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Current-Voltage Characteristics and Density of States in Amorphous Semiconductor-based TFTs

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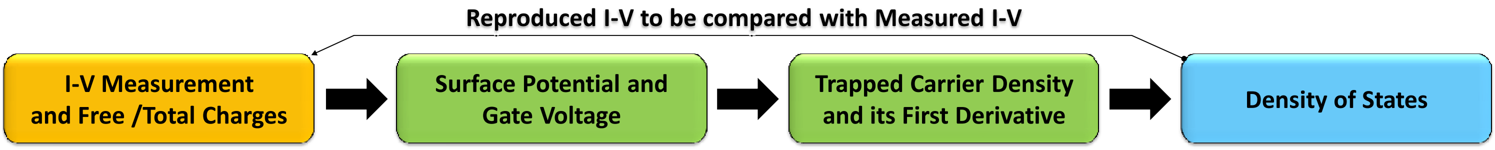
Introduction

- Current-Voltage characteristics related to density of states analytically based on TLC theory.
- Linear I-V measured at a small V_{DS} represented in a single relation to cover all operating regimes.

Results and Discussions



- Relationship between I-V and density of states:

  - Linear I-V relation with free change / carrier density:

$$I_{DS} = \mu_b Q_{free} (W/L) V_{DS} \quad \begin{cases} \lambda_{free} = (\lambda_D^{-1} + t_S^{-1})^{-1} \\ Q_{free} = q n_{free} \lambda_{free} \\ n_{free} = N_C \exp[(E_{F0} + q j_S - E_C)/kT] \end{cases}$$

  - Surface potential and gate bias:

$$\varphi_S = \frac{kT}{q} \ln\left(\frac{n_{free}(V_{GS})}{N_C}\right) - \frac{(E_{F0} - E_C)}{q} \equiv f(V_{GS})$$

  - Poisson-Boltzmann equation (PBE):

$$E_S \equiv g(V_{GS}) = \sqrt{\frac{2q}{\varepsilon_S} \int_0^{\varphi_S} n_{tot} d\varphi} \qquad n_{tot}(\varphi_S) = \frac{\varepsilon_S}{2q} \frac{\partial \left(g(f^{-1}(\varphi_S)) \right)^2}{\partial \varphi_S}$$

  - Density of states:

$$N_{deep,tail}(E) \approx \left. \frac{\partial (n_{tot} - n_{free})}{\partial \varphi_S} \right|_{E_F \to E}$$

- Derivation of PBE assuming GCA :

$$\frac{\partial^2 \varphi(x,y)}{\partial x^2} + \frac{\partial^2 \varphi(x,y)}{\partial y^2} = \frac{q}{\varepsilon_S} n_{tot} \qquad \frac{\partial^2 \varphi(x,y)}{\partial x^2} >> \frac{\partial^2 \varphi(x,y)}{\partial y^2}$$

$$\frac{d^2 \varphi(x)}{dx^2} = \frac{q}{\varepsilon_S} n_{tot} \qquad E = -\frac{d\varphi(x)}{dx}$$

$$\int_0^{E_S} E dE = \frac{q}{\varepsilon_S} \int_0^{\varphi_S} n_{tot} d\varphi \qquad \therefore E_S = \sqrt{\frac{2q}{\varepsilon_S} \int_0^{\varphi_S} n_{tot} d\varphi}$$

- Unified I-V relation for all regimes for $qV_{DS} << kT$:

  - Sub-threshold regime:

$$I_{DS} = \mu_b \frac{W}{L} \frac{kT}{q} Q_{free} \left(1 - \exp\left(-\frac{qV_{DS}}{kT} \right) \right)$$

$$Q_{free} = Q_0 \exp\left(\frac{q(V_{GS} - V_{FB})}{kT(1 + C_{deep}^* / C_{ox})} \right)$$

$$1 - \exp\left(-\frac{qV_{DS}}{kT} \right) = 1 - \left(1 - \frac{qV_{DS}}{kT} + higher\ order\ terms \right) \approx \frac{qV_{DS}}{kT}$$

$$\therefore I_{DS}(sub-threshold) = \mu_b Q_{free} \frac{W}{L} V_{DS} \quad \because qV_{DS} << kT$$

  - Above-threshold regime:

$$I_{DS} = \mu_{FET} \frac{W}{L} Q_{tot} V_{DS} \qquad \mu_{FET} Q_{tot} = \mu_b Q_{free}$$

$$\therefore I_{DS}(above-threshold) = \mu_b Q_{free} \frac{W}{L} V_{DS}$$

- Contact resistance and Q_{free}:

$$I_{DS} = \mu_b Q_{free} \frac{W}{L} V_{DS} \qquad g_m = \frac{dI_{DS}}{dV_{GS}} = \mu_b \frac{dQ_{free}}{dV_{GS}} \frac{W}{L} V_{DS}$$

$$V_{DS} \to V_{DS} - R_C I_{DS} \qquad I_{DS} = \mu_b Q_{free} \frac{W}{L} (V_{DS} - R_C I_{DS})$$

$$I_{DS} = \frac{\mu_b Q_{free} \frac{W}{L} V_{DS}}{1 + \mu_b Q_{free} \frac{W}{L} R_C} \qquad g_m' = \frac{g_m}{\left(1 + \mu_b Q_{free} \frac{W}{L} R_C \right)^2}$$

$$\therefore Q_{free} = \frac{I_{DS}}{\mu_b \frac{W}{L} (V_{DS} - R_C I_{DS})}$$

Conclusion

- Fully analytical formulations derived to retrieve the density of states in an amorphous semiconductor-based thin film transistor from its I-V relation while considering trap-limited conductor theory.

Related Publications:

- Sungsik Lee *et al.*, ***Scientific Reports*** (NPG), 2016.
- Sungsik Lee *et al.*, ***CAD-TFT 2014*** (invited talk).
- Arokia Nathan *et al.*, ***ESSCIRC 2013*** (invited talk).