ADVANCED FUNCTIONAL MATERIALS

Supporting Information

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Scalable Nanowire Photonic Crystals: Molding the Light Emission of InGaN

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Figure S1.

Illustration of the uniformity of InGaN photonic crystal molecules across a large area

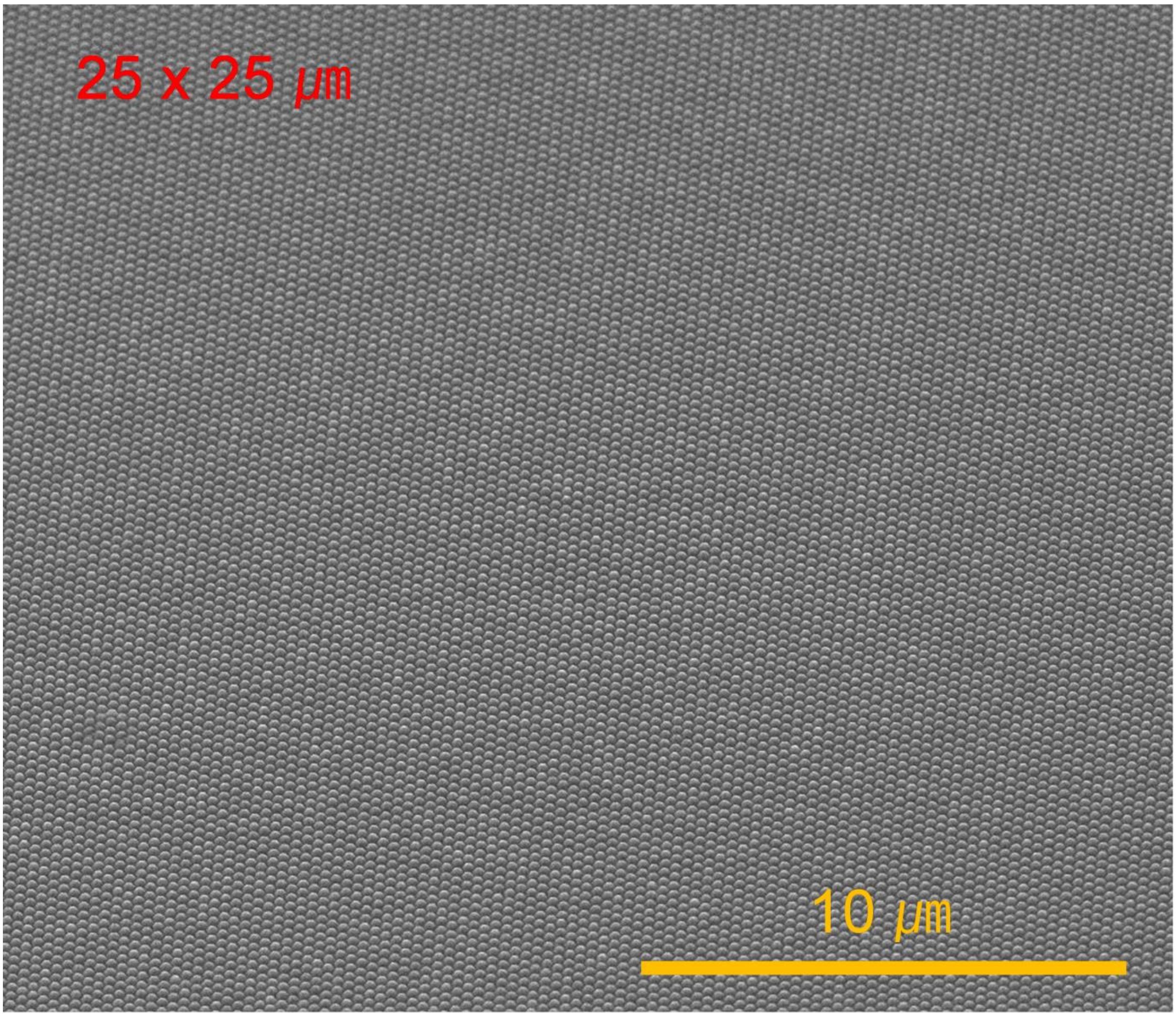

Figure S1. 45° tilted-view SEM image of the InGaN nanowire photonic crystal molecules arranged in a 25 μm x 25 μm area, showing extremely high uniformity across a large area.

Figure S2.

The emission stability of InGaN nanowire photonic crystal structures across a large area.

We have investigated the emission characteristics, including the uniformity and yield of InGaN nanowire photonic crystal structures fabricated in a large area. As illustrated in Figure S2a, six different points were measured in an areal size of 100 μm × 100 μm using a 405 nm laser as the excitation source at room temperature. The emission wavelengths remain nearly invariant at 505 nm with a narrow spectral linewidth of 12 nm for various regions of the nanowire photonic crystal structure, shown in Figure S2b. The extremely high yield and uniformity is attributed to the well-controlled nanowire size and position of the unique selective area epitaxy.

