Supporting Information

Single-Nanowire Thermo-Optic Modulator Based on a Varshni Shift

Zhangxing Shi, Jue Gong, Jianbin Zhang, Peizhen Xu, Ni Yao, Wei Fang, Pan Wang,* Xin Guo and Limin Tong*

State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engineering, Zhejiang University, Hangzhou 310027, China

Corresponding Author

*E-mail: nanopan@zju.edu.cn.

*E-mail: phytong@zju.edu.cn.

Estimation of propagation loss of the signal light in a fiber taper

To estimate the propagation loss of the signal light in optical fiber taper, we fabricated the fiber taper by using a flame-heated fiber-tapering system and measured the fiber transmittance (for 515-nm light) in real time during fiber pulling process. The waist of the fiber was tapered down to 1 μm. The length of taper region was ~2 cm and the normalized transmission curve as a function of time is shown in Figure S1. The curve shows the transmittance at 515 nm is ~70% and the loss is mainly caused by the disappearance of higher order waveguiding modes. Then we estimate the propagation loss of the signal light in a single optical fiber taper as ~84%, corresponding to a loss of ~0.76 dB.

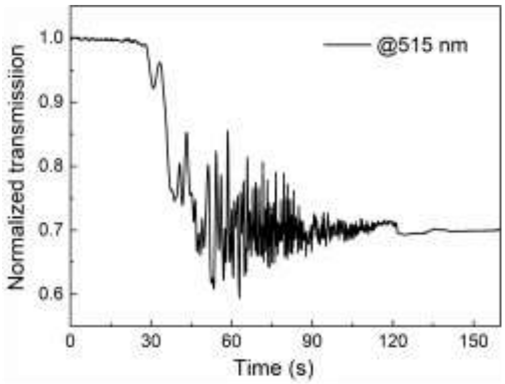

Figure S1. The normalized transmission curve of 515 nm laser as a function of time during the fiber tapering process.

Micromanipulation process of coupling a CdS nanowire with two fiber tapers

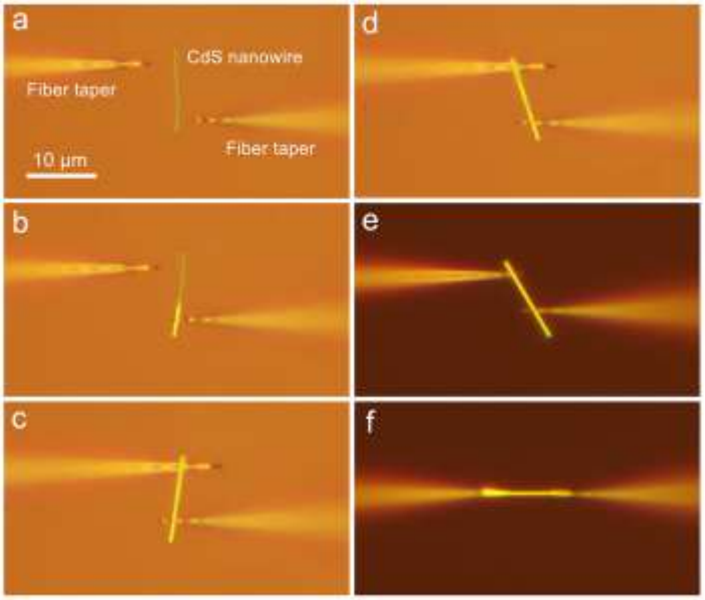

Figure S2. The micromanipulation was carried out by two fiber tapers (as shown in Figure S2a) separately mounted on two precisely controlled 3-dimension moving stages under an optical microscope. **a,** A single-crystal, 13-μm-length CdS nanowire is deposited on the surface of a MgF_2 substrate. **b,** Pick up one end of the nanowire with a fiber taper. **c-e,** Pick up the other end of the nanowire with another fiber taper and suspend the nanowire in the air. **f,** Adjust the direction of the nanowire to make it parallel to the tapers and its two ends adsorbed onto the two tapers, respectively.

Electric field distribution of a 170-nm-diameter CdS nanowire waveguiding a 515-nm light

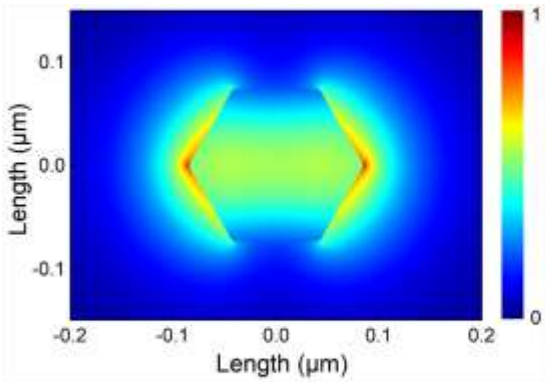

Figure S3. Simulated electric field distribution of the only waveguiding mode of a 170-nm-diameter CdS nanowire for a 515-nm light, with the color bar showing the normalized power density (simulated with FDTD).

