Ultrafast Generation of Coherent Photons in a Charge Noisy Quantum Dot

Yameng Cao[1,2], Anthony J. Bennett[2], David J. P. Ellis[2], Ian Farrer[3], David A. Ritchie[3], and Andrew J. Shields[2]

The Big Question

How to prevent the noisy charge environment in quantum dots from affecting the coherence of emitted photons?

① Introduction

Self-assembled InAs/GaAs quantum dots strongly confine electrons and holes, giving them quantized energy levels. Quantum dots are recognised as a promising candidate for implementing quantum technologies.

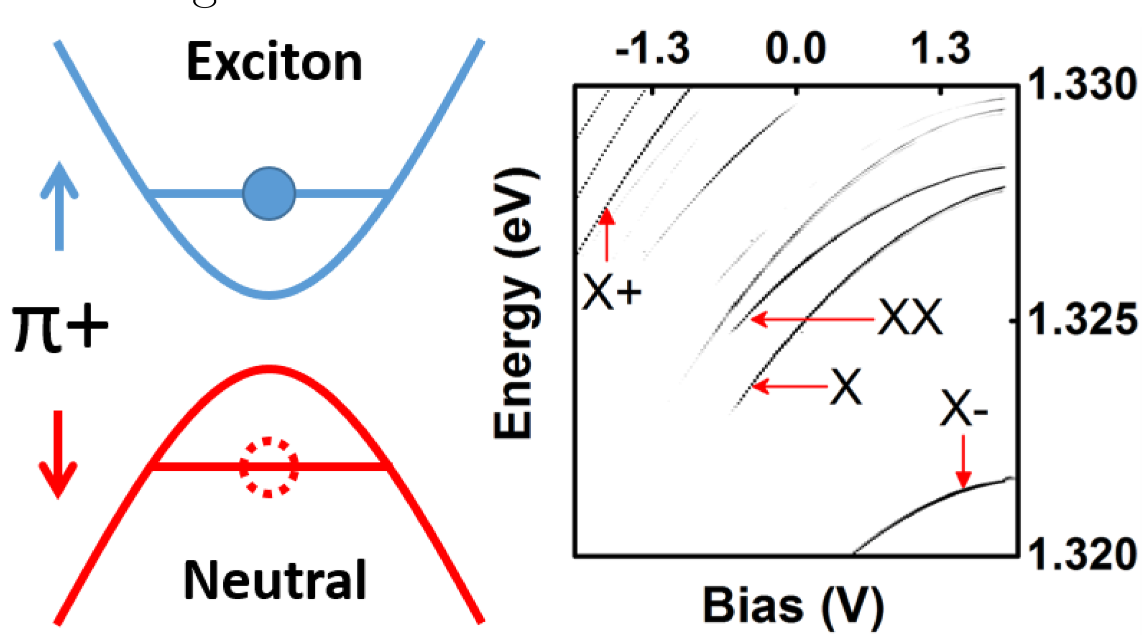

Figure 1: Qubits represented as spins states of electrons and holes, coupled to circular polarization states of photons.

- Dipole allowed transitions follow the selection rule $\Delta S = \pm 1$ those with $\Delta S = \pm 2$ are dark.
- Bright states are non-degenerate, due to electron-hole exchange interaction. This is the exciton fine structure, typically split by $\sim 40 - 60\,\mu eV$ in our sample.
- Non-degenerate eigenstates couple to horizontal (H) or vertically (V) polarized photons.
- The quantum confined Stark effect allows tuning of the transition properties, such as emission energy [1], fine structure splitting [2] and electron and hole g-factors [3].
- Charge noise [4] present in quantum dots lead to undesirable effects that can cause reduced single photon indistinguishability and spectral wandering.
- Combining electrical and optical control can avoid these effects while maintaining the tunable degrees of freedom.

