Supplementary Information

Non-Antireflective Scheme for Efficiency Enhancement of Cu(In,Ga)Se_2 Nanotip Arrays Solar Cells

Yu-Kuang Liao[†], Yi-Chung Wang[§], Yu-Ting Yen[§], Chia-Hsiang Chen[§], Dan-Hua Hsieh[‡], Shih-Chen Chen[†], Chih-Chung Lai[§], Wei-Chen Kuo[†], Jenh-Yi Juang[†], Kaung-Hsiung Wu[†], Shun-Jen Cheng[†], Chih-Huang Lai[§], Fang-I Lai[¥], Shou-Yi Kuo[£], Hao-Chung Kuo[‡,], and Yu-Lun Chueh[§,*]*

[‡]Department of Photonics and Institute of Electro-optical Engineering and [†]Department of Electro-physics, National Chiao-Tung University, Hsinchu, 30010, Taiwan (ROC)

[§]Department of Materials Science and Engineering, National Tsing-Hua University, Hsinchu 30013, Taiwan (ROC)

[¥]Department of Photonic Engineering, Yuan-Ze University, Taoyuan 32003, Taiwan (ROC)

[£]Department of Electronic Engineering, Chang-Gung University, Taoyuang 33302, Taiwan (ROC)

E-mail: ylchueh@mx.nthu.edu.tw(Yu-Lun Chueh), hckuo@faculty.nctu.edu.tw(Hao-Chung Kuo)

Temperature-dependence PL Measurements

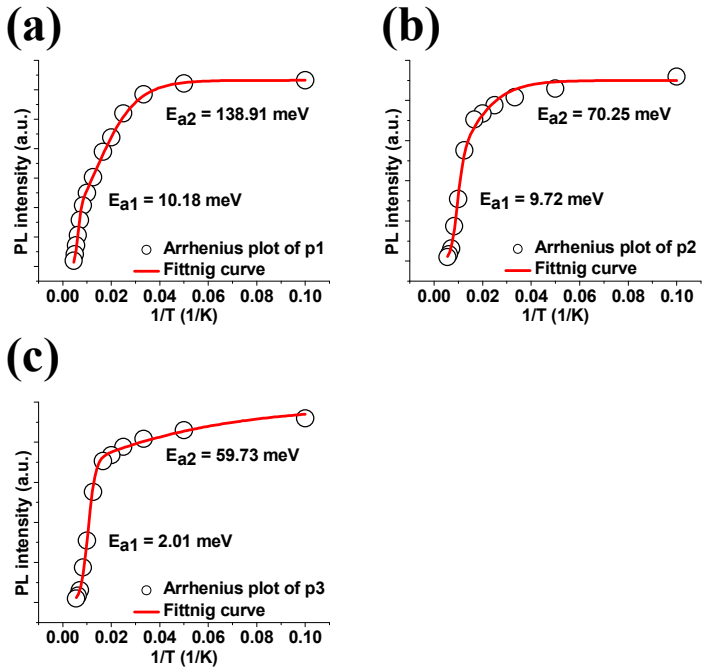

Figure S1 Arrhenius plots of (a) p1, (b) p2 and (c) p3 obtained from the CIGS TF. The obtained values of activation energy at low/high temperature are labeled at their corresponding temperature range.

Power-dependence PL Measurements

DAP Saturation Effect

In the condition of low excitation power, the ionized DAPs are under saturation level therefore the PL intensity of corresponding recombination emission is linearly depending upon the excitation power (k=1). On the contrary, when approaching the saturation level under high excitation power, a sublinear dependence has emerged (k<1) due to the quantity of excited DAPs approaching to its upper limit. Blue shift and expansion of FWHM are also exhibited due to DAP saturation. These are caused by DAP mechanisms at different excitation levels. While the excitation power is low (Figure S2a), ionized DAPs are far apart such that Coulomb interaction between donor and acceptor is irrelevant. DAPs recombination is consequently independent of separation distance and exhibits constant photon energy (neglecting the Coulomb term in eq 1) as well as FWHM. As a high excitation power is applied and approaches the level of DAPs saturation (Figure S2b). Recombination between closed DAPs happens so that Coulomb interaction starts to play a role and results in a blue shift in PL emission peak (a surplus contribution of the Coulomb term in eq 1 in main paper). Since the photon energy of PL emission has become a function of the distance between DAP, FWHM is also increased showing that the separation between ionized DAPs distributes over a range of distances.

