

Tunable emission and conductivity enhancement by tellurium doping in CdS nanowires for optoelectronic applications



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ABSTRACT

Improvement of the optical and electrical characteristics is essential to get advanced performance from one dimensional (1D) material. Here, we report the first synthesis of a single crystalline Te-doped CdS nanowires (NWs) by a chemical-vapor-deposition (CVD) method. Room temperature photoluminescence (PL) spectra showed that Te concentration plays an important role in tuning emission color from orange to infrared (IR). Decrease in bandgap and PL intensity with increase in Te concentration was observed as compared to undoped CdS NWs. Red and IR emissions were found at 736.5 and 881 nm for doping concentration > 6.06%. To our best knowledge, IR emission band has been observed for the first time in CdS NWs. Red-shift of LO phonon mode and its overtone in Raman spectra, and lifetime of red and IR emissions are longer than bandgap of host indicating the doping effect of CdS NWs. Energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) of the Te-doped CdS NWs further confirms the presence of Te in the CdS NWs. Output characteristics confirm enhanced output current I_{ds} with the increase in doping concentration. A possible growth mechanism was proposed. Doping technique offers to develop high-quality, a very stable, effective, and easily-applicable way to enhance the performance of one dimensional optoelectronic devices and solar cell applications.

1. Introduction

Low-dimensional semiconductor nanostructures such as nanowires (NWs), nanorods (NRs), nanobelts (NBs), and nanosheets (NSs) were widely studied due to their unique electrical and optical properties over traditional bulk materials [1–7]. Due to considerable band-gaps of around 1.5–3.7 eV, one dimensional (1D) nanostructures draw a great deal of research attention for field-effect transistors (FET) and optoelectronic device applications. Among the 1D nanostructures, special emphasis was given to semiconducting NWs due to its wide range applications in light emitting diodes (LEDs), waveguides, lasers, sensors, photodetectors, solar cells, and FETs [8–10]. Numerous semiconductor NWs were synthesized [11–13]. Among them, cadmium sulfide (CdS) NWs is attracting great interest due to its wide direct bandgap (2.42 eV) and potential applications in nano-optoelectronics and nanoelectronics [1,9,14–18].

Intentional doping can greatly modify the optical, electrical transport, and magnetic properties of the host semiconductor [19]. Unintentionally doped 1D CdS nanostructures have high resistivities,

which will limit its performances in both electronic and optoelectronic devices [20]. While the conductivity of CdS can be significantly enhanced by doping with indium, the incorporation of Mn leads the formation of the ternary compound $Cd_{1-x}Mn_xS$, whose optical and magnetic properties notably differ from those of pristine CdS [21–23]. Up to now, different methods have been developed in the synthesis of doped CdS NWs [24–28]. An approach to modify the optical and electrical properties of 1D semiconductor nanostructures, an appropriate elemental doping is convenient way for facilitating the fabrication of many nano-optoelectronic and nano-electric devices [29–32]. In the past studies, different efforts have been paid to improve the optical and electrical properties of CdS based NWs by incorporating different elements [22,30,32]. All these dopants show cationic doping in CdS nanostructures in which these dopants substituted for Cd sites [22,30,32]. However, according to the best of our knowledge, there is not a single report available on the anionic doping in 1D-CdS nanostructures, where dopants substituted for S sites. These different types of doping materials can exhibit different optical/electrical properties for CdS, owing to the different treatments of Cd and S in the CdS

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structure. Therefore, it is strongly desired that later kind of dopant must be synthesized and explored its novel optical and electrical properties.

Tellurium (Te) as a chalcogen element could serve as an anionic dopant in CdS. Previously; it is doped into Zn based semiconductor 1D nanostructures (ZnS and ZnO) and changed its optical properties [33,34]. A large number of reports are available on the CdS nanostructures doped with transition metals/post-transition metals other than Te. A few reports are available on Te doped thin films/quantum dots [35–40]. However, no study is available on Te doped in 1D CdS nanostructures. Herein, we report the first successful synthesis of high quality Te-doped CdS NWs prepared by thermal evaporation method. Different analysis techniques have been used to confirm the presence of dopant in the CdS NWs. The optical and electrical properties from single NWs with different doping level were studied. Our study leads to a tuning of dopant emission color from Te-doped CdS NWs, in the range of orange to IR by varying the dopant concentration. New IR emission as well as enhancement in output current I_{ds} associated with dopant concentration is discussed.

