Solution-processed polymer solar cells offer the attractive prospect of providing high-efficiency lightweight, flexible, low-cost and large-area photovoltaic modules through cheap roll-to-roll fabrication at a low processing temperature. To date, the power conversion efficiency (PCE) of state-of-the-art single-junction polymer solar cells has reached ~9%–11% as a result of impressive efforts in developing novel medium-bandgap polymer donor materials, optimizing the photovoltaic blend morphology, interface engineering, and novel light management structures. Single-junction solar cells are now approaching the practical efficiency limit of ~11%–12%. Improving the PCE of polymer solar cells beyond 15% is required to become competitive with other thin-film photovoltaic technologies. With this aim, multijunction devices with tandem or triple-junction configurations have received considerable attention from researchers in the past few years. Multijunction solar cells are generally fabricated via the serial connection of wide-bandgap and low-bandgap subcells with complementary absorption spectra to achieve a broader solar spectral coverage and to reduce the thermalization losses. A record certified PCE of 10.6% has been reported for polymer tandem solar cells and PCEs of triple-junction polymer solar cells reaching 11%–12% have also been reported by several groups. Such high efficiencies are mainly credited to the successful synthesis of high-performance medium-bandgap (E_g = 1.5–1.8 eV) and low-bandgap (E_g < 1.5 eV) polymer donors and the development of novel efficient interface and interconnecting layers (ICL) that enable the electrical and optical coupling between the subcells. However, the lack of high-performance wide-bandgap polymers still remains one of the main limiting factors to further improve the PCE of multijunction solar cells.

The performance of wide-bandgap front subcells is of crucial importance for achieving highly efficient multijunction solar cells since the front cell with the highest open-circuit voltage (V_oc) delivers the most energy output among the subcells. Requirements for the front cell include (i) having a high V_oc with a small loss compared to E_g, (ii) having a high external quantum efficiency (EQE > 80%) at shorter wavelengths to achieve sufficient current density, (iii) having a high PCE within a broad range of photactive layer thickness to achieve current matching with other subcells, and (iv) having excellent chemical stability to allow following materials processing and thermal treatment. Despite the recent efforts in developing wide-bandgap polymer donors, high-performance polymer solar cells that fulfill all requirements for the front cell are not available presently.

In this article, we report the utilization of hydrogenated amorphous silicon (a-Si:H) as an alternative to the wide-bandgap polymer to construct hybrid a-Si:H/polymer tandem and triple-junction solar cells. A high PCE of 11.6% is achieved in hybrid a-Si:H/polymer tandem solar cells with the combination of a-Si:H and a low-bandgap polymer. The PCE further increases to 13.2% in hybrid a-Si:H/a-Si:H/polymer triple-junction solar cells by using a light-trapping front electrode. The a-Si:H absorber materials have a tunable bandgap from 1.60 to 1.75 eV, corresponding to a V_oc variation from 0.88 up to 1 V. The a-Si:H solar cells possess high EQE at short wavelengths, high fill factor (FF), and almost unity internal quantum efficiency (IQE) over a broad range of absorber layer thickness. These properties make an a-Si:H solar cell a suitable candidate for the front subcell in polymer-based multijunction devices. The hybrid approach combines the advantages of both a-Si:H and polymer solar cells, such as abundant raw materials, light weight and flexibility, low cost and low processing temperature. More importantly, the well-established processing of a-Si:H-based devices is technically compatible with the following fabrication of polymer solar cells.
Figure 1a illustrates the device architecture of the hybrid a-Si:H/polymer tandem solar cells. The low-bandgap polymer subcell is connected in series with the front a-Si:H subcell by an ICL that consists of an Al-doped ZnO (AZO)/Ag/MoO₃ layer stack. The MoO₃ film also serves as hole transport layer (HTL) for the polymer solar cell while the thin (1 nm) Ag improves the ohmicity of the AZO/MoO₃ recombination contact. A schematic representation of the hybrid a-Si:H/a-Si:H/polymer triple-junction solar cell is displayed in Figure 1b. The two a-Si:H subcells are interconnected via a tunnel recombination junction, which is formed by the heavily n-doped layer of the front cell and the heavily p-doped layer of the middle cell.

