

Electronic Supplementary Information (ESI) for Journal of Materials Chemistry

Aligned Networks of Cadmium Sulfide Nanowires for Highly-Flexible Photodetectors with Improved Photoconductive Responses

Supplementary Information

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1. Sample Preparation

(1) Cadmium Sulfide Nanowire (CdS NW) Growth

Single-crystalline CdS NWs were synthesized in a horizontal tube furnace by a chemical vapor deposition (CVD) method. A CdS powder was first placed at the center of an alumina tube furnace as a source material, while an 8 nm-thick Au film was placed at the downstream position of the source material. For the growth of CdS NWs, the furnace was rapidly heated to 650 °C at a rate of 32.5 °C/min under a constant argon (Ar) flow. When the temperature reached 650 °C, the tube was evacuated to a base pressure of 10^{-3} torr. The tube was kept at these temperature and pressure conditions for 45 minutes. After then, the tube was purged with a constant Ar flow of 300 sccm and cooled down slowly.

(2) Preparing Functionalized CdS NW Suspension

As-grown CdS NW substrates were functionalized with carboxylic acid groups by dipping the substrates in the mercapto-propanoic acid (MPA, Sigma, USA) solution (1:50 v/v in chloroform) for 2 hours. For preventing a MPA aggregation, the substrates were immediately rinsed with clean chloroform and de-ionized (D. I.) water. And then, the substrates were placed in D. I. water and sonicated for 1 minute to prepare well-dispersed CdS NW suspensions.

(3) Polyimide Coating

SiO₂ and Si substrates were purchased from WaferMarket.com. The polymeric acid liquid (Vtec PI 1388 liquid, USA) was coated on the SiO₂ substrate at the speed of 1300 rpm for 50 seconds using a spin-coator. And then, it was cured on a hot plate in a N₂ gas environment. For the curing process, the temperature of the hot plate was ramped from 120 to 250 °C with a ramping rate of 5 °C min⁻¹, and then the temperature was sustained at the final temperature for 1 hour. Afterward, an aluminum oxide (Al₂O₃) layer with thickness of 30 nm was deposited on the PI layer via the atomic layer deposition (ALD) (Lucida D, NCD Co.) process at 170 °C.

(4) Surface Molecular Patterning

μm -sized various surface patterns were obtained by the photolithography (MA-6, Karl Suss) technique using the photoresist (AZ 5214) on the Al_2O_3 (300 Å) layer deposited on the polyimide substrate. The patterned substrates were dipped in the octadecyltrichlorosilane (OTS) solution in anhydrous hexane (1:500 (v/v), Sigma-Aldrich, USA) for 400 ~ 600 seconds. To prevent an OTS aggregation, the substrates were immediately rinsed with clean anhydrous hexane, and the photoresist was removed with acetone. After then, the OTS-patterned substrates were dipped in the aminopropyltriethoxysilane (APTES) solution in ethanol (1:50 (v/v), Sigma-Aldrich, USA) for 30 ~ 60 minutes to obtain positively-charged regions. The substrates were immediately rinsed with clean ethanol to prevent an APTES aggregation.

(5) Nanowire Assembly

The functionalized CdS NW suspensions were dropped on the OTS-APTES patterned substrate. The solvent was evaporated for 6 hours at room temperature. After then, the CdS NW patterned substrate was rinsed thoroughly with D.I. water and 1,2-dichlorobenzene (J. T. Baker, USA).

(6) Device Fabrication

Source and drain electrodes were fabricated using conventional photolithography followed by thermal evaporation ($\text{Au/Ti} = 50 \text{ nm}/10 \text{ nm}$, thermal evaporator, Multira 1800, ODiS) and a lift-off process. After a top-gate insulating layer (Al_2O_3 , thickness ~ 40 nm) was deposited via an ALD process at 180 °C, the top-gate electrode ($\text{Au/Ti} = 50 \text{ nm}/10 \text{ nm}$) was fabricated via the thermal evaporation process and the lift-off process. Lastly, an additional Al_2O_3 encapsulating layer (150 nm) and polyimide film were deposited on the device to form an encapsulating layer.

2. Characterization

(1) SEM Measurements

SEM images were taken using a Quanta 200 3D (FEI) and S-4800 (Hitachi).

(2) TEM Measurements

High resolution transmission electron microscopy (TEM) images and SAED patterns were taken using a 200kV field emission TEM (Tecnai F-20).

(3) Noise Measurements

The noise characteristics of the photodetectors based on aligned CdS NWs were measured with a fast Fourier transform (FFT) network analyzer (SR770, Stanford Research Systems, USA) and low-noise current preamplifier (SR570, Stanford Research Systems, USA).

