

Transition from single-photon emission to superradiance in dense WSe₂ quantum emitter arrays

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Cooperative light emission arises when multiple indistinguishable quantum emitters interact coherently through a shared electromagnetic field, dramatically changing emission characteristics and offering opportunities for generating entangled quantum states for quantum computing, quantum information processing, and secure communications. A key example is superradiance, in which coupled quantum light emitters radiate collectively and emit in phase, producing an enhanced, high-intensity burst of light.¹ However, superradiance remains challenging to realize in solid-state materials because it requires interacting emitters to be identical, while quantum emitters in these systems are inevitably subject to variations in their local environment, including strain, carrier fluctuations, and surrounding defects. Two-dimensional semiconductors, particularly monolayer tungsten diselenide (WSe₂), offer a promising platform due to their atomically thin structure, strong excitonic interactions, and sensitivity to local strain, enabling spatial and spectral control of quantum emitters which provides new opportunities for realizing scalable cooperative quantum light sources.

In this work, we demonstrate superradiant emission and the transition from single-photon to superradiant light emission in strained monolayer WSe₂ suspended over dense nanocavity arrays, with uniform localized strain controlled through electrostatic interactions.² Computational studies have predicted a critical inter-emitter spacing $d_{\text{critical}} \leq 0.3\text{--}0.4\lambda$ for achieving superradiance in two-dimensional systems, where λ is the emission wavelength.³ By comparing devices with inter-emitter spacings of $d = 0.5\lambda$ and 0.26λ , we show that emitters remain isolated single-photon sources when $d > d_{\text{critical}}$, whereas reducing the spacing below this threshold produces pronounced photon bunching, fast radiative lifetime, and enhanced peak intensity—the characteristic signatures of superradiance. Furthermore, electrostatic back-gating enhances both emitter intensity and superradiant emission, consistent with increased exciton populations funneling toward deeply bound defects under electrostatic gating. These results demonstrate a powerful new platform for highly controlled, large-scale quantum light emission in two-dimensional materials, and establish inter-emitter spacing and electrostatic gating as effective controls for engineering cooperative quantum light emission in two-dimensional materials.

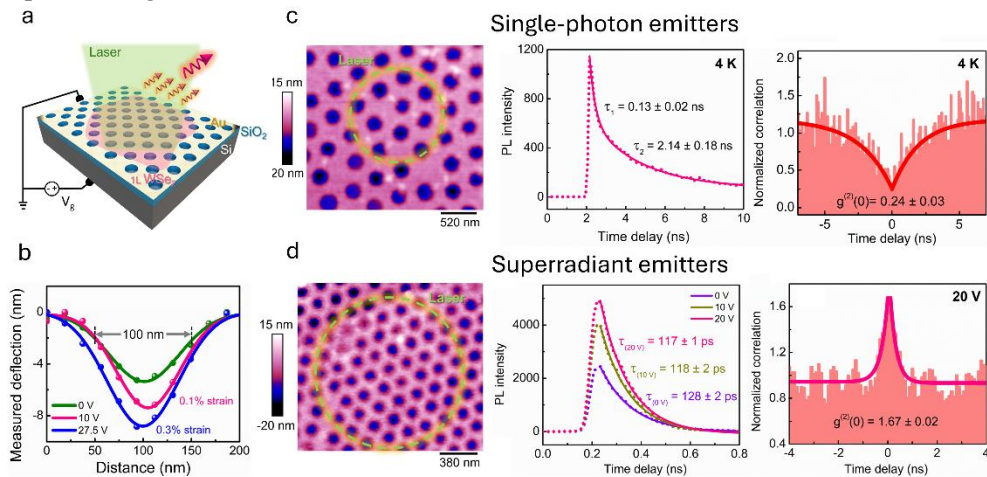


Figure 1 **a.** Schematic diagram of electrostatic straining approach. **b.** Monolayer deflections at different applied voltages. **(c, d.)** AFM topographic image, photoluminescence lifetime, and second-order correlation function of WSe₂ monolayer suspended on devices with inter-cavity spacings of $d = 0.5\lambda$ (c) and $d = 0.26\lambda$ (d), revealing the transition from isolated single-photon emitters (c) to superradiant emitters (d).