2. Experimental

2.1. Synthesis of Te-doped CdS NWs

Te-doped CdS NWs were prepared by a high-temperature chemical reduction method in a horizontal tube furnace (HTF). 1 g mixture of pure CdS (99.999%) and Te (99.997%) nanoscale powders from Sigma–Aldrich used as a precursor (evaporation source) was loaded in ceramic boat and inserted into the central region of the quartz tube. To support the NWs growth n-type silicon substrates were employed. Si wafers was subsequently cleaned in acetone, isopropanol, and dried in a N_2 flow. Thin layer of Au (~5 nm thickness) was deposited on Si wafers using a sputtering method. Si substrate was inserted into downstream position, 10–12 cm away from the central heating zone of quartz tube. The furnace was evacuated to $\sim 10^{-5}$ Torr and a high purity mixed gas of Ar and H_2 (10%) was introduced into the tube at a rate of 30 Standard-state Cubic Centimeter per Minute (Scm). Then the furnace was heated to 830 °C in 50 min. After for about 40 min

reaction time the furnace was allowed to cool down naturally to room temperature. A thick yellow colored layer of product collected on the substrate was analyzed. Undoped CdS nanowires were also synthesized under the same conditions except for the use of the Te dopant, for comparison and marked as u-CdS NWs.

2.2. Material characterizations

CdS nanowires were characterized by scanning electron microscope (SEM) and high resolution transmission electron microscopy (HRTEM). The phase purity of the product was examined via X-ray diffraction (XRD) by using a Bruker D8-advance X-ray diffractometer with Cu K α radiation, keeping the operation voltage and current at 40 kV and 40 mA, respectively. The 2θ ranges from 20° to 65° with a step of 0.02° and a count time of 2 s. Photoluminescence (PL) spectra were measured by laser confocal PL microscopy using continuous wave (cw) laser 405 nm as an excitation source. The laser wavelength of the Raman micro-spectrometer was 514 nm, and power was kept below 1.0 mW to avoid laser-induced heating. The laser spot size of the Raman spectroscopy was 0.7 μ m for a 514 nm wavelength. PL lifetime decay profiles were recorded by the time correlated single photon counting (TCSPC) system (Picoquant ‘Timeharp 200’) along with narrow-bandpass filters 510, 730, and 880 nm, respectively. The pulsed diode laser at 405 nm (tens of ps pulse-width) was used (Picoquant ‘PDL 800-B’, 10–80 MHz) as the excitation source. Pt (Platinum) source and drain electrodes with thickness 0.3 μ m were pattern with focused-ion beam (FIB). All electrical transport measurements were performed with Keithley 4200 source meter in vacuum under ambient condition.

3. Results and discussion

3.1. Structural properties

Fig. 1(a) shows SEM image of Te-doped CdS NWs. The NWs have lengths ca. 20–50 μ m and the diameters in the range from 120–200 nm. A local enlargement of this image (Fig. 1(b)) indicates that the NWs surfaces are very well clean, smooth and free of visible particle

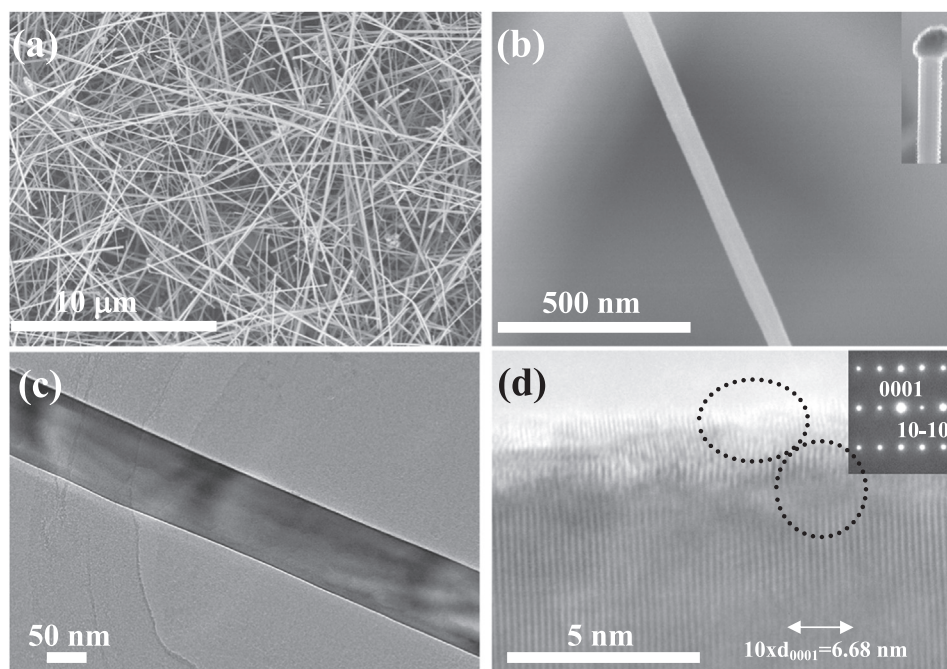


Fig. 1. (a) and (b) SEM images of Te-doped CdS NWs with Te content=13.06%. (c) TEM image of a single Te-doped CdS NW. (d) HRTEM image shows that (0001) fringes are separated by a distance of about 0.668 nm. The inset corresponds to the SAED pattern.

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