A physical parameter based on DC *I-V* numerical model of amorphous InGaZnO Thin Film Transistors

Yong Woo Jeon, Sangwon Lee, Sungchul Kim, Hyunkwang Jung, Dongsik Kong, Yongsik Kim,
Minkyung Bae, Dong Myong Kim[1], and Dae Hwan Kim [a)]
School of Electrical Engineering, Kookmin University, 861-1, Jeongneung-dong, Seongbuk-gu, Seoul, 136-702, KOREA [a)]drlife@kookmin.ac.kr

Abstract

In this paper, the physical parameter based numerical DC I-V model of an amorphous InGaZnO (*a*-IGZO) thin film transistor (TFT) is presented. Firstly, the proposed model can describes all operation regions. In the DC model, simultaneously, the effects of localized trapped charges and free carriers are considerations. Secondly, the acceptor-like density of states (N_{TA}=5×10^{18} cm^{-3} , N_{DA}=6×10^{16} cm^{-3} , kT_{TA}=0.074 eV, kT_{DA}=1.3 eV ,with the formulas of exponential tail and deep states) of *a*-IGZO TFT was extracted by using the DC model.

I. Introduction

Multi-component amorphous oxide semiconductor (*i.e.*, InGaZnO (IGZO), InZnO, and GaZnO)-based thin-film transistors (TFTs) have been under active research and development because of their room temperature (RT) fabrication process, higher mobility than those of covalent semiconductor TFTs, low cost, compatibility with transparent and rollable electronics applications. Because the electrical characteristics of IGZO TFTs are mainly dependent on both the electron concentration (n) and the density of states (DOS: $g(E)$) of the IGZO active layer, the extraction of n and $g(E)$ is very important in the modeling and characterization of their devices and circuits. Whereas the process parameter (*i.e.*, the oxygen partial pressure and/or the radio frequency (RF) power during RT sputtering process)-dependence of the carrier density and the mobility by Hall measurement in IGZO thin-film have been well understood by many research groups [1-3], only a few groups have extracted the acceptor-like $g(E)$ using numerical simulation-based fitting from experiment results [4-5].

This paper introduce the improved DC *I-V* model compared with existing model[7]. In addition to the simple and accurate method extract $g(E)$ compared with [4],[5],[6].

II. Device Structure

The fabricated TFT has an Etch Stopper bottom gate, and the *a*-IGZO active layer is deposited by RF magnetron sputtering at room temperature. A gate-insulator (SiN_x/SiO_x) thickness, *a*-IGZO active layer thickness (T_{IGZO}), channel length (L) and channel width (W) are designed to be 400/50 nm, 50 nm, 100 μm, 400 μm, respectively.

III. Physical parameter based DC I-V Model

In this paper, the model is presented for n-channel device and metal/insulator/semiconductor/insulator structure.

Because the active layer is connected to the source and drain regions far from the center of the active layer, the back interface potential($\phi_B=\phi(x=T_{IGZO})$) is the floating potential. Therefore, potential profile is changed for each gate bias(V_{GS}). The potential profile is important because the difference between Conduction Band Minimum Energy Level (E_C) and Fermi energy level(E_F) is determined charge density.

Fig.1 shows E_C-E_F considered potential profile is defined as E_{FB}-$\phi(V_{GS},x)$ by $E_{FB} = E_C - E_F$ @ (V_{GS}=V_{FB}).

When the sum of charge existing in active layer becomes zero, E_C turn into flat.

To obtain E_{FB}, we should know both $g(E)$ and N_D. Lets us suppose that N_D exist in active layer uniformly doping as a parameter represented doping effect of oxygen vacancy and zinc interstitial.

Eq. (1) is not only the key value when you decide E_{FB} , but also could present the properties that as the value of N_D becomes bigger, electron concentration gets higher[7].

Fig. 2 shows the process of drain current calculation .

By dividing the active layer into the multi-meshed layers, approximating that charge density is constant in each meshed layer, and numerically integrating Poisson's Equations through all the meshed layers to the surface from the back interface.

If the value of the assumed ϕ_S is not equal with the calculated ϕ_S, makes a change to the value of ϕ_B.

And when the value is equal, you should compare specified V_{GS} and calculated V_{GS} whether they meet Gauss's law or not.
If the result is not equal, you should find solution to meet the Gauss's law, changing the value of ϕ_S.

Once it go through a loop, you can find the profile of charge, electric field and potential in active layer and can calculate drain current with Eq. (3).

