 Silicon-based Multi-junction Solar Cells

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Abstract: Great concerns on increasing global energy demand and environmental sustainability have aroused tremendous research interests in developing clean and renewable energy, especially inexhaustible clean solar power, to compete with excessive used fossil fuels. Among numerous photovoltaic (PV) technology candidates with various materials and architecture systems to address the issues of providing affordable and clean solar energy, multi-junction solar cells (MJSC) become the first choice owing to their unique advantages, including high photovoltage, reduced carrier thermalization loss, and high efficiency potentials, which also enable their particular applications in household and industrial scales. MJSCs based on the earth-abundant element, silicon, can further open reliable pathways to achieve the goal. We herein report our latest progress in fabricating high-performing MJSCs. As the sub-cells in MJSCs, high-performing single-junction silicon thin film solar cells, on the basis of highly transparent and conductive transparent conducting oxides with strong light scattering capabilities and transparent n-type nc-SiO\textsubscript{x}:H doping materials to maximize the light coupling and trapping in solar cells, were independently achieved for a-Si:H with an initial efficiency of 4.59\% (V\textsubscript{oc}=0.99V), a-Si: H cells with 11.3\% (V\textsubscript{oc}=0.93V), a-SiGe: H cells with 10.59\% (V\textsubscript{oc}=0.74V), and \mu c-Si: H with 10.54\% (V\textsubscript{oc}=0.55V). Silicon heterojunction solar cells (SHJ) with an initial efficiency of 20.54\% (V\textsubscript{oc}=0.70V), which can act as the bottom cells in MJSCs due to their narrow optical band-gap, were also realized by effectively passivating the highly-recombinative interfaces with i-a-Si:H, p-nc-Si:H/p a-a-Si:H dual-emitter layers, and n-SiO\textsubscript{x}:H back reflector. After combining with the single-junction sub-cells and optimizing the current-matching, an outstanding initial efficiency of 10.3\% (V\textsubscript{oc}=1.96V), 11.63\% (V\textsubscript{oc}=1.75V), 13.65\% (V\textsubscript{oc}=1.39V), and 14.26\% (V\textsubscript{oc}=1.52V) were respectively achieved for double-junction a-Si:H/a-Si:H, a-Si:H/a-SiGe:H, a-Si:H/\mu c-Si:H, a-Si:H/SHJ solar cells. Further based on the optimized low-loss tunnel recombination junctions to connect the sub-cells, higher performance triple-junction and quadruple-junction MJSCs with an initial efficiency of 16.07\% (V\textsubscript{oc}=2.19V) and 15.03\% (V\textsubscript{oc}=3.02V) were achieved for a-Si:H/a-SiGe:H/\mu c-Si:H and a-SiC:H/a-Si:H/a-SiGe:H/\mu c-Si:H solar cells. Besides the silicon MJSCs, new-type perovskite/SHJ tandem solar cells are also being developed. A thin PC61BM buffer layer has been introduced between TiO\textsubscript{2} electron transporting layer and perovskite absorber in n-i-p planar perovskite solar cells (PSCs), which could passivate the defects or dangling bonds parasitizing on the TiO\textsubscript{2} surface, and optimize the device band alignment. By this advanced technology, the good device performance of PSCs could provide an effective current matching between the top and sub solar cells, which achieved a reverse-scanned efficiency over 20\%.

Keywords: solar cells, silicon, perovskite, Tandem