References

1. Rainò, G. *et al.* *MRS Bulletin* **45**, 841–848 (2020).
2. Wu, F.C.M. *et al.* *Nano Letters* **25** (27), 10983–10989 (2025).
3. Masson, S.J., Asenjo-Garcia, A. *Nat Commun* **13**, 2285 (2022).

Supplementary Pages

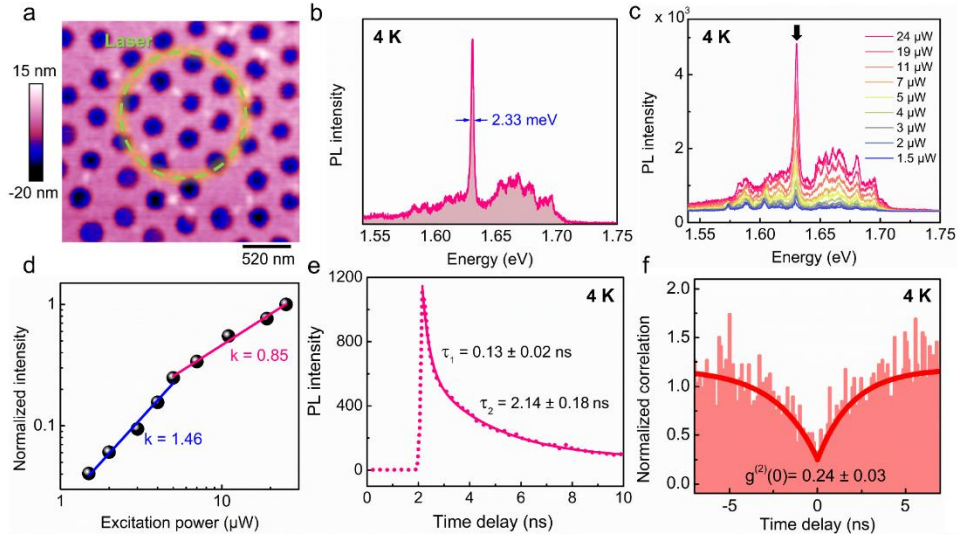


Figure 2. Single-photon emission from 1L WSe₂ suspended over 370-nm pitch, 185-nm diameter cavities. (a) AFM topographic image of 1L WSe₂ suspended over 185-nm diameter cavities. Green dashed line indicates a representative excitation area with laser spot diameter of ~ 1.3 μm , irradiating ~ 10 cavities simultaneously. (b) Photoluminescence intensity spectra measured at 4 K, showing a sharp, localized emitter at 1.63 eV with a linewidth of 2.33 meV. (c) Power-dependent photoluminescence spectra and (d) normalized emitter intensity as a function of excitation power for the 1.63 eV emitter, revealing a superlinear behavior of emitter intensity at excitation powers of ≤ 5 μW , with slope $k = 1.46$. (e) Time-resolved photoluminescence of the emitter at 1.63 eV shown in (c) (black arrow indicates the chosen emitter), showing a long component of emitter lifetime of 2.14 ± 0.18 ns. (f) Normalized second-order correlation function of the chosen emitter at 1.63 eV, revealing strong antibunching behavior with $g^{(2)}(0) = 0.24 \pm 0.03$.