② Charge Noise

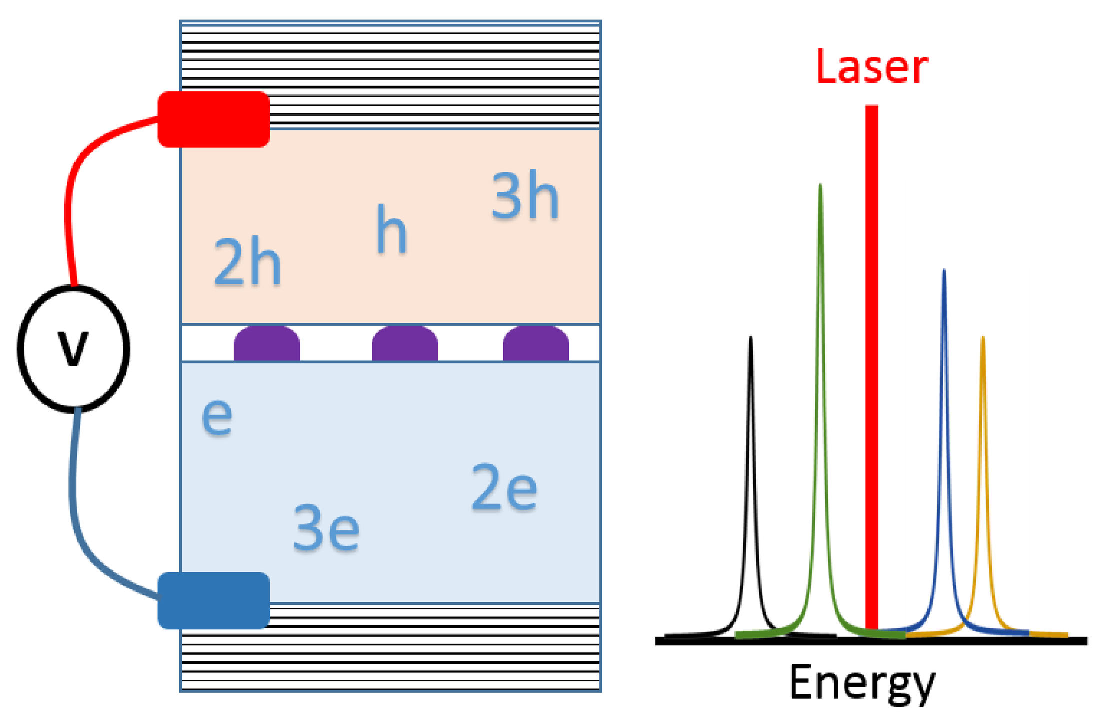

Figure 2: Trapped charges fluctuate, causing spectral jitter.

- Electron and hole pair surrounded by impurities in the lattice.
- Trapping and releasing of charges occurs randomly under electrical and non-resonant optical control.
- Through the Coulomb effect, exciton spectral position jitters.

