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Photoelectric effect and transport properties of a single CdS nanoribbon

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Abstract

A single CdS nanoribbon-based photoelectric detector was fabricated by the shadow mask technique and conventional lithography. Atomic force microscopy (AFM) and micro-Raman techniques were applied to acquire the morphology and structure of a single CdS nanoribbon. Transmission electron microscopy reveals a single crystalline interior with a few local defects. From the current–voltage (*I–V*) measurements, it is found that the maximum current reached 15 μA, and the photoconductivity variation could be as high as 25,000, as well as the corresponding current density is estimated to be about $7.0\times10^5\,A/cm^2$. Besides the ohmic characteristic of the *I–V* curve by photoelectric effect, the nonlinear *I–V* curve owing to the Schottky contact is also found. The transient photocurrent response indicates the slow process by carrier trapping.

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1. Introduction

Recently, with the development of nanostructured materials, semiconductor nanowires or nanoribbons have stimulated considerable interest for their potential applications in photoelectric devices such as sensors, memory, and solar cells

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[1–3]. Thus it is important to know the photoelectric effect among individual nanowires or nanoribbons.

One-dimensional semiconductor nanowires, nanoribbons or nanobelts, and nanorods are potentially ideal functional components for nanometer-scale electronics and optoelectronics [4–6]. Yang et al. have recently demonstrated that the conductivity of ZnO nanowires is extremely sensitive to ultraviolet light exposure [7]. In the nanowires 4–6 orders of magnitude photoelectric response was found, but the photocurrent was very small, typically in a range of several hundreds of nanoamperes. Photoconductivity has also been observed in homogeneous InP nanowires [8].

Due to their high photosensitivity and high quantum efficiency in luminescence, thin films of CdS semiconductor compound are very attractive for applications in solar cells. For a bulk or film CdS, it usually has a 4–5 orders of magnitude increase in photocurrent under illumination, but the active area is in the range of several tens of mm^2. To our knowledge, there is no report on the photoelectric effect in individual CdS nanoribbons with the active area of several tens of μm^2.

In this paper, we report on the fabrication of a single CdS nanoribbon device by the shadow mask technique. The fabricated device shows a high photosensitivity (up to a factor of 25,000 times in the conductivity) under illumination by a 515 nm laser with an estimated power density of 400 mW/cm^2, an appreciably fast response time (<500 ms). The maximum photocurrent can reach as high as 15 μA and the photocurrent can be reversibly switched on and off by modulating the laser beam. The paper will focus on the photoelectric effect of single CdS nanoribbons measured by I–V characterization and complementarily interrogated by other techniques.

2. Experimental

The fabrication of CdS nanostructures was performed by thermal evaporation of CdS (sublimation at 980 °C) powders in the absence of any catalyst. Details of experimental setup and procedures can be found elsewhere [9]. The deposition was carried out in a high-temperature tube furnace. CdS powder (2 g) c (99.99%, from ARCO) was placed in the center of the tube. The tube was then sealed and pumped down to a base pressure of 2×10^{-2} Torr. Ar was used as the processing gas at a flow rate of 100 sccm. The deposition temperature was maintained at 1100 °C. The general morphology of the products was examined by scanning electron microscopy (SEM, LEO 1450VP). Powder X-ray diffraction (XRD, Rigakau RU-300 with $CuK_{\alpha1}$ radiation) was employed to examine the sample crystallinity. Detailed microstructure and chemical composition analysis of the individual nanoribbons were carried out using transmission electron microscopy (TEM, Tecnai 20) and micro-Raman spectroscopy (Renishaw System 1000).

To fabricate nanodevices, CdS nanoribbons or nanobelts were first dispersed in 2-propanol, and then deposited on a 500 nm thick silicon oxide onto oxidized silicon substrate. Electrical contacts to the nanoribbon were fabricated by exploiting a gold wire (diameter was 25 μm) as a shadow mask. Ti/Au (30/300 nm) contact electrodes were made by e-beam evaporation on both ends of the nanoribbon. Electrical transport measurements on a single CdS nanoribbon were performed by employing a Keithley 6517A electrometer with a noise level <10 pA. Photoelectric effect experiments were performed under a 515 nm laser radiation with an estimated power density of 400 mW/cm^2.

3. Results and discussion

3.1. SEM and AFM images

A typical SEM image of a single CdS nanoribbon bridged between two Ti/Au microelectrodes is shown in Fig. 1 (a). High-resolution TEM in Fig. 1 (b) indicates that CdS nanoribbon grows along its (1 2 0) crystalline direction. Together with the cross-section TEM examination (not shown here), it is found that these nanoribbons possess low index termination surfaces of (0 1 0), (0 0 2), and$(2\,\bar{1}\,0)$. Stacking faults along the nanoribbons growth direction are commonly found in the