(4) Photoconductivity Measurements

A solar simulator (Oriel® Instruments) was utilized as a light source to measure the photoconductivity of flexible photodetectors based on aligned CdS NWs. The light source was a white light, and its power density was 100 mW/cm². The intensity of the light was controlled by optical power filters. The photoconductive characteristics were measured with a Keithly 4200 semiconductor parameter analyzer.

(5) Photoluminescence (PL) Measurements

The micro-PL measurements were carried out at room temperature using the 488-nm line of an Ar laser with a power of 1 mW. The emitted light was collected by an objective lens (×40 magnification, NA = 0.65) and detected with a liquid-nitrogen cooled charge-coupled device. The emission polarization was analyzed with a linear polarizer in combination with a half- λ plate placed in front of the monochromator to correct the polarization-dependent response of both the monochromator and the detector.

(6) Absorption Measurements

The absorption measurements were carried out at room temperature using Cary 100 UV-Visible Spectrophotometer (Agilent) with a wavelength range of 350 nm - 800 nm.

3. Supplementary Figures



Fig. S1 Optical microscope image of a SiO₂ substrate with as-grown CdS NWs on it.

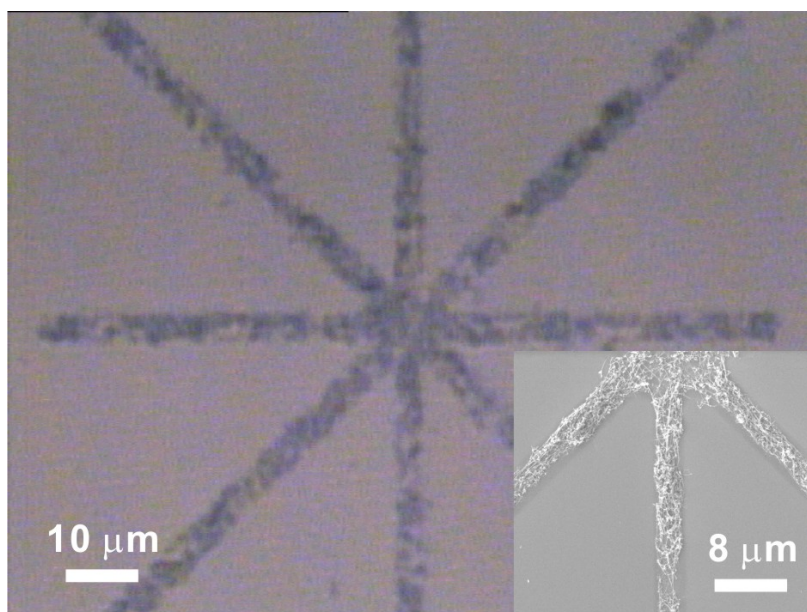


Fig. S2 Optical microscope image of arbitrarily-shaped patterns of CdS NWs assembled on the Au substrates. The inset shows the SEM image of the CdS NW patterns.

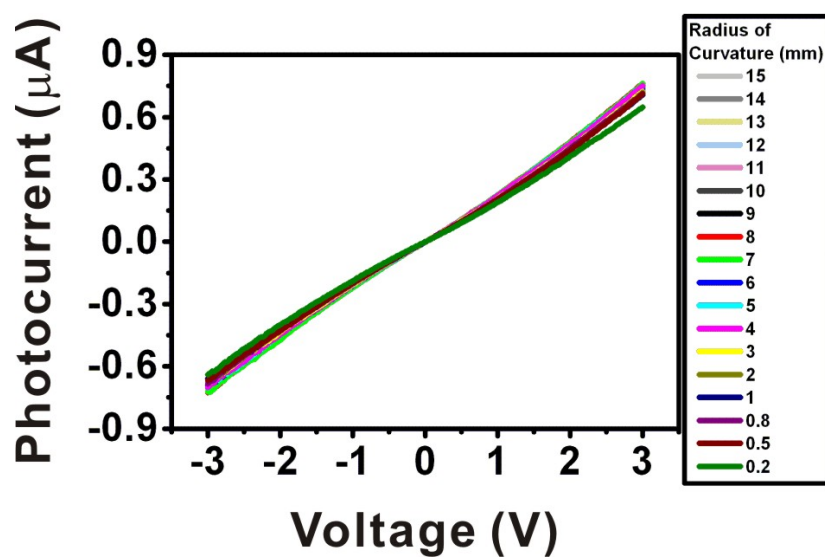


Fig. S3 Photocurrents of a flexible photodetector based on aligned CdS NWs bent with different radii of curvature.