Microelectronic Engineering 126 (2014) 27–30

Contents lists available at ScienceDirect

Microelectronic Engineering

journal homepage: www.elsevier.com/locate/mee

Single CdS nanowire photodetector fabricated by FIB

Lei Li [a], Shuming Yang [a,b,*], Xiaotong Zhang [a], Liangjun Wang [a], Zhuangde Jiang [a], Qinjing Lin [a], Chenying Wang [a,c], Feng Han [a], Niancai Peng [a]

[a] State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Shaanxi 710049, China
[b] State Key Laboratory of Digital Manufacturing Equipment & Technology, Huazhong University of Science and Technology, Wuhan 430074, China
[c] State Key Laboratory of Precision Measuring Technology and Instruments (Tianjin University and Tsinghua University), Tianjin 300072, China

ARTICLE INFO

Article history:
Received 17 October 2013
Received in revised form 3 March 2014
Accepted 31 March 2014
Available online 12 April 2014

Keywords:
Cadmium sulfide (CdS) nanowire
Photodetector
Focused ion beam (FIB)

ABSTRACT

In this paper, a photodetector based on single cadmium sulfide (CdS) nanowire was fabricated using focused ion beam (FIB) technique. The nanowire manipulation, transferring and electrode fabrication process by the FIB and its influence on the photodetector performance were studied. CdS nanowire was synthesized by Vapor–Phase–Transport (VPT) method. CdS powder was thermally evaporated at 950 °C in the Argon (Ar) gas as the source material. High Resolution Transmission Electron Microscope (HRTEM) and X-ray Diffraction (XRD) experiment results showed that the nanowire presented wurtzite CdS structure and good crystal quality. The photoresponse time and recovery time of the photodetector were 150 ms and 53 ms, respectively. The photosensitivity was 2.83, and the low sensitivity was caused by the deposition of Ga on the surface of the nanowire and electrode gap during the FIB fabricating process.

1. Introduction

Cadmium sulfide (CdS) has a direct band gap of 2.4 eV at room temperature and high photosensitivity in the visible light region [1,2]. There have been some researches about CdS nanowire synthesis and photodetectors based on CdS nanowire [2,3]. Jang et al. have synthesized CdS nanowire with several micrometers long using solvothermal method [4]. Routkevitch et al. used the porous anodic aluminum oxide (AAO) as the template to fabricated CdS nanowire in the AAO pores [5]. Ge et al. have fabricated CdS nanowire by chemical vapor deposition (CVD) method using the $CdCl_2$ and *S* as the source material [6]. But the above methods need complex reaction materials [6] or the nanowire was too short to manipulate [4,5]. In our experiment, CdS nanowire with tens of micrometers long was synthesized, and only CdS powder was used as the source material. The nanowire was easy to separate and manipulate during the FIB fabrication process. In the process of the single nanowire photodetector research, it is important for the nanowire photodetector to realize reliable single nanowire electrical contact. There are some potential methods to do this job, such as e-beam lithography [7], dielectrophoresis [8], micro grid mask technique [2,9] and Focused ion beam (FIB) etc [1,10]. Compared with the other methods, FIB is easy to form ohmic contact and reliable electrical contact, besides FIB has powerful ability in manipulating the nanowires for integration with multifunctional and multicolor optoelectronic devices.

In this paper, single CdS nanowire photodetector was fabricated using FIB. The influence of the fabricating process on the photoresponse performance and current–voltage *(I-V)* characteristic was studied.

2. Experiments

2.1. CdS nanowire synthesis and characterization

CdS nanowire was synthesized by VPT method. High purity CdS powder was thermally evaporated in the horizontal tube furnace at 950 °C in the Argon (Ar) ambience. The air pressure was 0.7 bar. Polished Si substrate coated with 5 nm Au film was placed downstream as the nanowire growth substrate [11]. The as-grown CdS nanowire was characterized by Scanning Electron Microscope (SEM, SU-8010 Hitachi, operated at 10 kV, 5 μA). X-ray Diffraction (XRD, XPert Pro MPD) was carried out with monochromatic Cu Kα irradiation and normal θ–2θ scan mode. TEM (JEOL JEM-2100) with the operating voltage of 200 kV was used to obtain further insight of single CdS nanowire. For TEM experiment, the as grown nanowire was ultrasonically dispersed into deionized water, dropped onto the micro Cu grids with carbon membrane, and dried naturally.

* Corresponding author at: State Key Laboratory for Manufacturing Systems Engineering, Xi'an Jiaotong University, Shaanxi 710049, China. Tel./fax: +86 29 82668616.
E-mail address: shuming.yang@mail.xjtu.edu.cn (S. Yang).

http://dx.doi.org/10.1016/j.mee.2014.03.046
0167-9317/

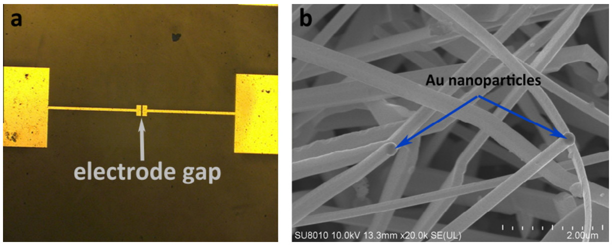

Fig. 1. (a) Optical microscope image of the extraction electrode and (b) the SEM image of the CdS nanowire.

