Supporting Information

Nanoscale Optical Properties of Indium Gallium Nitride/Gallium Nitride Nanodisk-in-Rod Heterostructures

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Ensemble photoluminescence spectrum from InGaN/GaN nanodisk-in-rod heterostructure

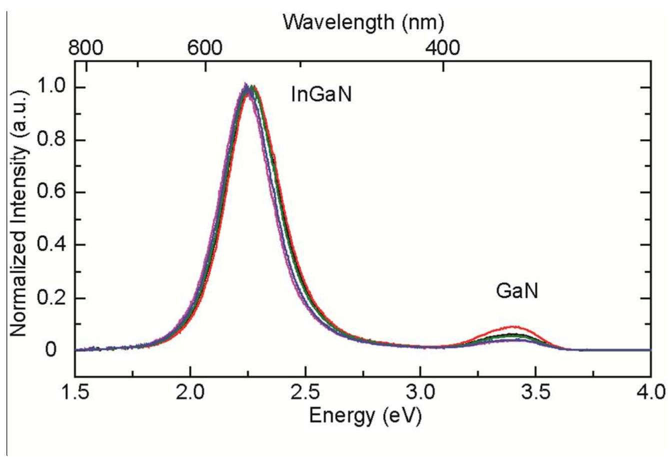

Figure S1. Normalized photoluminescence (PL) spectra taken from five different positions of InGaN-GaN nanodisk-in-rods on the substrate. GaN PL peak is observed at 3.41 eV. Emission band centered at 2.30 eV was assigned to PL emission from InGaN nanodisks. Exact peak positions from five separate measurements from different regions on the nanorod ensemble range from 2.28 to 2.34 eV that together with the relatively broad emission peak indicate slight differences in In composition from nanodisks across the growth substrate.

Geometry of nanorods ‘standing-up’ on grid for transmission electron microscopy

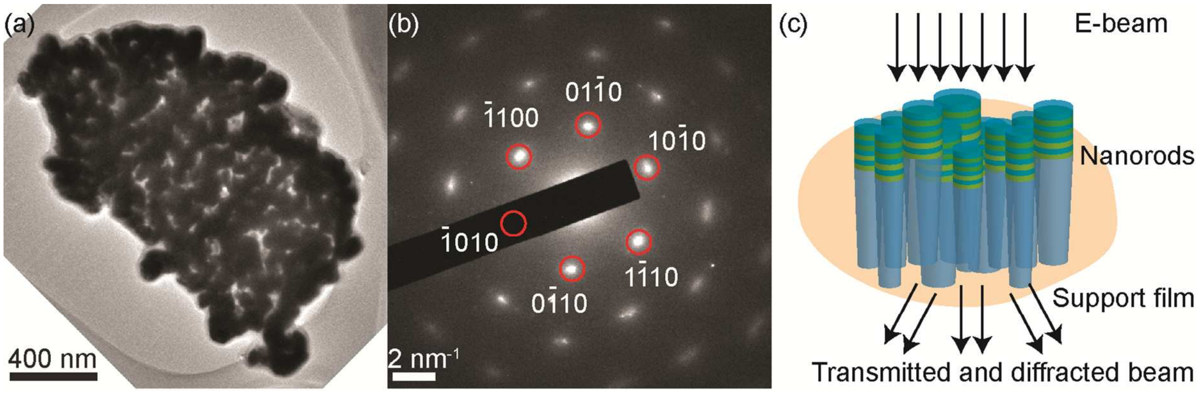

Figure S2. (a) TEM image of a cluster of GaN nanorods with InGaN nanodisks standing up on a TEM grid. (b) Corresponding SAD pattern showing {1-100} family of diffraction spots, which confirms that the TEM image in (a) is a top-down view of a cluster of nanorods viewed along their growth axis. (c) A schematic of the sample geometry for TEM observation in (a) and (b).

