Electronic Supplementary Material (ESI) for Nanoscale.

Influence of Plasmonic Array Geometry on Energy Transfer from a Quantum Well to a Quantum Dot Layer

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SUPPORTING INFORMATION

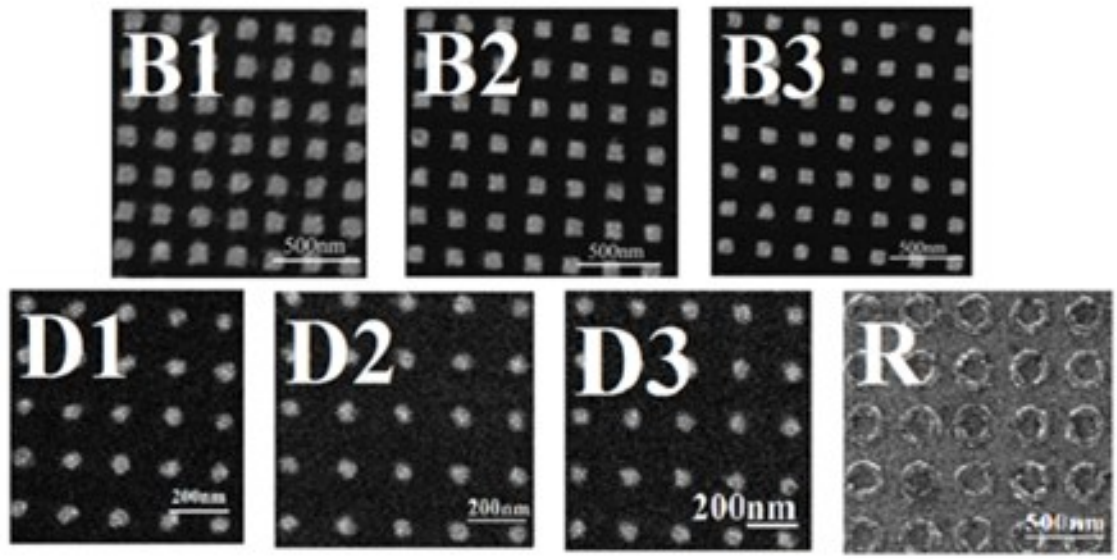

Figure S1: HIM images of B1, B2, B3 arrays (scale bar 500nm); D1, D2, D3 arrays (scale bar 200nm) and Ring array (scale bar 500nm).

The average PL lifetime is given by Equation (S1),

$$\tau_{Avg} = \frac{I_1 \cdot {t_1}^2 + I_2 \cdot {t_2}^2}{I_1 t_1 + I_2 t_2} \quad \text{(S1)}$$

where I_1 and I_2 are the intensity amplitudes of the exponential decays with two different lifetimes t_1 and t_2, respectively.