Estimation of propagation loss of the signal light in a CdS nanowire

A 170-nm-diameter long CdS nanowire, with its left part attached to a substrate via Van der Waals force and right part suspended in air (Fig. S4a), was used to measure the propagation loss of the signal light at room temperature. The CW switch light with a power of 0.3 mW was focused down to a 3-μm-diameter spot to locally excite the photoluminescence of the nanowire along its length. A CCD camera was used to image the nanowire excited at different positions (Fig. S4b-g), and the output of the waveguiding photoluminescence at the right end of the nanowire was collected and then analyzed with a spectrometer (QE65000, Ocean Optics, with 5 s integration time).

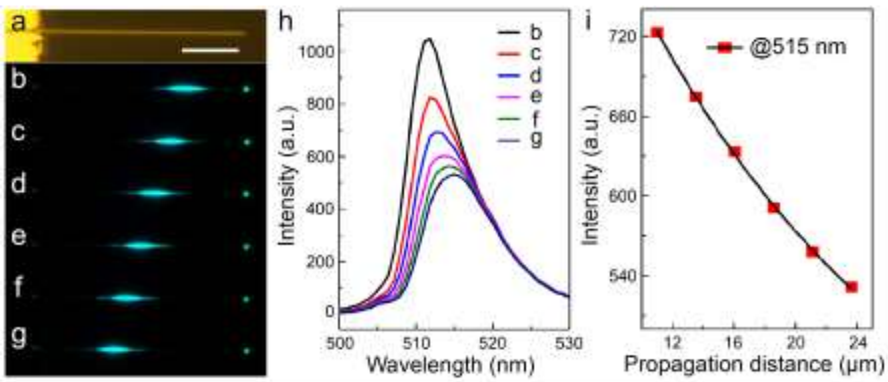

Figure S4. a, Bright-field optical microscope image of a suspended 170-nm-diameter long CdS nanowire. Scale bar, 10 μm. **b-g,** Photoluminescence images of the CdS nanowire locally excited at different positions along its length. **h,** Photoluminescence spectra collected at the right end of the nanowire excited at different positions by the switch light as shown in Fig. S4b-g. **i,** Propagation-length-dependent photoluminescence output intensities of the CdS nanowire at the wavelength of 515 nm. The experimental data is fitted using a first-order exponential decay (black line).

As shown in Fig. S4h, with the increase of the distance between the excitation spot and the right end of the nanowire (from 11 to 23.5 μm in step of 2.5 μm), the output of the waveguiding photoluminescence decreases gradually. The shorter the wavelength, the faster the intensity decreases. This is due to the self-absorption of the waveguiding photoluminescence by the CdS nanowire. Figure S4i shows the propagation-length-dependent output intensity at 515-nm wavelength extracted from the spectra shown in Fig. S4h. The output intensity decreases exponentially with the increase of the propagation length, giving a propagation loss of ~0.107 dB/μm for the signal light at 515-nm wavelength. In this case, for our single nanowire TO modulator, which was formed by a 13.5-μm-length nanowire, the insertion loss is as low as 1.44 dB.

Calculation of the temperature distribution of a CdS nanowire

Single-nanowire modulators can also be integrated with SOI platforms for on-chip applications by replacing fiber tapers with silicon waveguides. However, the heat generated in the nanowire may affect the operation of neighboring devices and limit the integration density. To explore this, we simulated the temperature distribution of a 170-nm-diameter 5-μm-length CdS nanowire with a thermal power of 24 μW generated in the nanowire in a steady state (simulated with COMSOL).

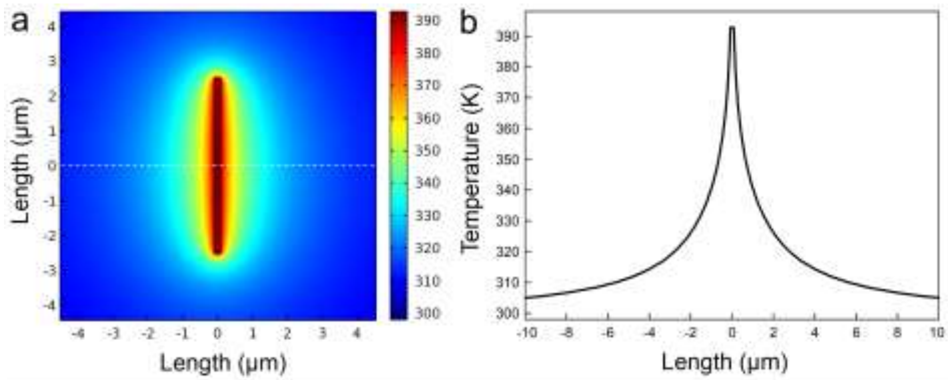

Figure S5. a, Simulated temperature distribution of a 170-nm-diameter CdS nanowire in a steady state. The black box in the center represents the boundary of the nanowire. **b,** Temperature distribution along the horizontal dashed line in (**a**).

As shown in Fig. S5a, outside the CdS nanowire, temperature decreases quickly with the increase of the distance away from the nanowire. The temperature distribution along the horizontal dashed line in Fig. S5a is shown in Fig. S5b. Although the temperature at the nanowire surface is as high as 393 K (corresponding to the temperature of the nanowire under a 91-μW-power switch light), it decreases quickly to 326 K and 309 K with a distance of 2 and 6 μm away from the nanowire, respectively (the ambient temperature is set to be 298.15 K).