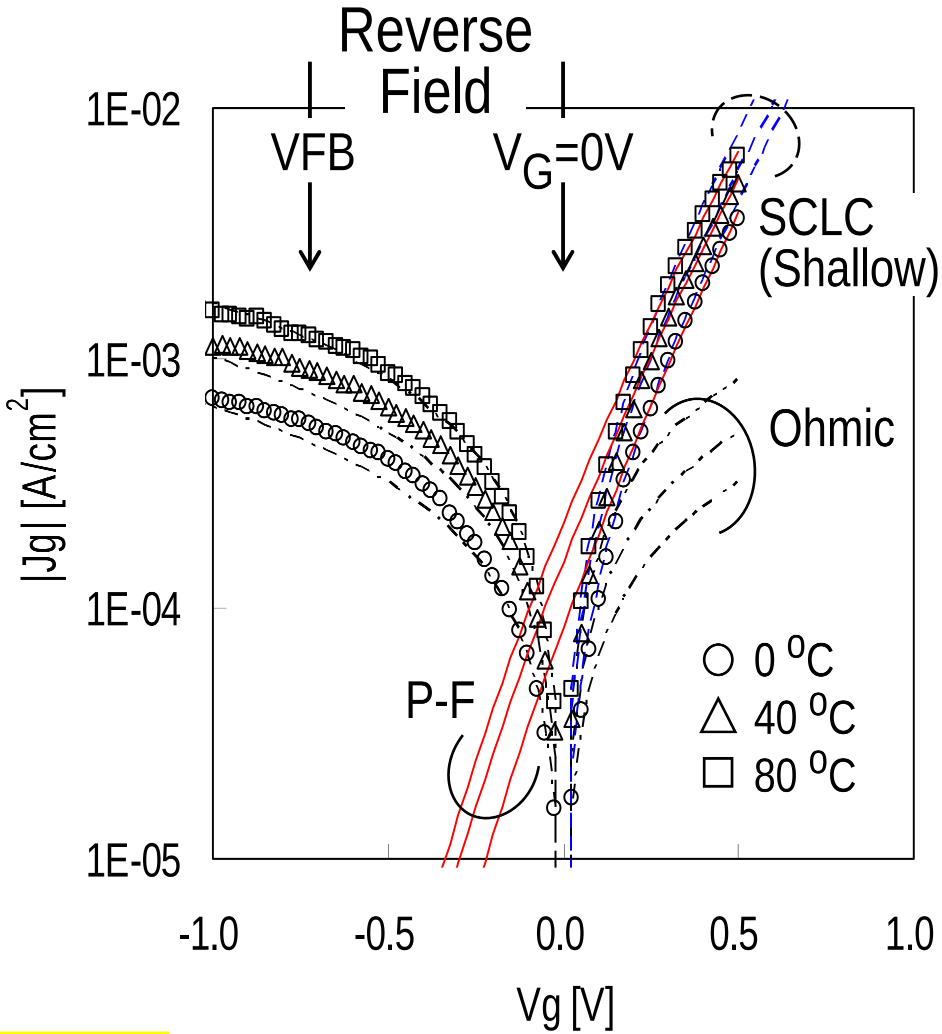
Lu_2O_3の耐湿性により、電気特性が改善した

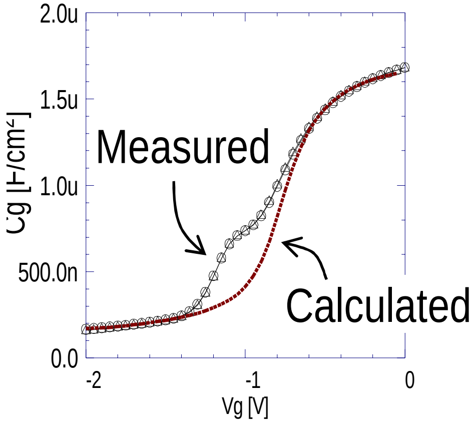
Conduction Modes and Expressions

	Mode		Expression	
Bulk-Free	Schottky*	(1)	$\ln(J) \propto E^{1/2}$	$\ln(J/T^2) \propto -1/T$
	DT**	(2)	$\ln(J) \propto E$	
	F-N	(3)	$\ln(J/E^2) \propto 1/E$	$J \propto T^2$ *(weak)*
	Ohmic	(4)	$J \propto E$	$\ln(J) \propto -1/T$
Bulk-Limited	Poole	(5)	$\ln(J)\,\alpha\, E$	
	P-F	(6)	$\ln(J/E) \propto E^{1/2}$	$\ln(J) \propto -1/T$
	SCLC***	(7)	$\ln(J/\ \ E) \propto E$	
		(8)	$J \propto E^2$	

*Thermionic Current, **Direct Tunneling Current,
***Space-Charge-Limited Current : single trap level for shallow (7) and deep (8) distributi

Al Electrode Case – Leakage Current





Q.EOT 1.54 nm
O.TOX 4.7nm
RDC 11.9

2003.11.30.修正

超高真空アニール後のLa_2O_3薄膜中のトラップ準位