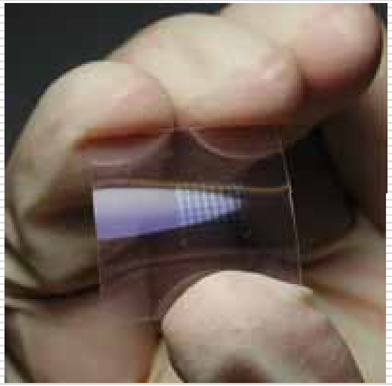
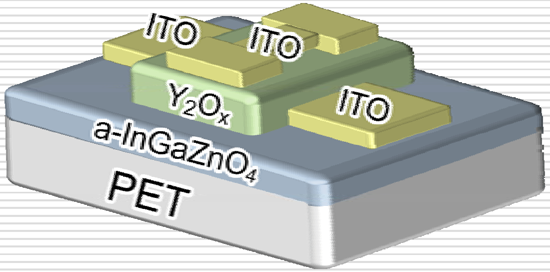
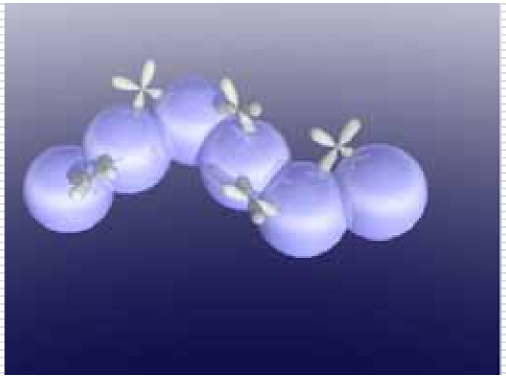
Transparent Amorphous Oxide Semiconductors and Their TTFT Application







Hideo HOSONO

Frontier Collaborative Research Center
& Materials and Structures Laboratory,
Tokyo Institute of Technology, Yokohama, JAPAN
& ERATO-SORST, Japan Science and Technology Agency

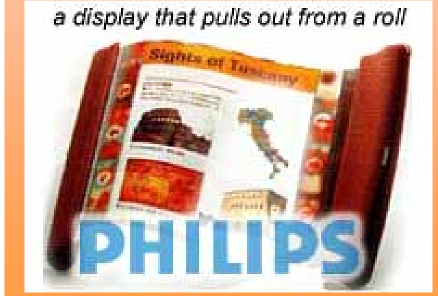
Thin Film Transistor : Switching device in display

present : TFT on glass → **future : TFT on plastic**

Semiconductor:a-Si:H → **?**

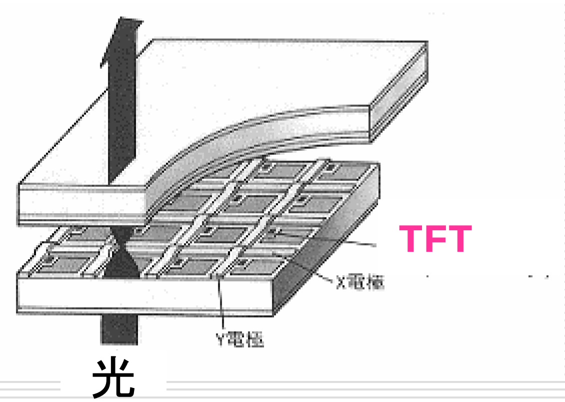
http://www.pioneer.co.jp/

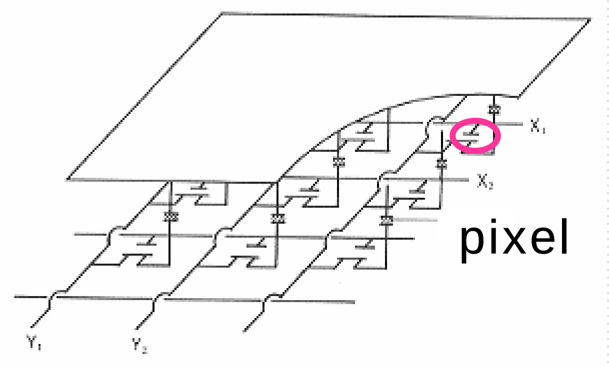
Electronics everywhere

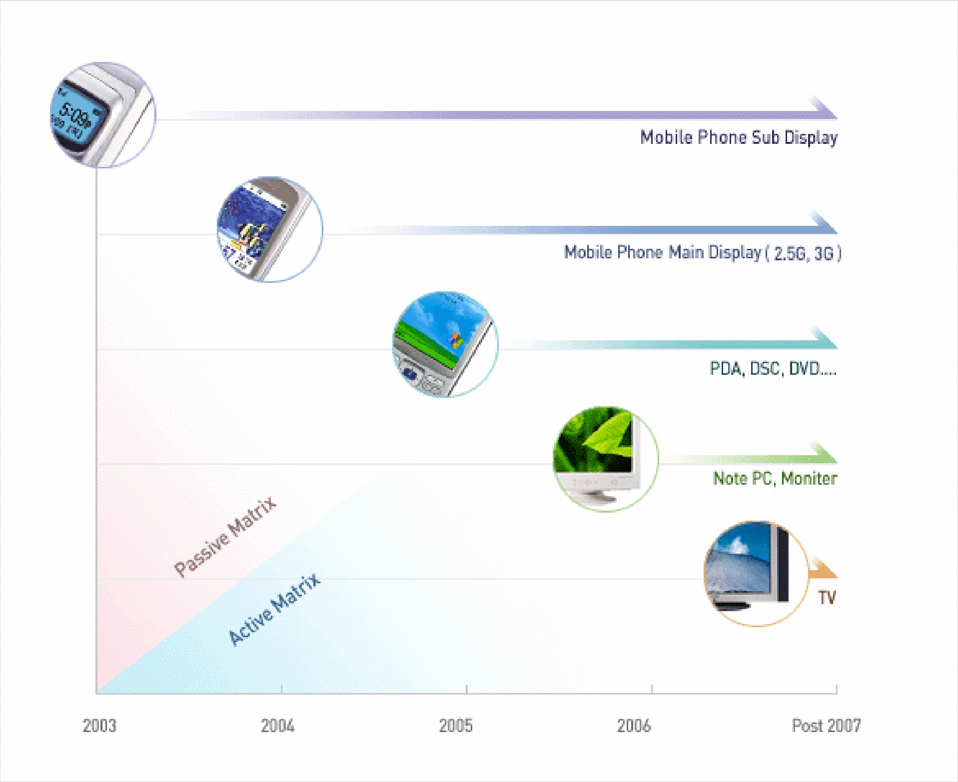


Giant-microelectronics → **flexible electronics**,

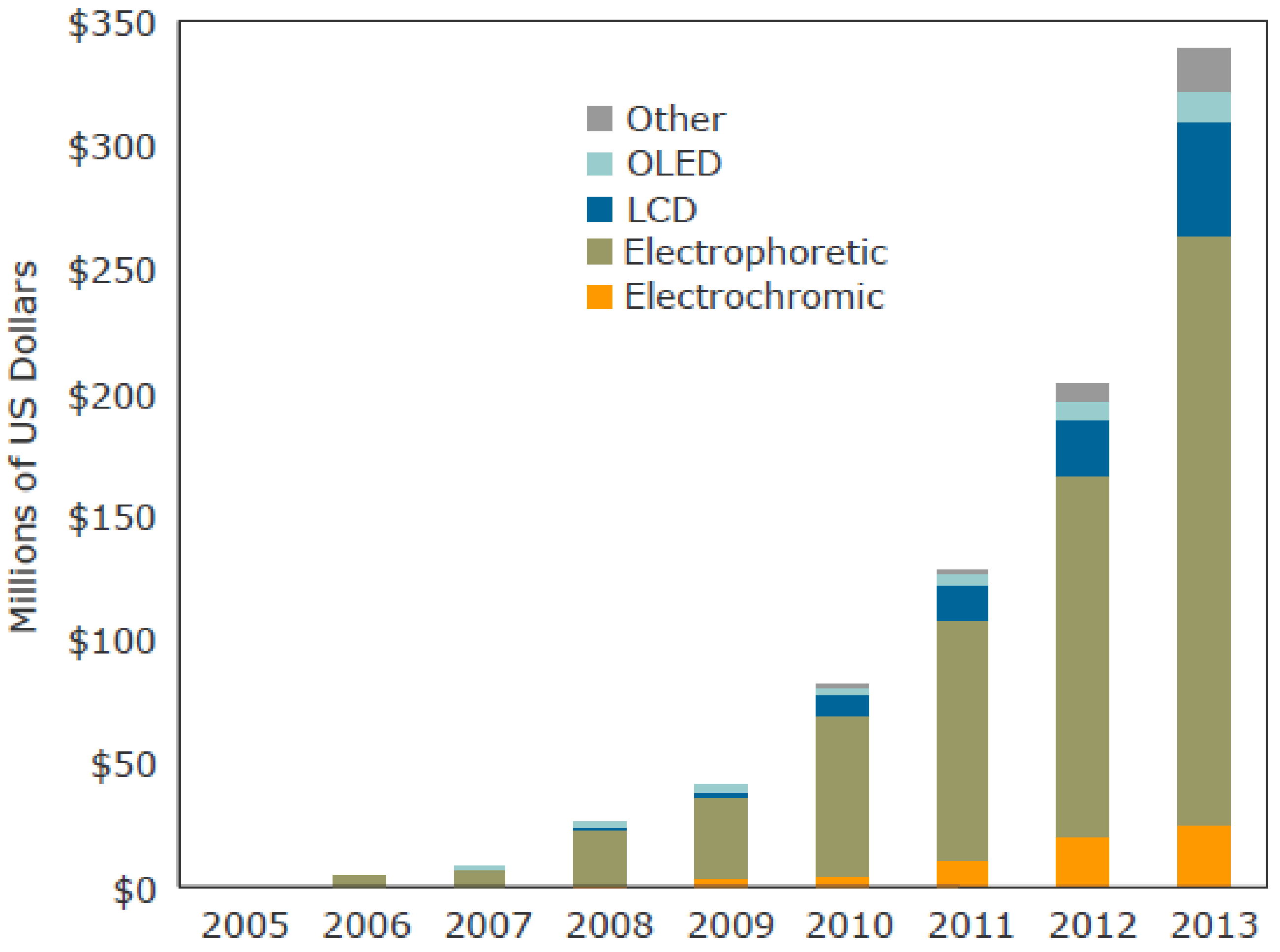
TFT: Active Matrix Display







Market Forecast of Flexible Display



Sources :iSuppli

Examples of Flexible TFT

a-Si on SUS foil

LG. Philips LCD

Heavy
Expensive (Passivation)

LG Philips

poly-Si
(Transfer Technique)