To study the nanoscale optical properties, the nanorods were removed from the growth substrate by sonication, and drop casted onto copper grids with lacey carbon for TEM investigations. Besides nanorods lying sideways, micrometer sized clusters of nanorods were also found standing up on the TEM grid. The TEM image of such clusters, such as shown Figure S2a, is a projection of the nanorod ensemble along the growth axis. To verify the exact sample geometry, selective area diffraction was performed on this nanorod ensemble, revealing a spot pattern with hexagonal symmetry (Figure S2b) thus confirming that the nanorod growth axis is oriented parallel to the electron beam, *i.e.* top down view.

Analysis of spectrum imaging using cathodoluminescence in scanning transmission electron microscopy (CL-STEM)

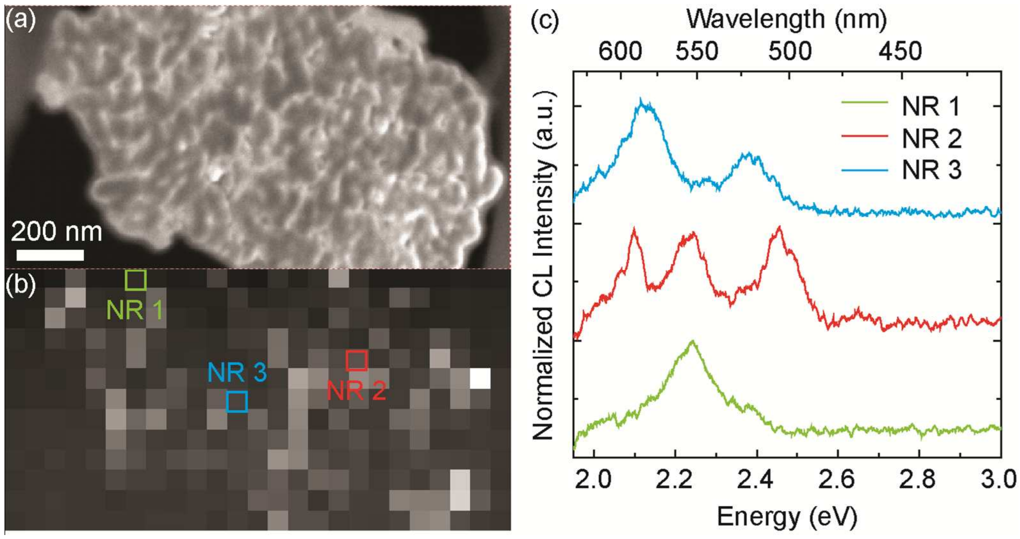

Figure S3. CL spectrum imaging of a nanorod ensemble viewed from top-down along the growth axis. (a) STEM image of a region of interest. (b) Corresponding normalized CL intensity map collected by a CCD detector. Range of spectrum integration: 1.95 – 3.23 eV. (c) CL spectra from individual nanorods (NR 1-3), as labeled in (b). Up to three different CL emission peaks can be observed. The geometry of the sample is same to Figure S2.

