Extended detailed-balance analysis and light management in high-efficiency solar cells
Hidefumi AKIYAMA (ISSP, Univ. of Tokyo)
E-mail: golgo@issp.u-tokyo.ac.jp

We developed an extended detailed-balance-theory analysis of multi-junction solar cells, which enables us to calculate upper-limit efficiencies and optimized band-gap designs of single- and multi-junction solar cells with active materials of realistic quality [1,2]. Light management is very important in solar cells. To obtain high-efficiency, we should care light management not only for incoming sun light, but also for outgoing luminescence light, such as photon recycling and luminescence coupling. The above extended detailed-balance theory includes all these effects, by which we can evaluate contributions of these effects in solar cells with realistic material quality [1,2]. For example, three different types of intermediate reflector designs for light management shown in Fig. 1 cause difference in the optimized efficiency for internal radiative efficiency $\eta_{\text{int}}=1$, but almost no difference for $\eta_{\text{int}}=0.1$ or below, as shown in Fig. 2.

Our extended detailed-balance theory is useful not only for theoretical predictions and designs, but also for analysis of experimental data [3-6]. In fact, we experimentally characterized external and radiative efficiency and derived contribution of luminescence coupling and photon recycling by analyzing data of absolute electro-luminescence intensity or external radiative efficiency [3,6].

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