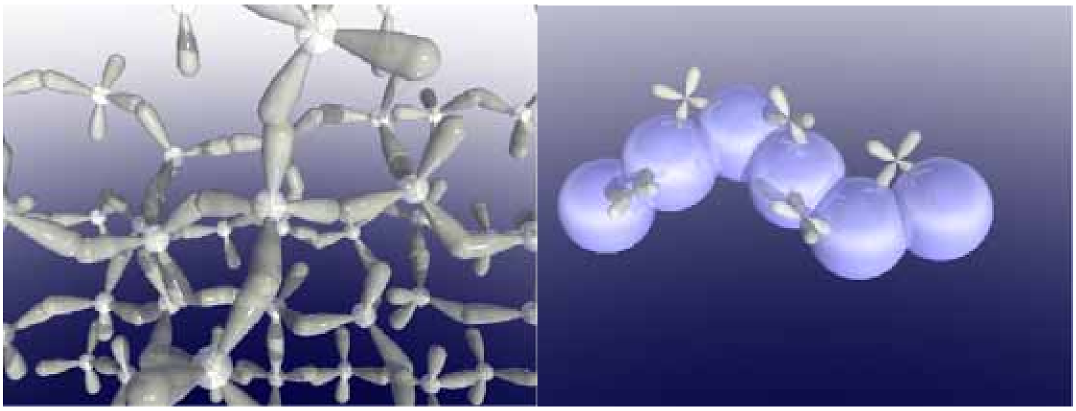
Program & Abstract of

International Symposium on Transparent Amorphous Oxide Semiconductor (TAOS 2006)



Suzukake Hall

Suzukakedai Campus, Tokyo Institute of Technology

November 22, 2006

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PROGRAM

Morning Session Chairman Masahiro Hirano

9:30~10:00 A1 Amorphous Oxide Semiconductors : Introduction

Hideo Hosono

Frontier Collaboration Research Center, Tokyo Institute of Technology, JAPAN

10:00~10:15 A2 University-Industry Collaboration for Promoting Innovation

---The story of totally useless information---

Isamu Shimizu

National Center for Industrial Property Information and Training, JAPAN

10:15~10:45 A3 Is the future of TFTs transparent?

E. Fortunato, P. Barquinha, L. Pereira, G. Gonçalves, R. Martins

Departamento de Ciência dos Materiais/CENIMAT, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa and CEMOP/UNINOVA, PORTUGAL

Coffee Break

11:10~11:40 A4 Amorphous Oxide Semiconductors: Materials, Carrier Transport and TFT Characteristics

Kenji Nomura[1],Toshio Kamiya[1, 2], Hiromichi Ohta[1],Masahiro Hirano[1],Hideo Hosono[1, 2, 3]

[1] Transparent Electro-Active Materials Project, ERATO-SORST, JST, JAPAN

[2]Materials and Structures Laboratory, Tokyo Institute of Technology, JAPAN

[3] Frontier Collaborative Research Center, Tokyo Institute of Technology, JAPAN

11:40~12:10 A5 Evaluation of TAOS by Hard X-ray Photoemission Spectroscopy at SPring-8

Keisuke Kobayashi1, 2), Eiji Ikenaga2), Jung Jin Kim2), Shigenori Ueda1), Masaaki Kobata2)

1) SPring-8/NIMS Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyougo 679-5148, JAPAN
2) SPring-8/JASRI Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyougo 679-5198, JAPAN

12:10~12:40 A6 Atomic and Electronic Structure of Defects in Gate Oxides

----Implication for Microelectronic Devices----

Jacob L. Gavartin, **Peter V. Sushko**, Alexander L. Shluger

Department of Physics and Astronomy,

University College London, Gower Street, WC1E 6BT, UK

Lunch

Afternoon Session **Chairman** **Hideo Hosono**

14:00~14:30 P1 InGaZnO4:Sn based thin film transistors

H. Kato, H. Fujisawa, N. Sekine, and H. Kawakami

Fuji Electric Advanced Technology Co., Ltd. JAPAN

14:30~15:00 P2 Amorphous Gallium-Indium-Zinc Oxide Thin Film Transistors ; Constant current stability

[1]**Donghun Kang,**[1]Chang Jung Kim, [1]Hyuck Lim, [1]Sunil Kim, [1]Jaechul Park, [1]Ihun Song, [2]Eunha Lee1, [2]Jaecheol Lee and Youngsoo Park