A highly efficient multijunction solar cell requires delicate bandgap engineering for each subcell to simultaneously obtain a high $V_{oc}$ and a high matched current density. For both the hybrid tandem and triple-junction solar cells shown in Figure 1, a blend of near-infrared polymer poly[$2,5$-bis(2-hexyldecyl-2,3,5,6-tetrahydro-3,6-dioxopyrrolo[3,4c]pyrrole-1,4-diyl]-alt-$[3',3''$-dimethyl-$2,2',5',2''$-terthiophene-$5,5''$-diyl]] (PMDPP3T) and PC₆₀BM (chemical structures shown in Figure 2a) was used as the absorber in the back cells. PMDPP3T, which has previously been selected to construct highly efficient multijunction polymer solar cells, is one of the most efficient low-bandgap polymers up to now.[19] The bandgaps of the a-Si:H absorbers were tuned through the variation of deposition temperature, processing pressure, and H₂/SiH₄ gas flow ratio.[30,31] The well-optimized high-quality a-Si:H films have bandgaps that can be tuned from 1.60 to 1.75 eV, corresponding to the $V_{oc}$ tuning from 0.88 up to 1 V. The photovoltaic performance of three typical a-Si:H single-junction solar cells with variable bandgaps is presented in Table 1, together with the performance of the single-junction PMDPP3T:PC₆₀BM polymer solar cell. All a-Si:H cells exhibit a lower $E_{g} - qV_{oc}$ energy loss than state-of-the-art wide-bandgap polymer donors used for polymer tandem or triple-junction solar cells such as P3HT, BDT-FBT-2T, PSEHTT, PIDT-phanQ, and PBDDTPD (Table S1, www.MaterialsViews.com).
Meanwhile, the a-Si:H cells have a high FF >70% and high EQE at the short wavelengths, with peak EQE >80% as displayed in Figure 2b. The superior performance of a-Si:H solar cells indicates that a well-optimized a-Si:H solar cell has the potential to outperform the polymer counterpart as the front subcell in a multijunction device. From the analysis of the spectral coverage and the single-junction solar cell performance, the 2# a-Si:H and 1# a-Si:H show a high potential for application as the front cell in the tandem and triple-junction solar cells, respectively. As a demonstration to build up triple-junction solar cells, we utilized the 3# a-Si:H as the middle cell. As we will discuss later, it would also be possible to replace the a-Si:H middle cell with a medium-bandgap polymer solar cell, provided it would have a high EQE in the wavelength range 500–800 nm.

In addition to the performance of the subcells, the ICL between a-Si:H and polymer subcells plays an important role in achieving highly efficient multijunction solar cells. Electrically, an efficient ICL should form an ohmic recombination contact between the subcells and have a suitable work-function difference to sum up the $V_{oc}$ of the individual subcells. Previous studies have shown that AZO/Ag/MoO$_3$, AZO/pH-neutral poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (n-PEDOT:PSS), and ITO/PEDOT:PSS are efficient ICLs to electrically connect the a-Si:H and polymer constituent subcells.$^{[28,29,34]}$ However, the role of the optical properties of the ICL in the hybrid multijunction solar cells has not yet been well recognized and studied. Here we will discuss the importance of the optical characteristics of the ICL in the a-Si:H/polymer tandem solar cell and show that an AZO/Ag/MoO$_3$ ICL can result in better performance than AZO/n-PEDOT:PSS (or ITO/PEDOT:PSS).

As displayed in Figure 3a, the a-Si:H layer has a higher refractive index ($n$) than the ICL and the PMDPP3T:PC$_{60}$BM blend layer. With an Al optical reflector at the back side, a Fabry–Perot optical microcavity is formed in the ICL and PMDPP3T:PC$_{60}$BM layers.$^{[15]}$ The thickness of the spacer layer (ICL+PMDPP3T:PC$_{60}$BM) determines the electrical field distribution of the incident light in the cavity, which will have a significant influence on the useful light absorption in the polymer subcell. Optically we have to consider two important factors for the ICL. First, the thickness of the ICL should be optimized to allow maximal absorption in the PMDPP3T:PC$_{60}$BM photoactive layer. Second, the parasitic absorption in the ICL should be as low as possible.

As shown in Figure 3b, the simulated photocurrent density ($J_{ph}$) in the polymer back cell is sensitive to the AZO thickness and back cell thickness. A high $J_{ph}$ > 10.5 mA cm$^{-2}$ can be obtained in two regions. One is in range of back cell thicknesses of 140–160 nm and the other one is in the range of back cell thicknesses of 290–320 nm. Considering the thickness-dependent photovoltaic performance of polymer solar cells (Figure S1, Supporting Information), the thinner cell is preferred to achieve higher $V_{oc}$ and FF. Thus, in the following content, we focus on a back cell thickness less than 200 nm.