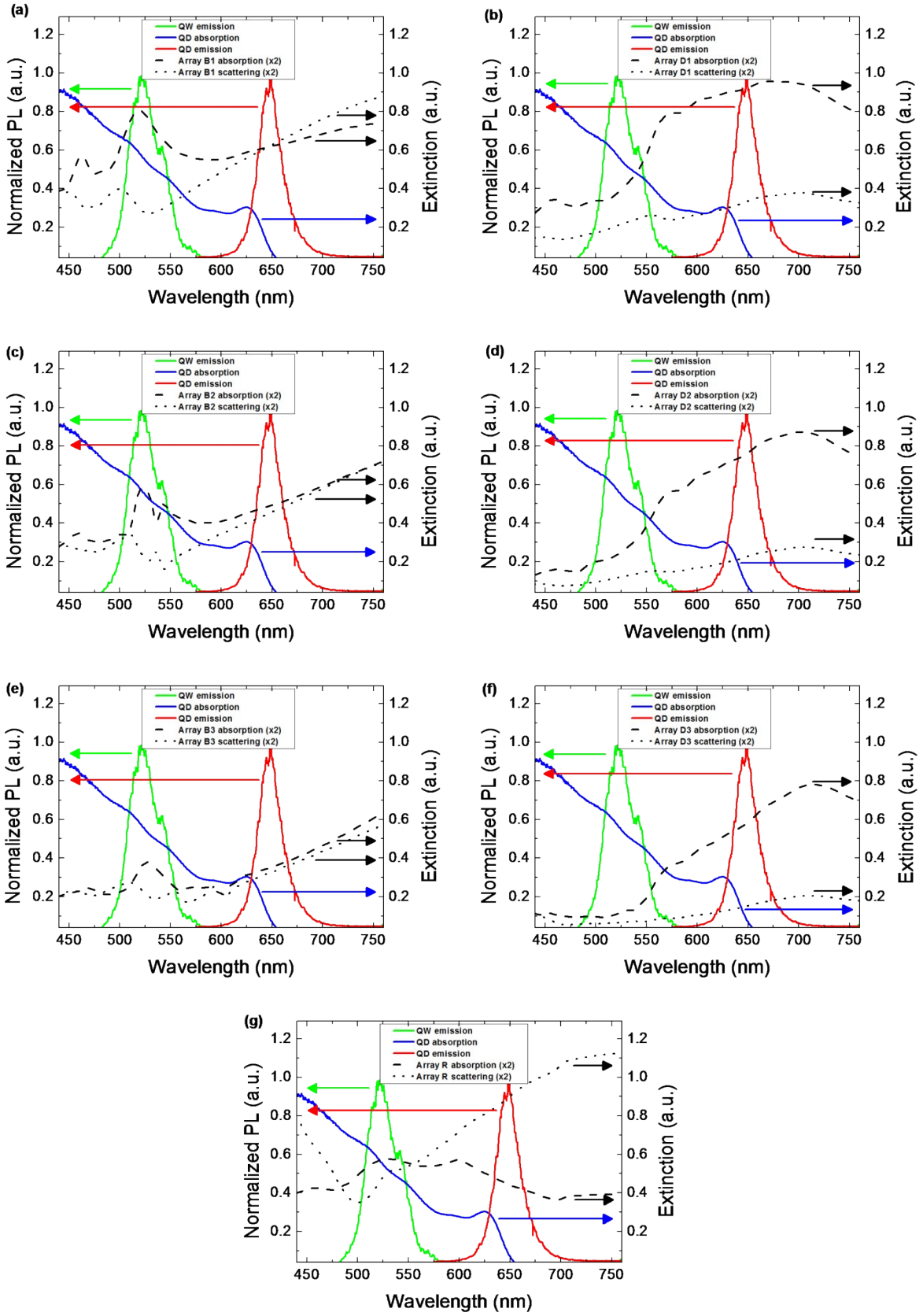

Figure S2: QW PL (green line), QD absorption (blue line) and PL (red line) spectra, along with absorption (dashed black line) and scattering (dotted black line) spectra for Box arrays B1, B2, B3 (a,c,e), Disc arrays D1, D2, D3 (b,d,f) and Ring array (g), respectively.