SEIKO EPSON

Difficulty in large area fabrication
Expensive

SEIKO EPSON

Organic TFT

Philips & Polymer Vision
Plastic Logic

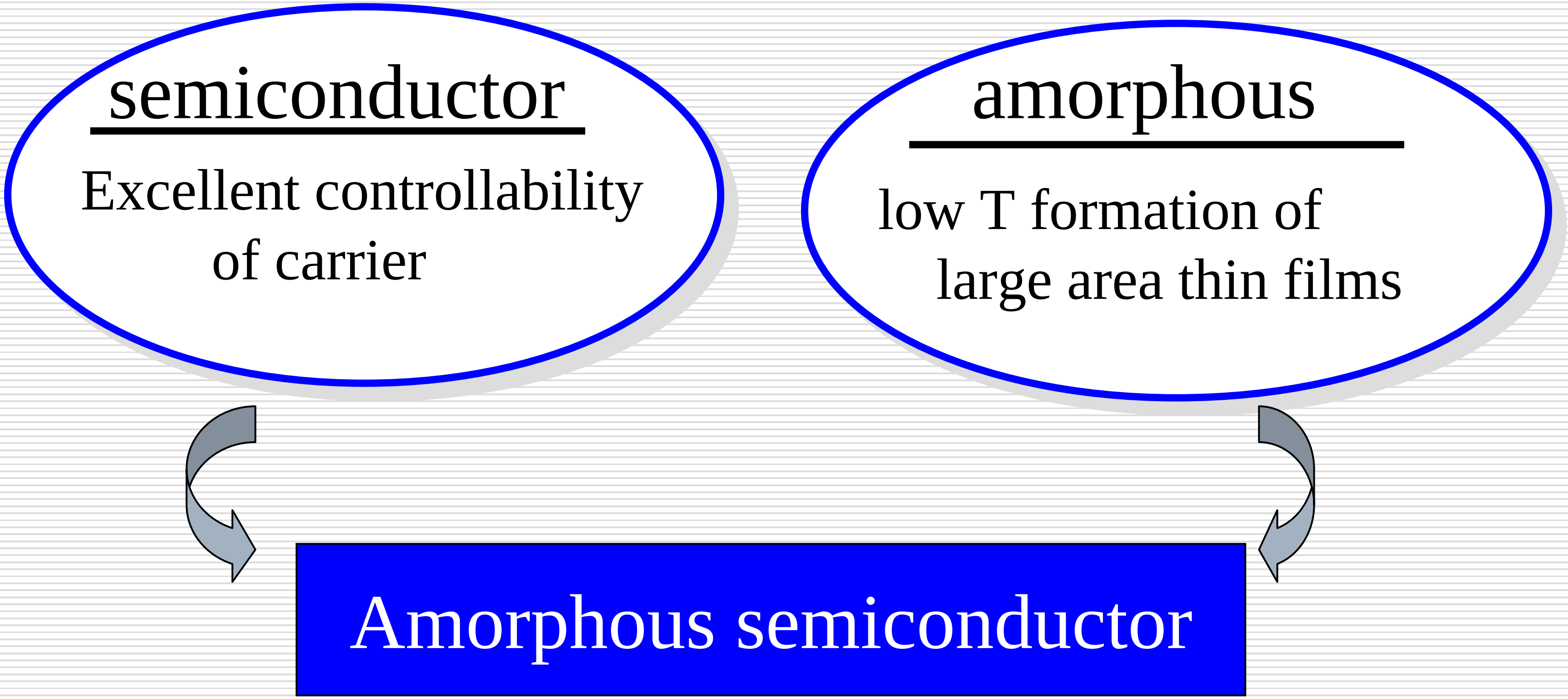
Low mobility
Poor stability

Plastic Logic

Novel Material

Low process temperature
Long-term stability
High mobility

Why amorphous semiconductor



semiconductor

Excellent controllability of carrier

amorphous

low T formation of large area thin films

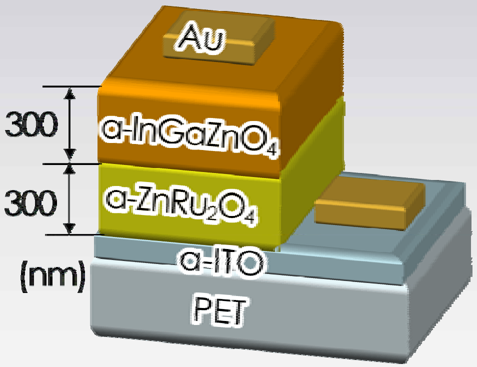
Amorphous semiconductor

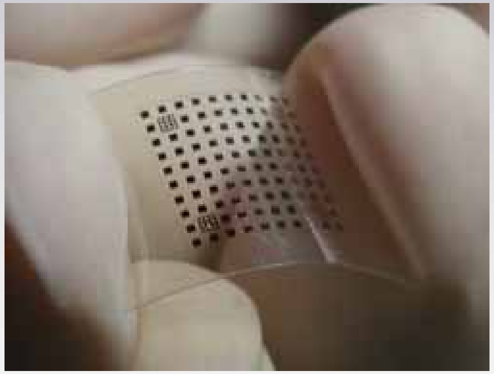
Why Amorphous oxide semiconductor (AOS)?

- Wide controllability of carrier concentration.
- High optical transparency in invisible region.
- Room temperature and large area deposition.
- Unique carrier transport properties

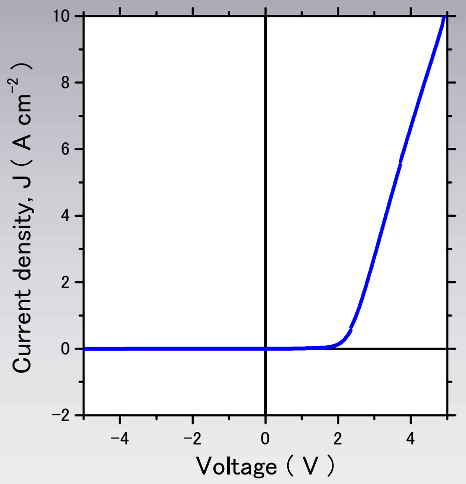
➡ **Transparent & Flexible electronics**

AOSs based flexible *pn* diodes





Adv. Mater. **15**,1409 (2003)



- A rectifying ratio : >10^3
- V_{th} : ~2V

History of amorphous semiconductor

1950. 1960. 1970. 1980. 1990. 2000

Photoconductivity in a-Se(Xerography)

Glassy semicond.(V_2O_5 based oxide)

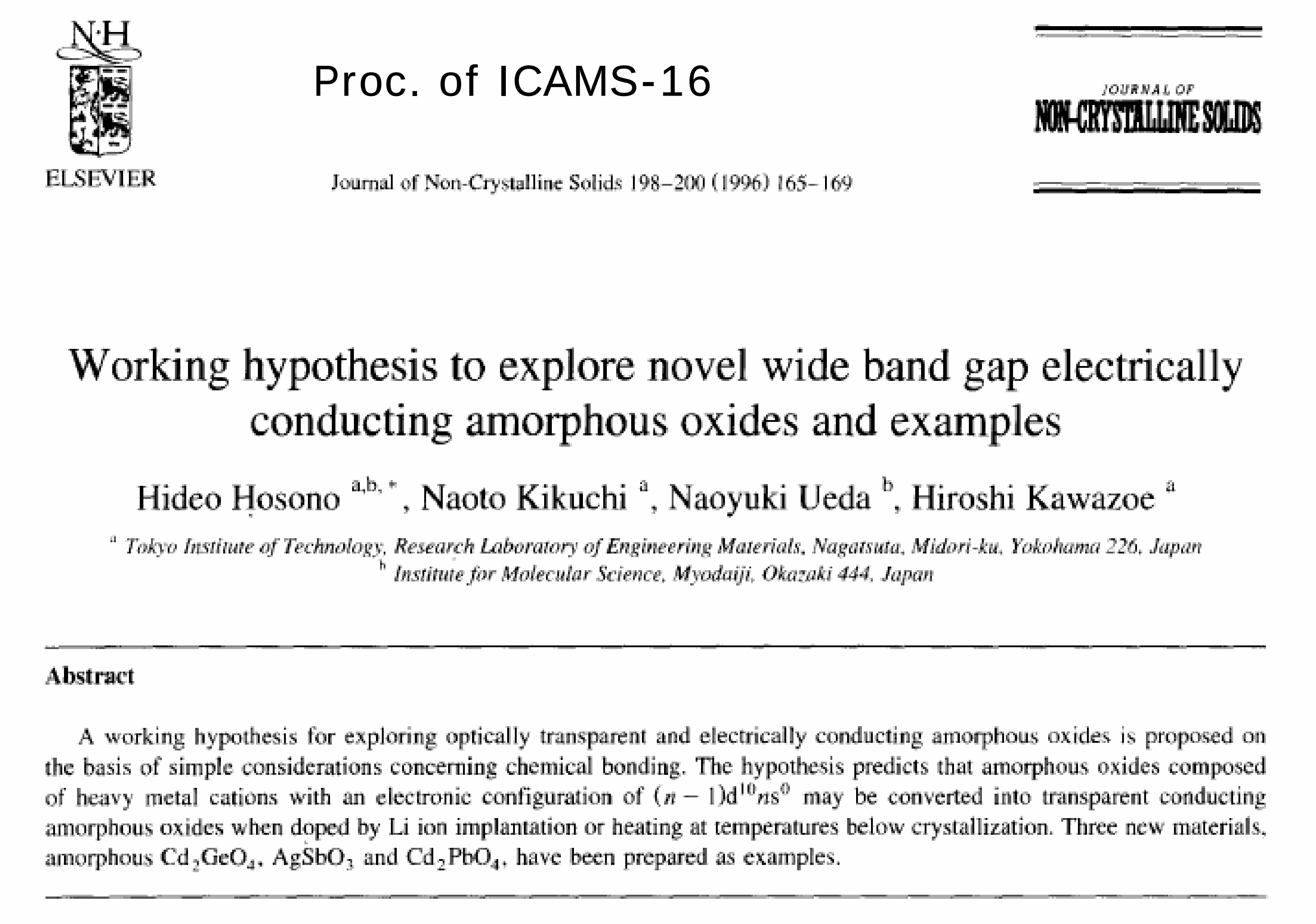
Chalcogenide glass→DVD)

Switching and memory effect in a-chal. film

a-Si:H→‘Giant-Microelectronics’

Flexible electronics
(novel a-sc)

Proposal of materials design concept for a-TAOS with large mobility



Proc. of ICAMS-16

ELSEVIER

Journal of Non-Crystalline Solids 198–200 (1996) 165–169

JOURNAL OF NON-CRYSTALLINE SOLIDS

Working hypothesis to explore novel wide band gap electrically conducting amorphous oxides and examples

Hideo Hosono [a,b,*], Naoto Kikuchi [a], Naoyuki Ueda [b], Hiroshi Kawazoe [a]

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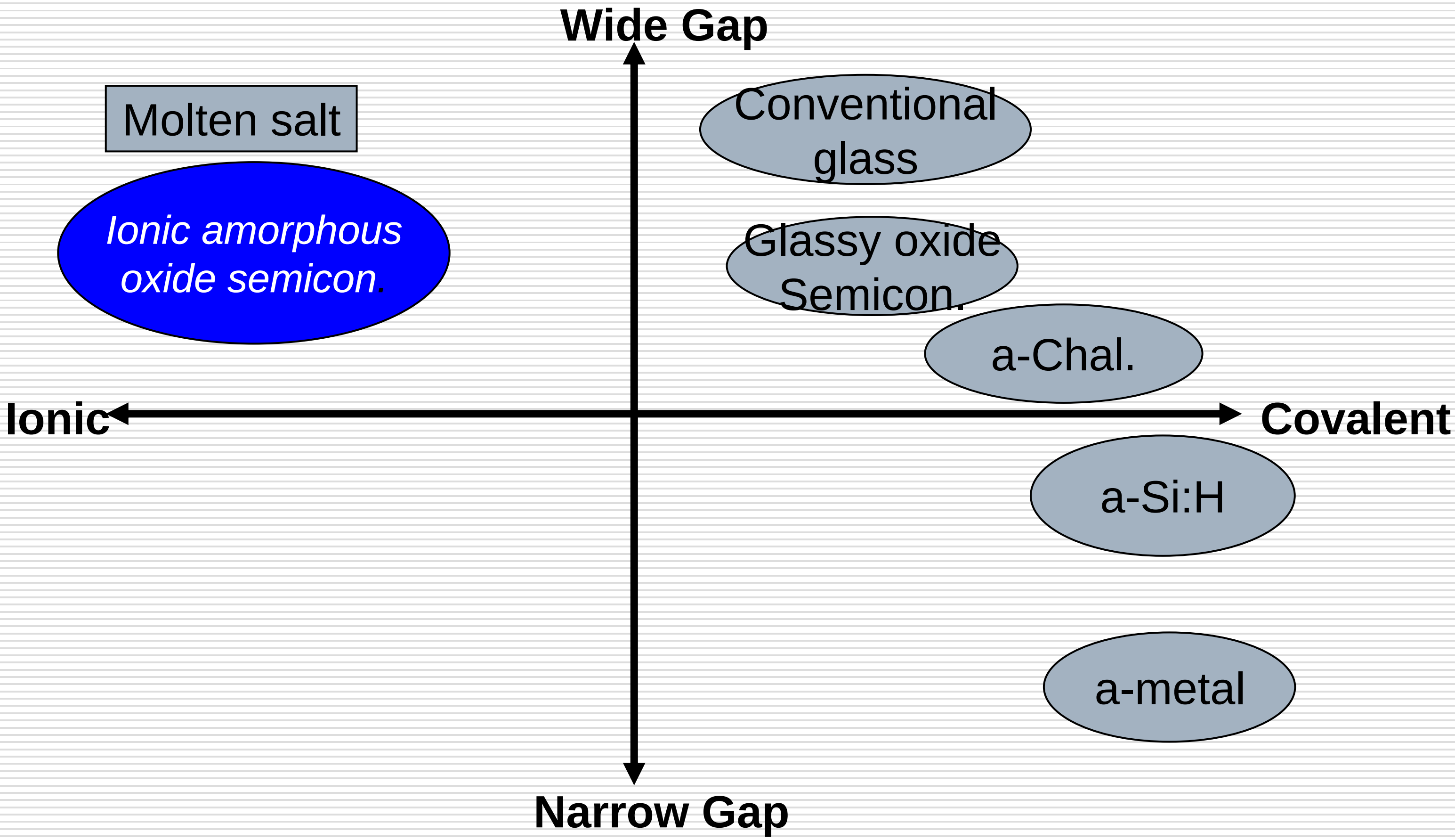
[b] *Institute for Molecular Science, Myodaiji, Okazaki 444, Japan*

Abstract

A working hypothesis for exploring optically transparent and electrically conducting amorphous oxides is proposed on the basis of simple considerations concerning chemical bonding. The hypothesis predicts that amorphous oxides composed of heavy metal cations with an electronic configuration of $(n-1)d^{10}ns^0$ may be converted into transparent conducting amorphous oxides when doped by Li ion implantation or heating at temperatures below crystallization. Three new materials, amorphous Cd_2GeO_4, $AgSbO_3$ and Cd_2PbO_4, have been prepared as examples.

Ionic Amorphous Oxide Semiconductor : novel class of a-Semicon.



Wide Gap

Molten salt

Ionic amorphous oxide semicon.

Conventional glass

Glassy oxide Semicon.

a-Chal.

