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New modeling for thermionic-photo-current and open-circuit voltage in (GIS) Schottky Solar Cells

Abstract

Grown oxide layers (insulators) bridging a graphene layer to n-silicon in G/I/S solar cells have been shown to reduce recombination at the cell junction. Under illumination, the built-in field at the Graphene-Silicon junction, forces minority photo-generated holes to the interface and ultimately to the G-side, while photoelectrons thermionically escape from the G-side to the semiconductor. Electrons from the graphene side may obtain sufficient energy to overcome the junction barrier by simultaneous thermionic emission (TE) and tunneling through the oxide layer to the semiconductor side. Graphene-based Schottky solar cells illuminated from the G-side respond to solar photons at energies above the semiconductor's band gap, hence minority-hole photo-generation. Minority holes diffuse to the junction and aided by the built-in field tunnel through the junction to the graphene side. The interface is essentially a double barrier as a combination of junction Schottky barrier ($q\Phi_B$) and the ox-layer. In this communication, we model the following currents crossing the GIS junction (a) thermionic current from the Graphene side to the semiconductor J_{TE} and (b) hole-current J_P from the n-Si side to the G-side. We <u>derive</u> J_{TE} as a thermionic current that depends on a number of parameters, such as temperature T, Schottky barrier height $q\Phi_B$, and voltage V across the device, specifically, we find that TE current is a strong function of $T^{3/2}$ as $J_{TE} \sim T^{3/2} \exp(-q\Phi_B/kT) \exp(-\chi^{1/2}\delta) [\exp(qV/kT)-1]$. Once these electrons migrate to the n-region, they join the majority electron flow to the load under illumination. The electron tunneling probability $\exp(-\chi^{1/2}\delta)$ guarantees electron flow to the semiconductor (δ = the oxide thickness). On the other hand, photo-generated hole-current is derived from standard techniques leading to $J_p = (qD_p p_n^*/L_p) \exp(qV/kT)-1)-(\alpha L_p qF_\lambda (e^{-\alpha w}/(1+\alpha L_p))$, where F_λ is the solar photon flux, with flat quasi-Fermi level through the depletion region ($p_n^* = p_{no}(e^{qV/kT})$, p_{no} = background hole in the n-region, w is the depletion width at the junction, a is the absorption coefficient, and L_p is hole diffusion current). These holes eventually will tunnel through the oxide to the graphene side. By neglecting recombination at the depletion region, we calculate the total current $J = L_{ight} - J_{dark}$, and the deduce open-circuit voltage. Based on the two current expressions above, we deduce increased open circuit voltage as follows:

$$V_{oc} = \frac{kT}{q}\left[\ln\left(\frac{\alpha L_p qF_\lambda e^{-\alpha w}}{J_{oo}(1+\alpha L_p)}\right) + \frac{q\Phi_B}{kT} + \chi_n^{1/2}\delta\right]$$

; $J_{oo} = A^* T^{3/2}$ is a new current pre-factor, with A^* an appropriate (and explicitly derived) Richardson's constant.