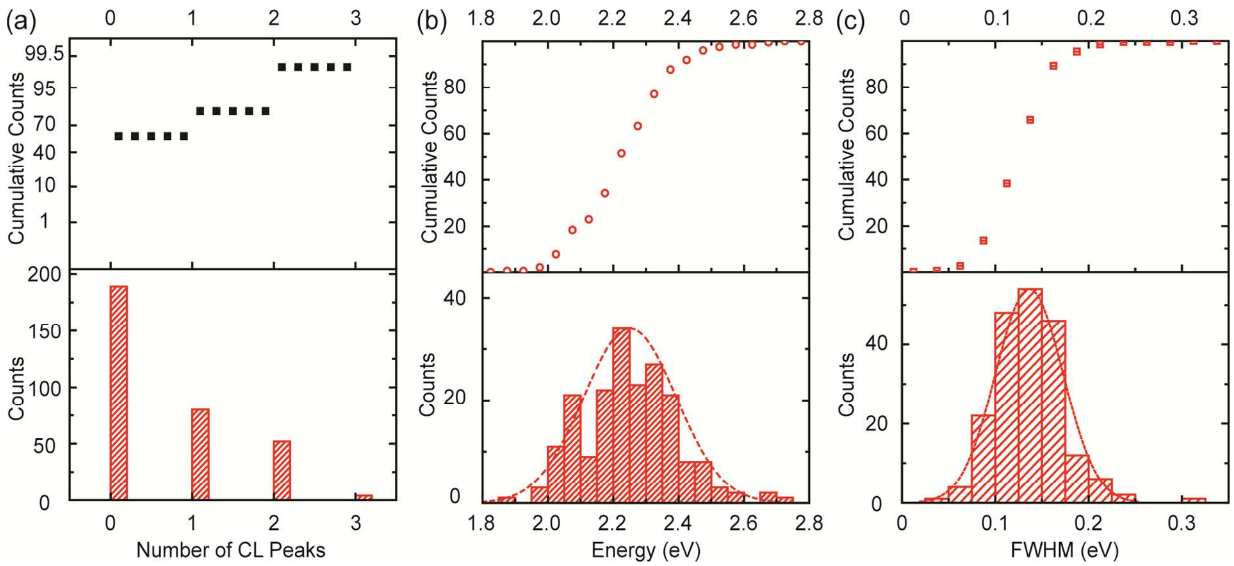

Figure S4. Statistics of InGaN-GaN nanodisk-in-rod ensemble emission characteristics. (a) Histogram and cumulative distribution of number of CL peaks observed from individual nanorods. (b) Histogram and cumulative distribution of CL peak centered observed from individual nanorods. (c) Histogram and cumulative distribution of CL peak full width half maximum (FWHM) observed from individual nanorods. The statistics were obtained by performing Gaussian peak fitting of the CL spectrum image as shown in Figure S3.

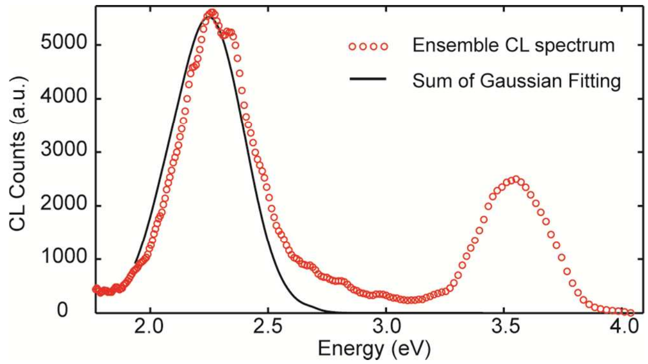

Figure S5. CL spectrum of nanorod ensemble (red open circle) as shown in Figure 2c of the main text, and the summed spectrum from individual Gaussian peak fitting from Figure S3. The close matching of the ensemble spectrum and the sum of fitted spectra validates the effectiveness and accuracy of Gaussian peak fitting.

Stacking fault related CL quenching in InGaN/GaN nanodisk-in-rod structures with different number of nanodisks

