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Wavelength tunable single-photon source with a side gate

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1. Introduction

Single self-assembled quantum dot is one of the most promising candidates for a practical single photon source because it generates stable and high single photon flux [1], which is required for future implementation in the field of quantum information including quantum cryptography and quantum computing. Many schemes for scalable quantum information processing rely on quantum interference between photons generated by independent sources [2,3]. To realize the interference, a source of single photons with controlled emission wavelength would be indispensable because the self-assembled quantum dots show a broad distribution of emission wavelengths.

In this work, we show a wavelength controlled single photon emission based on a self-assembled quantum dot embedded in a side-gate device.

2. Device fabrication and characteristic

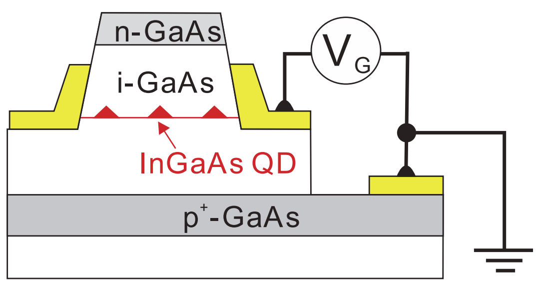

Fig. 1 Schematic design of a single photon emitting device with a side gate.

The single photon emitting device structure containing a single layer of self-assembled InGaAs quantum dots is shown in Fig. 1. The dots were grown by molecular beam epitaxy on (001)-oriented semi-insulating GaAs substrate. A p^+-type back contact is separated from InGaAs quantum dots by a 150 nm i-GaAs barrier. A vertical pillar structure with a side gate electrode was fabricated with electron beam writing, dry etching, and metal deposition [4,5]. The side-gate structure will allow for higher photon collection efficiency, compared with conventional Schottky diode type structures with shadow mask apertures. A dc gate bias between a side Ti/Au side gate and the back contact allows for wavelength controlled photon emission.

All measurements are performed in a He-flow cryostat at 5 K. Microphotoluminescence spectroscopy is implemented by focusing 50 μW of 846 nm laser through an objective onto the sample surface. The emission is then directed to a spectrometer equipped with a charge coupled device (CCD) array or to two avalanche photodiodes (APDs) for correlation measurements performed using a Hanbury Brown–Twiss (HBT) interferometer.

Figure 2(a) shows the photoluminescence spectrum from a single dot in the device. The emission peaks are identified based on excitation power dependence and cross-correlation measurements. Asymmetric correlation line due to cascade evolution from the biexciton state to the exciton state has been observed. Thus, the neutral exciton (X) and biexciton (XX) are labeled. The emission energy of X decreases with increasing gate bias voltage, due to the quantum confined Stark effect, as shown in Fig. 2(b).

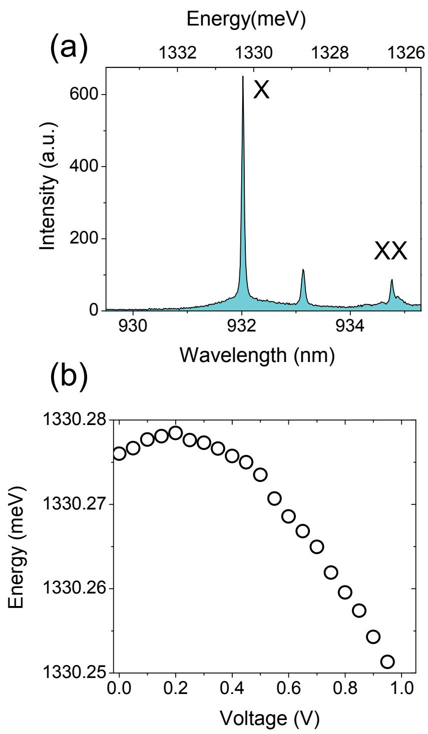

Fig. 2 (a) Time integrated photoluminescence spectrum for the the dot studied. (b) Emission energy of the exciton (X) as a function of gate bias voltage.