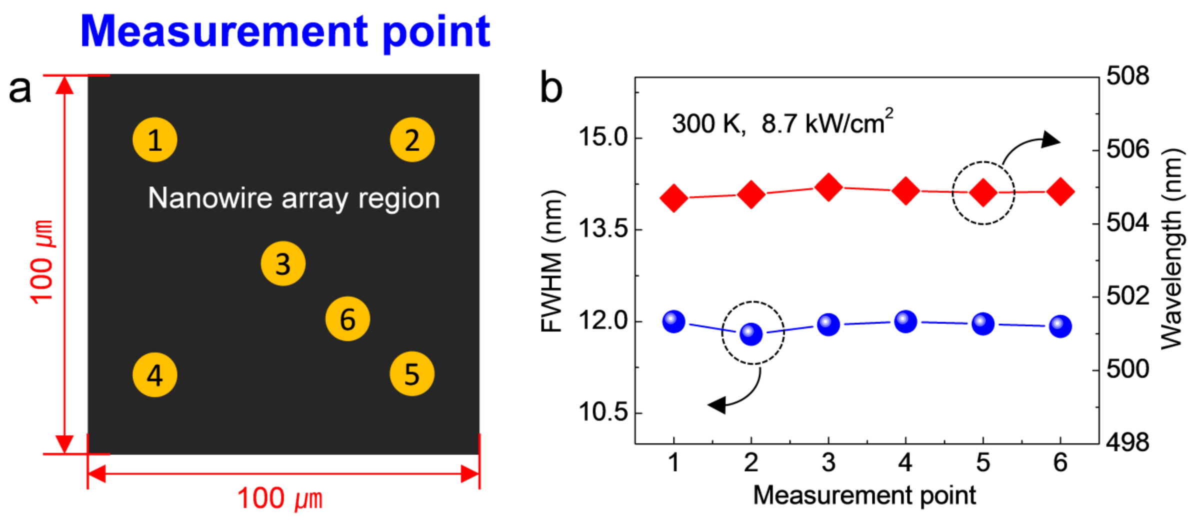

Figure S2. a) Schematic of the InGaN nanowire photonic crystal structure fabricated in an areal size of 100 μm × 100 μm and six different positions for the photoluminescence measurement. b) Variations of the emission peak and spectral linewidth vs. measurement point.

Figure S3.

Cathodoluminescence (CL) mapping measurement spectrally resolved at different emission wavelengths and with different design parameters.

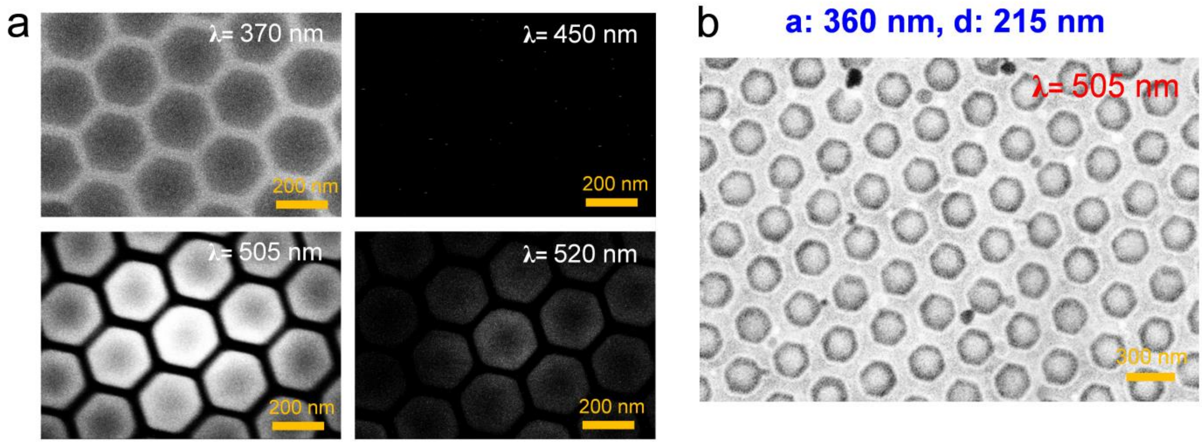

Figure S3. a) Spectrally resolved CL mapping images collected at various wavelengths of 370, 450, 505 and 520 nm, respectively, showing the presence of band edge mode and strong optical confinement effect only at an emission wavelength of 505 nm. b) CL mapping image at a wavelength of 505 nm for InGaN nanowire arrays with a relatively large spacing compared to the optimum design shown in a), showing the absence of the band edge mode. Due to the weaker emission for the image shown in b), the measurement was performed with a relatively long integration time to clearly show the light distribution.

