Supplementary information

Manuscript title: Negative Thermal Quenching of Photoluminescence in Annealed ZnO/Al_2O_3 Core/Shell Nanorods

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The longitudes of ZnO and ZnO/Al_2O_3 NRs

The lengths of ZnO and ZnO/Al_2O_3 NRs were measured from the side view SEM images shown in Figure S1. All the NRs have the length of 7-10 μm.

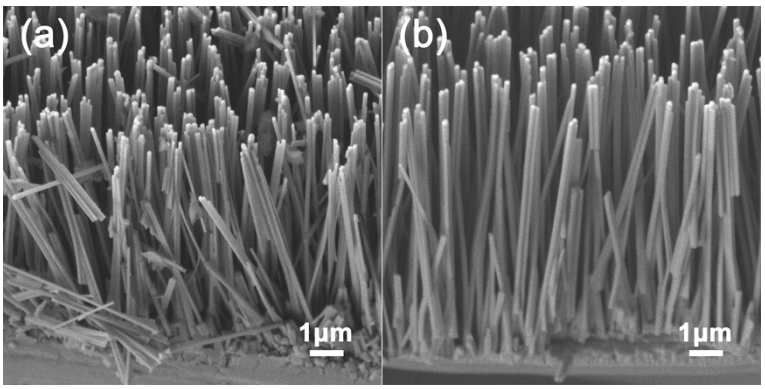

Figure S1. Side view SEM images of (a) annealed ZnO NRs and (b) annealed ZnO/Al_2O_3 NRs. The sample stage was tilted with 30 degrees.

HRTEM images for an as-grown ZnO NR and an as-grown ZnO/Al_2O_3 NR

The crystal qualities of as-grown ZnO NRs and as-grown ZnO/Al_2O_3 NRs were characterized by HRTEM, and the results are shown in Figure S2. As seen, both ZnO NRs grow along the c-axis (marked by white arrows) with a perfect single crystal wurtzite structure, while the Al_2O_3 shell is amorphous for the as-grown ZnO/Al_2O_3 NR.

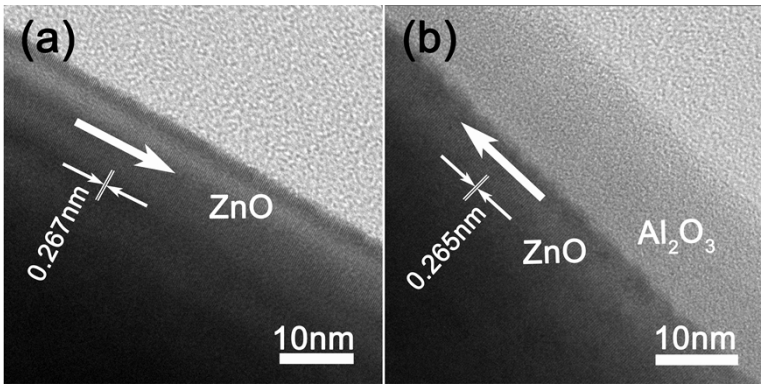

Figure S2. HRTEM images of an (a) as-grown ZnO NR and (b) as-grown ZnO/Al_2O_3 NR.

Absorption of various NRs samples

Absorption of all ZnO and ZnO/Al_2O_3 NRs samples were acquired by transferring the NRs onto a transparent polydimethylsiloxane (PDMS) substrate. UV-visible absorption spectra were obtained using a U-4100 spectrophotometer (HITACHI), and the results are given in Figure S3. As seen, all the NRs samples show nearly the same intensity and absorption edge at ~390 nm.

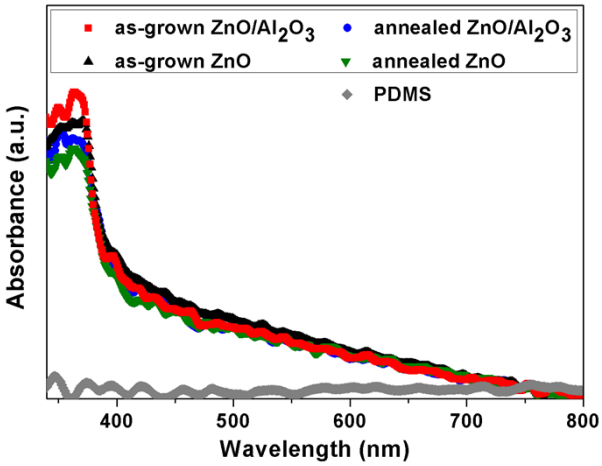

Figure S3. Absorption spectra for the as-grown ZnO/Al_2O_3 NRs, annealed ZnO/Al_2O_3 NRs, as-grown ZnO NRs, and annealed ZnO NRs, respectively. The absorption property of the transparent PDMS substrate is also plotted.