![Figure 2.](https://example.com/figure2.png)

**Figure 2.** a) Chemical structures of PMDPP3T and PC$_{60}$BM. b) EQE curves of single-junction a-Si:H solar cells with various bandgaps and PMDPP3T:PC$_{60}$BM polymer solar cell as shown in Table 1.

**Table 1.** Characteristics of optimized single-junction a-Si:H and PMDPP3T:PC$_{60}$BM solar cells.

<table>
<thead>
<tr>
<th>Single-junction cell</th>
<th>$E_{g,\text{opt}}$</th>
<th>$V_{oc}$</th>
<th>$J_{sc}$</th>
<th>FF</th>
<th>PCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si:H a)</td>
<td>1.73</td>
<td>0.98</td>
<td>12.7</td>
<td>75</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>1.68</td>
<td>0.95</td>
<td>13.8</td>
<td>74</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td>1.60</td>
<td>0.89</td>
<td>16.2</td>
<td>73</td>
<td>10.4</td>
</tr>
<tr>
<td>PMDPP3T:PC$_{60}$BM b)</td>
<td>1.30</td>
<td>0.61</td>
<td>15.7</td>
<td>60</td>
<td>5.7</td>
</tr>
</tbody>
</table>

$E_{g,\text{opt}}$, optical bandgap; $J_{sc}$, short-circuit current density; a) a-Si:H solar cells were deposited on as-grown textured SnO$_2$:F substrates, thickness $\approx$ 300 nm; b) Polymer solar cells were processed on flat glass/ITO substrates with PEDOT:PSS as the HTL, thickness = 140 nm.
fixed back cell thickness (range 120–200 nm), $J_{ph}$ decreases with the increase of AZO thickness. Obviously, a thinner AZO layer in the ICL can deliver a higher maximal $J_{ph}$ in the back cell with the variation of back cell thickness as displayed in Figure 3d. To achieve a balanced current density in each subcell, the front cell thickness also needs to be varied in practical tandem devices. Figure 3c presents the $J_{ph}$ of the front and back cells as a function of back cell thickness, with the front cell thickness varying from 100 to 400 nm. It can be clearly seen that the $J_{ph}$ of the front cell is mainly determined by the front cell thickness and depends only weakly on the back cell thickness and AZO thickness (Figure S2, Supporting Information). One important characteristic is that the optimal back cell thickness has little dependence on the front cell thickness. The optimal back cell thickness for obtaining maximal $J_{ph}$ in the back cell mainly depends on the thickness of the ICL. Practically, the AZO layer should be at least 30 nm to obtain a uniform layer and form an efficient recombination contact. Thus, 30 nm thick AZO was used in the optimized multijunction solar cells to achieve maximal $J_{ph}$ in the back cell.

Next we compare the ICLs AZO/Ag/MoO$_3$ and AZO/n-PEDOT:PSS. As the HTL, the n-PEDOT:PSS layer (normally 30–60 nm is needed) is necessarily thicker than the MoO$_3$ layer (~10 nm). It also has a higher absorption coefficient than MoO$_3$. This results in a higher optical loss in the n-PEDOT:PSS layer. Figure 3d clearly shows that the AZO/Ag/MoO$_3$ can lead to a higher maximal $J_{ph}$ in the back cell than the AZO/n-PEDOT:PSS for a certain AZO thickness. The maximal $J_{ph}$ in the back cell is also very sensitive to the thickness of the n-PEDOT:PSS layer and a thicker n-PEDOT:PSS layer results in a lower $J_{ph}$. Figure S3 (Supporting Information) shows the $J$–$V$ characteristics of two hybrid tandem solar cells with AZO/Ag/MoO$_3$ and AZO/n-PEDOT:PSS as ICLs as a function of the AZO thickness. The thickness of MoO$_3$ is 10 nm and the n-PEDOT:PSS is 40 or 60 nm thick. The front cell thickness is kept constant at 440 nm in (b) and (d).