1) Semiconductor Device and Material Lab, KOREA

2) AE center, Samsung Advanced Institute of Technology, KOREA

15:00~15:30 P3 Recent Developments in Transparent, Flexible, and Printed Electronics

Gregory S. Herman

Hewlett-Packard Company

Advanced Materials and Processes Laboratory, USA

Coffee Break

16:00~16:30 P4 Amorphous In-Ga-Zn-O based TFTs, circuits and OLED drivers

Hideya Kumomi

Canon Research Center, JAPAN

16:30~17:00 P5 Amorphous IGZO Based TFTs and Their Applications to Electronic Paper

Manabu Ito, Masato Kon, C. Miyazaki, M. Ishizaki and Y. Ugajin

Technical Research Institute, Toppan Printing Co., Ltd. JAPAN

17:00~17:30 P6 Issues on TAOS TFTs probed by nanowire transistors

Toshio Kamiya

Materials and Structures Research Laboratory, Tokyo Institute of Technology, JAPAN

Reception Party

A1 Amorphous Oxide Semiconductors : Introduction

Hideo HOSONO

Frontier Collaborative Research Center & Materials and Structures Laboratory,

Tokyo Institute of Technology, ERATO-SORST, Japan Science and Technology Agency

The most important feature of semiconductors is in the controllability of carrier concentration over several orders of magnitude. A unique advantage of amorphous materials over crystalline materials is capability of large-area deposition of uniform thin films at low temperatures. Research on amorphous semiconductors started in 1950s to seek materials which can have both of these advantages. **Figure 1** summarizes the brief history of amorphous semiconductors. The largest impact on electronics is the discovery of hydrogenated amorphous silicon (a-Si:H) by Spear and LeComber in 1975. This is the first material which can control carrier type and concentration by impurity doping as in crystalline Si, and it opened a new frontier called 'Giant Micro- electronics' which means electronics based on circuits fabricated on a large area substrate. A thin film transistor (TFT) substrate fabricated using a-Si:H on glass is now a fundamental building block of the circuit for active-matrix flat-panel displays.

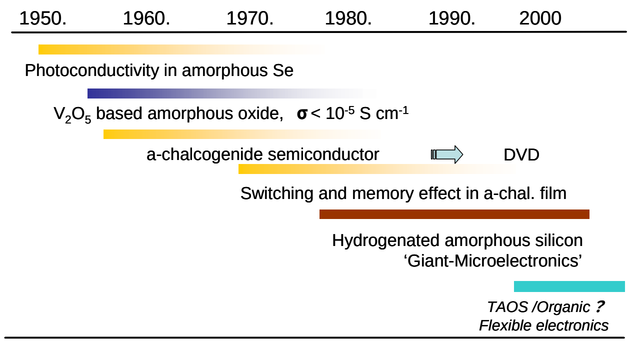


Fig.1. History of amorphous semiconductors an new fields

Amorphous oxide semiconductors have a long history comparable to amorphous chalcogenides such as a-Se. The history of amorphous oxide semiconductors started in 1954. A glass group of Sheffield University in UK reported electronic conductive glasses containing a large amount of V_2O_5 in Nature. This report was a breakthrough in glass science: it broke a common sense, "a glass is an insulator". Since then, a series of oxide glasses composed of a variable-valence transition metal oxide and glass-forming oxides such as P_2O_5 is named "glassy semiconductors". Electronic conduction in the glassy semiconductors is primarily controlled by variable-range hopping between transition metal cations with different valence states. Thus, the carrier drift mobility is very small such as 10^{-4} cm^2(Vs)$^{-1}$ and is comparable to those of conventional chalcogenide glasses. Although many papers have been reported, no application has appeared to date as far as I know.

Recently, a new electronics is rapidly emerging for applications which cannot be fabricated by Si MOS technology. This frontier named "flexible electronics" is characterized by electronic circuits fabricated on organic(soft) plastic substrates instead of inorganic (hard) glasses. This area was born to meet a strong demand for large-area displays because glass substrates, which are heavy and fragile, are obviously inconvenient. Amorphous semiconductors are much preferable than crystalline semiconductors for flexible electronics. So far, organic molecule semiconductors have been almost exclusively examined for such applications but their performance and chemical instability are not sufficient for practical applications: e.g. field-effect mobilities of organic TFTs are too low to drive high-resolution, high-speed OLED displays.