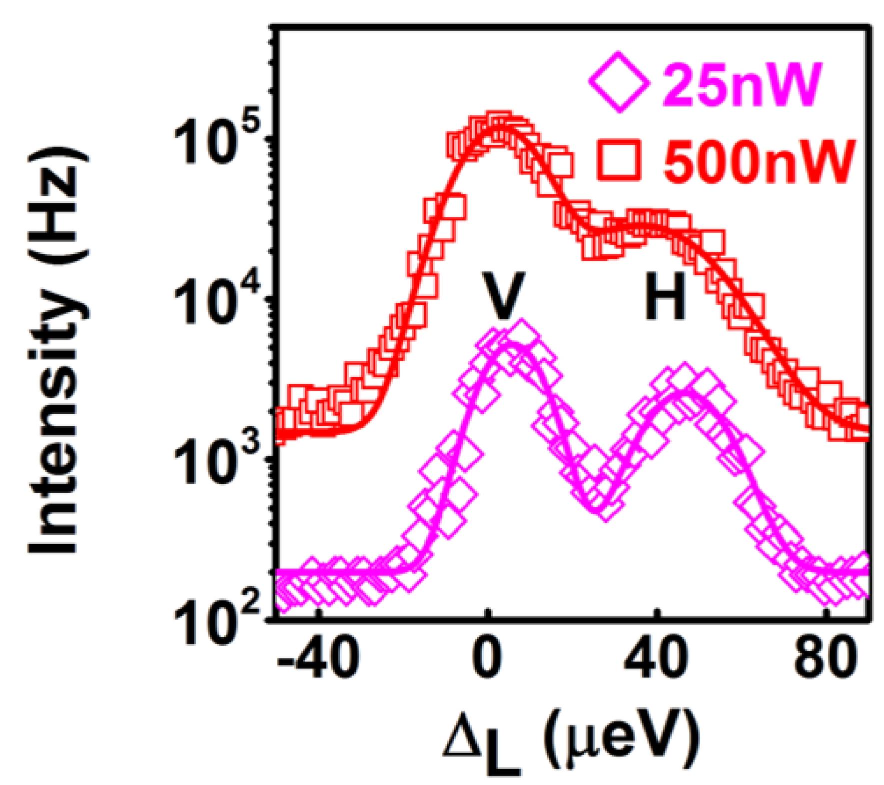

Figure 3: Broadened emission spectrum due to charge noise

- Emission spectrum recorded (circle) with respect to laser detuning Δ_L, fitted (line) with double-Gaussian.
- Fitted spectral width greater than $15\,\mu eV$, power broadening effects are negligible at $25\,nW$ laser excitation power.
- Spectrum represents the fluctuating spectral positions as the exciton interacts with the noisy charge environment.

③ Ultrafast Coherent Photons

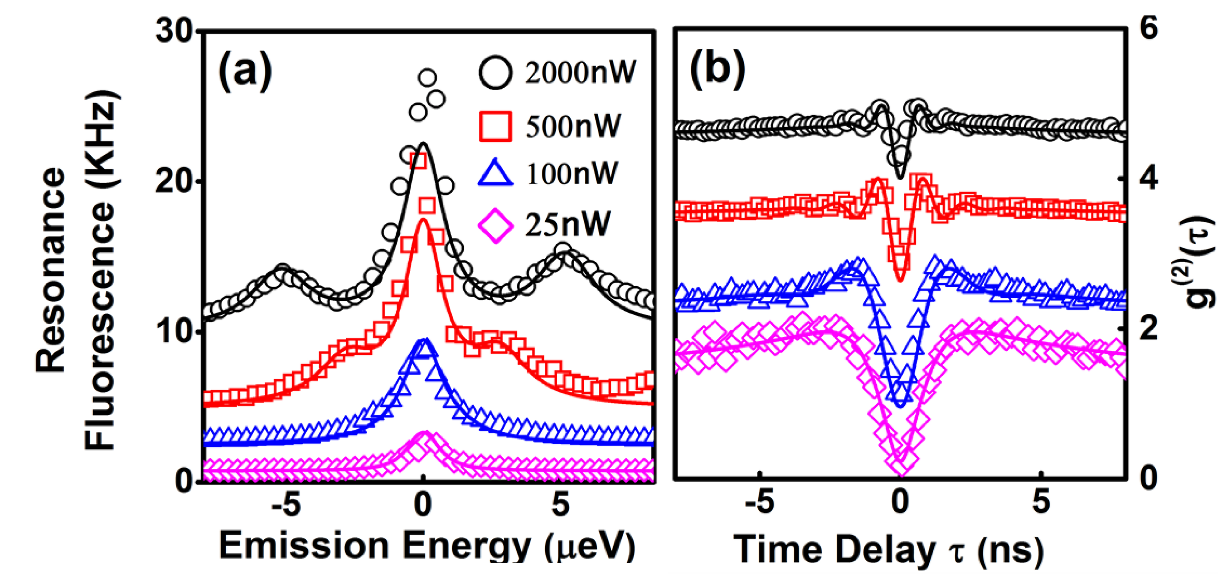

Figure 4: **a** Resonant fluorescence spectrum, **b** second order intensity correlation measurement.

- Resonant excitation removed all trace of spectral noise and the spectral width at $25\,nw$ excitation power is below $1\,\mu eV$, detuning Δ_L was fixed.
- Simulations accounted for the broadening.
- The narrow width and Rabi oscillations at $\pm\tau$ are evidence of coherent photons, with $T_2 \geq 1\,ns$.