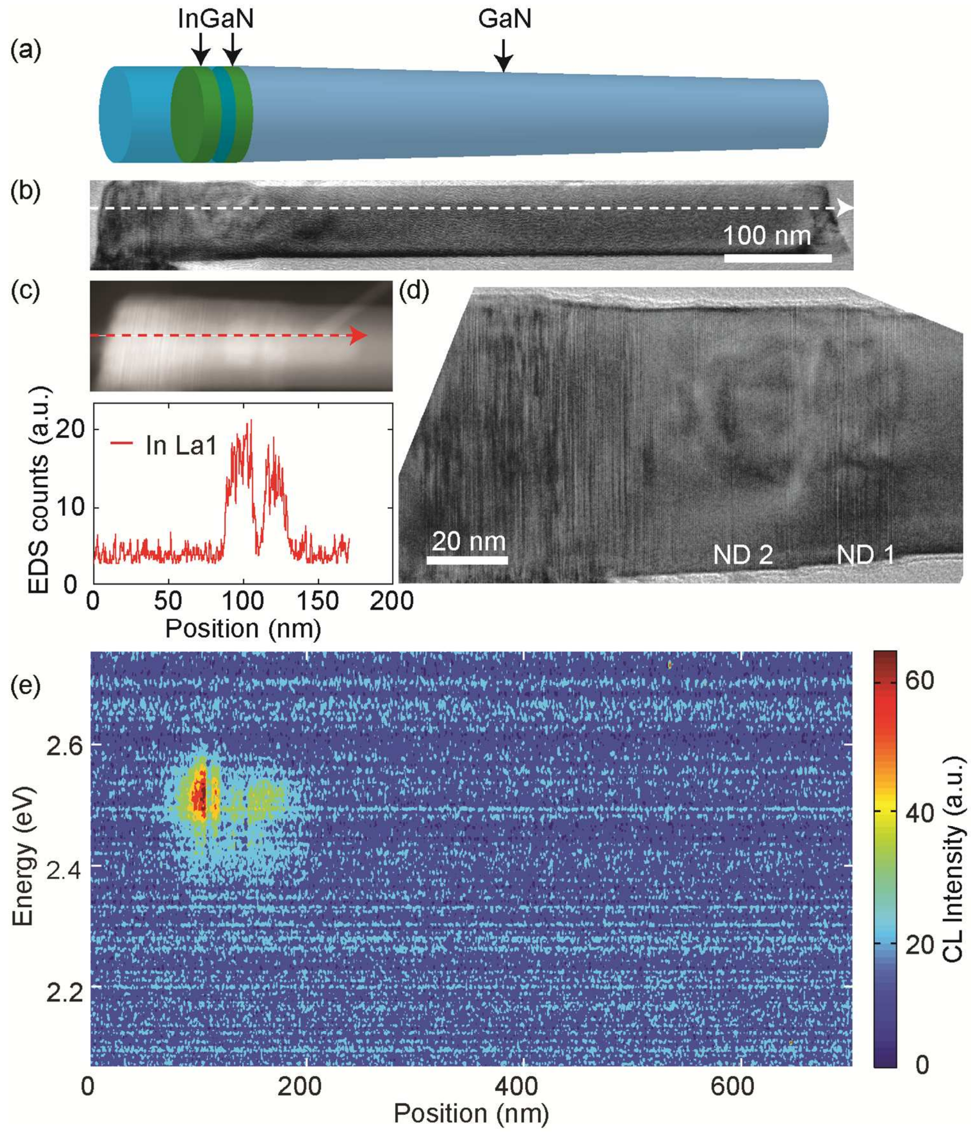

Figure S6. Stacking fault related CL quenching in a GaN nanorod with two InGaN nanodisks. (a) Schematic representation of a GaN nanorod with two InGaN nanodisks. (b) Bright field TEM image of the nanorod with arrow indicating the direction of CL line scan shown in (e). (c) EDS line profile of indium signals from the nanodisks. The corresponding STEM image is shown above with the arrow indicating the line scan direction. (d) High resolution TEM image of the same nanorod. Multiple stacking faults cut through ND1, while ND2 is relatively defect free. (e)

CL line scan map along the white arrow in (a), from the top to the bottom of the nanorod. Bright CL emission is only observed in ND2.