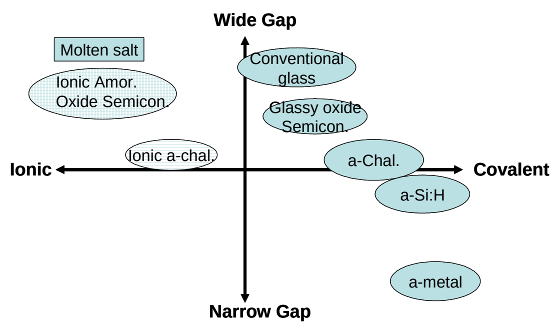


Fig2. Landscape of amorphous materials

We started material exploration of ionic oxide semiconductors in 1994 as a part of grand strategy for cultivation of transparent oxide semiconductors towards future transparent electronics.

Figure 2 lustrates a location map of the various types of amorphous materials on the plane constituting of a chemical bonding nature axis and a band gap axis. One may easily notice from the figure that conventional amorphous materials are composed of chemical bonds having high covalency and transparent (wide gap) materials are electrically insulating. It is seen that a transparent, ionic, amorphous semiconductor is an unexplored class of amorphous semiconductor. As an extremely high quenching rate is needed to obtain an ionic amorphous oxide compared with a conventional oxide glass, physical deposition techniques from vapor phase on a substrate at room temperature (RT) are appropriate for this purpose

Table 1 summarizes the bonding nature and carrier transport properties of various classes of amorphous semiconductors. The unique feature of TAOS is its high electron mobility, which is close to that in the crystalline phase. The dominant mechanism for electron transport in amorphous semiconductors reported so far is hopping-type, while band conduction is easily realized in TAOS by electron-doping. This striking difference may be attributed to the low density of state of tail state in TAOS.

Table 1. Bonding nature and carrier transport properties of various amorphous oxide semiconductors

Material System	Chemical bond	Mecha -nism	Hall effect	Mobility (cm^2/Vs^{-1})	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

Research progress of our group is enlisted in Table 2 along with incorporation of TAOS–related research in international conferences. It is evident that AOSs have begun to attract attention both in fundamental research and application to high performance TFT after almost a decade of incubation time.

Table 2. Research progress and International conference

1995 Proposal of transparent AOS @ICANS-16
1996 Material design concept(*J.Non-Cryst.Sol*)
2003 Discovery of P-type AOS and realization of PN-diode (*Advanced Materials*)
2003 High performance transparent transistor using crystalline OS (*Science*)
2004 Flexible high performance transistor using transparent AOS(*Nature*)

2005.9 AOS was incorporated as a session @ICANS-21
2005.12 10 papers @ MRS(Boston)
2006.5 >180 papers @E-MRS(Nice)
2007.5 Oxide TFT sesson(SID)

[1] review. H.Hosono, *Ionic Amorphous Oxide Semiconductors: materials design, carrier transport, and device application*, J. Non-Cryst. Sol. **352**, 851-858 (2006).

A2 University-Industry Collaboration for Promoting Innovation

-The story of totally useless information-

Isamu SHIMIZU

Chairman

National Center for Industrial Property Information and Training

Abstract

First, an old story related to developing a-Si:H photoreceptor for electrophotography is briefly introduced as an example of Univ./Ind. collaboration performed in old time. In addition, a funny detective story concerning to Hydrogen in a-Si network will be explained for finding the authorities (criminals) who stood in the way of earlier development of Hydrogenated Amorphous Silicon.

Finally, let me introduce the current context in University-Industry collaboration in Japan.

A3

Is the future of TFTs transparent?

E. Fortunato, P. Barquinha, L. Pereira, G. Gonçalves, R. Martins

Departamento de Ciência dos Materiais/CENIMAT, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa and CEMOP/UNINOVA, Campus da Caparica, Caparica, 2829-516 Portugal

The recent application of wide band gap oxide semiconductors to transparent thin film transistors (TTFTs) is making a fast and growing (r)evolution on the contemporary solid-state electronics. In this paper we present some of the recent results we have obtained using wide band gap oxide semiconductors, like zin oxide, indium zinc oxide and gallium indium zinc oxide, produced by rf sputtering at room temperature. The devices work in the enhancement mode and exhibit excellent saturation drain currents. On-off ratios above 10^6 are achieved. The optical transmittance data in the visible range reveals average transmittance higher than 80 %, including the glass substrate. Channel mobilities are also quite respectable, with some devices presenting values around 25 cm^2/Vs, even without any annealing or other post deposition improvement processes.

