Deposition of ternary alloys of cadmium seleno-sulfide thin films on nanoporous TiO_2 for solar cells applications

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Cadmium seleno-sufide nanocrystals prepared from chemical baths (CBs) with different compositions and conditions were used in fabricating semiconductor-sensitized solar cells (SSSCs) of nanoporous TiO_2 films. The composition of the baths was varied so a bath of different $CdSe_xS_{(1-x)}$ is prepared for different compositions of sensitizers. "x" is the molar ratio of the selenium content of each bath. Two types of CBs were studies; ammonia-based chemical bath and NTA-based chemical bath (NTA: sodium nitrilotriacetate) (1).

Photoelectrochemical (PEC) experiments were performed to explore the overall performance of the cells (Table 1).

Table 1. PEC results of TiO_2 films sensitized with different $CdSe_xS_{(1-x)}$ compositions. The films are sensitized in a chemical bath based on NTA as complexing agent.

Sensitizer on TiO_2	V_{oc} (mV)	J_{sc} (mA/cm^2)	ff (%)	η (%)
CdS	-325	1.32	33.4	0.14
$CdSe_{0.25}S_{0.75}$	-518	9.06	32.8	1.54
$CdSe_{0.5}S_{0.5}$	-535	9.97	31.8	1.70
$CdSe_{0.75}S_{0.25}$	-502	9.47	31.7	1.51
$CdSe_{0.95}S_{0.05}$	-477	4.98	36.1	0.86
CdSe	-453	3.79	44.8	0.77

Incident photon to current efficiency (IPCE) of the cells (Table 2) accompanied by light harvesting efficiency (LHE) spectra were used to evaluate light absorption and electron injection properties of all of various $CdSe_xS_{(1-x)}$ compositions. Accordingly TiO_2 films with a composition of $CdSe_{0.5}S_{0.5}$ of sensitizer prepared from NTA baths were the most efficient cells among all the other compositions prepared from the same bath (Table 1). Films with $CdSe_{0.25}S_{0.75}$ bath composition show the highest efficiency among the films prepared from NH_3 containing CBs.

Table 2. Maximum IPCE values of TiO_2 films sensitized with different $CdSe_xS_{(1-x)}$ compositions in NH_3 or NTA-based CBs.

Sensitizer on TiO_2	Max. IPCE for films prepared at NH_3-based baths (%)	Max. IPCE for films prepared at NTA-based baths (%)
CdS	27.8	26.0
$CdSe_{0.25}S_{0.75}$	38.6	48.8
$CdSe_{0.5}S_{0.5}$	26.2	33.1
$CdSe_{0.75}S_{0.25}$	24.0	29.6
$CdSe_{0.95}S_{0.05}$	21.9	23.7
CdSe	24.8	15.0

The efficiency values were calculated based on equation 1:

$$\eta = [(Jsc \times Voc \times ff) / I_0] \times 100 \qquad [1]$$

where η is photoelectrochemcial efficiency of the cells, Jsc is short circuit photocurrent, Voc is open circuit photovoltage, ff is fill factor and I_0 is the photon flux.

Fill factor (ff) was obtained from equation 2:

$$ff = (J_{mpp} \times V_{mmp}) / (Jsc \times Voc) \qquad [2]$$

where J_{mmp} and V_{mmp} are short circuit photocurrent and open circuit photovoltage at the maximum power point of the J-V curve of the cells.

To evaluate the composition of the sensitized TiO_2 films, sensitizers from different CBs were analyzed with energy dispersive x-ray (EDX) and also atomic absorption spectroscopy (AAS) (2). The results show that depending on the initial pH of the baths and the deposition mechanism that prevails in each bath, different cadmium species including the desired cadmium seleno-sulfide sensitizer and $Cd(OH)_2$ were produced on the surface of TiO_2 films (3). So the CB and the deposition mechanism affect the amount of the deposited sensitizers and some other species such as $Cd(OH)_2$. This can directly affect the electron injection efficiency in cells as well as the recombination processes. Open circuit photovoltage decay (OCVD) technique has been employed to study the recombination processes and how the preparative procedures can influence the presence of the recombination sites on the surface (4). Based on OCVD results it was shown that films prepared form NTA chemical baths have less recombination and hence better electron injection efficiency.

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