Charge Transport in Amorphous Metal-Oxide In-Ga–Zn–O Semiconductor Films and Their Use for Thin-Film Transistor Applications

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In recent years transparent amorphous oxide semiconductor, In-Ga–Zn–O (a-IGZO) [1], attracted a lot of interest because it has a potential to overtake α-Si:H in applications in backplanes for large-area active matrix displays and holds much promise for emerging transparent flexible electronics due to its high mobility, reasonable bias stability and superior spatial uniformity over a wide area, and the films can be fabricated by a conventional sputtering method. a-IGZO belongs to new class of high-mobility thin-film semiconductors enabling the realization of the next generation of thin film transistor (TFT) technology and eventually opens new frontier for large-area electronics called 'flexible electronics,' which means electronic circuits fabricated on flexible plastic substrates. The high level of activity on these devices is because, even though the material is amorphous, it can offer a carrier mobility of 10-50 cm^2/Vs. This is 10–20 times greater than a-Si:H, and the higher mobility is advantageous for driving organic light emitting diode, OLED, displays. Also, due to the amorphous nature of the material, it may have better uniformity than poly-Si, which is the currently preferred TFT technology for commercial, hand-held AMOLED displays.

In this work [2] we describe electrical transport properties in a-IGZO TFTs. We suggest a model based on Effective Medium approximation (EMA) which is able to describe charge-carrier transport in a disordered semiconductor with a significant degree of degeneration realized at high carrier concentrations, especially relevant to a-IGZO TFT, when the Fermi level is very close to the mobility edge (transport band edge). The EMA model is based on a straightforward averaging of the Fermi-Dirac carrier distributions using suitably normalized cumulative density-of-state (DOS) distribution that includes both extended (delocalized) states and the localized states. The key assumption of the model is that the charge-carriers move through delocalized states and that, in addition to the tail of localized states, the disorder can give rise to spatial energy variation of the transport band edge being described by a Gaussian distribution. The principal advantage of the present EMA model is its ability to describe universally effective drift- and Hall mobility in heterogeneous materials as a function of disorder, temperature and carrier concentration within the same theoretical formalism. It can explain a puzzling observation of activated and a carrier-concentration dependent Hall mobility in a disordered system featuring an ideal Hall effect. The present model has been successfully applied to describe experimental results on the charge transport in a-IGZO TFT. In particular, the model reproduces well both Meyer-Neldel (MN) compensation behavior for the charge-carrier mobility and inverse-MN effect for the conductivity observed in the same a-IGZO. The model was further supported by *ab initio* calculations revealing that the amorphization of IGZO gives rise to variation of the conduction band edge rather than to the creation of localized states. The obtained changes agrees with the one we used to describe the charge transport. We found that the band edge variation dominates the charge-carrier transport in high-quality a-IGZO TFTs in above-threshold voltage region, whereas the localized states need not to be invoked to account for the experimental results in this material. Moreover, charge scattering effects were shown to have a noticeable contribution to the temperature dependent transport in a-IGZO films.

[1] K. Nomura, H. Ohta, A. Takagi, T. Kamiya, M. Hirano, H. Hosono, Nature, 432, 488 (2004).
[2] A. Kadashchuk, I. I. Fishchuk, J. Genoe, P. Heremans, Phys. Rev. B. (submitted).