3. Photon correlation measurements

In order to check for the emission of single quantum dot, we performed second-order correlation-function $g^{(2)}(\tau)$ measurements with the HBT. Figure 3 (a) and (b) show the normalized cw photon correlation function $g^{(2)}(\tau)$ for the neutral exciton emission line X at zero gate bias voltage (V_g = 0 V) and under applied voltage (V_g = 0.8 V), respectively. The height of the peak at time zero, $g^{(2)}(0)$, is the probability of measuring coincidences on the two single photon detectors at zero time delay. To extract the value, the auto-correlation data are fitted by

$$g^{(2)}(\tau) = 1 - \left(1 - g^{(2)}(0)\right)\exp\left(-\frac{|\tau|}{\tau_0}\right). \qquad (1)$$

At V_g = 0 V, the second-order correlation shows sufficiently high degree of photon-antibunching with $g^{(2)}(0)$ = 0.07. This clearly demonstrates single photon emission from the single dot. The lifetime τ_0 =0.8 ns is consistent with our previous time-resolved photoluminescence measurements [6]. Even under applied bias voltage, where the emission wavelength is shifted, similar high degree of photon-antibunching has been observed. For example, at V_g = 0.8 V, the obtained second-order correlation value $g^{(2)}(0)$ is 0.14. A slight increase of the value can be attributed to a reduced emission intensity which relatively increases contribution from uncorrelated background emission. Thus, photon antibunching is quantified through a measurement of the second-order intensity correlation at time zero $g^2(0)$ under applied side-gate bias voltages.

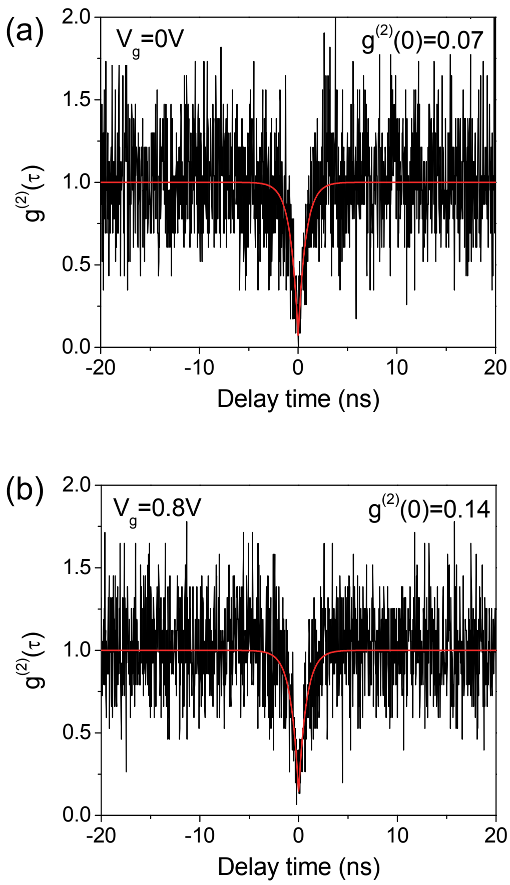

Fig. 3 Measured cw second order correlation function $g^{(2)}(\tau)$ for the X line at the gate voltages (a) V_g =0 V, and (b) V_g=0.8 V.

4. Conclusions

In conclusion we have demonstrated the photoexcited efficient wavelength tunable single photon source with a side-gate. The photon emission of the quantum dot demonstrates clear antibunching with an $g^{(2)}(0) < 0.2$ even under applied side-gate voltages. Although the emission energy shift is only 30 μeV in the prototype device, we believe the tuning range can be easily extended by refining the device structure. Thus, our results present an important step toward the realization of a wavelength tunable electrically driven single photon source. The side-gate device structure will be promising as the single source which allows for both the high photon-collection efficiency and the gate controllability.

Acknowledgements

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