The high performances presented by these TTFTs associated to a high electron mobility, at least two orders of magnitude higher than that of conventional amorphous silicon TFTs and a low threshold voltage, opens new doors for applications in flexible, wearable, disposable portable electronics as well as battery-powered applications.

A4 Amorphous Oxide Semiconductors: Materials, Carrier Transport and TFT Characteristics

Kenji Nomura[1], Toshio Kamiya[1, 2], Hiromichi Ohta[1], Masahiro Hirano[1] and Hideo Hosono[1, 2, 3]

[1] *Transparent Electro-Active Materials Project, ERATO-SORST, JST, JAPAN*

[2] *Materials and Structures Laboratory, Tokyo Institute of Technology, JAPAN*

[3] *Frontier Collaborative Research Center, Tokyo Institute of Technology, JAPAN*

Amorphous oxide semiconductor (AOS) is a material that can develop high performance low-temperature processed electronic devices such as flexible devices because they have a high electron mobility >> 10 $cm^2(Vs)^{-1}$ even when the films are deposited at room temperature (RT). However, some AOS materials have uncontrollable carriers generated from oxygen vacancy. Therefore, it is indispensable to design and explore a suitable material having both properties of large mobility and stable controllability of carrier concentration for practical applications.

Here we present our concept of material design and exportation of AOS for high-performance flexible TFTs. We focus mainly on In_2O_3-Ga_2O_3-ZnO ternaly system because the incorporation of cations with large ionic valence such as Ga^{3+} and Al^{3+} to high conductive oxides such as In_2O_3 and ZnO is effective to control the carrier concentration due to their strong metal–oxygen bonds.

All the films were deposited at RT by conventional pulsed laser deposition (PLD) using ceramic targets. Oxygen partial pressure during the deposition was kept at 1 Pa. Although In_2O_3 and ZnO exhibited high mobilities ~20 $cm^2(Vs)^{-1}$ even in the RT-deposited films, these were polycrystalline: but polycrystalline channel is undesirable to obtain uniform TFT characteristics due to grain boundary effects. Stable amorphous films with smooth surfaces were obtained in the binary and ternary systems. In-rich films such as a-In-Zn-O (IZO) exhibited large mobility about 40 $cm^2(Vs)^{-1}$, but excess carriers were easily induced even in the film was kept in air, and it is difficult to fabricate a device with controllable characteristics such as a threshold voltage and off-current. We found that a-In-Ga-Zn-O (a-IGZO) has capability to control carrier concentration at below 10^{15} cm^{-3} with good stability and good reproductively, in addition to the reasonably large mobilities >15 $cm^2(Vs)^{-1}$.

The fabricated device using a-IGZO (molar ratio In:Ga:Zn: =1:1:1) channel exhibited good performances such as a field-effect mobility ~10 $cm^2(Vs)^{-1}$ and subthreshold slope ~0.25 V / decade, which is much improved from those for a-Si:H and organics based devices. Detailed carrier transport and structure model of a-IGZO will also be presented.

A5 Evaluation of TAOS by Hard X-ray Photoemission Spectroscopy at SPring-8

Keisuke Kobayashi[1, 2], Eiji Ikenaga[2], Jung Jin Kim[2], Shigenori Ueda[1], and Masaaki Kobata[2]

1) SPring-8/NIMS Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyougo 679-5148, Japan
2) SPring-8/JASRI Kouto 1-1-1, Sayo-cho, Sayo-gun, Hyougo 679-5198, Japan

Since the first test experiment in 2002 at BL29XU, we have been developing hard X-ray photoemission spectroscopy (HX-PES) with the excitation energy of 6-10 keV X-rays at SPring-8 in collaboration with SPring-8/RIKEN. Due to the high kinetic energy of photoelectrons[1-6], the probing depth of HX-PES is much larger comparing to the conventional X-ray PES using Al Kα. It was verified that photoelectrons emitted from buried layers more than 20 nm below the surface are detectable. Highest energy resolution of 55 meV has been achieved at $h\nu$=8 keV, and 100 -300 meV resolutions at $h\nu$=8 keV are available for practical applications. The throughput of the measurements is so high as to enable measurements of Au 4f and Au valence band spectra within 60 sec and 300 sec accumulation times, respectively. Taking the advantage of large probing depth, we have adopted HX-PES to investigate various kinds of thin films grown at laboratories. Since there is no surface cleaning procedure applicable to the thin film materials, conventional photoemission spectroscopy is inefficient for the investigation of the "bulk" nature of this class of materials. Thus HX-PES is almost to be the only method for this purpose.

