Organic Hole Conducting Layer Achieves 80.5% Fill Factor in Conventional Silicon Solar Cells

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Abstract

The emergence of organic-silicon interface engineering offers a practical means to reduce the cost of conventional silicon solar cells by adopting low-temperature, diffusion free, solution processes. In this work, we incorporate a small-molecule material(bis(1-phenylisoq uinoline) (acetylacetonate)iridium(III), Ir(piq)2(acac)) which acts as a hole conducting layer in conventional silicon solar cells via a scalable blade coating technique. The device with the organic hole-conducting material exhibits a superior fill factor of 80.48% with a power conversion efficiency up to 12.59%, resulting from the reduced junction barrier between the metal-silicon interface. The device characteristics are also comparable to those with the conventional aluminum back surface field, directing a viable route to the development of organic interface engineering for silicon solar cells.

1. Introduction

In recent years, crystalline silicon (c-Si) solar cells have been dominating the worldwide photovoltaic market. Thus, there is a need for the evolution of processing technologies. Achieving high-efficiency silicon solar cells requires superior carrier selective contacts (CSC) and great surface passivation contacts. However, the conventional c-Si solar cells still employ conventional high-vacuum, high-temperature semiconductor processes to fabricate a highly doped n and p-type layer, which could reduce the minority carrier recombination. To replace the complex diffusion or deposition process, researchers search for dopant-free carrier-selective material, such as transition metal oxides, alkali metal fluorides, and organic materials for the formation of CSC[1-2]. Among those, organic materials show great potential due to their low-temperature, solution-based fabrication process and simple manufacturing. Luminescent materials have high photoluminescence quantum yield, which indicates a high radiative recombination, but we could achieve a novel carrier-conducting concept via nonradiative resonant energy transfer (NRET)[3]. NRET is an interaction between acceptors and donors in which the excitation energy of a donor is transferred to an acceptor. NRET requires three factors: (1) the acceptors' absorption spectrum should overlap the donors' emission spectrum, (2) the transition of dipole orientation must be parallel, and (3) the separation of donor and acceptor excitons must be sufficiently small (typically <10 nm). In similar cases, Ir(piq)2(acac) of the luminescent materials acts as donors, whereas the Si acts as acceptors. When the nonradiative resonant energy is transferred to Si, due to the built-in potential, the energy could be separated electrons and holes. Thus, a newly generated charge-carrier could be transported, and novel carrier-conducting mechanism is achieved.

In this report, we introduce Ir(piq)2(acac) as a hole-conducting layer into hybrid heterojunction solar cells. From the current density-voltage (J-V) characteristics, contact resistance (ρ_c) measurement and band alignment, we demonstrate the potential of organic materials acting as the hole selective contact (HSC). The highest fill factor (FF) can be over 80% and the power conversion efficiency (PCE) is 12.59% for the device with Ir(piq)2(acac) interlayer while to reference device has a FF of 76.89% and a PCE of 11.56%.

2. Experiments

Solar cells were fabricated on (100)-oriented p-type 6-inch silicon with 180 um thickness. After RCA cleaning, SiNx layer was deposited on the backside by PECVD as a protective layer, and the front side was textured with random pyramids by etching the wafer in a potassium hydroxide (KOH). In the next step, for making a highly conductive n-type diffusion layer (sheet resistance ~120 Ω /sq) on the surface of the pyramid to form an n+/p junction. POC13 diffusion through the furnace tube was per-formed. Prior to the blade-coating Ir(piq)2(acac) on the backside, the substrates were dipped into hydrofluoric acid (HF) to remove the native oxide layer. Further, the samples were annealed at 150°C for 10 min after blade coating. The silver (Ag) with 100 nm was evaporated thermally on the front and backside, subsequently. The process flow is showed in Figure 1.



Fig.1 The process flow of hybrid heterojunction solar cells

3. Results & Discussions

As seen in figure 2 (a), Ir(piq)2(acac) is a soluble in organic solvent, luminescent material, which has been widely used in organic light emitting diodes as the hole-conducting laver (HTL). Ir(piq)2(acac) possesses а lowest-unoccupied-molecular-orbital (LUMO) value of 3.20 eV which is higher than the conduction band of Si and highest-occupied-molecular-orbital (HOMO) value of 5.20 eV, which is close to the valance band of Si. The Ir(piq)2(acac) interfacial layer between Ag/Si interface of a hybrid heterojunction solar cell results in an energy band diagram as shown in figure2 (b).



Fig.2 (a) Chemical structure of Ir(piq)2(acac). (b) Energy band diagram of the hybrid heterojunction solar cell with Si and Ag and Ir(piq)2(acac) interlayer. (c) Schematic of Ir(piq)2(acac)/p-Si heterojunction device



Fig.3 Contact resistance measurement of (a) reference and (b) Ir(piq)2(acac)/p-Si contact

The Ir(piq)2(acac) film drastically improves the contact behavior, leading to Ohmic contact, and the ρ_c decreased from 159.37 Ω cm2 (not shown) to 0.082 Ω cm2 as shown in figure 3. It can be observed from the results that the decrease in the barrier between Ag and Si is due to Ir(piq)2(acac) interlayer.



Fig.4 (a) J-V characteristics and (b) EQE spectra of the fabricated devices with and without the Ir(piq)2(acac) layer

 Table I The photovoltaic characteristics of the hybrid heterojunction solar cell

Polished	Voc(mV)	Jsc(mA/cm2)	FF(%)	PCE(%)
Ref.	543.91	27.63	76.89	11.56
Ir(piq)	552.24	28.33	80.48	12.59
2(acac)	$554.92\pm$	$28.03 \!\pm\! 0.25$	$80.05 \!\pm\! 0.48$	$12.45\pm$
	0.00			0.41

Finally, figure 4 shows the J-V curves under an AM1.5G illumination condition and the external quantum efficiency (EQE) spectra for the Ir(piq)2(acac) device, compared to the reference device. From figure 4 (a), it is evident that the reduced series resistance and increased shunt resistance resulted in improved the FF over 80 %. Moreover, due to the Ir(piq)2(acac) interlayer between the p-Si and Ag interface, the EQE value was slightly improved as shown in figure 4 (b). The overall device statistics, including average and standard deviation for short-circuit current density (Jsc), open-circuit voltage (Voc), FF and PCE are summarized in Table 1. Compared to the reference device with PCE of 11.56%, the device with Ir(piq)2(acac), has the outstanding FF of over 80% and the best efficiency achieves 12.59%. The enhancement may be attributed to two key points : (1)due to the HOMO level of Ir(piq)2(acac) is close to the valance band of Si, the interfacial NRET with minimal energy loss, and the newly generated charge-carrier could flow out to the external circuit to complete a novel carrier-conducting concept. (2) the energy band alignment for the HOMO level of Ir(piq)2(acac) is close to the valance band of Si meaning hole-conducting is achieved, which blocks electron recombination at Si/Ag interface successfully.

4. Conclusions

In conclusion, the dopant-free concept for conventional n+/p-type solar cells by solution processes is demonstrated. Interface engineering via Ir(piq)2(acac) interlayer enhances carriers conducting and decrease the barrier between metal and semiconductor, which achieves a power conversion efficiency of 12.59% with a fill factor of 80.48%. These results show the great potential of Ir(piq)2(acac), which may be applied in other devices in the future.

References

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