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An empirical model for leakage current in poly-silicon thin film transistor

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Abstract

The electric fields present in drain depletion region of poly-silicon thin film transistors (poly-Si TFTs) result in the enhancement of emission rate from the traps. An empirical relation between the field enhanced emission rate and electric field is proposed, which can be used to model the leakage current of poly-Si TFTs as a function of gate bias and temperature. The leakage current shows good agreement with the experimental data over wide range of temperature and gate bias. The model can be useful for circuit simulation.

Keywords: Leakage current; Poly-silicon thin film transistors; Poole–Frenkel effect

1. Introduction

Poly-silicon thin film transistors (poly-Si TFTs) have been attracting considerable attention for large area electronics applications, in particular, active matrix liquid crystal display applications like high definition television, projection displays and portable devices. However, the poly-Si TFTs suffer from relatively high off-current and this can be a serious limitation for its application in the large area electronics. For example, in the case of active matrix flat panel displays, the leakage current limits the time for which the video information can remain on a pixel before refreshing.

Several mechanisms have been proposed as the possible source of off-current [1], such as the Poole–Frenkel enhanced emission from traps, trap assisted tunneling, and band-to-band tunneling, with the dominance of band-to-band tunneling at low temperatures and combined effect of the Poole–Frenkel enhanced emission and trap assisted tunneling at high temperatures.

Several other authors [2–4] have suggested that the leakage current is the result of thermionic emission including the Poole–Frenkel effect. The proposed models in Refs. [2,,3] though analytical need numerical integration hence are not attractive for circuit simulation.

The expression deduced by Vincent et al. [5] for field enhanced emission rate due to thermionic and thermionic field emission involves numerical integration. A simplified expression for field enhanced emission rate was reported in Ref. [6], where the authors suggested that field enhanced emission rate ratio e'_n/e_n can be approximated by a straight line for a reasonable range of electric field ε and has functional dependence of the form

$$\frac{e'_n}{e_n} = \exp\left(\frac{\varepsilon}{\varepsilon_0}\right)^n \quad (1)$$

with n and ε_0 obtained from fit to the e'_n/e_n vs. ε curves. In this paper we propose an explicit relationship between ε_0 and temperature to determine the field enhanced emission rate ratio e'_n/e_n at different temperatures. The proposed relation is used for determining the leakage current in poly-Si TFTs at different gate bias and temperature. The leakage current thus calculated can be useful in circuit simulation studies.

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2. Model

In the absence of electric field the electron emission rate of a trap e_n is given by

$$e_n = \sigma_n v_n N_c \exp\left[-\frac{(E_c - E_t)}{kT}\right], \tag{2}$$

where E_t is the trap energy, σ_n is the electron capture cross-section, v_n is the thermal velocity of electron and N_c is the effective density of states in the conduction band (appropriate expression for hole emission rate can be obtained similarly). The expression for field enhanced emission rate deduced by Vincent et al. [5] in the presence of electric field can be written as

$$e'_n = e_n\left[\exp\left(\frac{\Delta E_i}{kT}\right) + \int_{\Delta E_i/kT}^{E_i/kT} \exp\left\{z - z^{3/2} \times \left[\frac{4}{3}\frac{(2m^*)^{1/2}(kT)^{3/2}}{q\hbar\varepsilon}\right]\left[1 - \left(\frac{\Delta E_i}{zkT}\right)^{5/3}\right]\right\} dz\right], \tag{3}$$

where $E_i = E_c - E_t$, m^* is the electron effective mass and ε is the electric field. The field induced barrier lowering ΔE_i due to the Poole–Frenkel effect is given by

$$\Delta E_i = \begin{cases} 0 & \text{Dirac well,} \\ q(q\varepsilon/\pi\epsilon_s)^{1/2} & \text{Coulomb well,} \end{cases}$$

where ϵ_s is the semiconductor permittivity. The first term on the right-hand side of the Eq. (3) inside the bracket is the contribution of the Poole–Frenkel effect responsible for enhancement of pure thermal emission. The second term is the contribution of phonon assisted tunneling with the Poole–Frenkel barrier lowering taken into account.