Ionic

Covalent

a-Si:H

a-metal

Narrow Gap

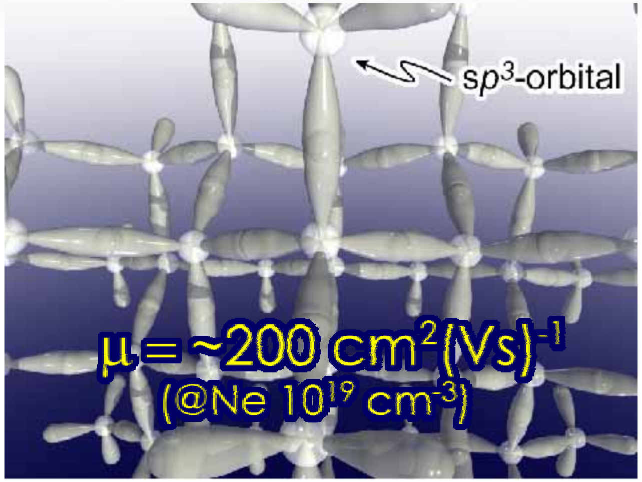
Material design concept (electron pathway)

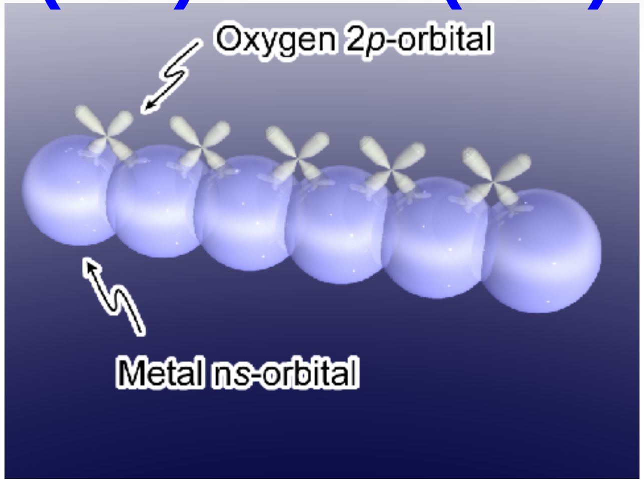
covalent semicon.

ionic oxide semicon.

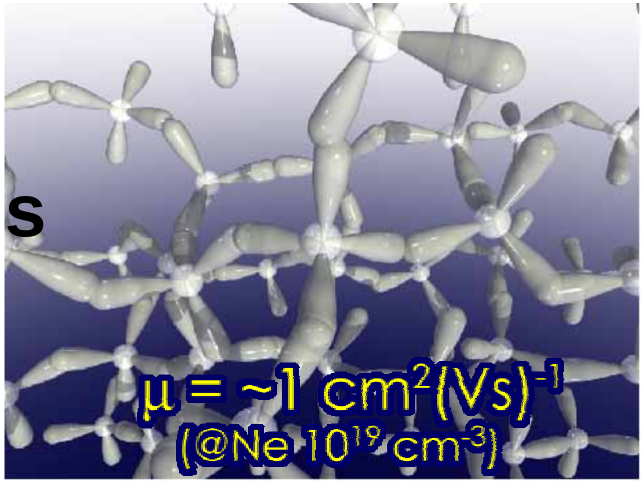
M:(n-1)d^{10}ns^{0} (n≥4)

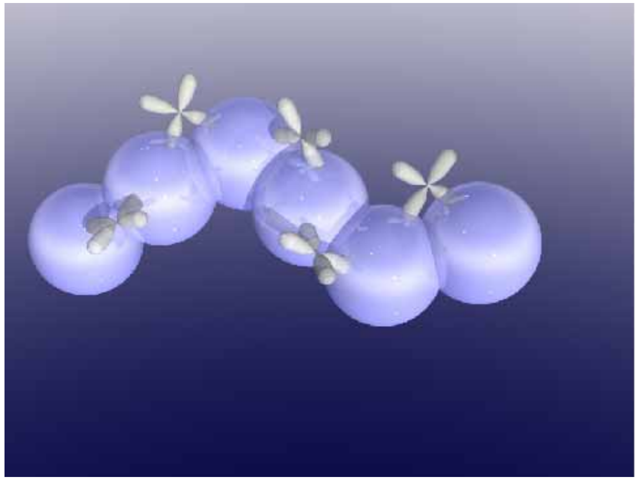
crystal





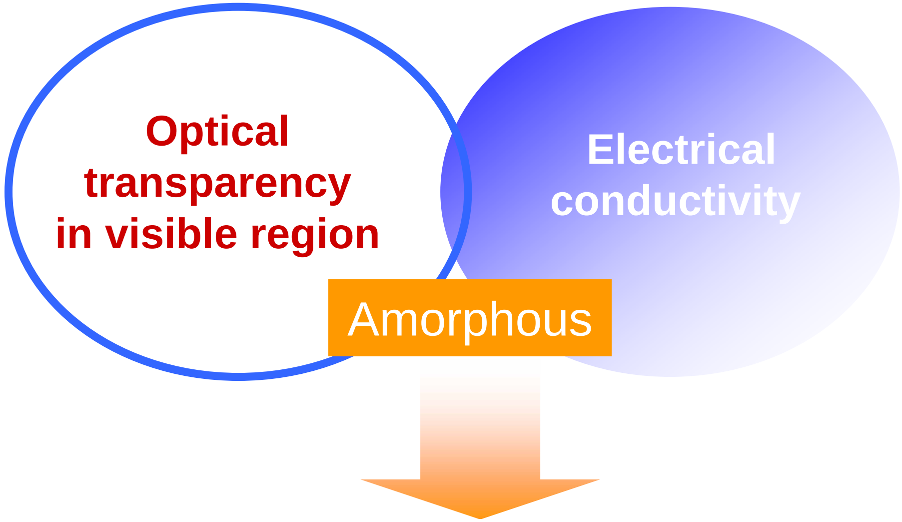
amorphous





JNCS(1996)

Ionic amorphous oxide semiconductors （N-type）



Transparent amorphous oxide semiconductors

e.g. a-2CdO·GeO$_2$, a-CdO·PbO$_x$, a-AgSbO$_3$, a-InGaO$_3$(ZnO)$_m$

(found in1995-2001)

a-In$_2$O$_3$:Sn

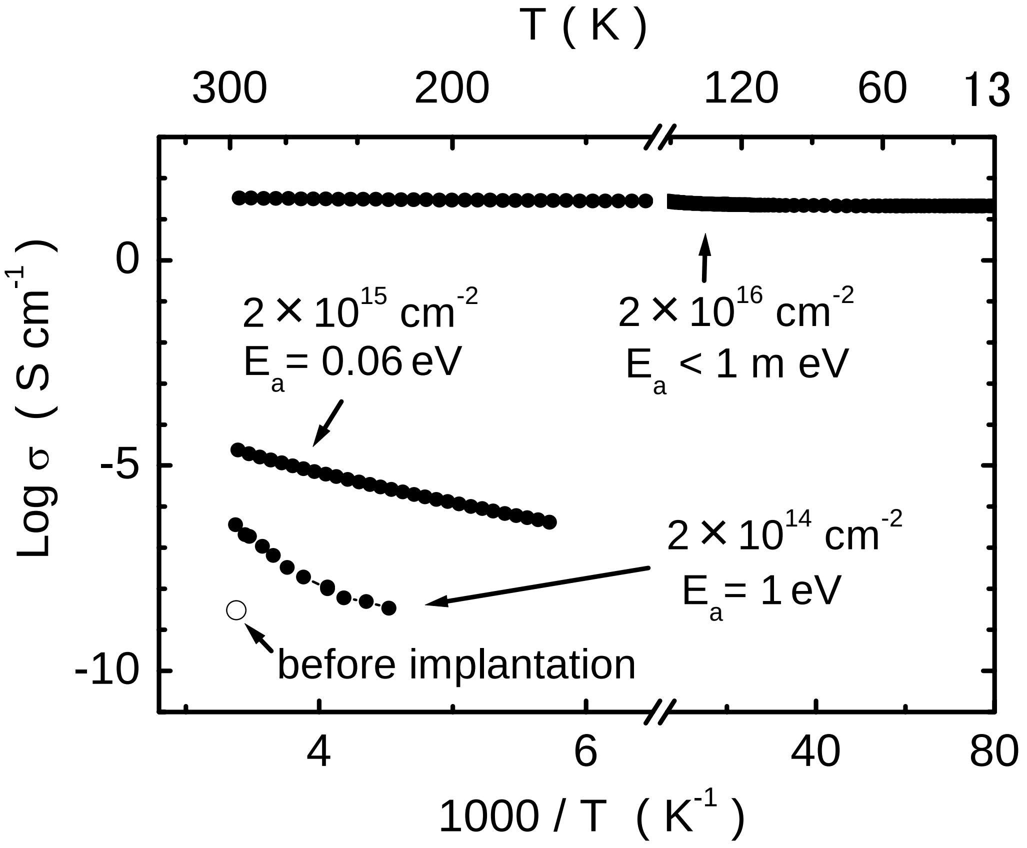
Advantages

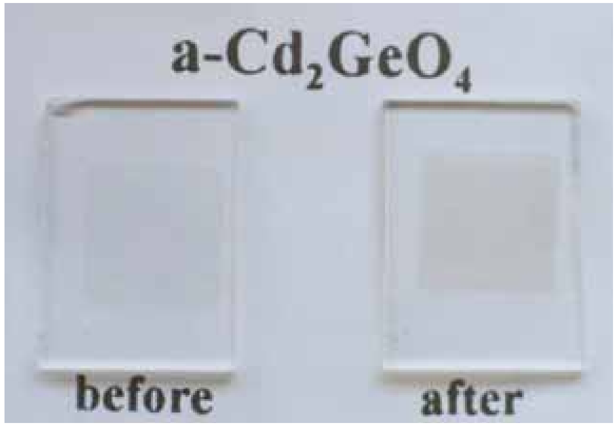
- ･Low temperature deposition ⇒ flexible electronic device
- ･No long range ordering ⇒ reduction of severe requirements for PN-junction
- ･Large electron mobility compared to the conventional a-semiconductors.

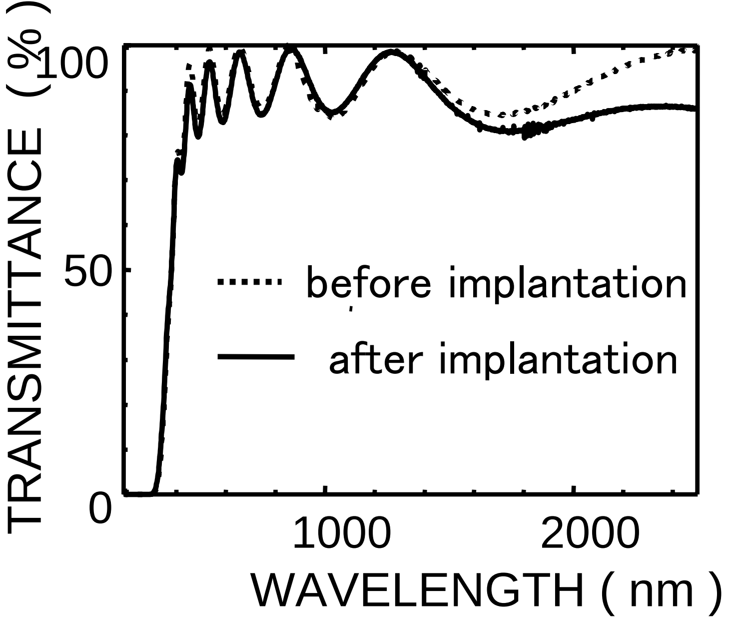
Conductivity change upon H^+- implantation

H^+:40kV+70kV

Sample: sputtered thin film(300nm^t)