2.2. Single CdS Nanowire Photodetector FIB Fabrication

The heavily doped p-Si coated with 300 nm SiO_2 layer was used as the device substrate. The extraction electrode (Pt/Ti 200 nm/ 20 nm) with the gap width of 22 μm was fabricated by conventional UV photolithography technique, as shown in Fig. 1a. Single CdS nanowire photodetector was fabricated using FIB (FIB/SEM Dual, FEI). First, the as-grown CdS nanowires were ultrasonically transferred from the Si substrate to the micro Cu grid. Next the micro Cu grid together with the extraction electrode was placed into the FIB chamber. And then the selected CdS nanowire was soldered with the nano tungsten (W) probe using Pt as the solder, and alligned with the extraction electrode by the nano manipulator (MM3A-EM, Kleindiek Nanotechnik, Germany, the resolution of *X*/*Y*/*Z* axises are 5 nm, 3.5 nm and 0.25 nm, respectively.). Finally the nanowire was cut off from the *W* probe using Ga ion beam, and soldered with the extraction electrode by Gallium (Ga) ion beam assisted deposition of Pt. The deposition of Pt was carried out by introducing dimethyl-methyl-cyclopentadienyl-Pt precursor gas into the Ga ion beam. The *I-V* and photoresponse characteristics were measured by a semiconductor characterization system (4200SCS, Keithley).

3. Results and discussion

3.1. Structure and morphology

Fig. 1b was the SEM image of the as-grown CdS nanowire arrays. The length of CdS nanowires was from several micrometers to several hundred micrometers. The nanowire diameter was in the range of tens of nanometers to several hundred nanometers. There were Au catalyst nanoparticles on top of the CdS nanowires

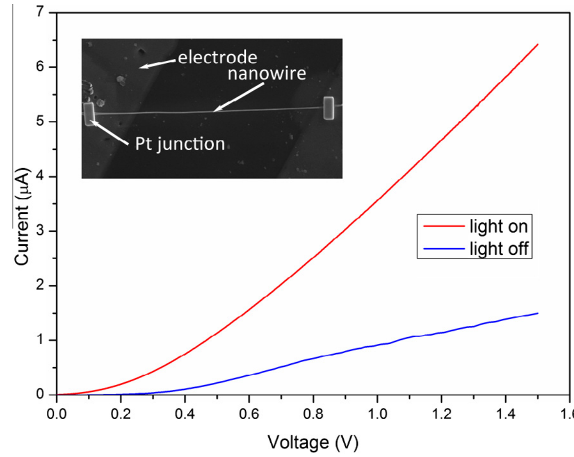

Fig. 3. The SEM image of the photodetector and *I–V* curves of the device.

validated the Vapor–Liquid–Solid (VLS) growth mechanism [12]. Fig. 2a was the XRD pattern of the CdS nanowire. The diffractive peaks revealed that the nanowire was hexagonal structure of CdS. The lattice constants was $a = 4.153$ Å and $c = 6.723$ Å, consistent with the value in JCPDS card (No. 41-1049), and no diffraction peaks of CdO, Cd, S or other impurities appeared. The nanowire crystal structure was further investigated by HRTEM. Fig. 2b showed the HRTEM image of the CdS nanowire, and revealed that the nanowire was high crystal quality. The distance between the adjacent lattice planes was 0.67 nm, corresponded to the hexagonal CdS crystal (0001) interplanar distance [12]. The upper right insert of Fig. 2b was the Selected Area Electron Diffraction (SAED) pattern of the nanowire (the central transmission spot was shielded), and indicated that the as grown CdS nanowire was single crystal structure.

3.2. Device fabrication and photoresponse measurement

The upper left insert of Fig. 3 was the SEM image of the finished single nanowire photodeterctor. The bright gray region was the Pt extraction electrodes, and the gap width of the extraction electrode was 22 μm. The nanowire was connected with the Pt extraction electrodes by the Pt junctions (two small rectangles in the image). It was known that Pt had a high work function W_m of 5.64 eV [13], and Schottky contact formed when Pt was in contact with the n-

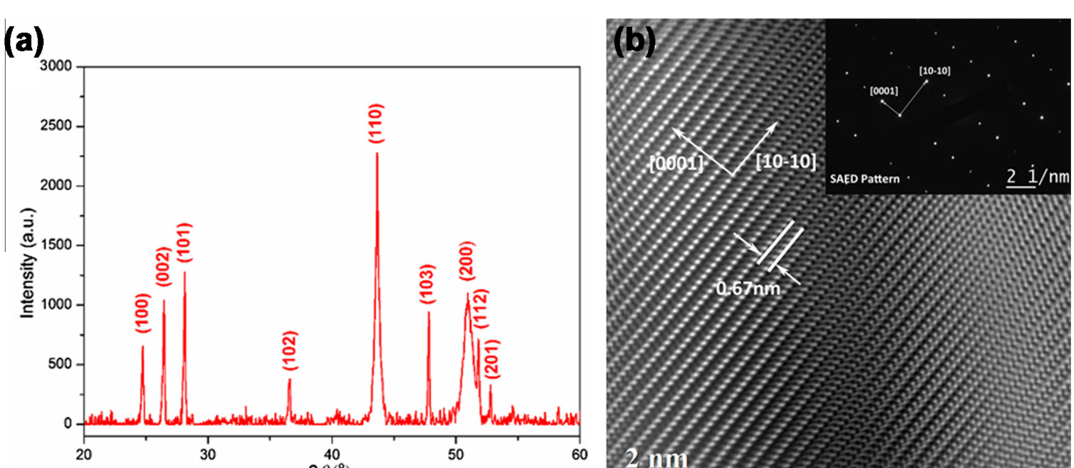

Fig. 2. (a) XRD pattern and (b) HRTEM and SAED images of the CdS nanowire.