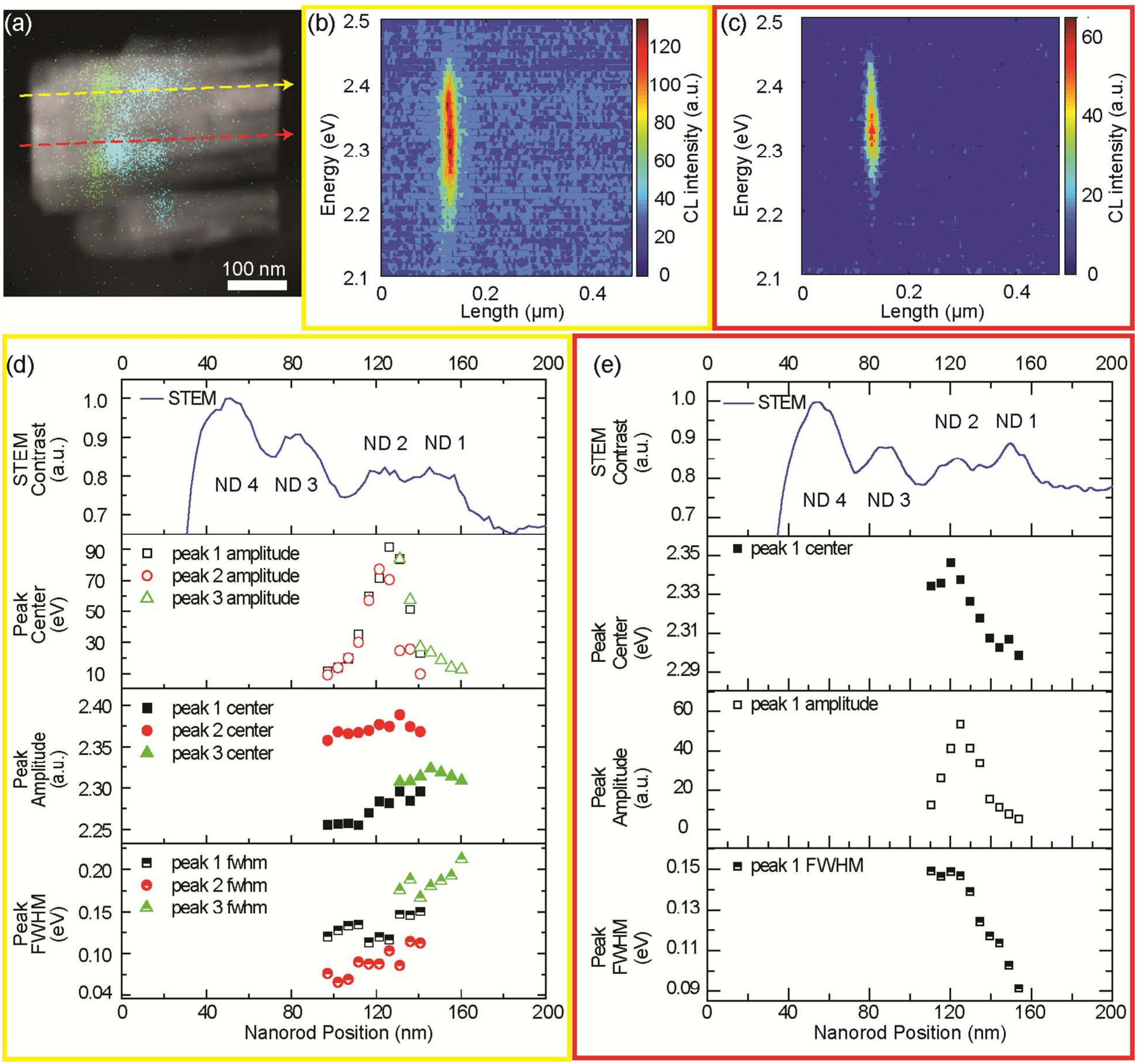

Figure S7. Additional examples of CL quenching in ND 3 and 4 compared to ND 1 and 2 (from same batch of sample as Figure 4 of the main text). (a) Overlaid monochromatic CL (green: 2.35 eV from InGaN, blue: 3.50 eV from GaN) onto STEM image. (b) and (c) CL spectrum image along the orange and red line in (a). (d) and (e) STEM and corresponding Gaussian fitted CL emission peak properties, as extracted from (b) and (c). The nanodisks could be observed from the STEM contrast, as regions with more indium have higher contrast. In both cases, strongest CL emission corresponds to ND 2, while no CL emission is observed from ND 3 and ND 4.