The field enhanced emission rate expressed by Eq. (3) is not suitable for circuit simulations as it involves numerical integration. For the electric field present in the poly-Si TFTs at the depletion layer formed between drain and channel, Eq. (3) may be approximated by the expression given below

$$e'_n = e_n\left\{\exp\left(\frac{\varepsilon}{\varepsilon_0}\right)^{\gamma}\right\}, \tag{4}$$

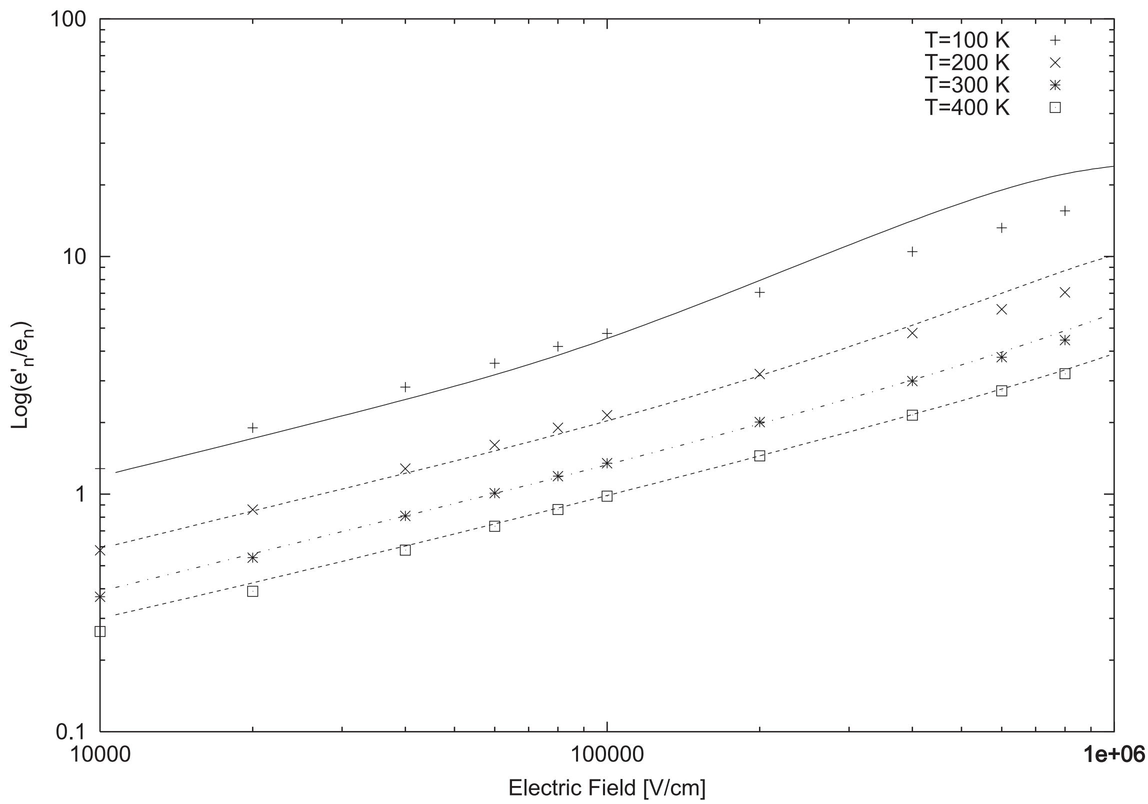

Fig. 1. Enhanced emission rate ratio e'_n/e_n vs. electric field for a Coulomb well with $E_i = E_g/2$. The lines indicate the exact expression and symbols indicate the proposed expression. The values of α, β and γ are 15.0, 2.0 and 0.57, respectively.