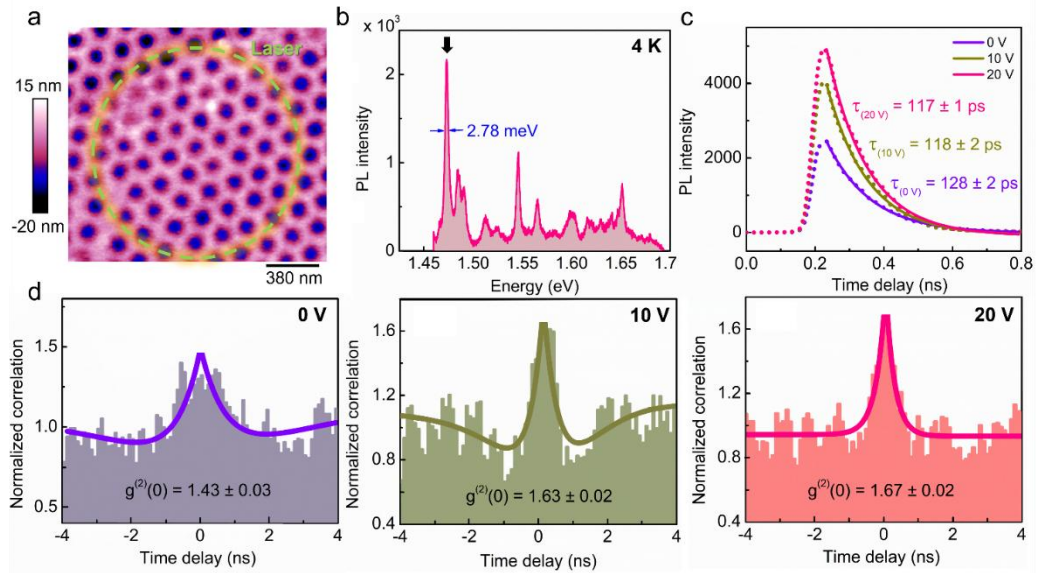


Figure 3. Cooperative emission from 1L WSe₂ suspended over 200-nm pitch, 100-nm diameter cavities. (a) AFM topographic image of 1L WSe₂ suspended over dense 100-nm diameter cavities, showing a simultaneous ~ 50 -cavity excitation given a laser excitation spot size of ~ 1.3 μm . (b) Photoluminescence intensity spectrum measured at 4 K, revealing sharp localized emission peaks. An emitter at 1.48 eV with a linewidth of 2.78 meV was chosen for time-resolved photoluminescence and second-order correlation measurements. (c) Time-resolved photoluminescence of the emitter at 1.48 eV measured at $V_g = 0$ V, 10 V, and 20 V. A decrease in emitter lifetime from 128 ± 2 ps ($V_g = 0$ V) to 117 ± 1 ps ($V_g = 20$ V) is attributed to improved cooperative emission using electrostatic gating. (d) Second-order correlation function at different bias voltages, revealing an improvement in cooperative emission from a $g^{(2)}(0) = 1.43 \pm 0.03$ ($V_g = 0$ V) to $g^{(2)}(0) = 1.67 \pm 0.02$ ($V_g = 20$ V).

References

1. Rainò, G. *et al. MRS Bulletin* **45**, 841–848 (2020).
2. Wu, F.C.M. *et al. Nano Letters* **25** (27), 10983–10989 (2025).
3. Masson, S.J., Asenjo-Garcia, A. *Nat Commun* **13**, 2285 (2022).

