多重量子井戸を用いた InGaP 太陽電池におけるキャリア輸送モデリング

Carrier Transport Modeling in Multiple Quantum Well Based InGaP Solar Cells

Univ. Tokyo [1], RCAST[2] °Hsiang-Hung Huang[1], Kasidit Toprasertpong[1], Kentaroh Watanabe[2], Delamarre Amaury[2], Masakazu Sugiyama[1,2] and Yoshiaki Nakano[1]

E-mail: h.h.huang@hotaka.t.u-tokyo.ac.jp

$In_{0.49}Ga_{0.51}P$ solar cells lattice-matched to GaAs substrate have been highly expected to be good candidates for serving the subcells of multi-junction solar cell technology. However, up to date the associated offset voltage $W_{oc} = E_g - V_{oc}/q$, a typical figure of merit for evaluating cell performance, remains unideal (~ 0.4 V) and need to be improved. On the other hand, according to the reciprocity relation proposed by U. Raw [1], open-circuit voltage of solar cells V_{oc} can be enhanced by improving the radiative efficiency of the devices. Moreover, photovoltaic devices with multiple quantum wells (MQW) have been reported to exhibit better radiative efficiency than that of the bulk material, thus a better W_{oc}, with a drawback of degraded carrier transport.

In this work, we attempt to facilitate the cell performance by introducing stress-balanced (SB) $In_{1-x}Ga_xP/In_{1-y}Ga_yP$ MQWs designs into the conventional $In_{0.49}Ga_{0.51}P$ host material on GaAs substrate. In order to firstly provide a comparable carrier transport characteristics with respect to the $In_{0.49}Ga_{0.51}P$, we employ the effective mobility model proposed by K. Toprasertpong et al.[2], which has not yet been applied to InGaP system, to qualitatively explore the suitable thicknesses and the composition for the MQW designs for improving the cell efficiency.

Fig. 1 (a) shows the schematic of the $In_{1-x}Ga_xP/In_{1-y}Ga_yP$ MQW unit (conduction band only). Fig. 1 (b) displays the schematic of all the possible carrier transport mechanisms: thermal (μ_{th}), direct tunneling (μ_{tun}) and thermally assisted tunneling (μ_{thtun}) escape. Given the SB condition, the required thickness ratios (in log scale) can be determined as

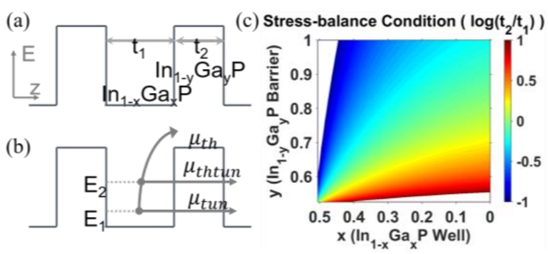

Fig. 1. (a) The unit of the MQW design (b) The schematic of the carrier transport mechanisms (c) The thickness ratio (t_2/t_1) in log scale following stress-balance condition. (white shaded areas depict out of range of the color bar.)

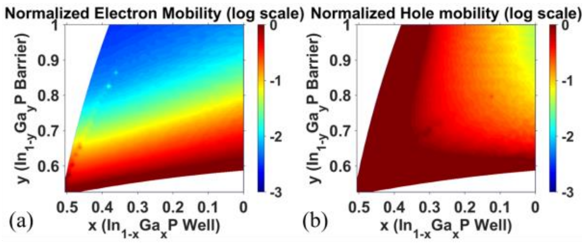

Fig. 2. The effective mobility map normalized to the bulk values of $In_{0.49}Ga_{0.51}P$ (μ_n = 3225 cm^2/Vs, μ_p = 150 cm^2/Vs) solved at $E_{g,eff}$ = 1.91 eV for (a) electrons $\mu_{eff,n}$ and (b) holes $\mu_{eff,p}$. (the plot is in log scale.)

depicted in Fig.1 (c). In order to make a fair comparison with an $In_{0.49}Ga_{0.51}P$ bulk (Eg = 1.91 eV, μ_n = 3225 cm^2/Vs, μ_p = 150 cm^2/Vs), the thicknesses t_1 and t_2 are constrained so that the effective bandgap energies $E_{g,eff}$ (transition energy of e1-hh1 essentially) are equal to 1.91 eV.

Fig. 2 presents the calculated effective electron and hole mobilities normalized by bulk values, 3225 cm^2/Vs and 150 cm^2/Vs, respectively (in log scale). The white-filled areas where t_2/t_1 larger than 5 and smaller than 0.2 illustrate the regions where the model is not applicable. As can be observed from the Fig. 2, regardless of the relatively acceptable hole mobilities, as the gallium content in the barrier increases, the drastically degradation of electron mobility by several orders of magnitude from the value of $In_{0.49}Ga_{0.51}P$ bulk may cause a poor carrier collection, thereby a poor energy conversion efficiency. Based on empirical rules, we assume that for the regions with $\mu_{eff,n,p}$ greater than $0.1\times\mu_{In_{0.49}Ga_{0.51}P,n,p}$ to be the minimum requirement for achieving a comparable carrier collection efficiency. The required gallium amounts x and y can thus be determined from the regions with the normalized mobilities higher than 10^{-1} from Fig. 2.

Reference

[1] U. Rau, "Reciprocity relation between photovoltaic quantum efficiency and electroluminescent emission of solar cells," Phys. Rev. B - Condens. Matter Mater. Phys., vol. 76, no. 8, pp. 1–8, 2007.

[2] K. Toprasertpong, S. M. Goodnick, Y. Nakano, and M. Sugiyama, "Effective mobility for sequential carrier transport in multiple quantum well structures," Phys. Rev. B, vol. 96, no. 7, 2017.