Here in this opportunity, we will present the applications of HX-PES to IGZO and IZO thin films.

[1] K. Kobayashi et al., Appl. Phys. Lett. 83 (2003) 1005.

[2] Y. Takataet et al., Appl. Phys. Lett., 84 (2004) 4310.

[3] K. Kobayashi, Nucl. Instrum. Methods A 547, (2005) 98.

[4] Y. Takata et al., Nucl. Instrum. Methods. A 547, 50 (2005).

[5] K. Kobayashi, Proc. Synchrotron Radiation Instrumentation 2006, (AIP Conference Ser. To be published).

[6] Y. Takata et al., ibid.

A6 Atomic and electronic structure of defects in gate oxides: implication for microelectronic devices

Jacob L. Gavartin, Peter V. Sushko, Alexander L. Shluger

Department of Physics and Astronomy,

University College London, Gower Street, WC1E 6BT, UK

New TFT devices incorporating ionic amorphous oxide semiconductors represent complex combinations of oxides and interfaces. The performance and reliability of such devices strongly depend on our ability to control and eliminate defects always present in the bulk and at interfaces. Little is known about defects in amorphous In_2O_3-ZnO-Ga_2O_3 films and their interfaces with ITO and other oxide. To demonstrate possible effect of defects, in this talk we will discuss a better studied system: HfO_2 films grown on Si, and will draw parallels with defect structures in ZnO and other oxides. The performance of prototype MOSFETs based on high-k oxides such as HfO_2 is still affected by large concentrations of electron traps. Oxygen vacancies and interstitial ions as well as other defects in HfO_2 and SiO_2 films and at $HfO_2/SiO_2/Si$ interface are often implicated in causing these problems.

To aid defect metrology, we will present and discuss the results of calculations of the electronic structure and spectroscopic properties of oxygen vacancies in different charge states in the monoclinic phase of HfO_2, in amorphous SiO_2 and at the $HfO_2/SiO_2/Si$ interface.

First, we demonstrate that the flexibility of lattice and the nature of bonding are acutely related to the properties of defects it can host. For example, neutral oxygen vacancies in amorphous SiO_2 (a-SiO_2) are characterised by the strong displacement of two Si atoms near the vacancy, which pull the rest of the lattice with them. As a result, the field of displacement propagates as far as 10 Å from the defect site. The situation is opposite in the case of HfO_2, where the neutral oxygen vacancy causes almost no lattice distortions.

Second, we discuss different charge states of oxygen vacancies. Owing to the disordered structure of a-SiO_2 and the possibility of many lattice relaxation pathways, qualitatively different configurations of positively charged vacancies exist. In the case of HfO_2 our calculations predict the existence of five charge states of the vacancy, all of which differ only by the details of the atomic displacements near the vacancy sites. The predicted values of the thermal ionisation energies, excitation energies and principal values of the g-tensors allow us to make a credible assignment of available experimental data to specific defect configurations.

Finally, we will consider the interface structure and the band alignment in $HfO_2/SiO_2/Si$ system, some effects of HfO_2 amorphisation and electrical properties of defects located in various regions of the interface. Along with the already known defects, such as oxygen vacancies, Si-Hf bonds, P_b and E'centres, we have also identified and characterized a new defect in a form of Hf-Hf bond. We will discuss how disorder at the interface affects the distribution of defect properties.

P1 $InGaZnO_4$:Sn based thin film transistors

H. Kato, H. Fujisawa, N. Sekine, and H. Kawakami
Fuji Electric Advanced Technology Co., Ltd. Fuji-machi Hino-city 191-8502, Japan
kato-hisato@fujielectric.co.jp

Recently, flexible electronics have attracted much attention because of advantages such as low processing cost, less weight, and ease of large-scale manufacture. Amorphous $InGaZnO_4$ semiconductor thin film transistor (TFT) is one of the most promising technologies in the field of flexible electronics (1,2). In this study, fabrication technique and Sn-doping effect have been investigated for $InGaZnO_4$ sputtering process.