With the understanding of the optical effects of the ICL, we fabricated hybrid tandem solar cells with the device configuration as shown in Figure 1a. The tandem cells were constructed...
with 2# a-Si:H for the front cell and PMDPP3T:PC70BM blend for the back cell. The thicknesses of the AZO, Ag, and MoO3 layers in the ICL stack are 30, 1, and 10 nm, respectively. To find the maximal achievable balanced current density, optical modeling was conducted to determine the optimal thickness range of the photoactive layers in constituent subcells. The highest balanced $J_{sc}$ of tandem cell is expected for a front cell of $\approx 440$ nm and a back cell of $\approx 150$ nm (Figure S5, Supporting Information). The hybrid tandem solar cells were fabricated with these optimized subcell thicknesses and characterized under simulated solar illumination. Table 2 and Figure 4a,b present the photovoltaic performance of the fabricated tandem devices. The tandem devices have a high FF and a high $V_{oc}$ almost equal to the sum of the two subcells, indicating that the AZO/Ag/MoO3 stack is an effective ICL. The measured $J_{sc}$ values (10.7 mA cm$^{-2}$ on average) are consistent with the simulated value (10.6 mA cm$^{-2}$). The calculated $J_{sc}$ (limiting subcell 10.5 mA cm$^{-2}$) from the EQE measurements as shown in Figure 4b is also in good agreement with the measured photocurrent. The tandem cells (with a best PCE of 11.6%) exhibit a significant efficiency improvement with respect to the two single-junction reference cells (with PCEs of 8.4%)

<table>
<thead>
<tr>
<th>Device structure</th>
<th>Front TCO</th>
<th>Cell thickness [nm] front/middle/back</th>
<th>$V_{oc}$ [V]</th>
<th>$J_{sc}$ [mA cm$^{-2}$]</th>
<th>FF [%]</th>
<th>PCE[a] [%]</th>
<th>PCE$_{best}$ [%]</th>
</tr>
</thead>
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<tr>
<td>Tandem</td>
<td>Flat</td>
<td>440/150</td>
<td>1.55 ± 0.01</td>
<td>10.7 ± 0.2</td>
<td>67.6 ± 1.6</td>
<td>11.3 ± 0.3</td>
<td>11.6</td>
</tr>
<tr>
<td>triple[b)</td>
<td>Flat-1</td>
<td>85/500/110</td>
<td>2.38 ± 0.01</td>
<td>5.8 ± 0.2</td>
<td>71.0 ± 1.4</td>
<td>9.8 ± 0.2</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>Flat-2</td>
<td>85/500/150</td>
<td>2.38 ± 0.01</td>
<td>6.0 ± 0.2</td>
<td>71.0 ± 1.0</td>
<td>10.1 ± 0.3</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td>Textured-1</td>
<td>85/500/110</td>
<td>2.32 ± 0.05</td>
<td>7.9 ± 0.3</td>
<td>59.0 ± 4.8</td>
<td>10.7 ± 0.9</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Textured-2</td>
<td>85/500/150</td>
<td>2.30 ± 0.01</td>
<td>7.9 ± 0.2</td>
<td>66.0 ± 1.4</td>
<td>12.0 ± 0.4</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>Textured-3</td>
<td>90/1000/150</td>
<td>2.33 ± 0.01</td>
<td>8.6 ± 0.1</td>
<td>64.0 ± 1.3</td>
<td>13.0 ± 0.2</td>
<td>13.2</td>
</tr>
</tbody>
</table>

[a) Average performance taken from eight devices for tandem solar cells and at least four devices for triple-junction solar cells; b) The number after flat- or texture- distinguishes the various subcell thickness used in multijunction devices.

Figure 4. The $J$–$V$ characteristics and EQE curves of hybrid multijunction solar cells. a) $J$–$V$ curves of best performing hybrid tandem solar cell (flat) and respective single-junction reference cells. b) EQE of the flat tandem solar cell. c) $J$–$V$ curves of best performing hybrid triple-junction solar cells (flat-2, textured-2, and textured-3) and a-Si:H/a-Si:H tandem reference cell (same as the subcells in textured-3). d) EQE of hybrid triple-junction solar cell (textured-3).
and 5.5%), due to the complementary light absorption and the small spectral overlap between the optimized a-Si:H front cell and polymer back cell.

