A transparent photovoltaic device of NiO/ CdS arrays pn junction

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Abstract: The transparent NiO/CdS P-N junction device composite structure was prepared by hydrothermal method and radio frequency magnetron sputtering. The results show that the NiO is orderly arranged on the CdS arrays. In addition, the photoelectric properties of the transparent NiO/CdS device grown at different hydrothermal temperatures are also different. As revealed, the device prepared at 180℃exhibits a better photoelectric performance.

1. Introduction
Due to the excellent intrinsic properties, the Transparent Conductive Oxide (TCO) film has attracted lots of attentions: (1) good electrical conductivity.(2) high transmittance to visible light.(3) light selectivity. Especially the transparent P-N junction devices, composed of oxide thin films obtained excellent photoelectric conversion performance. Among them, the basic principle of photovoltaic effect is that, the sun irradiates on the semiconductor P-N junction to form a new hole-electron pair. Driven by the electric field of the P-N junction, the holes flow from the N region to the P region, and the electrons flow from the P region to the N region. After the circuit is connected, the current is formed to achieve the photovoltaic conversion, and are widely used in transparent solar cells, flat panel display, thin film solar cells, transparent optoelectronics and other technical fields.

The band gap of CdS is about 2.42eV [1], which can absorb and utilize a large range of visible light, and is regarded as an ideal material to fabricate the photoelectric device. Compared with other semiconductors, CdS obtains more suitable valence band and conduction band location, so which obtains strong oxidation ability and excellent visible light response ability. Particularly the CdS nanomaterials [2], which obtains volume effect, quantum size effect, surface interface effect, macro tunneling effect and other characteristics than other traditional materials, so which can be widely applied in photocatalysis, solar cells, luminescent materials and other fields. However, CdS still have some inherent drawbacks. First of all, the recombination rate of photo-generated electrons and holes is relatively higher. Secondly, the photocorrosion is easy to occur [3]. Aiming at these shortcomings, scholars have developed many ways to curb the compound rate and light corrosion phenomena, such as formation of semiconductor compound, introduction of graphene and amorphous carbon composite, ion doping and precious metal deposition. Especially the formation of pn junction, which can not only enhance the stability, but also increase the photoelectric conversion, thus, can be regarded as a promising method [4].

Undoubtedly, the p-type materials are considered as the core issues. Herein, the nickel oxide (NiO) [5], with a band gap of 3.6~4.0 eV [6] at room temperature is reported as wide band gap p-type semiconductor material and has attracted more and more attention, especially wide application in
catalyst materials, magnetic materials, gas sensors and photoelectric fields. Thus, the introduction of NiO to formation of NiO/CdS pn junction is considered as a perfectly method to achieve the photoelectric conversion[7].

In this paper, the CdS/NiO P-N junction device was prepared by hydrothermal and magnetron sputtering methods. The results show that the CdS/NiO P-N junction exhibits a high transparency and fast optical response. In addition, the enhancement mechanism of light response is studied.

2. Experiment

2.1. Materials
All the chemicals are analytical grade and purchased from Aladdin Industrial Corporation (Shanghai, China), the NiO target purchased from Crystal Technical Material (Hefei, China).

2.2. Preparation

2.2.1 Preparation of the CdS nanoarray
CdS arrays were synthesized by hydrothermal method. First, adding 0.15 mmol cadmium nitrate, 0.15 mmol urea acyl and 0.15 mmol glutathione into 60 mL deionized water, and stirring for 25 min. After the mixture becomes clear and transparent, the solution is transferred to a 50 mL Teflon lined stainless steel autoclave obtains a substrate with a conductive surface placed facing the bottom of the kettle. The hydrothermal reaction time is 190 min and different reaction temperature(150°C and 180°C) is carried out. After the reactor cool down to room temperature, the samples were washed repeatedly with anhydrous ethanol and dried at 60°C for 0.5 h. There, the samples with different reaction temperature are labelled as NiO/CdS-1 (150°C) and NiO/CdS-2 (180°C), respectively.

2.2.2 Preparation of NiO film
NiO films were prepared by RF magnetron sputtering using NiO target (the diameter 6cm) on the surface of CdS/glass slide substrate. The background vacuum, sputtering pressure, sputtering power, sputtering time, sputtering temperature were 6 × 10-4 Pa, 0.9 Pa, 125W, 45 min and 100°C, respectively. The sputtering gas was Ar(40 SCCM). Subsequently, the as-prepared samples were dried at 300 °C in vacuum for 1 h.

2.3 Characterization
Field-emission scanning electron microscope (FESEM, Hitachi S-4800) was used to investigate the surface morphology of the samples. UV-vis absorption spectro photometer (U-3900Hitachi) was employed to investigate transparency of the films. The PL spectra were recorded by a Hitachi F-7000 spectrofluorimeter at the excitation wavelength of 360 nm. The photoresponse such as the dark and illuminated currents was gauged by electrochemical workstation.
3. Results and discussions

Fig. 1 is the XRD of as-prepared NiO/CdS pn junction device. As revealed, the peaks at 24.807°, 26.507°, 28.182°, 43.960°, 47.839°, 51.824° and 66.772° are ascribed to the (100), (001), (101), (220), (103), (112) and (203) planes of CdS (PDF#41-1049), the peaks at 34.123°, 38.073° and 62.023° are ascribed to the (300), (301) and (331) planes of NiO (PDF#45-0946).

Fig. 2 is the SEM of the samples CdS nanoarrays.

Fig. 2 is the SEM of the surface of the CdS arrays, as revealed, which is uniform and smooth, and could effectively reduce the boundaries between the crystal grains, thereby reducing the boundary reflection and improving the electrical conductivity of the pn junction device.
Fig. 3. The optical transmittance spectra (T) of the CdS and CdS/NiO

Fig. 3 demonstrates the optical transmittance spectra (T) of the CdS nanoarrays and the CdS/NiO pn junction. As shown, all of the samples exhibit a high transparency in the visible light region. Further, due to the wider band gap of NiO, after introduction of NiO film, transparency of as-prepared pn device exhibits no obvious change, and at around ~500 nm.

Fig. 4. The PL of the CdS and CdS/NiO

Fig. 4 demonstrates the PL of CdS film and CdS/NiO pn junction with excitation of 360 nm. With the formation of NiO/CdS heterojunction, the PL exhibits obvious decrease, which is beneficial for photoelectric performance.
Fig. 5 demonstrates the photoelectric properties of the NiO/CdS-1 and NiO/CdS-2. The photoelectric measurement is carried out in room temperature with the illumination and darkness alternate 10 seconds and both of the curves under 0 bias voltage are fitted in uniform coordinate. As revealed, the photoelectric performance of as-prepared pn junction device exhibits an obvious enhancement of about ~10 folds with the increased reaction temperature, which indicate that the suitable reaction temperature is beneficial for the photoelectric performance.

Fig. 6 demonstrates that the electro chemical impedance interface charge carrier behavior, which can depict the photovoltaic conversion enhancement mechanism. As revealed, the reduction of impedance indicates that the NiO/CdS-2 obtains an optimal interfacial charge carriers transport, which is beneficial for the photovoltaic performance.

4. Conclusions
In this work, we have successfully prepared CdS/NiO pn junction device through a simple process and proved its excellent optical and photoelectric performance, which could be mainly attributed to that the remarkable p-n junction of CdS/NiO could take advantage of the visible light efficiently and obtain a decent carriers transport. With the high transmittance and photoelectric performance, the CdS/NiO pn junction device is regarded as a potential material in transparent-conductive field, and brings us a new vision for designing of transparent devices and solar energy device.

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