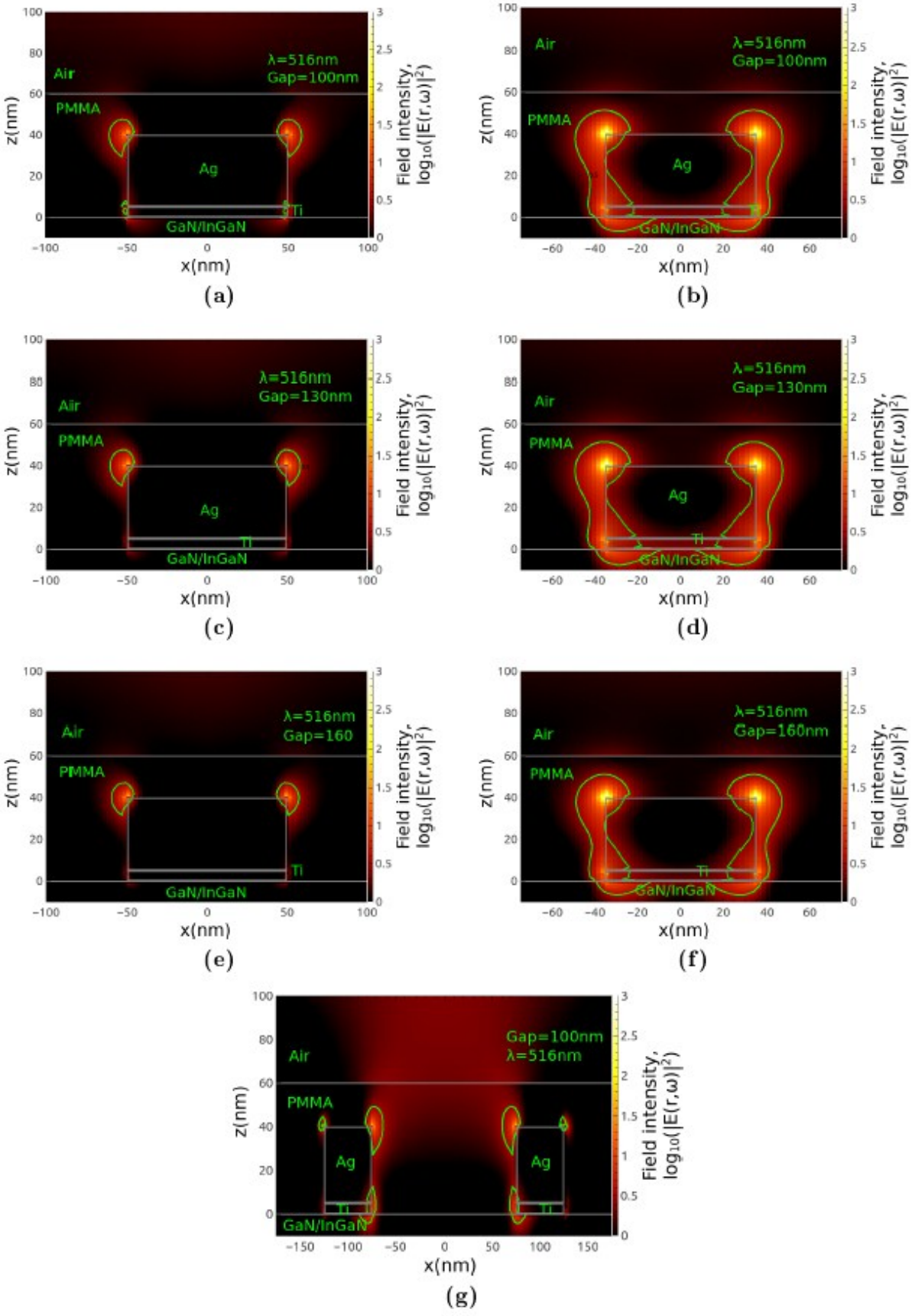

Figure S3: Maps of the field intensity in the x-z plane at the donor emission wavelength for Box arrays B1, B2, B3 (a,c,e), Disc arrays D1, D2, D3 (b,d,f) and Ring array (g), respectively under plane wave excitation. The green line gives $\log_{10}|E|^2 = 0.5$ for direct comparison.