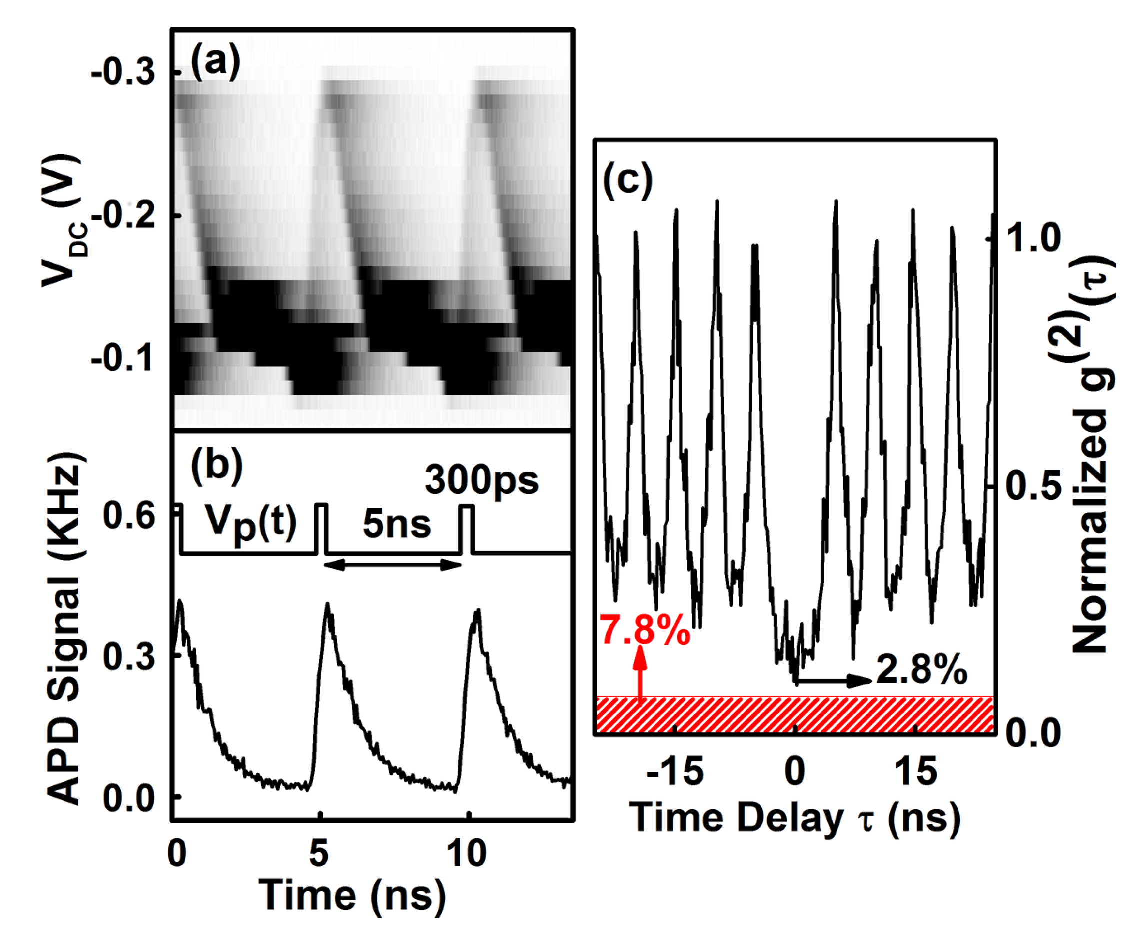

Figure 5: **a** Time resolved spectra with respect to offset bias. **b** Time resolved spectrum at $-0.29\ V$ offset. **c** $g^2(\tau)$ with $200\ MHz$ pulses.

- Emission energy can be electrically controlled by applying a rapidly oscillating bias $V_p(t)$.
- Pulses in $V_p(t)$ shift the transition in and out of resonance with a continuous wave laser at $200MHz$.
- $g^{(2)}(0) = 0.028 \pm 0.010$ was found after background substraction.

Conclusion & Outlook

- The fluctuating charge environment broadens spectral lines, reducing photon coherence. Yet narrow bandwidth photons can still be generated, using resonant driving, which acts as a charge noise "filter".
- We have shown that our electrically tunable device, driven by continuous wave resonant excitation, can generate single photons using ultrafast electrical pulses.
- It maybe of interest in the future to operate the device in an ultra low excitation power regime, to further explore its coherent properties.

For More Information

Please refer to:

- Ultrafast electrical control of a resonantly driven single photon source *arXiv preprint available soon.*

References

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Acknowledgements & Affiliations

Y.C. gratefully acknowledges financial support from both EPSRC CDT in Controlled Quantum Dynamics at Imperial College London and Toshiba Research Europe Ltd in Cambridge.

- [1] Controlled Quantum Dynamics, Imperial College London, London SW7 2AZ, United Kingdom.
- [2] Toshiba Research Europe Limited, Cambridge Research Laboratory, 208 Science Park, Milton Road, Cambridge, CB4 0GZ, United Kingdom.
- [3] Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, United Kingdom.

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