As shown in Figure 4b, the photon harvesting in tandem devices is not sufficient in the wavelength range between 550 and 700 nm where the solar spectrum has the highest photon flux. Adding an additional medium-bandgap subcell between the front and back cells has the prospect of more efficient photon harvesting in this wavelength range. To this purpose, hybrid triple-junction solar cells were constructed with a device configuration as shown in Figure 1b. The 1# and 3# a-Si:H materials were used as absorbers for the front cell and middle cell, respectively. From the optical modeling, we can see that the middle cell is the major current limiting subcell in the flat triple-junction configuration (Figure S6, Supporting Information). The a-Si:H has a low absorption coefficient in the wavelength range 550–750 nm. Without light trapping (the case of using flat AZO as the front electrode), the photon harvesting is not efficient. A thick middle cell (>500 nm) is needed to provide a balanced photocurrent density of ~6 mA cm$^{-2}$. To get a reasonably high photocurrent, we fabricated triple-junction solar cells with fixed front and middle cell thickness of 85 and 500 nm, respectively. The back cell thickness is 110 or 150 nm, which results in best PCEs of 10.1% and 10.4%, respectively. However, the efficiency achieved by flat triple-junction solar cells is still lower than that of the flat tandem solar cells due to the current limiting in the a-Si:H subcells.

To improve the photocurrent densities of the two a-Si:H subcells in triple-junction devices, a front electrode consisting of a thin layer of highly transparent conductive In$_2$O$_3$:H (IOH) and a layer of as-grown mildly textured ZnO was adopted for the triple-junction solar cells as shown in Figure 1c,d. The sharp pyramidal structures of the ZnO layer can efficiently scatter the incident light and thereby enhance the light path in the photoactive layers. In addition, the textured ZnO/Si interface in the front can reduce the light reflection and enhance the light in-coupling into the photoactive layers. Furthermore, the front electrode that combines IOH with nondoped ZnO is more transparent than AZO- and ITO-based front electrodes.\[34\]

The lateral size and height of the pyramidal surface features (as shown in Figure 1d) are carefully designed to simultaneously obtain strong light absorption enhancement in the a-Si:H subcells and to enable the following fabrication of high-performance polymer solar cells. As shown in Table 2, the cells on the textured front electrode (textured-1) have the best PCE of 12.0%, which represents an absolute increase of 1.9% with respect to the flat reference cell (flat-1), mainly due to the improvement of $J_{sc}$ from 5.8 to 7.9 mA cm$^{-2}$. With the light-trapping substrates, both the front and middle a-Si:H subcells exhibit a considerable increase in spectral response due to the strong scattering and more efficient light in-coupling (Figure S7, Supporting Information). Especially for the current-limiting middle a-Si:H subcell, a strong enhancement in photon harvesting and thus EQE is observed at wavelengths from 550 to 750 nm for which the absorption coefficient of 3# a-Si:H is low. Similar to the flat devices, the PCE of textured cells (textured-2) is slightly improved by using a thicker back cell (thickness up to 150 nm), with a best PCE of 12.4%. From the optical modeling (Figure S8, Supporting Information) and EQE curves we can see that the middle a-Si:H subcell is still current limiting in the case of textured-2. For the front a-Si:H subcell and back polymer solar cell, the photocurrent density can reach well above 8.5 mA cm$^{-2}$. To achieve a higher photocurrent, the thickness of the middle a-Si:H cell was doubled up to 1 μm for devices textured-3. As a result, a record high PCE of 13.2% is obtained with a reasonable current matching between subcells as revealed by the optical modeling and the EQE curves in Figure 4d. The measured $J_{sc}$ from $J–V$ characterization agrees well with the calculated $J_{sc}$ from the EQE curves. The minor discrepancy between the $J–V$ and EQE measurements can be due to the uncertainties in the EQE measurements,\[37\] i.e., incomplete current saturation of the subcells (due to the available bias light sources and spectral overlap between subcells) and the performance degradation of the polymer back cells after exposure in air overnight before the EQE measurements (see the Supporting Information).