Thermally oxidized Si was used for a substrate, where oxide acts as gate insulator and Si substrate acts as gate electrode. $InGaZnO_4$:Sn film was deposited by RF magnetron sputtering at room temperature on thermally oxidized Si substrate. Then, $InGaZnO_4$:Sn film was annealed in air at 400 ºC for compensation of oxygen vacancies. By XRD analysis, $InGaZnO_4$:Sn film was confirmed to maintain amorphous structure after annealing process. Finally, a 50 nm Cu was evaporated through a shadow mask for source and drain electrodes, where the channel width (W) and channel length (L) were 1 mm and 50μm.

Figure 1 shows the transfer characteristic of fabricated $InGaZnO_4$:Sn TFT. The fabricated TFT showed *n*-type enhancement behavior without hysteresis. The saturation mobility (μ) and on/off ratio of $InGaZnO_4$:Sn TFT were 19 cm^2/Vs and more than 10^5, respectively. Obtained μ is 1.5 times higher than that of $InGaZnO_4$ TFT.

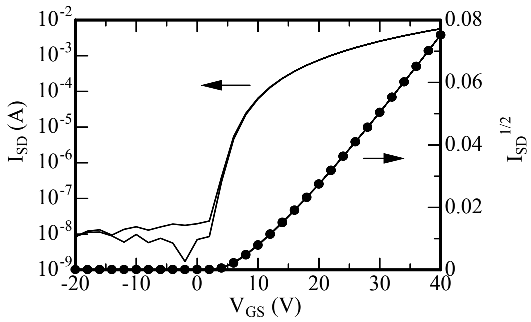


Fig. 1 I_{SD}-V_{GS} characteristics of $InGaZnO_4$:Sn semiconductor FET (L/W＝50/1000μm)

1) K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, and H. Hosono, *Nature* **488**, 432, (2004).

2) H. Yabuta, M. Sano, K. Abe, T. Aiba, T. Den, H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, *Appl. Phys. Lett.* **89**, 112123, (2006).

P2 **Amorphous Gallium-Indium-Zinc Oxide Thin Film Transistors; Constant current stability**

[1]Donghun Kang,[1]Chang Jung Kim, [1]Hyuck Lim, [1]Sunil Kim, [1]Jaechul Park, [1]Ihun Song, [2]Eunha Lee[1], [2]Jaecheol Lee and Youngsoo Park
[1] Semiconductor Device and Material Lab,
[2]AE center, Samsung Advanced Institute of Technology
Mt.14-1, Nongseo-Dong, Giheung-Gu, Yongin, Gyeonggi-Do, Korea 449-712

Rapid growing consumers' need for large scale displays drives technologies to reduce the production cost and find new material for displays. Organic Light Emitting Diode (OLED) has been considered as a strong candidate to meet the needs of the emerging markets. In order to realize large area OLED display, robust transistors against a constant current stress is required since OLEDs emit lights through the recombination of injected hole and electron. For LCD case, transistors work as a switch to charge capacitors.

Recently, intensive studies on oxide transistors have been performed to realize transparent electronics, showing good transistor performances. Theoretically, it is predicted that oxide transistors may have less trapping sources than amorphous Si due to the different chemical bonding character [1]. In addition, their resistivities can be tailored by several orders of magnitude by controlling defects and incorporating impurities. Therefore, in this study we investigate the feasibility of Gallium-Indium-Zinc-Oxide (GIZO) Thin Film Transistors (TFT) for OLED driving transistors.

The threshold voltage of GIZO TFTs shifted about 1.6V at 3μA for 100hours. When it was extrapolated to 30,000 hours, the shift was less than 2 volts. Such a remarkable stability could be explained by ionic bonding character of GIZO, which can allow more flexibility for non crystalline phase than covalent one. We believe that GIZO TFTs are very promising for OLED display application.

Reference

[1] Kenji Nomura, Hiromichi Ohta, Akihiro Takagi, Toshio Kamiya, Masahiro Hiroano & Hideo Hosono, Nature **432**(2004) 488-492.

P3 Recent Developments in Transparent, Flexible, and Printed Electronics

Gregory S. Herman

Hewlett-Packard Company, 1000 NE Circle Boulevard, Corvallis, Oregon 97330

Oxide based transparent materials have been extensively studied due to the direct commercial applications of displays, solar cells, sensors, and energy-efficient windows. Recently, there has been an increased interest in transparent electronics due to the possibility of forming active transparent components which can enable new applications. Many of these applications will require new transparent conductors (n-type and p-type), as well as both transparent thin-film transistors (TFT) and diodes. The integration and characterization of zinc tin oxide (ZTO) and zinc indium oxide (ZIO) TFTs on both rigid and flexible substrates will be presented. We have found that both of these ternary oxides give much better electrical performance (mobility, turn-on voltage, subthreshold slopes, etc.) than ZnO TFTs processed under similar conditions. Also, recent work on solution processed oxide channel materials will be presented including thin film transistors fabricated by thermal ink jet printing.