Temperature dependence of the DL intensities of various NRs samples

The integrated intensities of DL emission ranging from 420-650nm for various NRs samples are plotted in Figure S4. As seen, from 20K to 80K, the DL intensities for all samples vary slowly with increasing temperature. However, from 80K to room temperature (RT), the DL intensities for

the as-grown ZnO NRs, annealed ZnO NRs and as-grown ZnO/Al_2O_3 NRs drop rapidly, while that for the annealed ZnO/Al_2O_3 NRs increase markedly. This temperature dependence for DL emission is as same as that for the NBE emission. The inset shows the PL spectra of different NRs at 260K. It can be found that the DL intensity of the annealed ZnO/Al_2O_3 NRs is obviously stronger than those of other samples.

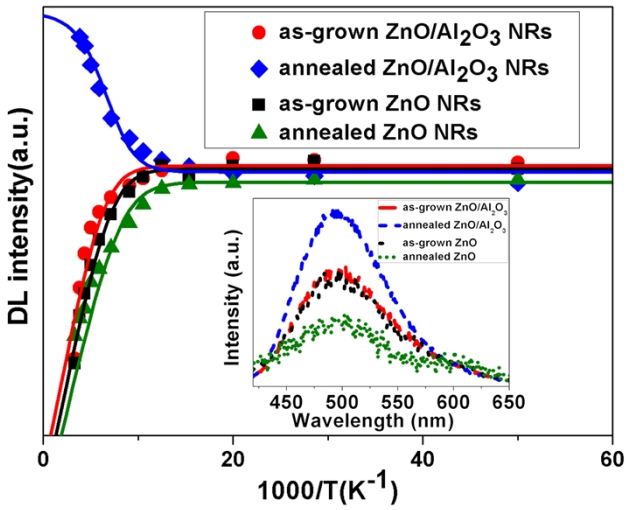

Figure S4. The temperature dependence of integrated DL intensity for the as grown ZnO/Al_2O_3 NRs, annealed ZnO/Al_2O_3 NRs, as grown ZnO NRs and annealed ZnO NRs, respectively. The solid lines are the fitting curves using Eq. (1). Inset shows the PL spectra of these samples at 260K.

Photoluminescence excitation spectrum (PLE) for various NRs samples

To better understand whether the deep level luminescence comes from different defect centers, we further investigate the photoluminescence excitation spectra (PLE) of different samples. The results are shown in Figure S5. It can be found that the NBE and DL emissions of four samples can only be excitated by UV light with the wavelength shorter than 380 nm and all PLE spectra vary smoothly, implying that the deep level luminescence of the sample does not come from different centers.

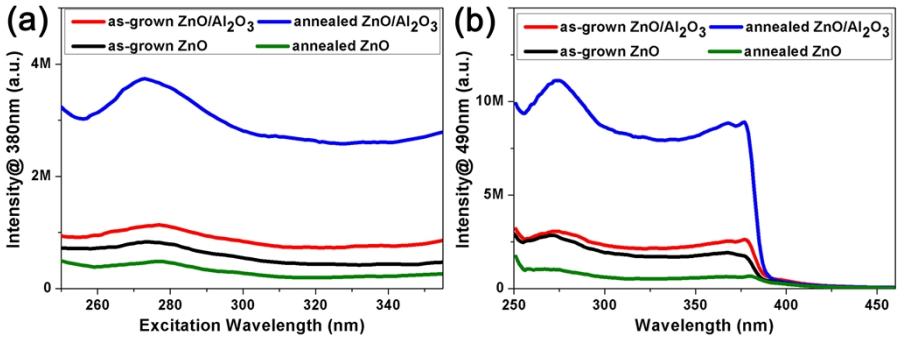

Figure S5. Photoluminescence excitation spectra of different samples collected at the wavelength of (a) 380nm and (b) 490nm. The collection bandwidth is 5nm.