

## Current-injection quantum-entangled-photon-pair emitter using GaAs quantum dots: Robustness against increasing temperature

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**Introduction** Recently, we have realized highly symmetric GaAs/AlGaAs quantum dots (QD) on GaAs (111)A surface by droplet epitaxy [1], and confirmed the generation of quantum entangled photon pairs [2]. In those studies, we used a short-pulsed laser for optical excitation. However, the development of an electrically driven device is essential for practical applications. In this study, we report high-temperature operating quantum-entangled-photon-pairs emitting diode based on GaAs/AlGaAs QDs on GaAs (111)A.

**Experimental** The sample was grown on  $n^+$ -GaAs(111)A by solid source molecular beam epitaxy. The growth sequence is following, (1) 50-nm  $n$ -GaAs, (2) 200 nm  $n$ -Al<sub>0.25</sub>Ga<sub>0.75</sub>As, (3) 120 nm Al<sub>0.25</sub>Ga<sub>0.75</sub>As, (4) 1 nm Al<sub>0.35</sub>Ga<sub>0.65</sub>As layers, (5) GaAs QDs by droplet epitaxy, (6) 80 nm Al<sub>0.25</sub>Ga<sub>0.75</sub>As, (7) 200 nm  $p$ -Al<sub>0.25</sub>Ga<sub>0.75</sub>As, (8) 20 nm  $p$ -Al<sub>0.25</sub>Ga<sub>0.75</sub>As, (9) 20 nm  $p$ -GaAs. After growing sample, bottom and top electrodes were formed on the sample. The electroluminescence (EL) was obtained from the  $10 \times 10 \mu\text{m}^2$  apertures in the top contact electrode in continuously injecting current. We used a micro objective lens with N.A. 0.8 for collection of the emission of an isolated single QD. The emitted photons simultaneously counted by three photon channels, i.e., biexciton (XX) and exciton (X) photons with a given polarization state, and X photons with an orthogonal polarization state.

**Results and Discussion** EL spectra of our single QDs show three lines identified as XX, X, and positively-charged X. Figure 1 (a) shows coincidence histograms measured at 10 K for XX and X with circular polarizations settings. The XX and X photons are clearly correlated, which is a proof for the formation of quantum entanglement. The same polarization correlation is observed at 50 K (Fig. 1(b)). Figure 1 (c) shows the fidelity to the Bell state as a function of temperature. The fidelity value decreases with temperature, and crosses the classical limit of 0.5 at  $\sim 65$  K, which is limited by the shallow confinement of charge carriers in GaAs/AlGaAs system. [3]

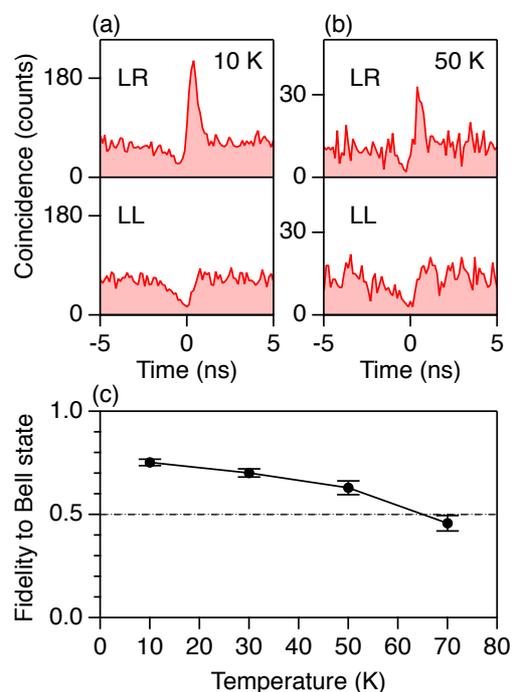


Figure 1 Coincidence histogram with XX and X for circular polarization setting measured at (a) 10 K and (b) 50 K. (c) Fidelity to the Bell state of emitted photons as function of operation temperature.

[1] T. Mano *et al.*, *Appl. Phys. Express* **3**, 065203 (2010).

[2] T. Kuroda *et al.*, *Phys. Rev. B* **88**, 041306(R) (2013).

[3] N. Ha *et al.*, *arXiv:1906.08454* (2019)