P4 Amorphous In-Ga-Zn-O based TFTs, circuits, and OLED drivers

Hideya Kumomi
Canon Research Center

Transparent amorphous oxide (TAOS) semiconductors have attracted keen attention since the high-performance thin-film transistors (TFTs) were demonstrated using amorphous In-Ga-Zn-O (a-IGZO) thin films for the semiconductor layers deposited on room-temperature plastic substrates by pulsed-laser deposition [1]. The TFT performance is confirmed also by using sputter deposition [2], which demonstrates the possibility of the large-area application. The dependence of the TFT characteristics on the metal composition is investigated in detail by a novel combinatorial approach [3], since the multi-metal amorphous can take any ratios of the composition. Various types of the TFT structures are examined from the top-gate and top-contact planar types to the bottom-gate and top-contact inverse-stagger types [4] which are popular in today's products using hydrogenated amorphous silicon TFTs.

Beyond the static (DC) characteristics of the TFTs, the dynamic (AC) properties are also studied using the experimental circuits composed of the a-IGZO TFTs [5]. The five-stages ring oscillator using the enhancement/enhancement inverters operates at 410 kHz at the input voltage of 18 V. The SPICE simulation using the DC characteristics of the TFTs qualitatively reproduces the experimental results, which suggests the possibility of the circuit design for the TAOS-TFTs. The organic light-emission-diode cells are driven by the simple circuits composed of the a-IGZO TFTs [4], which predicts the possible application to the giant-micro electronics such as flat-panel displays.

Thus the research of the TAOS TFTs now advances to the next stage where the stability and the reliability of the TFTs should become the issues to be addressed in the presumed applications to the circuits and the devices.

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano and H. Hosono, Nature **432**, 488 (2004).

[2] H. Yabuta, M. Sano, K. Abe, T. Aiba, T. Den, H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, Appl. Phys. Lett. **89**, 112123 (2006).

[3] T. Iwasaki, N. Itagaki, T. Den, H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, Mater. Res. Soc. Symp. Proc. **928**, 0928-GG10-04 (2006); Appl. Phys. Lett. (in preparation).

[4] H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, Thin Solid Films (in review).

[5] M. Ofuji, K. Abe, N. Kaji, R. Hayashi, M. Sano, H. Kumomi, K. Nomura, T. Kamiya, and H. Hosono, ECS Transactions **3**, 293 (2006).

P5 Amorphous IGZO Based TFTs and Their Applications to Electronic Paper

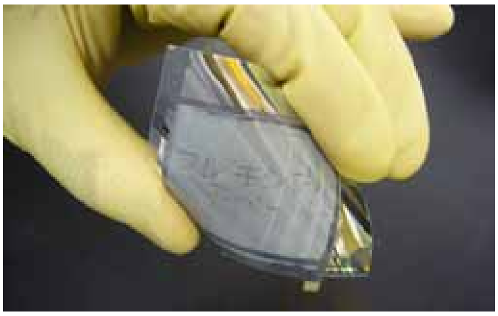
*) **Manabu Ito**, Masato Kon, C. Miyazaki, M. Ishizaki and Y. Ugajin

Technical Research Institute, Toppan Printing Co., Ltd.

We have demonstrated a flexible, active-matrix, electronic paper display driven with amorphous oxide semiconductors. A transparent and flexible backplane is deposited by standard sputtering technique at room temperature using amorphous In-Ga-Zn-O [1] as an active channel, which is fully compatible with plastic substrate and large scale manufacturing.

The bottom-gate thin-film transistor (TFT) was fabricated using *a*-InGaZnO film as an n-channel active layer on 125μm-thickness poly-ethylene-naphthalate (PEN). A 30nm-thick *a*-InGaZnO layer was deposited by RF magnetron sputtering technique using polycrystalline $InGaZnO_4$ target in Ar and O_2 gas ambient. A 280nm-thick SiON layer was also deposited by RF magnetron sputtering process for the gate insulator. As source, drain and gate electrodes, ITO was formed by DC magnetron sputtering technique. All the layers were deposited at room temperature. Source, drain, gate and channel were defined by standard photolithography and lift-off techniques.