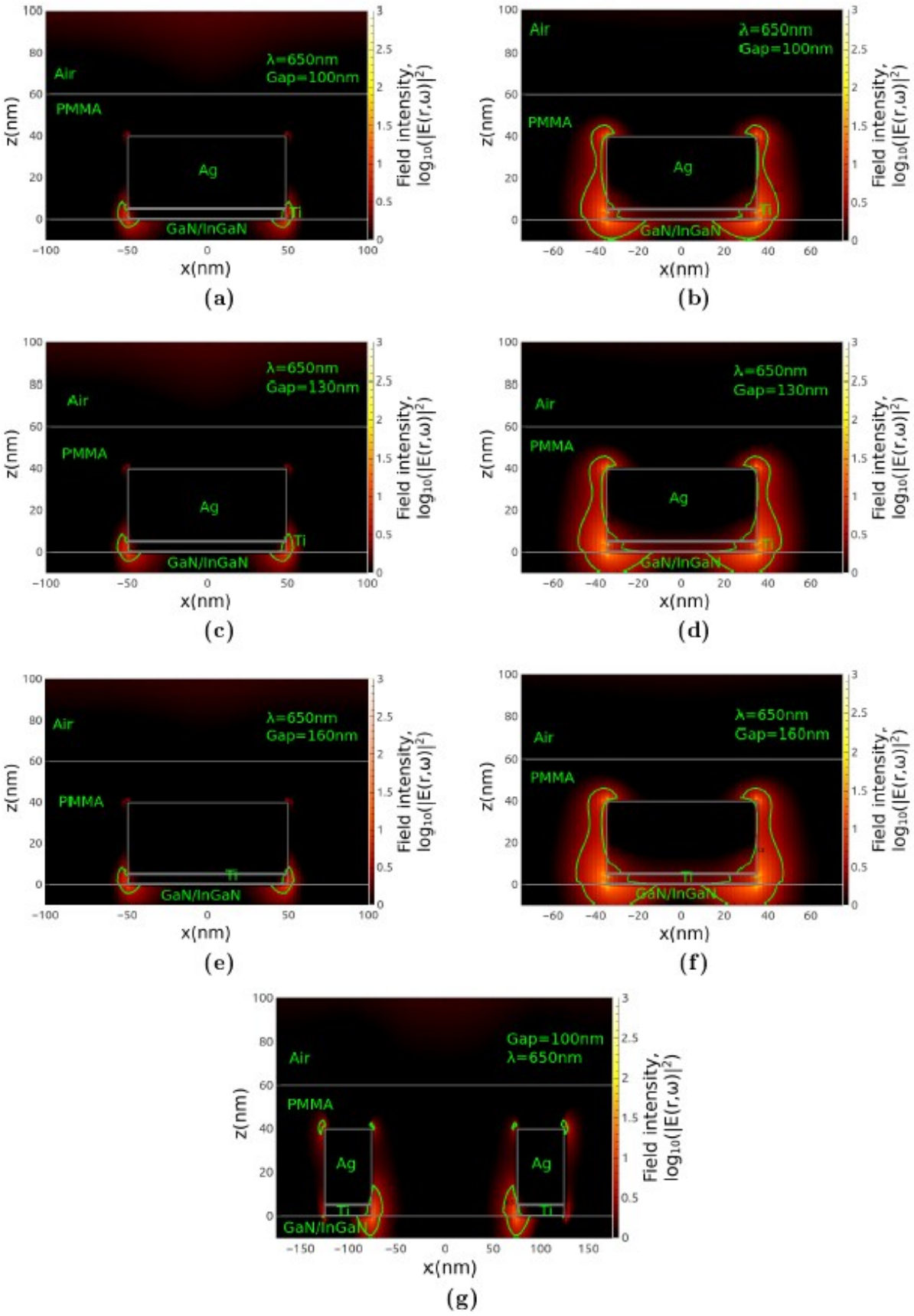

Figure S4: Maps of the field intensity in the x-z plane at the acceptor emission wavelength for Box arrays B1, B2, B3 (a,c,e), Disc arrays D1, D2, D3 (b,d,f) and Ring array (g), respectively under plane wave excitation. The green line gives $\log_{10}|E|^2 = 0.5$ for direct comparison.

The calculation of the injected carrier density, n, is given by Equation (S2),

$$n = \frac{P}{(h\nu)*\theta*d_{active}*f}*\left[1-\exp\left(-\alpha_{InGaN}d_{active}\right)\right]*(1-R) \quad , \quad \text{(S2)}$$

where P is the laser pumping power, $h\nu$ is the energy of the injected photons, θ is the spot size of pumping laser, d_{active} is the thicknesses of the active region, f is the repetition rate of pumping laser, α_{InGaN} is the absorption coefficient of the InGaN QW, and R is the reflectance at the wavelength of the pump laser at 405 nm, respectively.[1,2] Here the spot diameter is 0.43 μm, d_{active} is 2 nm, f is 10 MHz, α_{InGaN} is 10^4 cm^{-1} and R is 0.15.