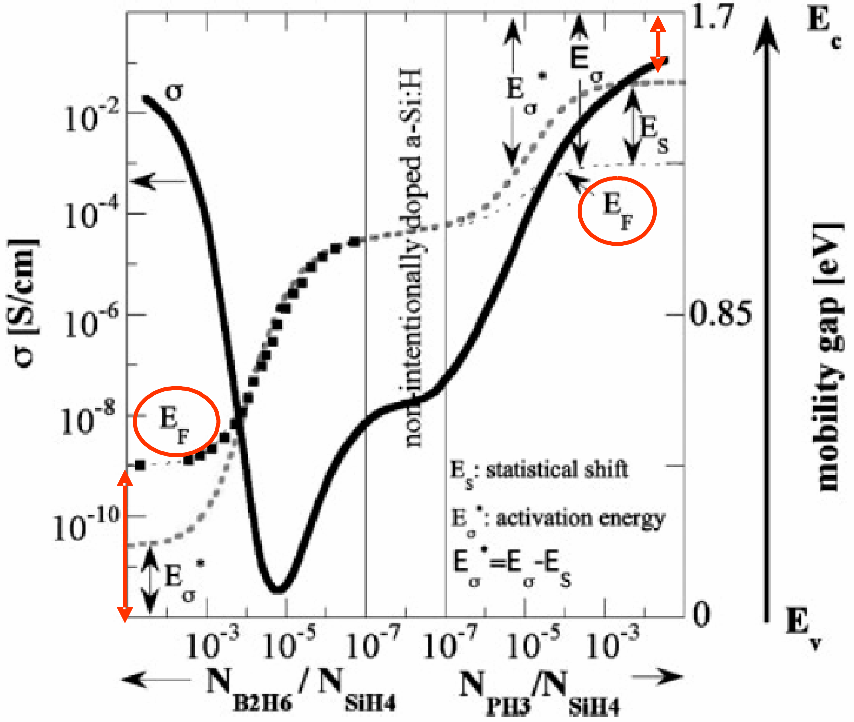


E_F is continuously controllable from
~$E_g/2$ to above mobility gap

A Mobility amorphous 15 cm^2(Vs)$^{-1}$ cf. crystal 20cm^2(Vs)$^{-1}$

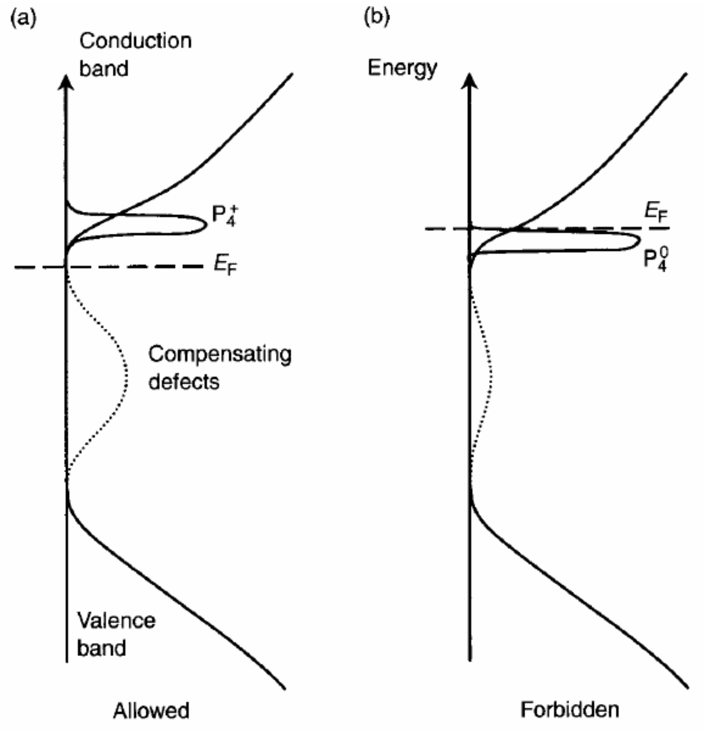
APL(1995)

a-Si:H doping limit



E_F cannot exceed mobility gap

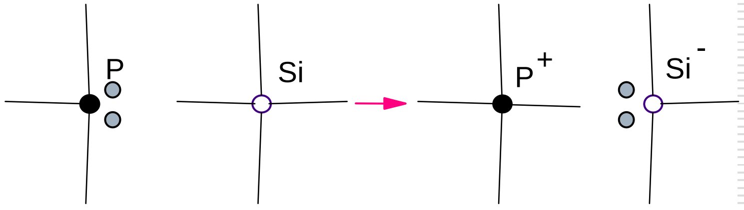
Why doping is inefficient for a-Si:H ?



E_F never enters conduction band extended states by doping

$P_3^0 + Si_4^0 \rightarrow P_4^+ + Si_3^-$

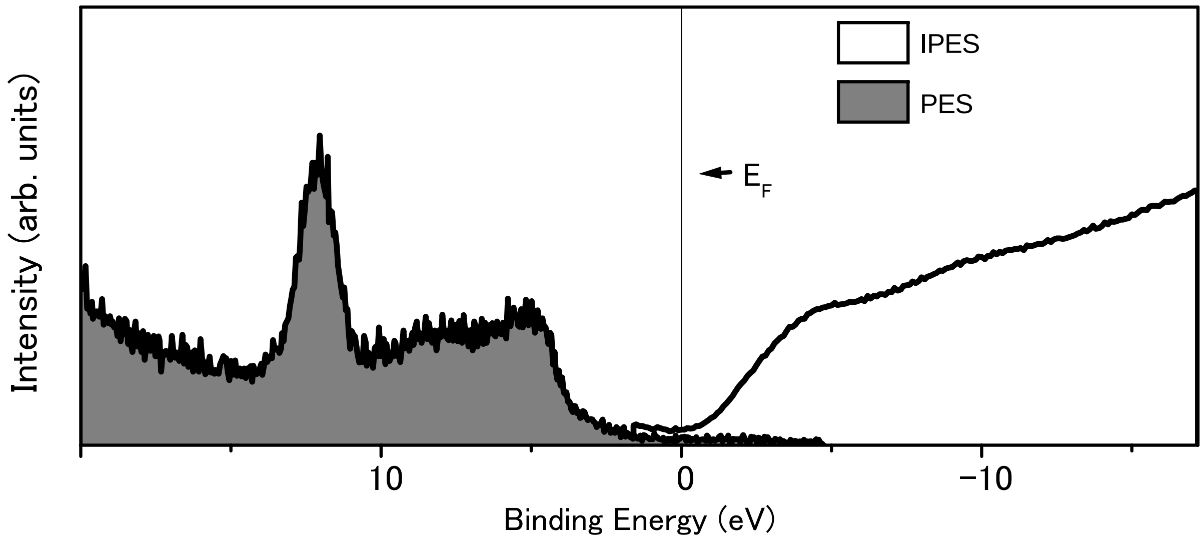
Doping creates D^- state

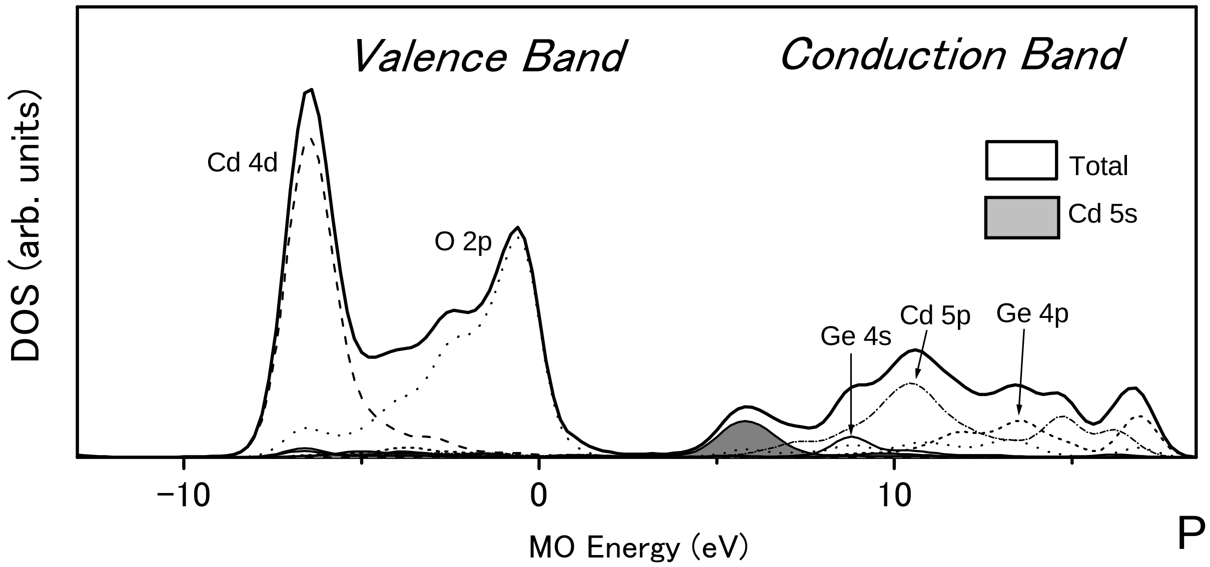


Carriers are NOT generated

Mott-Street model

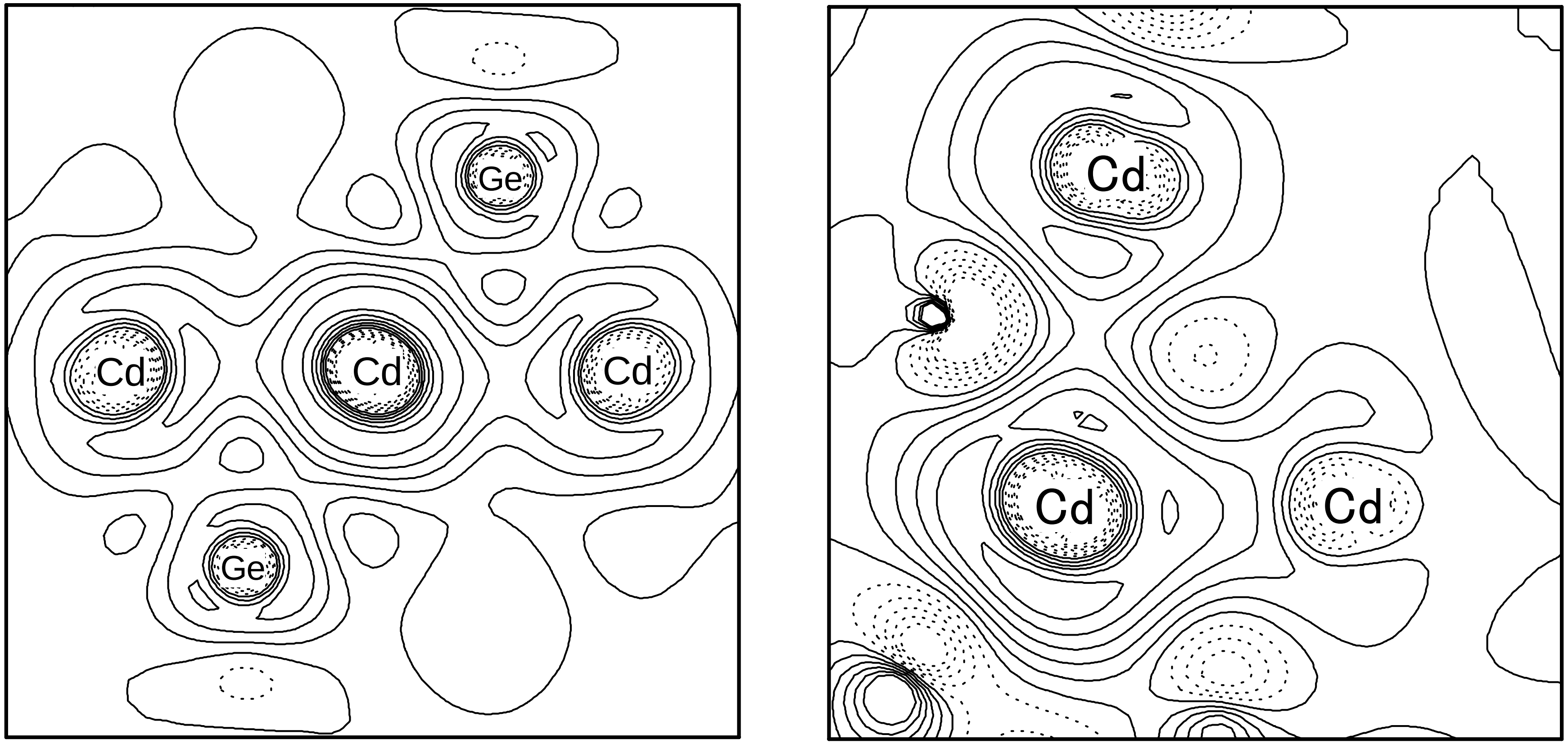
Observed and calculated DOS





Phys.Rev.B(2002)

