Supplementary Information

Dual Functionalized Freestanding TiO$_2$ Nanotube Arrays Coated with Ag Nanoparticles and Carbon Materials for Dye-Sensitized Solar Cells

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**Figure S1.** TEM images of TiO$_2$ nanotube arrays (a) without and (b) with carbon materials.
When carbon materials and Ag NPs were introduced on the TiO₂ nanotube arrays, the conduction band of the TiO₂ nanotube arrays was shifted to a lower energy level, since the work functions of the other two materials were both lower (−4.9 eV and −4.3 eV, respectively) as shown in Figure S2. Especially, when Ag NPs were introduced on the TiO₂ nanotube arrays, more electrons were collected on the Ag NPs to reduce the $V_{oc}$ and $ff$. However, due to the TiO₂ layer coated on the Ag NP surface, the electron density of the TiO₂ nanotube arrays was also increased due to the “charging effect”. Therefore, coating Ag NPs or carbon materials on the nanotube arrays did not affect the values of $V_{oc}$ and $ff$ of the associated DSSCs significantly.


**Table S1.** Parameters determined by EIS\(^a\).

<table>
<thead>
<tr>
<th>DSSCs based on open-ended TiO(_2) NTAs decorated</th>
<th>(R_w) (Ω)</th>
<th>(R_w/R_s)</th>
<th>(K_{\text{eff}}) [s(^{-1})]</th>
<th>(\tau) [ms]</th>
<th>(D_{\text{eff}}) [cm(^2)/s]</th>
<th>(L_n) [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>without Ag NPs and carbon materials</td>
<td>52.5</td>
<td>3.23</td>
<td>50.1</td>
<td>19.9</td>
<td>64.7 x 10(^{-5})</td>
<td>35.9</td>
</tr>
<tr>
<td>with Ag NPs</td>
<td>40.5</td>
<td>3.37</td>
<td>33.8</td>
<td>29.6</td>
<td>45.6 x 10(^{-5})</td>
<td>36.7</td>
</tr>
<tr>
<td>with carbon materials</td>
<td>40.6</td>
<td>3.38</td>
<td>35.1</td>
<td>28.5</td>
<td>47.4 x 10(^{-5})</td>
<td>36.7</td>
</tr>
<tr>
<td>with Ag NPs and carbon materials</td>
<td>31.6</td>
<td>3.40</td>
<td>25.1</td>
<td>39.8</td>
<td>34.1 x 10(^{-5})</td>
<td>36.8</td>
</tr>
</tbody>
</table>

\(^a\) EIS was measured with 20 μm-thick photoanode, composed with TiO\(_2\) nanotube arrays and nanoparticles under 100mW/cm\(^2\) lamp.