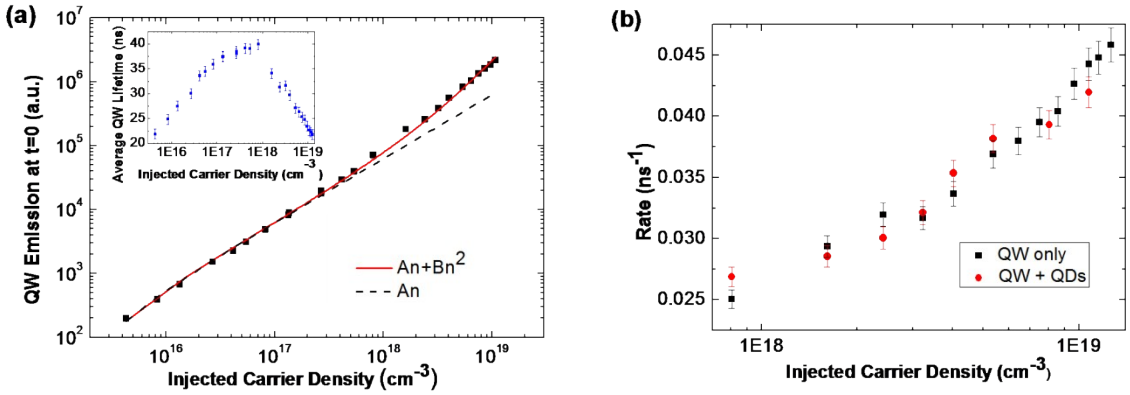

Figure S5 (a) The QW emission at t=0 as a function of injected carrier density. Inset: The average QW PL lifetime as a function of injected carrier density. (b). The spontaneous emission rate of the QW with (red circles) and without (black squares) QDs as a function of injected carrier density.

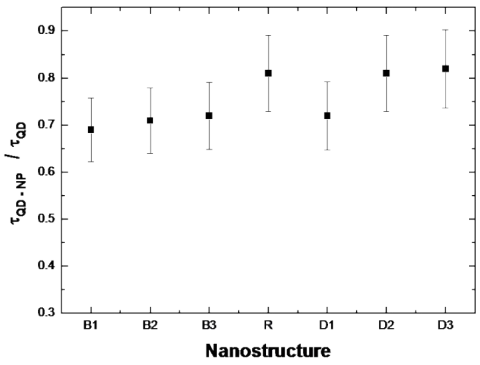

Figure S6: Lifetime ratio of the acceptor QDs on bulk GaN substrate as a function of nanostructure.

As described earlier, to determine whether the NP arrays cause direct quenching or enhancement of the QD emission, the different nanostructures were built directly onto bulk GaN. Figure S7 (a) shows the QD PL decays on and off the nanoring array on a GaN substrate. On the array the QD PL lifetime is reduced by (21 ± 2) % from 8.1 ns to 6.4 ns. Figure S7 (b) shows the QD lifetime on and off the nanoring array on the QW substrate. Here the QD lifetime on the array is increased by (10 ± 1) % due to pumping via plasmon-enhanced FRET from the QW to the QDs.