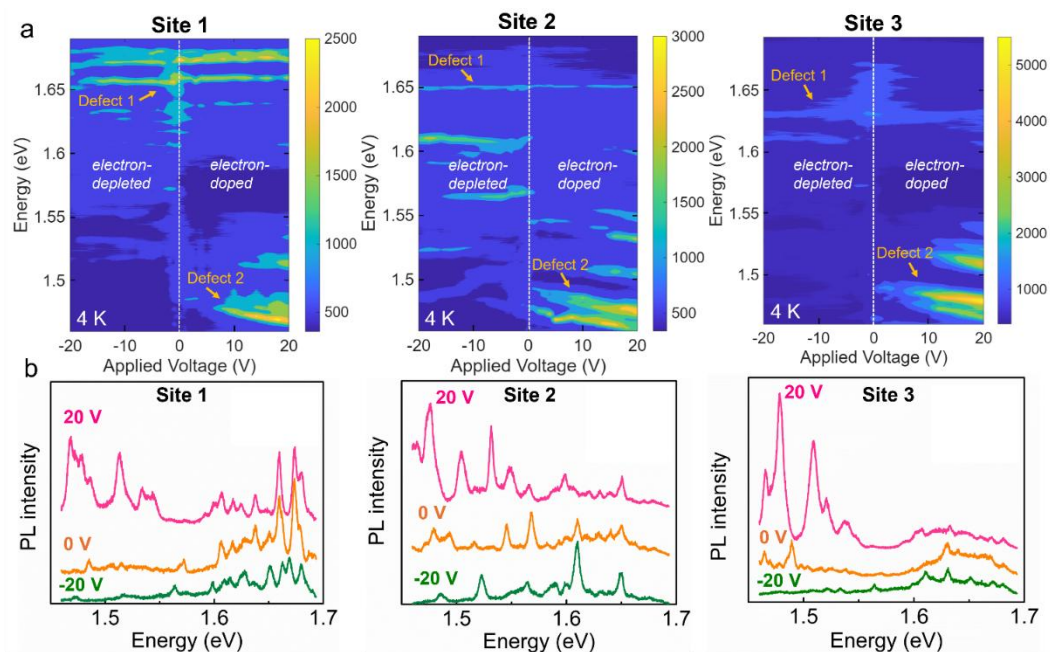


Figure 4. Control of localized emitters at different bias voltages. (a) Contour plots of photoluminescence intensity measured at 4 K at positive and negative bias voltages for three different sample locations. Localized emitters at two defect energy regions, located at ~ 1.65 eV and ~ 1.48 eV, are observed. (b) Representative photoluminescence intensity spectra measured at $V_g = 0$ V, 20 V, and -20 V, deduced from the contour maps plotted for three different sites. The localized emitters at low energies ~ 1.48 eV exhibited a pronounced increase in brightness and significantly become prominent at $V_g = 20$ V.

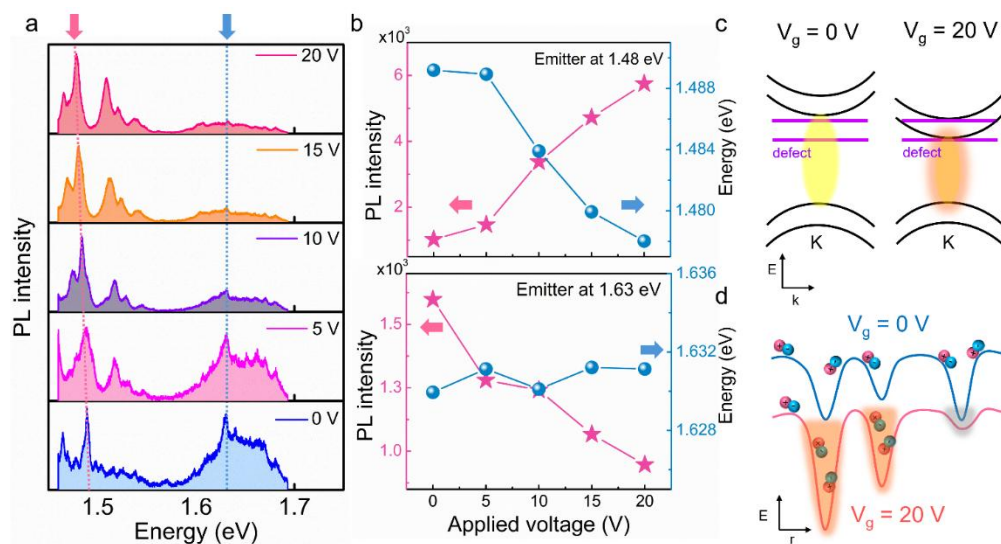


Figure 5. Exciton redistribution among different localized emitters. (a) Photoluminescence intensity spectra measured at 4 K deduced from Site 3 in Figure 4a, showing two prominent emission peaks at 1.48 eV and 1.63 eV, at $V_g = 0$ V, 5 V, 10 V, 15 V, and 20 V. (b) Intensity and peak energy as functions of applied bias voltage for emitters at 1.48 eV and 1.63 eV. (c, d) Schematic representation of the mechanism behind the increase in brightness of emitter at 1.48 eV with bias voltage. The application of bias voltage results in increased tensile strain, leading to hybridization of dark and defect excitons and control of depth of localized potential wells that funnel excitons (c). This results in exciton redistribution across different localized emitters, wherein photogenerated excitons funnel to energetically favorable localized emitters (d).

References

1. Rainò, G. *et al. MRS Bulletin* **45**, 841–848 (2020).
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