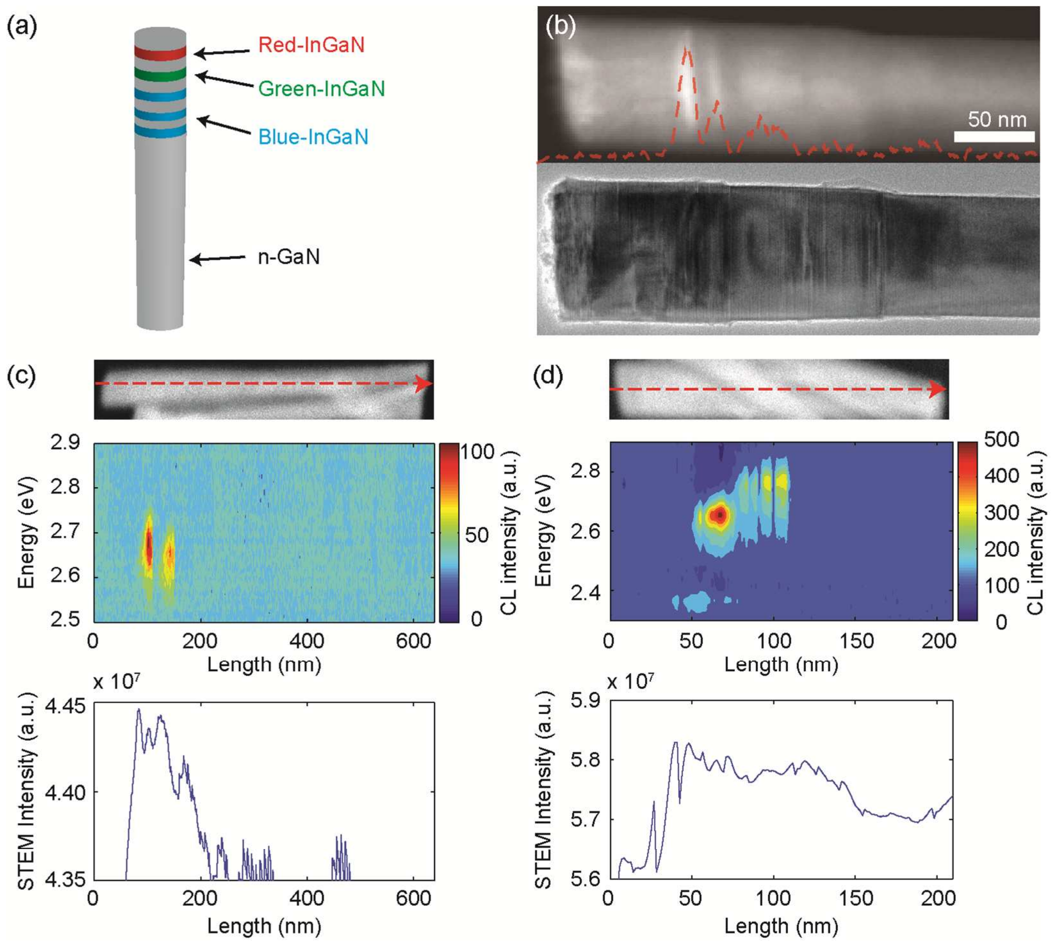

Figure S8. Stacking fault related CL quenching in GaN nanorods with 5 InGaN nanodisks. (a) Schematic of InGaN/GaN nanodisk-in-rod heterostructure. Five nanodisks were grown, with the compositions tuned for red, green and blue emissions. (b) Dark field STEM image and corresponding bright field TEM image along <11-20> zone axis. InGaN nanodisks are more visible in the dark filed STEM image via Z-contrast. EDS line profile of In Lα signal is superimposed in red. Stacking faults are more frequently observed in the top two red and green InGaN nanodisks, as well as the first two blue InGaN nanodisks grown. (c) and (d) Two representative examples of CL line scan spectrum image and corresponding STEM contrast, from 10 nanorods studied. Only strong blue emission from up to two nanodisks are observed, indicating CL quenching by stacking faults in other nanodisks.

