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A Two-Dimensional Transient Numerical Model for Amorphous Silicon Devices

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ABSTRACT

Charge transport in amorphous silicon is dominated by the presence of a high density of localized states within the energy gap. For field-effect devices such as the thin-film transistor (TFT), most of the induced channel charge is trapped in these states. This results in a reduced effective mobility typically an order of magnitude less than values for carriers in the extended states. As well, since the time constants associated with the traps vary over many orders of magnitude, the large-signal response depends on the progressive trapping and emission of carriers as they move through the device. Thus, detailed modeling of amorphous devices must include the localized states.

In this talk, we present a two-dimensional transient numerical model for amorphous silicon implemented in the CHORD simulator[1]. The code uses a finite-difference scheme based on triangular grids and will handle an arbitrary device structure. The solution technique is fully-coupled Newton-Raphson iteration.

Our a-Si:H model is based on Poisson's equation, electron and hole continuity equations and the drift-diffusion current expressions.

$$\nabla^2\psi = -\frac{q}{\varepsilon}\left[N_D - N_A + p - n + p_t - n_t\right]$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla\cdot\mathbf{J}_n - R_n$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla\cdot\mathbf{J}_p - R_p$$

Poisson's equation includes trapped carriers due to donor and acceptor states.

$$n_t = \sum_{traps}^{acceptor} N_{TA} f_n \qquad p_t = \sum_{traps}^{donor} N_{TD} f_p$$

where f_n is the trap occupancy function for electrons, f_p for holes ($f_p = 1 - f_n$). Trap-driven recombination is added in the continuity equations;

$$R_n = \sum_{traps}^{acceptor} N_{TA} \left[nC_n(1-f_n) - E_n f_n \right] + \sum_{traps}^{donor} N_{TD} \left[nC_n f_p - E_n(1-f_p) \right]$$

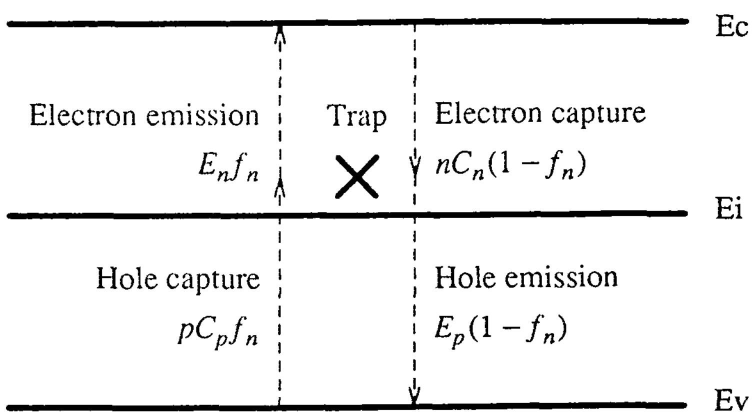
$$R_p = \sum_{traps}^{acceptor} N_{TA} \left[pC_p f_n - E_p(1-f_n) \right] + \sum_{traps}^{donor} N_{TD} \left[pC_p(1-f_p) - E_p f_p \right]$$

trapping rates are modeled using Shockley-Read-Hall rate equations.

$$\frac{\partial f_n}{\partial t} = nC_n(1-f_n) - E_n f_n - pC_p f_n + E_p(1-f_n)$$

$$\frac{\partial f_p}{\partial t} = -nC_n f_p + E_p(1-f_p) + pC_p(1-f_p) - E_p f_p$$

This is based on simple trapping and emission dynamics between a trap and the conduction and valence band.



The continuous distribution of localized states is approximated by a set of discrete traps in the energy gap.

An arbitrary trap distribution may be used and all trap densities, capture rates and emission rates may vary across the device. It is possible to reduce computer memory and execution times by using a static trapping model in areas of the device where dynamic trapping effects are expected to be minimal. Single carrier simulation may be used when device operation allows it. We illustrate the model with simulations of TFT operation.

References

1. J. R. F. McMacken and S. G. Chamberlain, CHORD: A modular semiconductor device simulation development tool incorporating external network models, *IEEE Transactions on Computer-Aided Design* **CAD-8**(8) pp. 826-836 (1989).