Contour map of wave function @ conduction band bottom

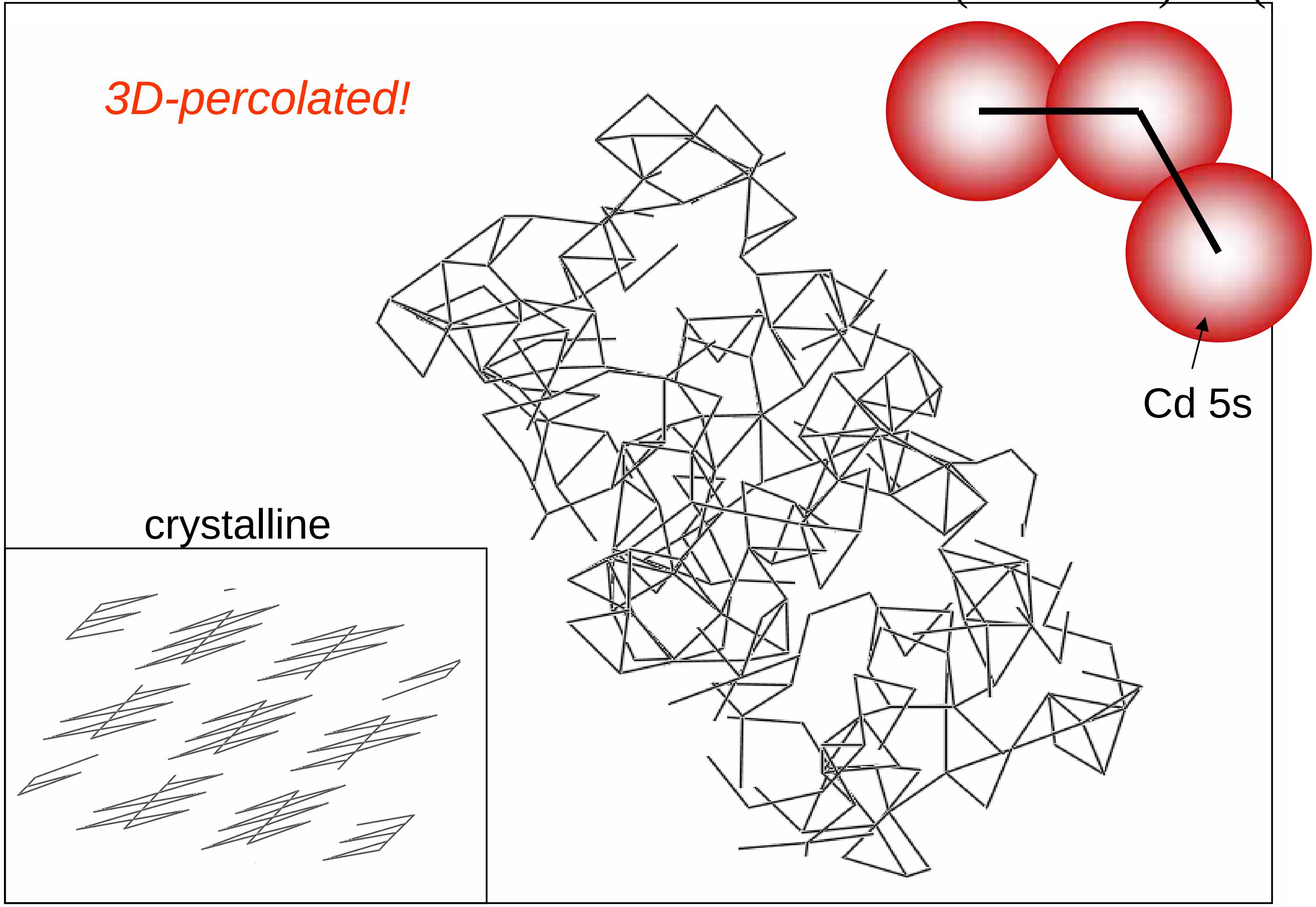


(a) crystalline

(b) amorphous

Cd-Cd correlations in RMC-fitted model

$$d(Cd^{2+}\text{-}Cd^{2+}) < 2r(\text{Cd 5s})$$



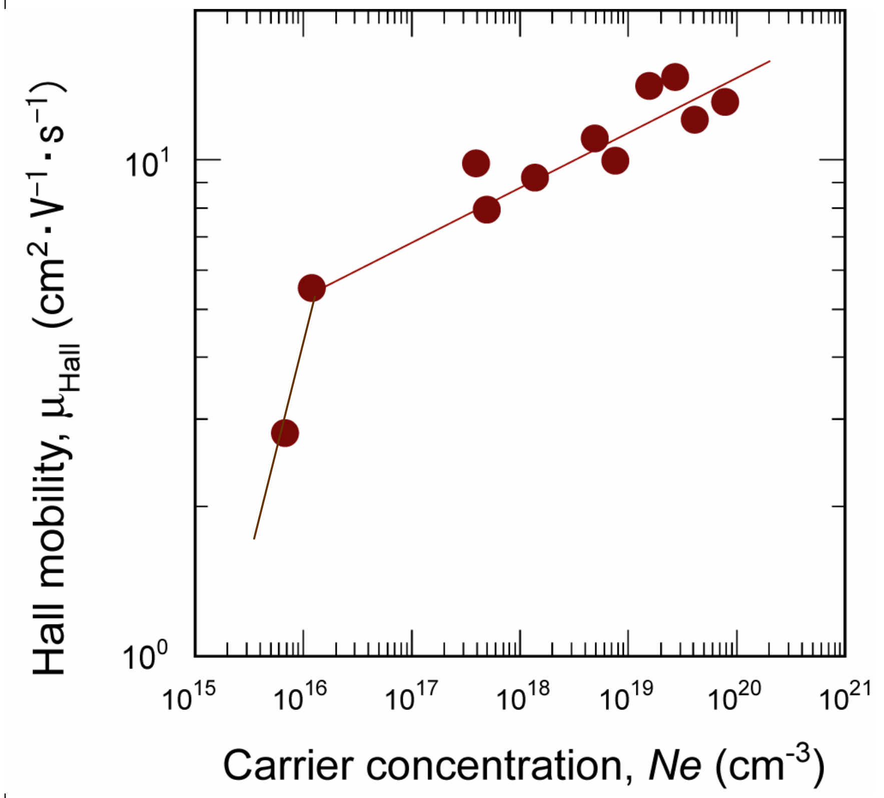
3D-percolated!

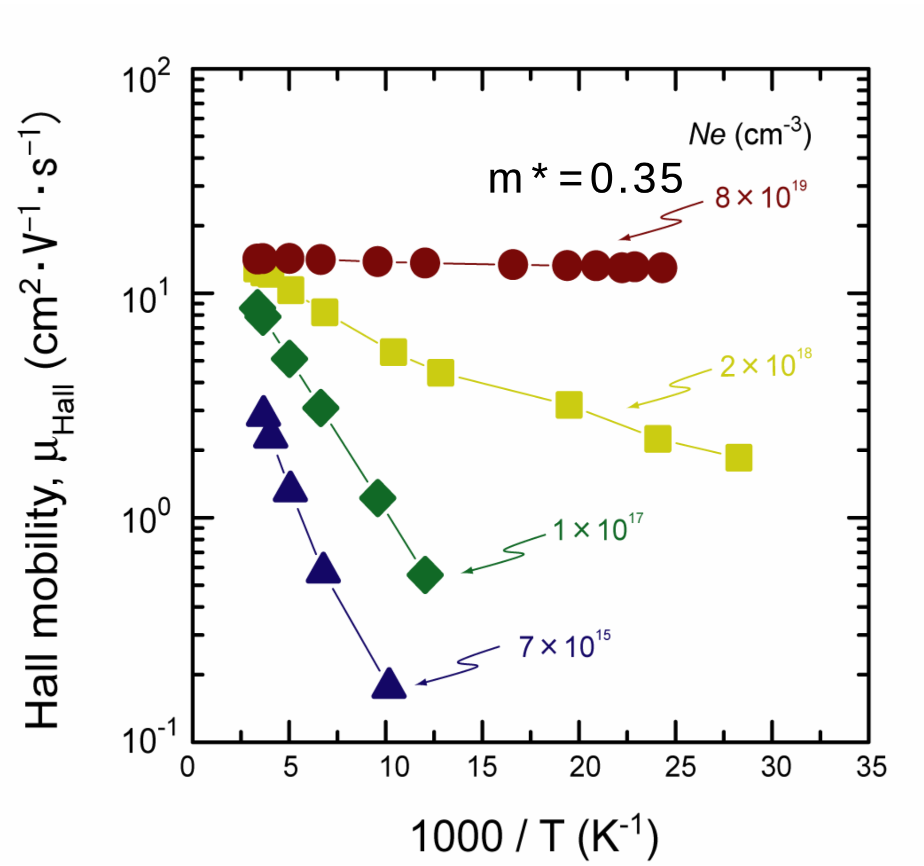
crystalline

Cd 5s

PRB(2002)

Electron Transport in a-IGZO

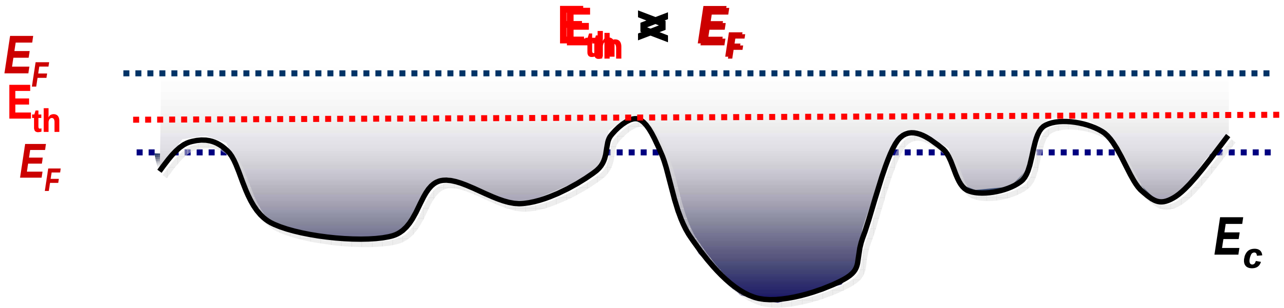




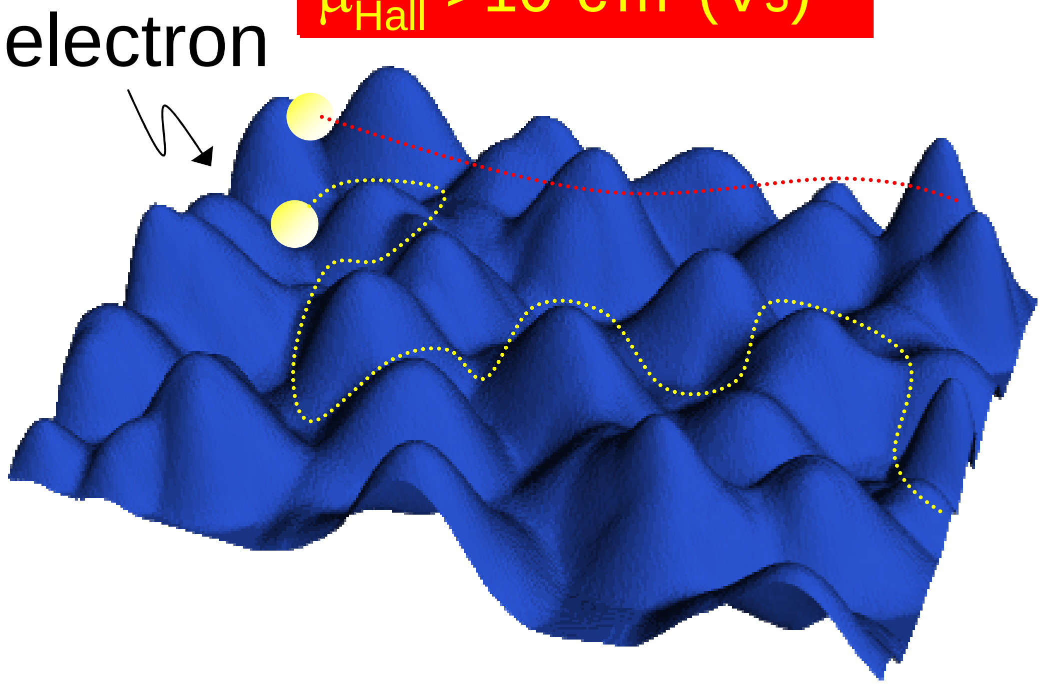
APL(2004)

Carrier Concentration and conduction

$N_e > 10^{18}\ cm^{-3}$



$\mu_{Hall} > 10\ cm^2(Vs)^{-1}$



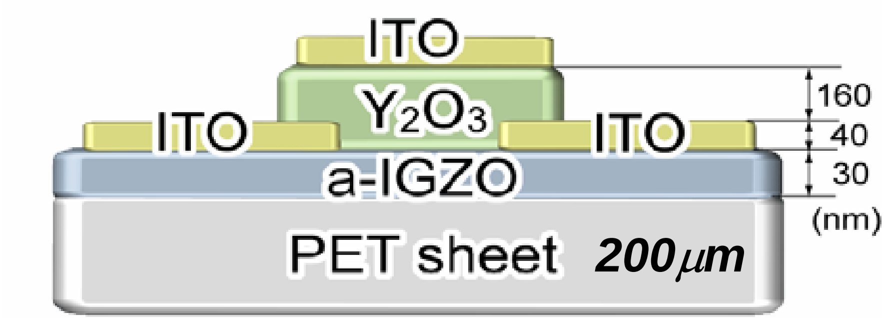
APL(2004),TSF(2005).

Ionic Amorphous Oxide Semicon.