The basic formula referred to [8], Eq. (3) was applied to Pao-Sah model[9]. we can calculate numerically throughout all operation region.

In Fig. 3 show that our model by using assumed parameter(Table. 1) agrees well with measured characteristics. As a result, we extract V_{FB}, E_{FB} and acceptor-like DOS (Table2).

If we extracted N_D or E_{FB} experimentally, can extract DOS more correctly and use for accurately SPICE Model for Circuit Simulation

IV. Conclusions

The physical parameter based numerical DC *I-V* model of an *a*-IGZO TFT is proposed. The proposed model can describes all operation regions. And the acceptor-like $g(E)$ of *a*-IGZO TFT was extracted by using the DC model.

Our results expected that the proposed DC I-V model is very useful for the device design and circuit simulation of *a*-IGZO TFTs.

Acknowledements

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MEST) (No. 2009-0080344).

References

[1] Y. Orikasa *et al.*, J. Appl. Phys., vol. 103, no. 11, pp. 113703-1-7, 2008.
[2] K. Nomura *et al.*, Nature, vol. 432, no. 7016, pp. 488-492, 2004.
[3] E. Fortunato *et al.*, Thin Solid Films, vol. 502, no. 1/2, pp. 104-107, 2006.
[4] H.-H. Hsieh *et al.*, *Appl. Phys. Lett.*, vol. 92, no. 13, pp. 133503-1-3, 2008.
[5] M. Kimura *et al.*, *Appl. Phys. Lett.*, vol. 92, no. 13, pp. 133512-1-3, 2008.
[6] C. Chen *et al.*, *IEEE Trans. Electron Devices,* vol. 56, no. 6,

pp.1177-1183, 2009
[7] Y-S. Kim *et al.*, *Phys. Rev. Lett.*, vol. 102, 086403, 2009
[8] J-H. Park *et al.*, *IEEE Electron Device Letters*, vol. 30, no. 10, pp. 1069-1071, 2009.
[9] N. D. Arora, *MOSFET modeling for VLSI simulation*, World Scientific, pp. 235-238, 2007.

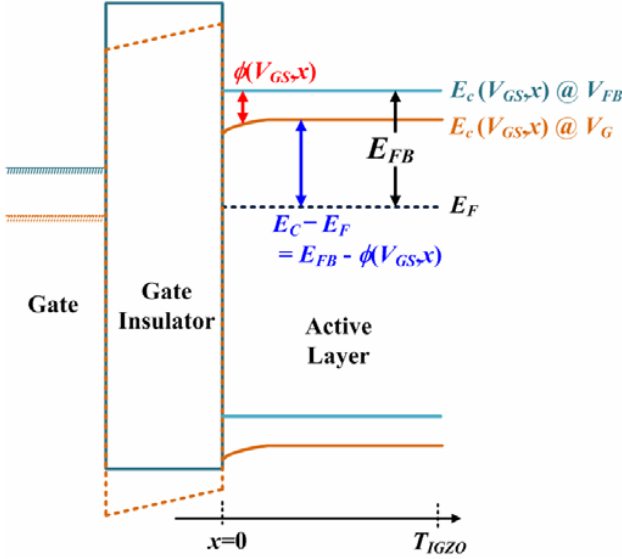

Fig. 1. Energy Band Diagram in *a*-IGZO TFTs.