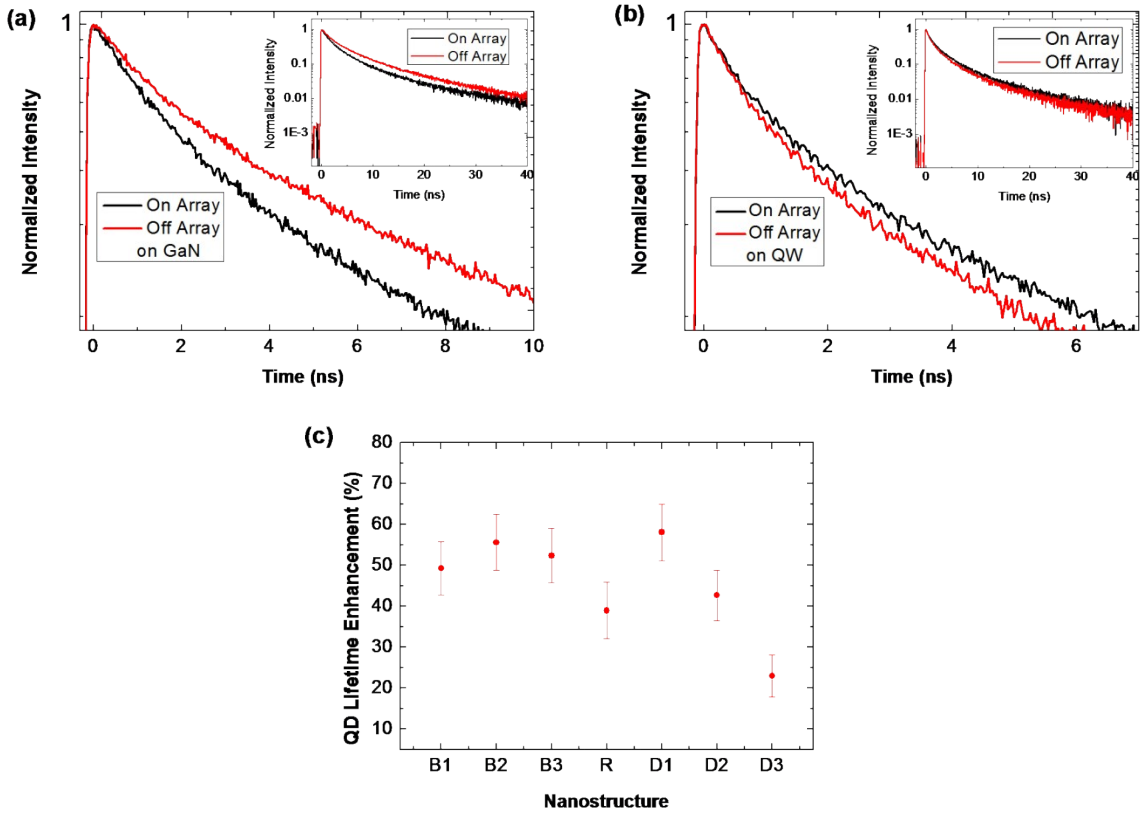

Figure S7: The QD PL decay on and off the Ag nanobox array on a GaN bulk layer. (b) QD PL decay on and off of Ag nanobox array on the QW sample. The insets show the PL decays over a 40 ns range. (c) QD lifetime enhancements as a function of nanostructure.

Similar analysis of the QD TRPL was completed for all the NP arrays. The overall QD lifetime increase is calculated as the ratio of the change in lifetime on GaN divided by the change in lifetime on the QW. Using the nanoring array as an example; we had a reduction on the NP array of (21 ± 2) % on GaN and an increase of (10 ± 1) % on the MNPs on the QW. Therefore overall QD lifetime increase on the nanoring array is given by 1.1/0.79 = 1.39, representing an overall QD lifetime increase of (39 ± 8) %. Figure S7 (c) shows the overall QD lifetime enhancement as a function of nanostructure. An overall increase in the QD lifetime is seen for all structures, providing further evidence from the acceptors that plasmon-enhanced FRET occurs for all NP arrays.

REFERENCES

[1] J. Lee, C. Chiu, C. C. Ke, P. C. Lin, T. Lu, H. Kuo and S. Wang, IEEE J. Sel. Topics Quantum Electron, 15(4), 1137-1143, **2009**

[2] H. Wang, Z. Ji, S. Qu, G. Wang, Y. Jiang, B. Liu, X. Xu, and H. Mino, Optics Express, vol. 20, no. 4, p. 3932, **2012**.