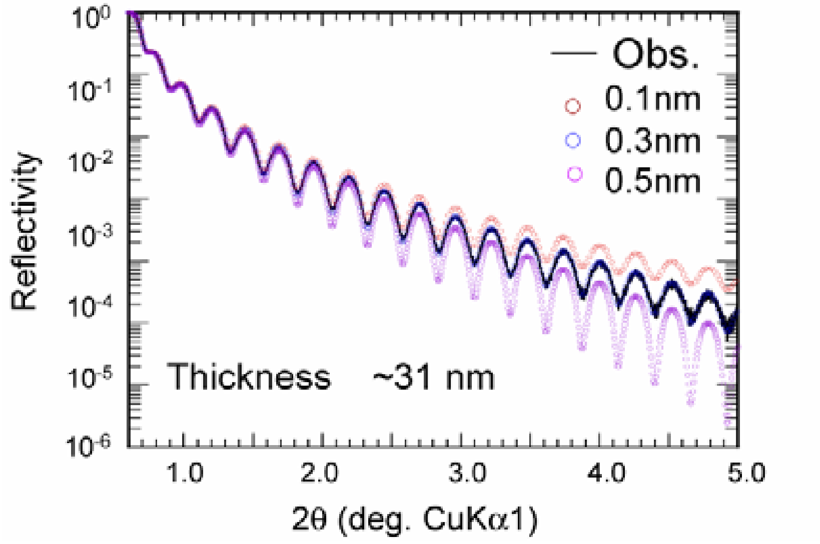
Material system	**Chemical bond**	**Mecha-nism**	**Hall effect**	**Mobility ($cm^2/(Vs)$)**	**Example**
Tetrahedral	covalent	hopping	abnormal	~1	Si:H
Chalcogenide	covalent	hopping	abnormal	$< 10^{-3}$	Tl_2Se-As_2Se_3
Oxides (glass semiconductors）	covalent + Ionic	hopping		$\sim 10^{-4}$	V_2O_5-P_2O_5
(Ionic amorphous oxide semicondutors)	Ionic	Band condu-ction	normal	10~60	In-Ga-Zn-O

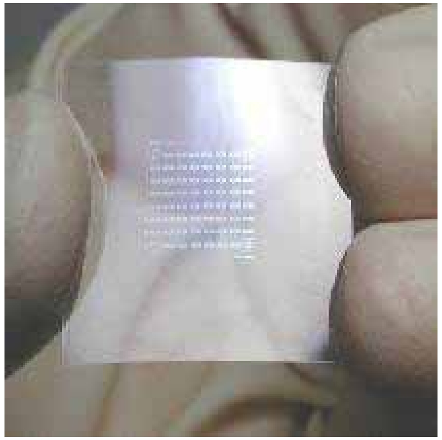
Transparent FET on plastic

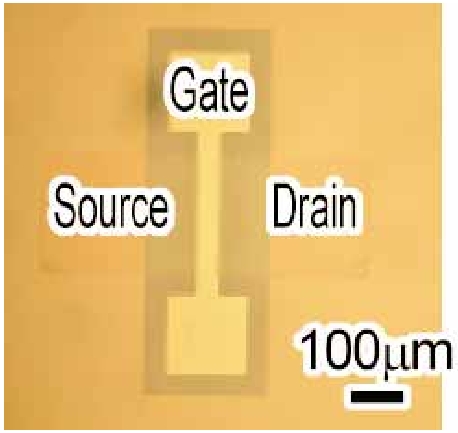
Device structure



(no passivation)



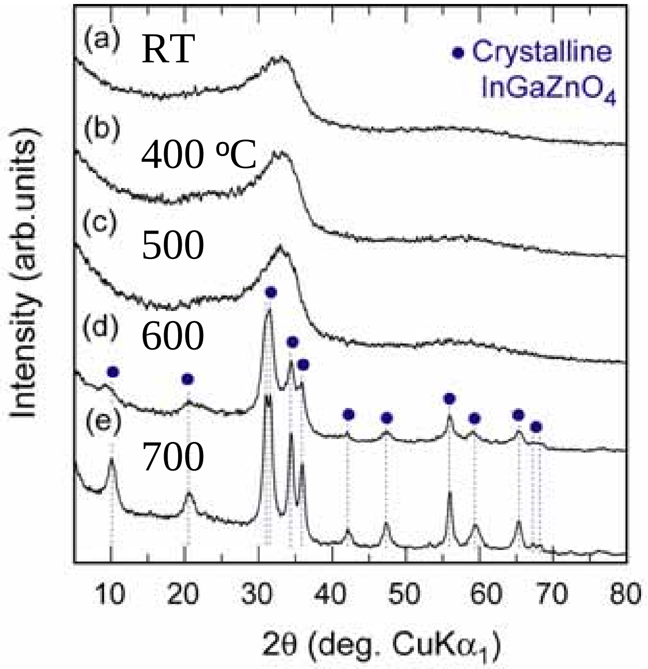


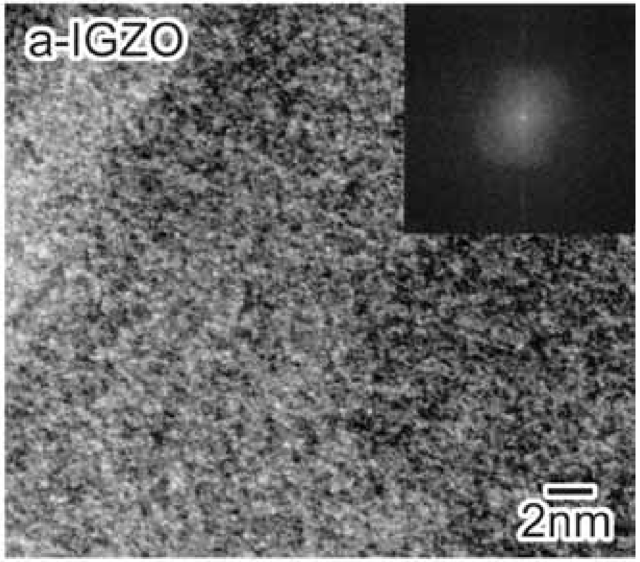


W / L : 200 / 50 (μm)

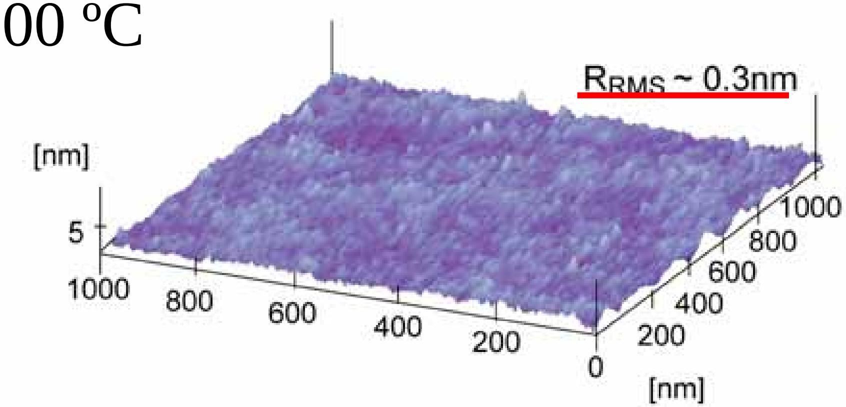
Amorphous $InGaZnO_4$ Thin Fims

t=200nm thick
Pulsed Laser deposition @ RT





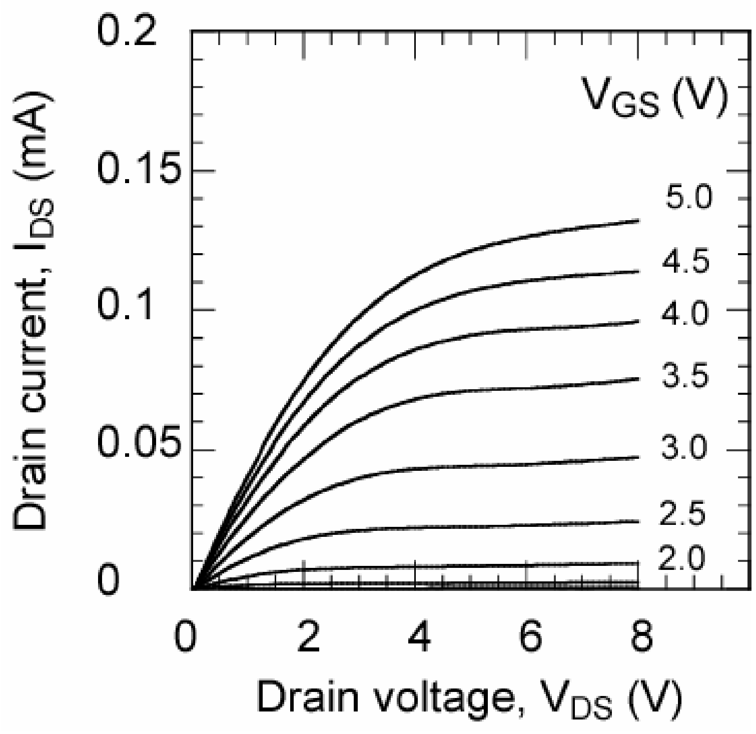
Stable up to ~500 ºC



Transistor Performance

output

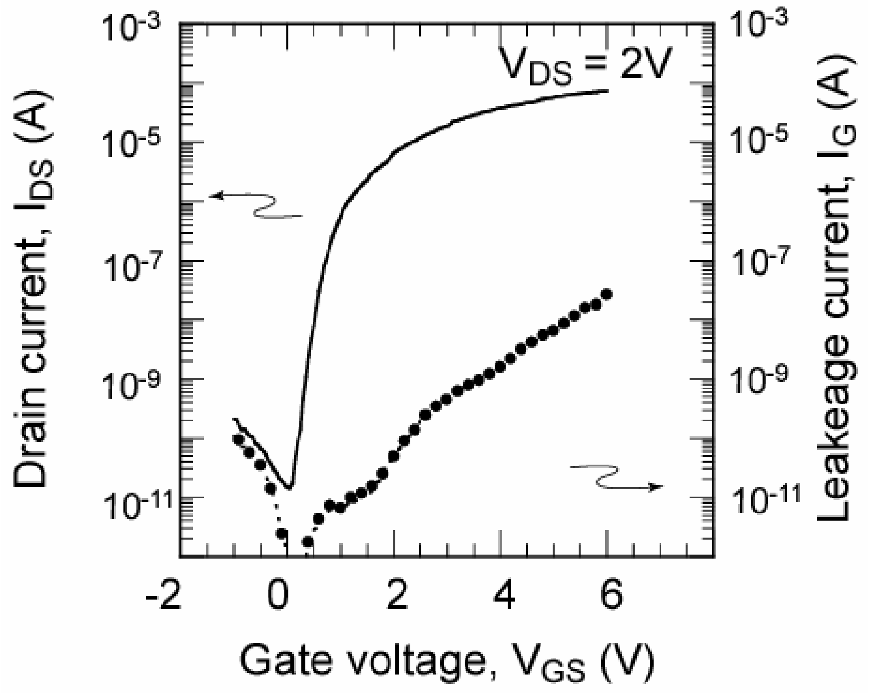
μ_{sat} = 12 cm^2(Vs)$^{-1}$



W / L : 200 / 10 (μm)

transfer

ON/OFF ratio =10^6



Nature(2004)

High performance transparent FET was fabricated on PET substrate

☐ Material exploration

High mobility & carrier controllability

➡ N-type AOS, In-Ga-Zn-O (a-IGZO)

$\mu_{Hall} > 15\ cm^2 (Vs)^{-1}$: $Ne < 10^{15}$ - $10^{21}\ cm^{-3}$

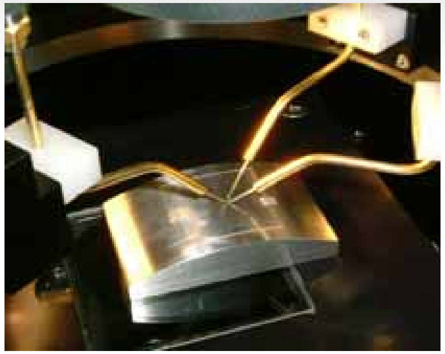
☐ Carrier transport

➡ Localized to extended state

$> 10\ cm^2 (Vs)^{-1}$ @$Ne > 10^{18}\ cm^{-3}$

☐ Device fabrication

➡ Y_2O_x (high k) as gate insulator & RT



☐ μ_{sat} ~ 12 $cm^2 (Vs)^{-1}$
cf. ~1 for a-Si:H, pentacene
c

☐ fON / OFF ratio ~10^6

☐ Normally-Off (V_{th} ~+1 V)

☐ S = ~0.2 V/dec

a-IGZO can be deposited on plastic by the same process as ITO

⇨ ***Large process merit***

Current Status of TFT for Elexible Displays

Channel material	**Pentacene**	a-Si:H	Poly-ZnO	**a-IGZO**
Thin Film Fabrication	Vacuum Evap.	CVD	PLD	**sputter**
Max. Tem.(℃)	<100	300	300	**RT**
Mobility($cm^2V^{-1}s^{-1}$)	0.5	0.5	～5	**～12**
Current ON/OFF ($\log_{10}$)	5～6	>6	～5	**～8**
S (V/decade)	0.2	0.4	1.3	**0.2**

Long Term Stability

- Spec for Large-sized OLED TV Panel

SID2006

70.1: ***Invited Paper:*** **Large-Sized Full Color AMOLED TV : Advancements and Issues**