Despite the fact that textured front electrodes can improve the light harvesting in the hybrid triple-junction solar cells, the rough interface deteriorates the $V_{oc}$ and FF of the devices as shown in Table 2. The mildly textured surfaces would not lead to worse electrical performance for a-Si:H solar cells.\[36\] However, the rough surfaces can be detrimental to the performance of polymer solar cells because achieving a uniform thickness for a thin (~150 nm) polymer layer on a corrugated surface is challenging. As shown in Figure S9 (Supporting Information), the rough a-Si:H/ICL interfaces that evolve from the mildly textured substrates lead to a severely nonuniform thickness in the photoactive layer of the polymer solar cells. Therefore, a delicate design of the surface textures is of crucial importance to achieve high-performance hybrid triple-junction solar cells. As shown in Figure S10 (Supporting Information), the mildly textured front electrodes as well optimized here result in better performance for hybrid tandem devices than the medium-textured or highly textured front electrodes, which are commonly used for high-efficiency a-Si:H solar cells.\[38\]

One solution to eliminate the use of textured substrates and the necessity for a thick a-Si:H middle subcell is to use a medium-bandgap polymer solar subcell as the middle junction in the triple-junction devices. Very recently, highly crystalline polymer donor materials with an optical bandgap of ~1.55 eV (i.e., PFIBT4T-2OD, PBDPFP-F-TT, PTB7-Th and PNTz4T) have demonstrated PCEs higher than 10% in single-junction devices.\[5-7,10\] Such high-performance medium-bandgap polymer solar cells have a high $J_{sc}$ (close to 20 mA cm$^{-2}$), a high FF (>70%), and high peak EQE (>80%) even for a photoactive layer up to 300 nm, making them nearly ideal for the middle subcell in the hybrid triple-junction solar cells. If the IQE of PMDPP3T polymer solar cells can be improved to be higher than 80%, it is realistic to achieve a matched photocurrent of ~9 mA cm$^{-2}$ in hybrid a-Si:H/medium-bandgap polymer/PMDPP3T triple-junction solar cells. Assuming a summed $V_{oc}$ of 2.37 V (0.98, 0.78, and 0.61 V for the three subcells) and considering a reasonable FF of 75%, a PCE beyond 15% is expected in the near future for hybrid multijunction photovoltaic devices with the combination of merits from both a-Si:H and polymer solar cells.

Compared to the previously reported full polymer tandem cells based on a wide-bandgap polymer and PMDPP3T (PCE = 8.9%),
the hybrid a-Si:H/PMDPP3T tandem devices here (PCE > 11%) have a higher efficiency.\textsuperscript{[19,28]} The better performance is mainly due to the superior device performance of a-Si:H front cell to the wide-bandgap polymer cell. First, the higher $V_{oc}$ and FF of the a-Si:H subcell lead to a higher $V_{oc} \times$ FF product in the tandem devices. In addition, the higher EQE of a-Si:H solar cell and the less spectral overlap with PMDPP3T result in a higher $J_{sc}$ value. Owing to the optical manipulation of the ICL and the bandgap engineering for each subcell, the hybrid tandem devices here also exhibit higher PCE than the previous record performance of 10.5% demonstrated by Kim et al.\textsuperscript{[28]} By using a proper light-trapping front electrode, the hybrid triple-junction solar cells also show better performance than the previous results obtained by Kim et al. and Roland et al., who reported 11.7% efficient hybrid triple-junction solar cell.\textsuperscript{[19,40]} The PCE of 13.2% here is higher than the best-performing full polymer triple-junction solar cell reported so far.\textsuperscript{[20,21]} In both tandem and triple-junction configurations, the utilization of a-Si:H front cell enables a higher summed $V_{oc}$ and a higher balanced $J_{sc}$ (achievable potentially at least) than the full polymer counterparts.

In summary, we have demonstrated highly efficient hybrid multijunction photovoltaic devices by combining vacuum-deposited a-Si:H and solution-processed polymer solar cells. The best PCEs of 11.6% and 13.2% have been obtained for the hybrid tandem and triple-junction configurations, respectively. The combined merits from both a-Si:H and polymer solar cells can significantly enhance the PCE in reference to all polymer-based counterparts. The effects of the optical characteristics of the ICL between a-Si:H and polymer subcells were analyzed in depth and optimized to achieve a higher photocurrent in the polymer subcell. In order to achieve a high balanced photocurrent in the triple-junction solar cells, a well-chosen mildly textured front electrode was used. The solution processing of polymer solar cells is fully compatible with the vacuum deposition of a-Si:H solar cells, which makes the hybrid devices applicable for the low-cost roll-to-roll mass production. The hybrid concept studied here can ultimately drive the PCE of polymer solar cell based photovoltaic devices to 15% and beyond in the near future, making low-cost, nontoxic, earth abundant, light weight, and large-area photovoltaic modules available for clean electricity generation.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Acknowledgements

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