ZnO nanowire based solar cells

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State-of-the-art in solar cells

Dye Sensitized Solar Cells

- Nanocrystalline, mesoporous TiO$_2$ photoelectrode on TCO.
- TiO$_2$ is photosensitized with a monolayer of dye.
- Efficient light harvesting with large dyed surface area: $\sim 1000 \times$ flat film

Emerging alternatives to DSSCs

Dye-sensitized nanowire solar cell

Device optical absorption spectrum can be tuned through selection of QD material and size.

Colloidal QDs can generate multiple electron-hole pairs per absorbed photon.

Nanowires provide a direct path to the substrate for efficient charge collection.

Quantum-dot-sensitized solar cells

How can we attach colloidal QDs onto the surface of nanowires?

Can the QDs harvest light while attached to the nanowires?

Will the QDs transfer photogenerated electrons to the nanowires?

What factors limit the overall performance of these devices?
Low temperature ZnO nanowire growth from zinc nitrate and Methenamine solution

Control of ZnO nanowire dimensions

Aspect Ratio

Length (µm)

Diameter (nm)

Number of Growth Cycles

1 cycle

4 cycles

8 cycles
CdSe quantum dots

- "One-pot synthesis" from CdO and tri-\textit{n}-octylphosphine selenide (TOPSe) in hexadecylamine (HDA) with tri-\textit{n}-octylphosphine oxide (TOPO),

- QDs are single-crystals with diameters of 3–4 nm and surface-coordinated with TOPO and HDA.

\begin{itemize}
  \item TOPO: \begin{tikzpicture}
    \draw (0,0) -- (0,0.5) -- (0.5,0.5) -- (0.5,0) -- cycle;
    \draw (0,0) -- (0,-0.5) -- (0.5,-0.5) -- (0.5,0);
    \draw (0,0) -- (0,-0.5);
    \draw (0.5,0) -- (0.5,-0.5);
    \draw (0,0) -- (0.5,0.5);
    \node at (-0.1,0.2) {O};
    \node at (0.5,-0.7) {P};
  \end{tikzpicture}
  
  \item HDA: \begin{tikzpicture}
    \draw (0,0) -- (0,0.5) -- (0.5,0.5) -- (0.5,0) -- cycle;
    \draw (0,0) -- (0,-0.5) -- (0.5,-0.5) -- (0.5,0);
    \draw (0,0) -- (0,-0.5);
    \draw (0.5,0) -- (0.5,-0.5);
    \draw (0,0) -- (0.5,0.5);
    \node at (-0.1,0.2) {H};
    \node at (0.5,-0.7) {N};
  \end{tikzpicture}
\end{itemize}

\begin{figure}
  \centering
  \includegraphics[width=\textwidth]{emission.png}
  \caption{Emission spectrum of CdSe quantum dots with peak assignments.}
\end{figure}
CdSe quantum dot size controlled by reaction time
Replace Alkyl ligands on CdSe with X-R-Y

Hexane phase

Methanol phase

As-synthesized' with TOPO ligands

Post surface exchange with MPA

\[ \text{Hexane phase} \quad \text{Methanol phase} \]

\[ \text{As-synthesized' with TOPO ligands} \quad \text{Post surface exchange with MPA} \]
CdSe quantum dots adsorbed on ZnO Nanowires
Attaching quantum dots to ZnO nanowires
CdSe quantum dots on ZnO nanowires
Optical absorption of CdSe QDs on ZnO nanowires

QD optical absorption was preserved when QDs were attached to the nanowires.
CdSe quantum dot sensitized solar cells

- Photovoltaic effect observed
- Electron transferred from QD to nanowire

(a) CdSe QDs on ZnO
(b) ZnO
(c) Current Density (mA/cm²)

[Graphs showing photocurrent, absorbance, and irradiance with and without O₂ plasma.]
CdSe quantum dot sensitized solar cells

\[ IPCE = LHE \times \varphi_{inj} \times \varphi_{coll} \]

- Internal quantum efficiency (IQE) as high as 45–58% between 500–600 nm.
- Power conversion efficiency limited by the LHE and available nanowire surface area.
CdSe quantum dots and ZnO nanowires form a new type of QDSSC.

Photogenerated electrons from CdSe transferred into ZnO.

$I_{sc} \approx 2 \text{ mA/cm}^2$, $V_{oc} \approx 0.6 \text{ V}$, $FF \sim 0.3$ for typical QDSSCs. $IQE$ as high as 58%.

Nanowire QDSSCs may be a promising solar cell design.

- Replace liquid electrolyte.
- Increase roughness factor of nanowires.