Kyuha Chung, Namdeog Kim, Joonhoo Choi, Changwoong Chu and Jong-moo Huh

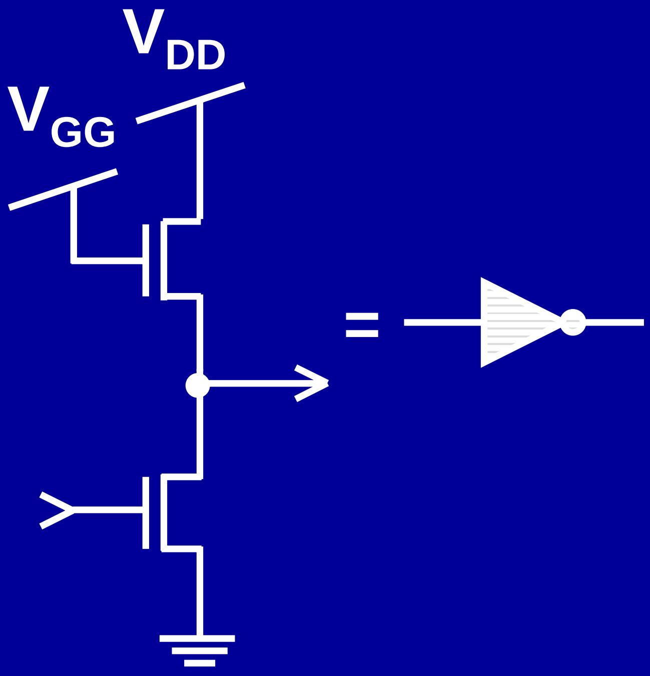
OLED Development Team, LCD Business, Samsung Electronics Co., Ltd., Kyunggi-do, Korea

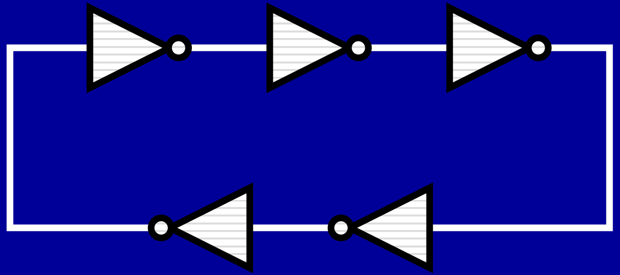
μ_{FE}	1-10 cm^2/Vs
ΔV_{TH}	< 1 V for 10^5 hrs

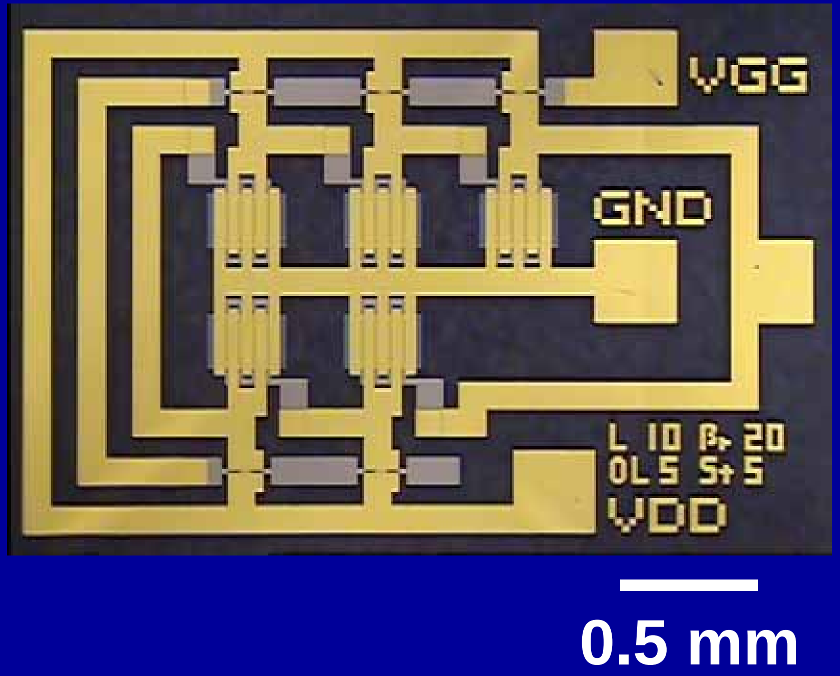
- **Long Team Stabilty Test(SAIT)**@E – MRS2006

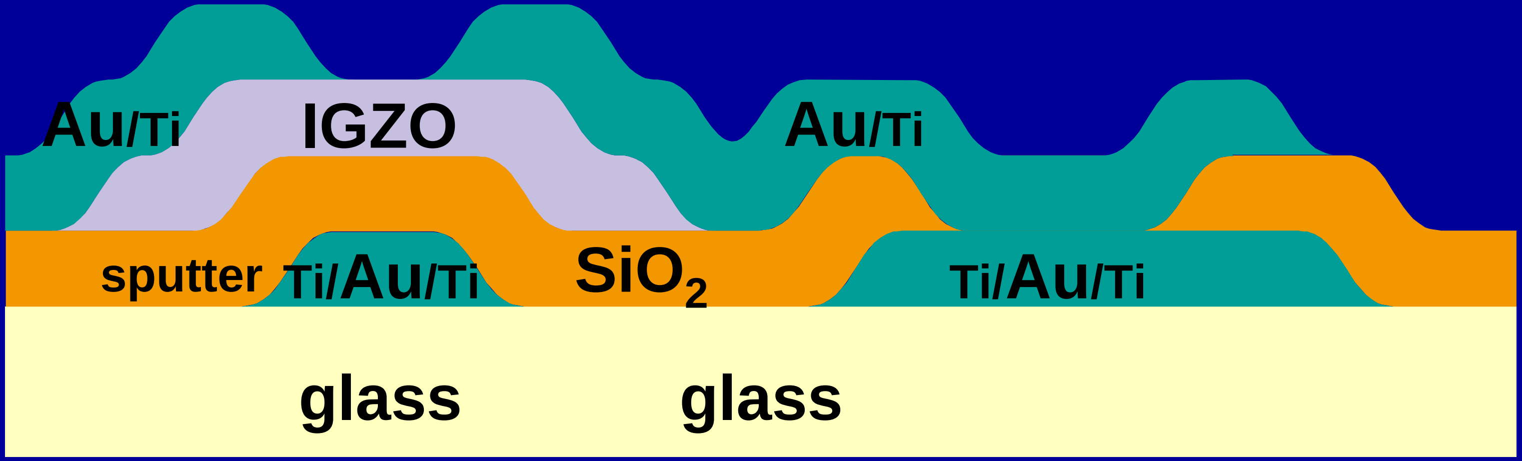
W/L=200/4 μm, 3 μA/Pixel x 300hrs			
Active Layer	ZnO	IZO	IGZO
ΔV_{TH} (V)	5.0	3.0	0.2

5-stage RO







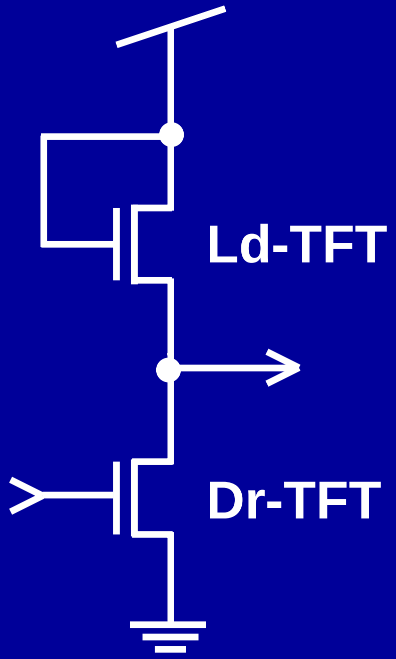


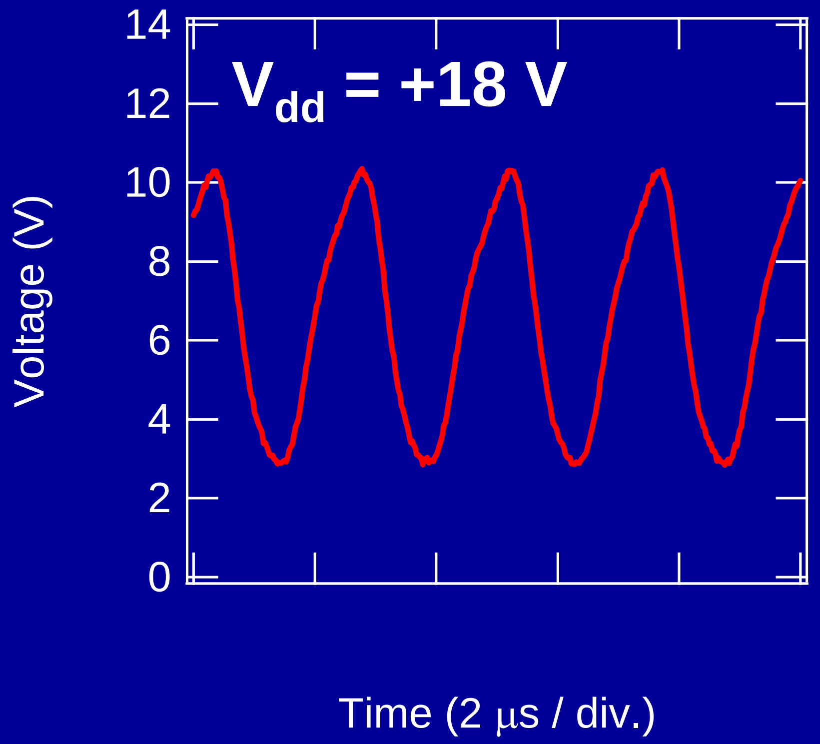
patterning

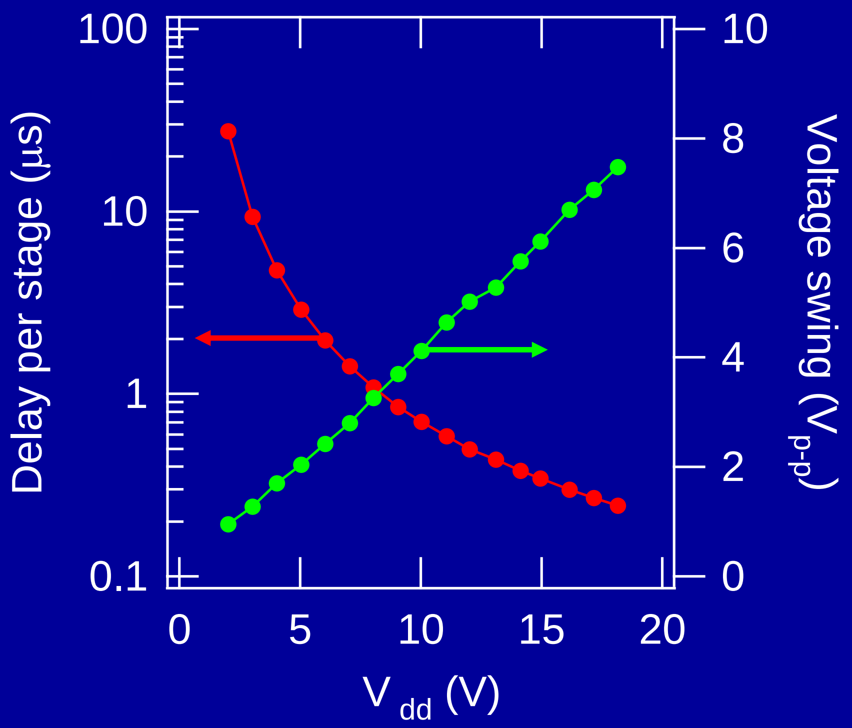
metals	lift-off
semiconductor	etching
insulator	etching