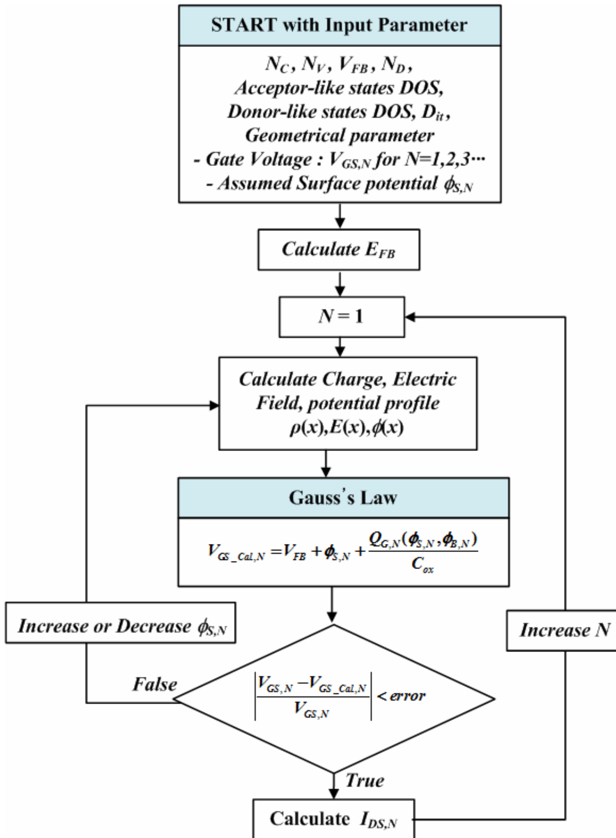

Fig. 2. Flow chart for the numerical DC I-V model

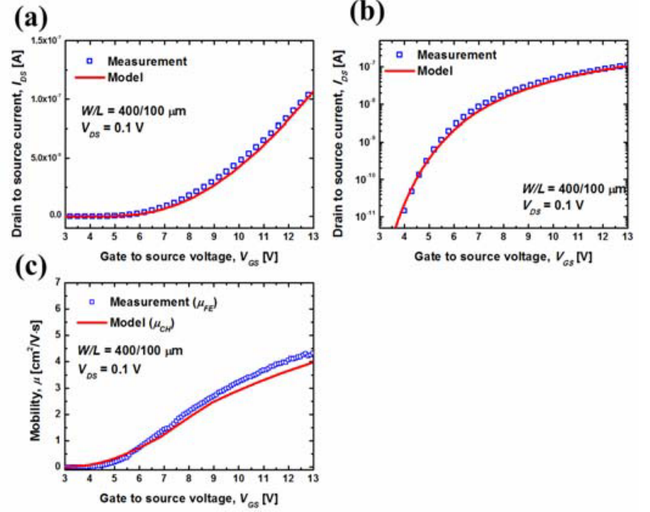

Fig. 3. (a) Measured transfer characteristics linear scale (b) semi-log scale (c) measured field effect mobility (μ_{FE}) with DC model.

Table I. Used model equations

Equations

$$q\times T_{gizo}\times\left(\int_{E_V}^{E_C} g(E)f(E)dE\Big|_{E_C-E_F=E_{FB}} + n_{free}(E_F) - N_D^{+}\right)=0 \quad (1)$$

$$\mu_{CH}(V_{GS},V_{CH}) = \mu_{BAND}\times\frac{Q_{free}}{Q_{free}+Q_{loc}} \quad [cm^2/Vs] \quad (2)$$

$$I_{DS} = q\frac{W}{L}\int_{V_S}^{V_S+V_D}\int_{0}^{x=T_{GIZO}} n_{free}(x,V_{CH})\times\mu_{CH}(x,V_{CH})\,dx\,dV_{CH} \quad (3)$$

$$=\mu_{BAND}\,q\frac{W}{L}\int_{V_S}^{V_S+V_D}\int_{\phi_B}^{\phi_S}\frac{\int_{\phi_B}^{\phi_S}\frac{n_{free}(\phi,V_{CH})}{E_{GIZO}(\phi,V_{CH})}d\phi}{Q_{free}(\phi,V_{CH})+Q_{loc}(\phi,V_{CH})}\times\frac{n_{free}(\phi,V_{CH})}{E_{GIZO}(\phi,V_{CH})}\,d\phi\,dV_{CH} \quad [A]$$

Table II. Input parameter and $g(E)$ model

Input Parameter and Model						
N_C [cm^{-3}]	μ_{BAND} [cm^2/Vs]	N_D [cm^{-3}]	N_{TD} [cm^{-3}]	kT_{TD} [eV]	N_{DD} [cm^{-3}]	kT_{DD} [eV]
3×10^{18}	9	5.5×10^{16}	5×10^{20}	0.08	10^{18}	0.65
$g(E)_{Donor} = N_{DD}\times\exp\left(\frac{E-E_C}{kT_{DD}}\right)+N_{TD}\times\exp\left(\frac{E-E_C}{kT_{TD}}\right)$						

Table III. Extracted parameter and $g(E)$ model

Extracted Parameter and Model					
V_{FB} [V]	E_{FB} [eV]	N_{TA} [cm^{-3}]	kT_{TA} [eV]	N_{DA} [cm^{-3}]	kT_{DA} [eV]
-1.65	1.1	5×10^{18}	0.074	6×10^{16}	1.3
$g(E)_{Acceptor} = N_{DA}\times\exp\left(\frac{E-E_C}{kT_{DA}}\right)+N_{TA}\times\exp\left(\frac{E-E_C}{kT_{TA}}\right)$					