We have fabricated 2-inch diagonal TFT array with 60 rows and 80 columns, whose pixel size is 500 μm × 500 μm. After the backplanes were processed, an E-ink imaging film was laminated onto the TFT backplanes. We have successfully displayed characters in black and white driven by amorphous oxide TFT array. The display can be bent without any performance loss. A two-inch flexible electrophoretic display weighs just about 1.3 *g* and its thickness is less than 320 μm which is around one sixth of liquid crystal display. We propose that the combination of E-ink imaging film and amorphous oxide backplanes provides an ideal solution for flexible electronic paper.



[1] K. Nomura *et al.*, Nature **432**, 488 (2004)

**) Corresponding author : Tel : +81-480-33-9128, Fax : +81-480-33-9022,*

E-mail address : manabu.ito@toppan.co.jp

P6 Issues on TAOS TFTs probed by nanowire transistors

Toshio Kamiya[1, 2], Kosuke Matsuzaki[1], Kenji Nomura[2], Masahiro Hirano[2,3] and Hideo Hosono [2, 3]

[1]*Materials and Structures Laboratory, Tokyo Institute of Technology, JAPAN*

[2] *Transparent Electro-Active Materials Project, ERATO-SORST, JST, JAPAN*

[3] *Frontier Collaborative Research Center, Tokyo Institute of Technology, JAPAN*

Transparent amorphous oxide semiconductors (TAOSs) exhibit excellent properties for low-temperature semiconductor materials: they may be formed at room temperature (RT) and work as active layers in semiconductor devices even without passivation treatments. In addition, they exhibit rather large electron mobilities greater than 10 cm^2/Vs even for RT-deposited films. Therefore thin-film transistors (TFTs) employing TAOSs for channels are now expected for new channel materials in flexible electronic devices. The first demonstration of a RT-fabricated TFT was reported in 2004 and the TFT exhibited a large field-effect mobility ~ 8 cm^2/Vs with good stability when amorphous In-Ga-Zn-O (a-IGZO) was used for channel. After that, many studies and demonstrations of TAOS devices have been reported by several groups in the world.

In this talk, we first summarize these progresses on TAOS materials and devices, and then will discuss about remaining issues. We used pulsed-laser deposition (PLD) in the first report of TAOS TFT for depositing the channel a-IGZO layer. It is now demonstrated by Canon group that RF-magnetron sputtering also produces a-IGZO layers and TFTs with similar carrier transport properties and TFT characteristics. Material exploration has been done by several group: e.g. we first examined TAOS materials in the In_2O_3 – ZnO – Ga_2O_3 systems and concluded that a-IGZO is the best among them from the viewpoint of stability in carrier transport properties and carrier concentration although larger electron mobilities were obtained in the In_2O_3 – ZnO binary system. The smallest hysteresis was also obtained in a-IGZO TFTs. As for devices, very recently a 410 kHz oscillation of 5-stage ring oscillator using a-IGZO TFT inverters has been demonstrated by Canon group, which proves the ability of high-frequency operation of a-IGZO TFTs. As for TAOS structures, we analyzed the local atomic structure and electronic structure by EXAFS and molecular dynamics/ab-initio calculations, which show edge-sharing (InO_6) octahedral network remains in the amorphous phase and results in the conduction band minimum mainly made of In 5s orbitals without forming a localized state.

As such, many progresses have been made in these a few years. However, still many issues remain to be discussed: e.g. long-range stability, miniaturization, insulator-channel interface structure, in-gap states, surface states, source/drain contacts problems, and so on. In the second half of this talk, we will discuss some of these issues by introducing nanowire transistor test structures, which enhances the effects of source/drain contacts and the surface states of the nanowire channels.

APPENDEX

Selected publications on amorphous oxide semiconductors

1. Hideo Hosono, *Ionic Amorphous Oxide Semiconductors: materials design, carrier transport, and device application*, J. Non-Cryst. Sol. **352**, 851-858 (2006).
2. Kenji Nomura, Akihiro Takagi, Toshio Kamiya, Hiromichi Ohta, Masahiro Hirano and Hideo Hosono, *Amorphous Oxide Semiconductors Towards High-Performance Flexible Thin-Film Transistors*, Jpn. J. Appl. Phys. **45**, 4303-4308 (2006).
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