To further confirm the formation of stable band edge modes in InGaN photonic crystals, we have performed more detailed spectrally resolved CL mapping measurements at different wavelengths. Figure S3a shows the CL mapping images collected at wavelengths of 370, 450, 505 and 520 nm, respectively. The CL image at 370 nm exhibits highly uniform contrast in the entire region. It was also noticed the spacing between nanowires shows brighter emission, which is due to the light emission from the underlying GaN template. No emission was observed at 450 nm wavelength since there is no light emission from the nanowires in this wavelength. At 505 nm, strong optical confinement effect at the center region of nanowire arrays was clearly observed. Significantly weaker emission was also measured at 520 nm. These studies provide unambiguous evidence for the direct measurement of the band edge mode in defect-free nanowire photonic crystals. We have further performed CL wavelength mapping measurement of InGaN nanowire arrays with a relatively larger spacing compared to the optimum design. The image taken at a wavelength of 505 nm is shown in Figure 3d, and no optical confinement effect was observed.

Figure S4.

Emission characteristics of InGaN nanowire photonic crystals vs. nanowire height.

We have also studied the dependence of the emission characteristics of InGaN nanowire photonic crystals on the height of nanowires. Five InGaN/AlGaN dot-in-nanowire photonic crystals, schematically shown in Figure S4a were investigated, which have identical designs except the height of the *n*-GaN segments were varied from ~380 nm to 460 nm. Each nanowire, schematically shown Figure S4a, consists of the *n*-GaN segment, ten vertically aligned InGaN/AlGaN quantum dots, and 30 nm *p*-GaN layer. PL emission of the InGaN nanowires was measured at room temperature with a 405 nm laser as the excitation source. Strong emission was observed at a wavelength of ~ 510 nm with a relatively narrow spectral linewidth of ~ 6 nm for nanowire arrays with heights varying from ~ 550 to 590 nm, shown Figure S4b. However, the light intensity showed a significant decrease when the nanowire height was reduced below 550 nm, accompanied by a significantly broadened linewidth. These studies show that the band edge mode and the Purcell effect depends critically on the nanowire height, in addition to the nanowire diameter and spacing.

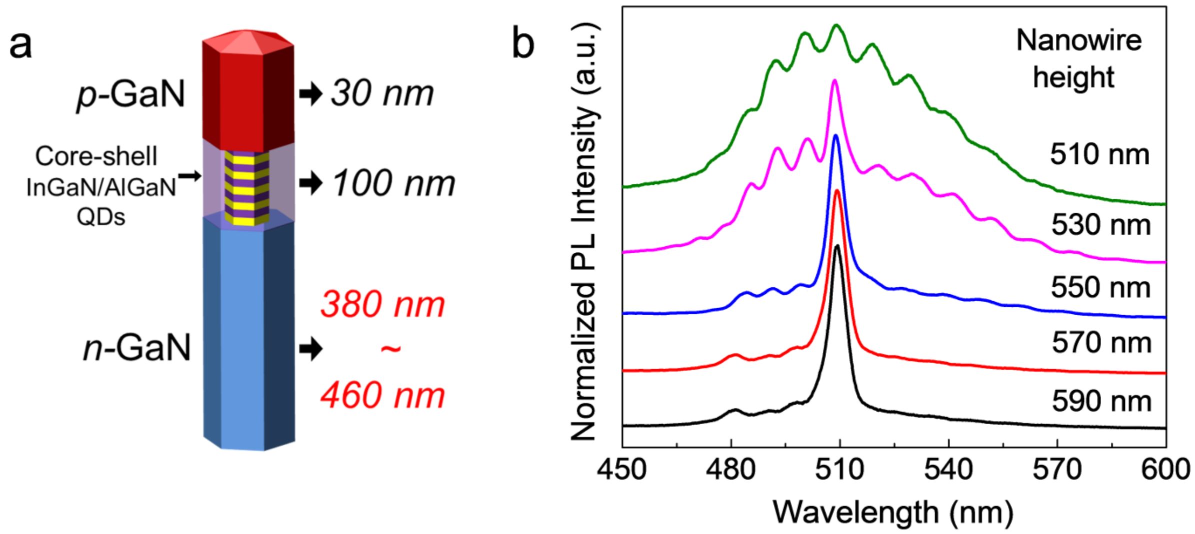

Figure S4. a) Illustration of bottom-up InGaN/AlGaN core-shell dot-in-nanowire structure. The n-GaN segment length was varied from 380 to 460 nm. b) PL emission spectra of InGaN nanowire structures measured at room-temperature for nanowire heights of ~ 510, ~ 530, ~ 550, ~ 570 and ~ 590 nm, respectively.