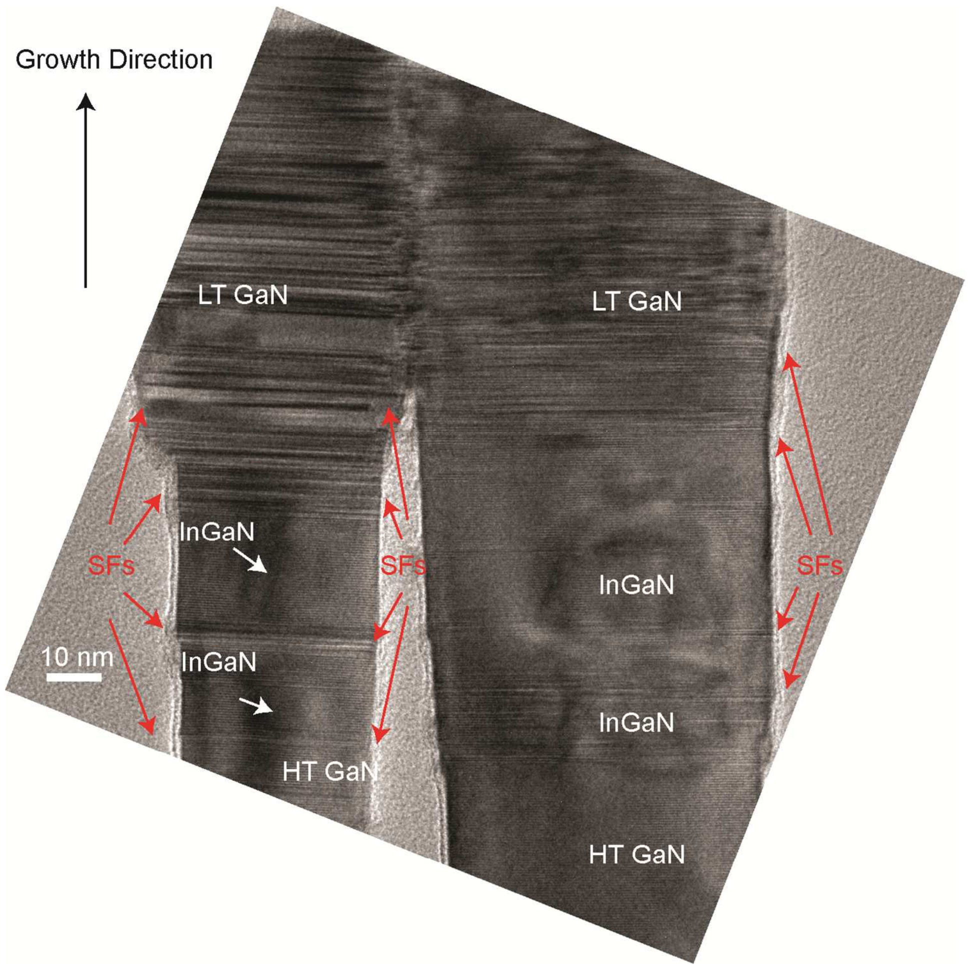

Figure S9. Bright field TEM image showing the stacking faults in a GaN nanorod with two InGaN nanodisks, from the same sample shown in Figure S6 High temperature (770 °C) grown GaN (HT GaN), InGaN nanodisks and low temperature (700 °C) grown GaN (LT GaN) were labelled inside the nanorods. Contrasts from stacking faults, which mostly propagate through the entire length of the nanorod, are also indicated.