Hybrid Nanostructures of Al-Catalyzed Si Nanowires and Mn-doped Perovskite $CsPbCl_3$ Nanocrystals for Thin Si Nanowire-based Photovoltaic cells

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Thin silicon (Si) solar cells have been candidates to suppress Si material consumption and to develop into flexible devices. These advantages have come with a trading-off in solar cell efficiency. Si nanowire (NW) structures on thin Si substrates are promising to minimize spectral mismatch optical loss to a great extent by efficient light absorption [1]. However, surface and bulk recombination losses play a dominant role in reducing carrier generation and power conversion efficiency (PCE). Therefore, overcoming these issues together with increasing photogenerated charge carriers is significant to realizing high-efficiency thin SiNW-based solar cells. In this study, thin Si samples provided by pre-chemical etching and post-mechanical polishing were used to demonstrate thin SiNW-based solar cells. Al-catalyzed SiNW formations and solar cell performances on both pre-etched and post-polished thin Si substrates were investigated. Radiative and nonradiative energy transfer (RET and NRET) using manganese (Mn)-doped perovskite ($CsPbCl_3$) nanocrystals (NCs) [2] were observed as hybrid nanostructure devices that combine absorbing components with SiNW-based solar cells to open new possibilities in broad light-harvesting.

In the experiment, the pre-etched thin Si substrates were prepared by $HF/H_2O_2/CH_3COOH$ solution, and bulk Si was used for post-polished samples. The Al-catalyzed SiNW formation was performed by vapor-liquid-solid (VLS) growth of chemical vapor deposition (CVD) [1]. The post-polished samples were mechanically polished at the back side. The p^+-Si shell layer was further deposited onto SiNWs to form solar cells. Then, Ti/Ag with a micro-grid pattern for the front electrode and Ag back contact were performed. After that, the $CsPbCl_3$ NC solution with various Mn doping was applied to the solar cells as illustrated in Fig. 1.

From the results, thin Si substrates were detected with high reflectance and transmittance at the long wavelength range. These are attributed to the back surface reflection and the sample thickness. The

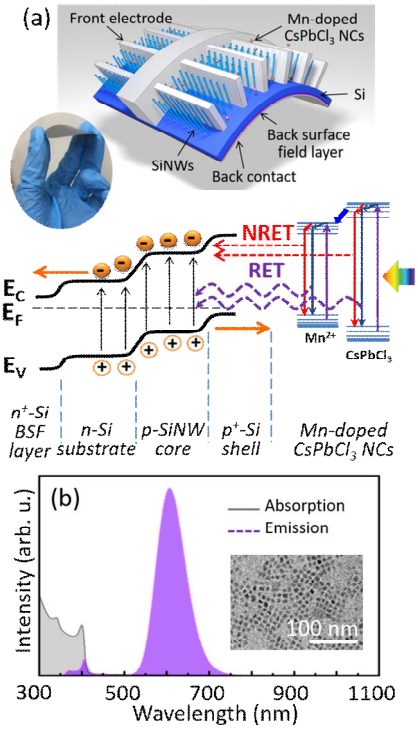

Fig. 1 (a) Photo of thin Si substrate and schematic of thin hybrid nanostructure solar cell. Energy diagram and illustration of energy transfer by both of radiative (RET) and non-radaiative (NERT) induced light absorption and subsequent charge separation in SiNW-based solar cells. (b) TEM image, photoluminescence spectra of Mn-doped $CsPbCl_3$.

vertical SiNW formation was better controlled on post-polished Si substrate along [111] direction. However, the PCE of both thin SiNW solar cells is comparable to around 6 %. After combining with Mn-doped $CsPbCl_3$ NCs, the $CsPbCl_3$ NCs acts as highly efficient radiative and non-radiative energy transfer centers as presented in Fig. 1. Mn-doping also drastically enhances photoluminescence quantum yields due to the charge transfer of photoinduced exciton from the $CsPbCl_3$ host to the dopant Mn^{2+} centers, leading to thin solar cell property enhancing and a high PCE up to 8 %. The preparation details, optimizations, and photovoltaic characteristics for the best pristine thin SiNW sample and hybrid nanostructure sample will be discussed on-site.

[1] W. Jevasuwan, *et al.*, Nanoscale. 13 [14] (2021) 6798-6808.
[2] M. Abdelbar, Nano Energy. 77 (2020) 105163.