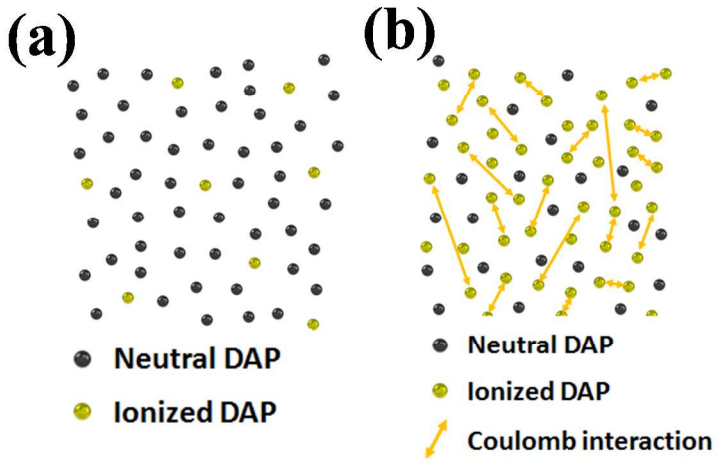

Figure S2 Schematic illustration of donor-acceptor pair excitation under (a) low excitation power and (b) high excitation power.

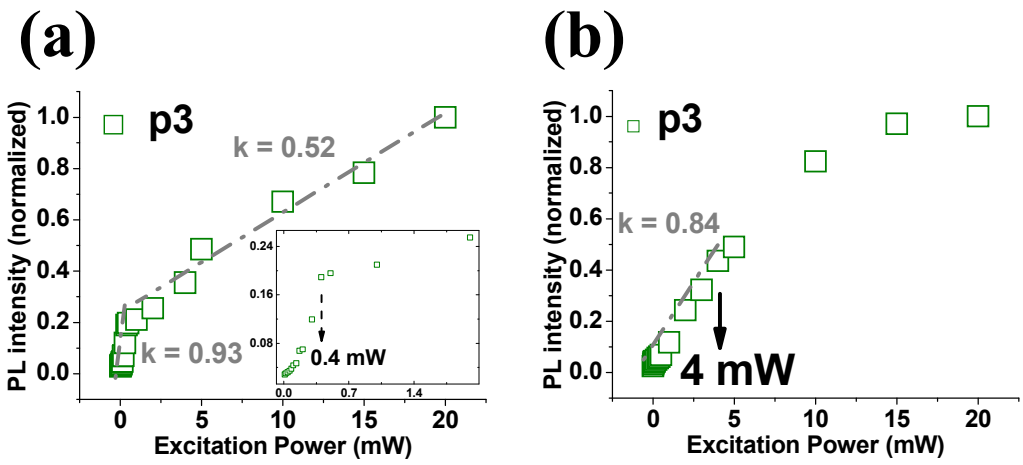

Figure S3 (a) PL intensity dependence upon excitation power of p3 obtained from CIGS TF and (b) that obtained from CIGS NTRs. Inset in (a) shows magnification around 0.4 mW. Results of curve fitting based on $I \propto L^k$ are shown in both (a) and (b).

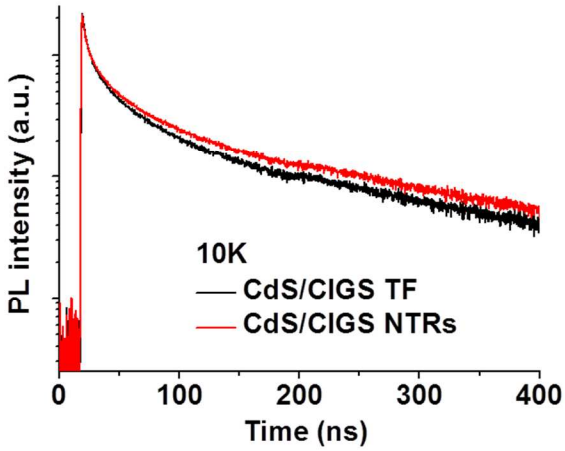

Figure S4 Time-resolved photoluminescence (TRPL) measurements of p2 peak obtained from CIGS TF and NTRs with CdS capping at 10K.