Area: 5 Perovskite Solar Cells

OPTICAL DEVICE DESIGN OF HIGHLY EFFICIENT $CH_3NH_3Pb(I,Br)_3$/Cu(In,Ga)Se_2-BASED DOUBLE AND TRIPLE TANDEM SOLAR CELLS

Masato Tamakoshi, Shohei Fujimoto, Takemasa Fujiseki and Hiroyuki Fujiwara

Gifu University, Japan

For single-junction hybrid perovskite solar cells, quite high conversion efficiencies of >20% have been realized [1]. Nevertheless, to achieve further drastic improvement in the efficiency, the fabrication of tandem-type solar cells is necessary. Although conversion efficiencies exceeding 30% have been proposed for $CH_3NH_3PbI_3$/Si double-tandem structures, rather approximated optical simulations have so far been carried out [2,3]. In this study, we have performed the explicit optical device simulation for two-terminal hybrid perovskite double-tandem solar cells consisting of a $CH_3NH_3Pb(I,Br)_3$ [$MAPb(I_{1-x}Br_x)_3$] top cell and a Cu(In,Ga)Se_2 (CIGSe) bottom cell. Furthermore, the triple-tandem cell architecture has also been investigated assuming $MAPb(I_{1-x}Br_x)_3$/$MAPbI_3$/CIGSe. In the simulations, the alloy compositions in the top and bottom cells were varied systematically to find the possible highest conversion efficiency within the device parameter space. Moreover, for the optical simulation, (i) a complete optical database was constructed for $MAPb(I_{1-x}Br_x)_3$ using the energy shift model [4] and (ii) a V-shaped Ga compositional profile used widely for CIGSe solar cells was reproduced completely by a procedure established earlier [5].

Figure 1(a) shows a double-tandem device structure constructed for the optical simulation and the resulting external quantum efficiency (EQE) spectra calculated for different Br compositions. The simulations were implemented using a global EQE simulation method developed earlier by our group [6]. In Figure 1(a), the Br composition *x* and the corresponding band gap of the top cell ($E_{g,top}$) are indicated for each EQE spectrum from which J_{sc} of the top and bottom cells can be determined. The V_{oc} values of each solar cell were obtained by a two step; (i) the initial V_{oc} values were calculated by $V_{oc,top}=E_{g,top}/q-0.5$ V and $V_{oc,bottom}=E_{g,bottom}/q-0.35$ V and (ii) these V_{oc} values were further corrected from J_{sc} calculated in the EQE simulations as well as the saturation current density (J_0) obtained from the single solar cells.

Figure 1(b) shows the conversion efficiencies of the $MAPb(I_{1-x}Br_x)_3$/CIGSe tandem solar cell obtained by varying $E_{g,top}$, $E_{g,bottom}$ and the thickness of the $MAPb(I_{1-x}Br_x)_3$ top layer (d_{top}) independently. As shown in this figure, when d_{top}=1000 nm, the maximum efficiency of 28.6% is obtained at $E_{g,top}$=1.73 eV (x=28 at.%) and $E_{g,bottom}$=1.10 eV. Thus, a similar efficiency can also be obtained for $MAPb(I_{1-x}Br_x)_3$/Si tandem solar cells. Since the $MAPb(I_{1-x}Br_x)_3$ layer thickness is relatively thick (1 μm), the above calculation reveals that the efficient optical confinement is necessary to realize a high conversion efficiency in the tandem-type solar cells. For $MAPb(I_{1-x}Br_x)_3$/$MAPbI_3$/CIGSe triple tandem cells, on the other hand, only the slight increase in the efficiency (29.2%) has been confirmed due to the mismatching of E_g.

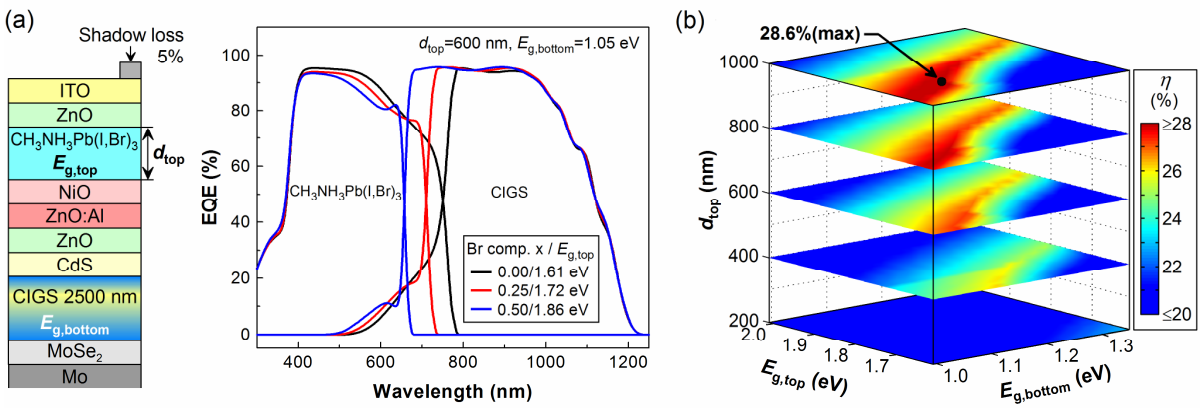

Figure 1: (a) Assumed device structure and the EQE simulation results and (b) conversion efficiencies of the tandem solar cells as functions of $E_{g,top}$, $E_{g,bottom}$ and d_{top}.

[1] Yang et al., *Science* **348**, 1234 (2015). [2] Loper et al. *IEEE J. Photovolt.* **4**, 1545 (2014). [3] Asadpour et al. *Appl. Phys. Lett.* **106**, 243902 (2015). [4] Snyder et al., *J. Appl. Phys.* **68**, 5925 (1990). [5] Hara et al., *Phys. Rev. Appl.* **2**, 034012 (2014). [6] Nakane et al., *J. Appl. Phys.* **120**, 064505 (2016).