$$L_{\mathrm{Ld}} = L_{\mathrm{Dr}} = 10\ \mu\mathrm{m}$$

$$\beta_{\mathrm{R}} = (W\,/\,L)_{\mathrm{Dr}}\,/\,(W\,/\,L)_{\mathrm{Ld}} = 5$$





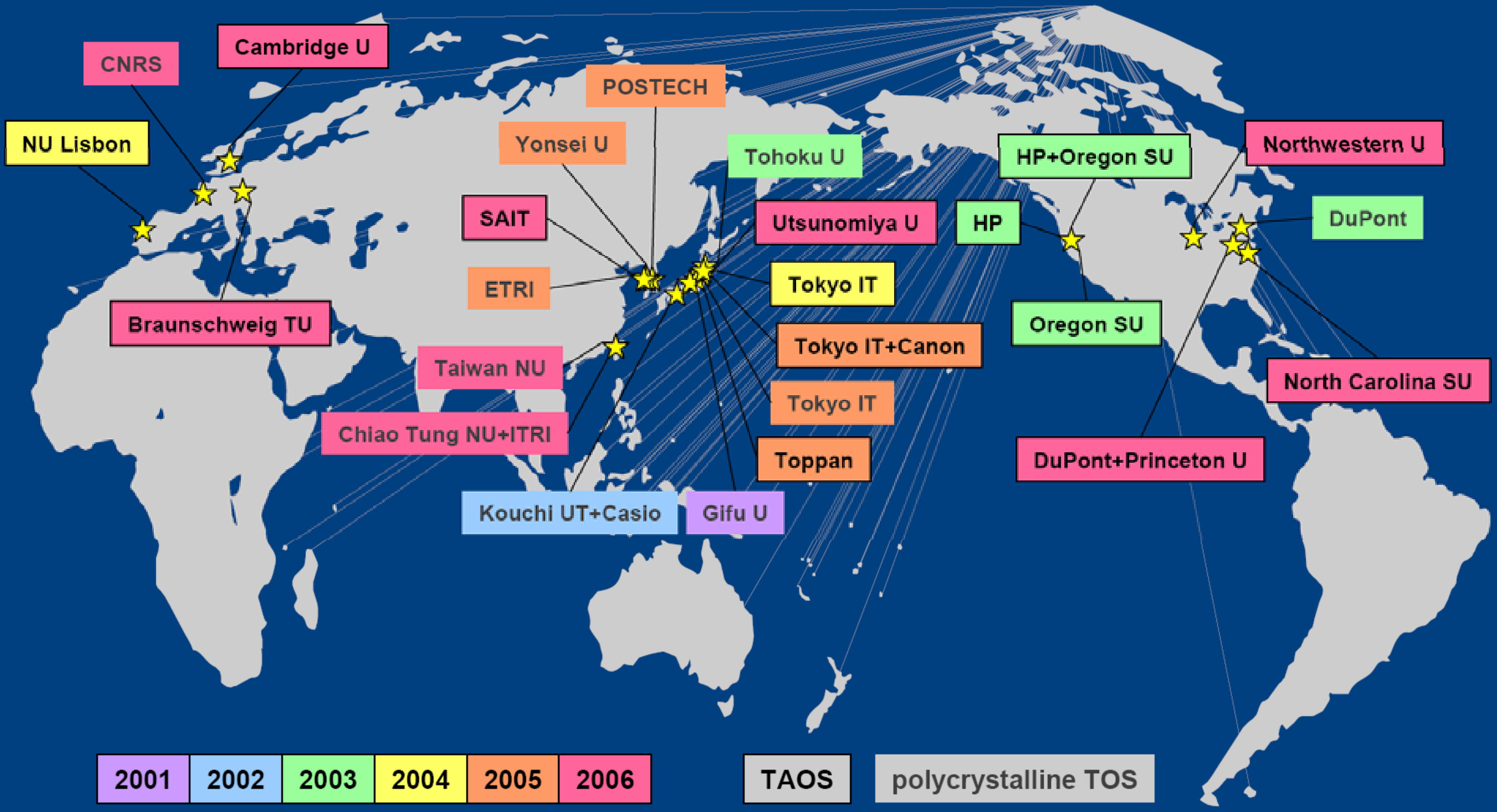


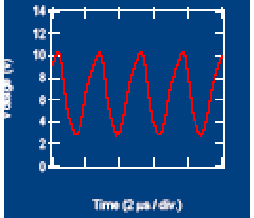
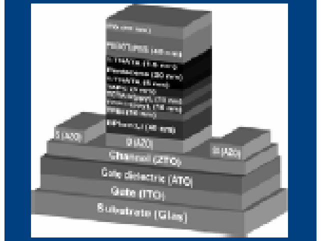
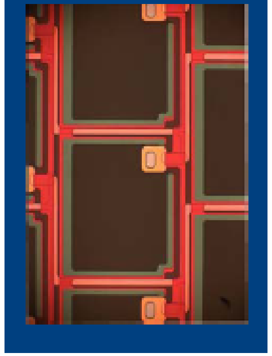
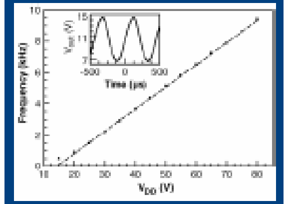
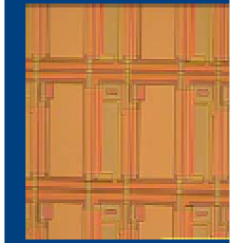
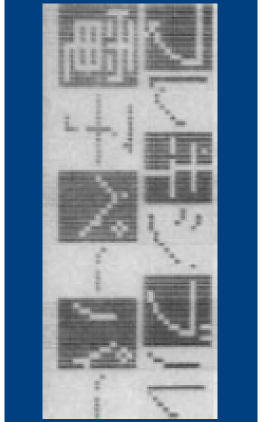
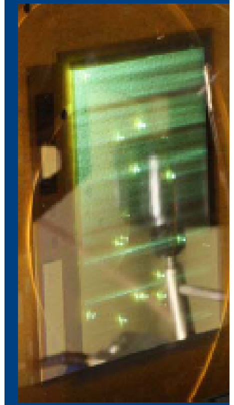
410 kHz (0.24 μs/stage), 7.5 V_{p-p}
@ V_{dd} = +18 (V)

amorphous/oxide TFT-based Ring Oscillators

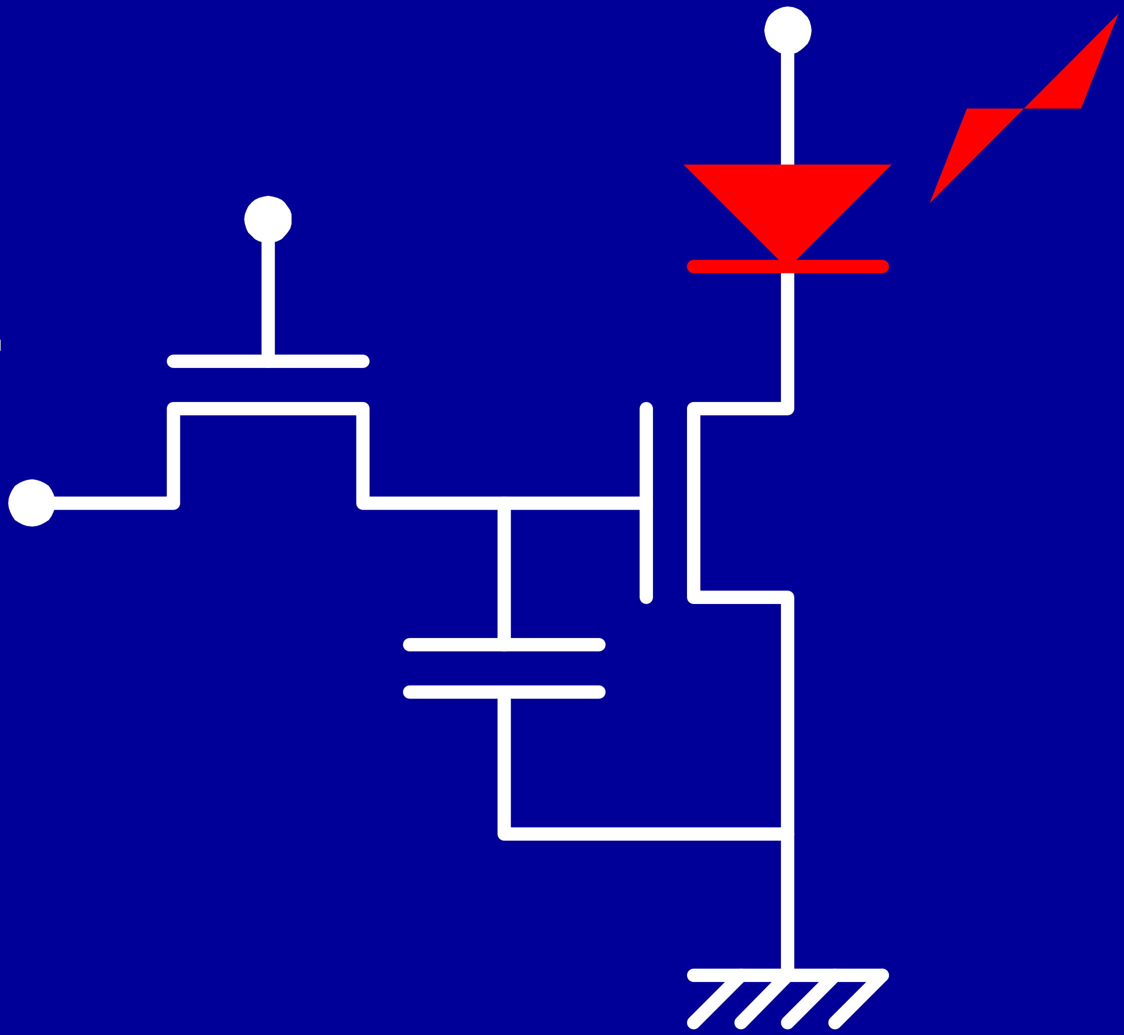
	a-Si:H	Organic	Oxide	
		P3HT	IGO	*a*-IGZO
L (μm)	5	2 – 5	60	?
V_{DD} (V)	+30	-80	+80	?
f_{OSC} (kHz)	83	106	9.5	?
Δt(μs/stage)	0.54	0.68	11	?
Ref.	EDL 5, 224 (1984)	APL 81, 1735 (2002)	SSE 50, 500 (2006)	

Worldwide T(A)OS-TFT Activities



	TIT Canon	Toppan	Braunschweig TU	Kochi IT Casio	HP Oregon SU	ETRI
mateials	IGZO	IGZO	ZTO	ZnO	IGO	ZnO
circuits/ devices	RO 	AM swich 1T (1C) ?	stacked OLED 	AM 	RO 	AM 
FPD application	AMOLED 	AM-ePaper 	stacked OLED 	AM-LCD 	-	AM-OLED 

OLED
monolithic
2Tr-1C
pixel driver



3.5’ OLED using TAOS-FET Backplane

Table 1 Specification of OLED panel driven by IGZO TFTs

Display size	3.5 inch diagonal
Resolution	176 (x 3) x 220
Display device	Top emission OLED
TFT	IGZO (W/L=10 μm /20 μm)

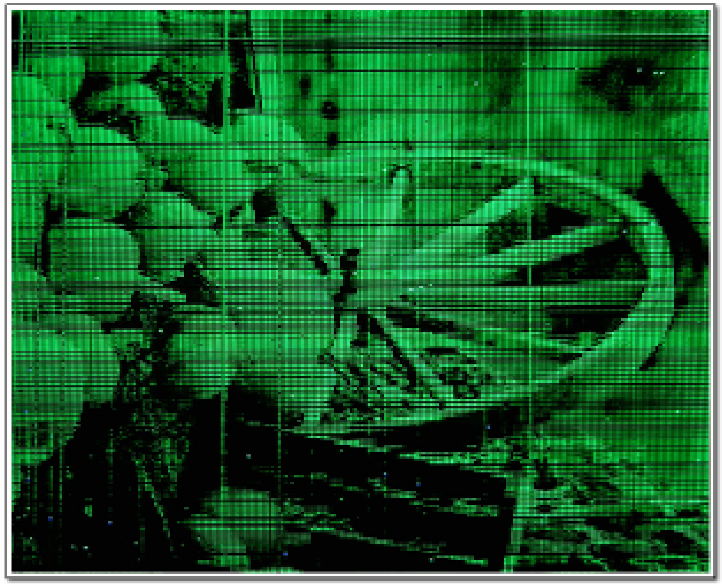
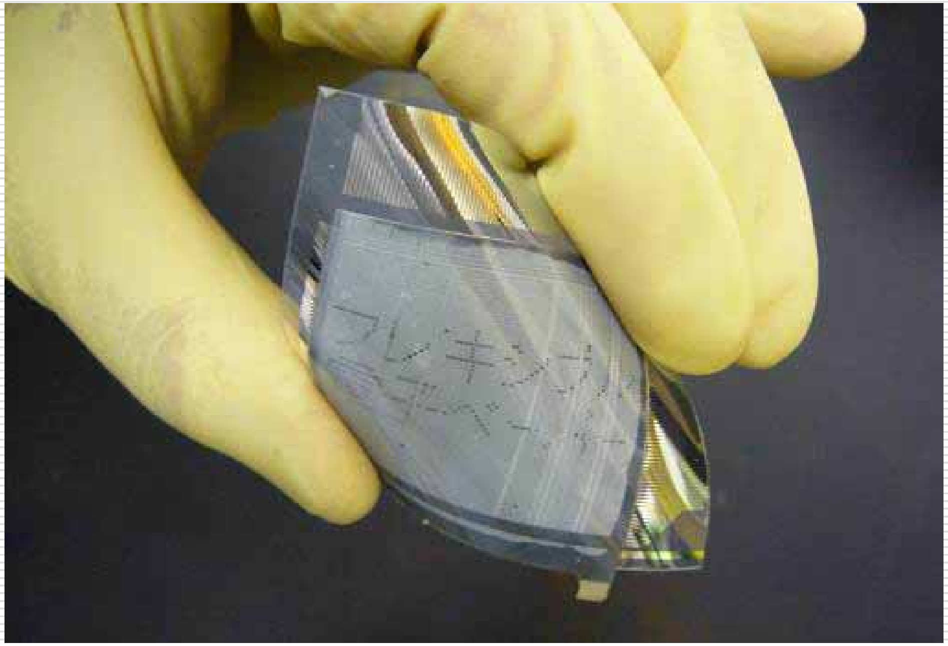


Fig. 8 Operation image of AM-OLED driven by IGZO TFTs

Gate insulator; Si_3N_4

LG (IDW ‘06)

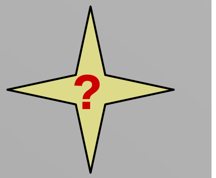
Images of Flexible Electrophoretic Displays Driven with a-IGZO TFT Array



Thickness : 320 μm
Weight : 1.3 g

Electrophoretic imaging film supplied by E·INK

Toward New Continent of Transparent Oxide Electronics



Flexible displays