TRANSPARENT OXIDE SEMICONDUCTORS: MATERIALS DESIGN, ELECTRONIC STRUCTURE, AND DEVICE APPLICATIONS

Hideo Hosono, Tokyo Institute of Technology, Japan
hosono@mces.titech.ac.jp

In 1995, I presented a materials design concept for transparent amorphous oxide semiconductors with a large electron mobility (TAOS) at the 16th International conference on amorphous semiconductors along with concrete example materials of TAOS and the paper was published in 1996 [1]. The basic concept of TAOS is that large electron mobility should be retained even in amorphous materials if the conduction band minimum is mainly composed of spatially large spread of metal ns-orbitals.[1] The validity of this design concept was demonstrated by analysis of electronic structure using photoemission experiments combined with calculations based on X-ray structural analysis [2]

In 2003 we reported high mobility TFTs (~80cm^2/Vs) using epitaxial thin films of InGaZnOx (IGZO) in Science [3] , and fabricated amorphous IGZO on plastic substrates in Nature with expectation for application to backplanes of flexible OLEDs [3]. The TFT mobility is ~10cm^2/V-s, which is larger by an order of magnitude than that of hydrogenated amorphous Si(a-Si:H). Since TAOS-TFTs can be easily fabricated on various types of substrates at low temperatures by conventional sputtering method and their mobility is 10-30cm^2/V-s.

IGZO-TFTs, which have been most extensively studied to date [5], are now used to drive displays for high precision LCDs and large-sized (55 and 65inches) OLED-TVs. Amorphous oxide semiconductor TFTs appears to be advantageous to drive large-sized OLEDs with respect to scalability, homogeneity and production cost. However, various technical issues still remain to be resolved when oxide TFTs are adopted as the driving transistors in OLEDs; currently applied small OLEDs are driven by p-channel LTPS-TFT using normal stacking structure (cathode top). Since oxide TFTs work only as n-channel, the device stacking sequence are required to be reverse with respect to stability and image clarity. There is an obstacle to realize inverted OLEDs which has performance comparable to that of conventional normal-type OLEDs, the absence of appropriate electron-injection and transport materials. We have developed new TAOS for this demand; amorphous C12A7:e [6] for e-injection and ZnO-based new TAOS for e-transport[7]. Both materials can form Ohmic contact with conventional cathode metals (ITO and Al). The inverted OLEDs fabricated using this material combination exhibit comparable or superior to that of conventional normal type device using Al/LiF cathode.

In this talk, I review the progress in oxide semiconductors for display application covering materials design concept and new materials for NBIS instability-free TFTs [8] and OLEDs

References

[1] H.Hosono et al. "Working hypothesis to explore novel wide band gap electrically conducting amorphous oxides and examples." Journal of Non-Crystalline Solids 198 (1996)165.
[2] S.Narushima et al. "Electronic structure and transport properties in the transparent amorphous oxide semiconductor 2 CdO· GeO_2." Physical Review B 66.3 (2002) 035203.
[3] K.Nomura et al. “Thin film transistor fabricated in single-crystalline transparent oxide semiconductor; Science, 300(2003) 1269.
[4] K.Nomura et al. "Room-temperature fabrication of transparent flexible thin-film transistors using amorphous oxide semiconductors." Nature 432(2004)7016.
[5] (Review) T.Kamiya, Toshio, K.Nomura and H.Hosono. "Present status of amorphous In–Ga–Zn–O thin-film transistors." Science and Technology of Advanced Materials 11 (2010)044305: H.Hosono, “How we made the IGZO transistor” Nat. Electron, 1(2018)428.
[6] H.Hosono et al.." Transparent amorphous oxide semiconductors for organic electronics: Application to inverted OLEDs; Proc. Natl. Acad. Sci. USA, 114,(2017)233.
[7] N.Nakamura et al. “Material Design of Transparent Oxide Semiconductors for Organic Electronics: Why Do Zinc Silicate Thin Films Have Exceptional Properties?; Adv. Electron. Mater.4(2018) 1700352.
[8] J.Kim et al. “Ultra-Wide Bandgap Amorphous Oxide Semiconductor for NBIS-free Thin Film Transistors” APL Mater. in press.