32nd URSI GASS, Montreal, 19-26 August 2017

Semiconductor Quantum Networks Using Quantum Dots

Je-Hyung Kim,[1,*] Christopher J. K. Richardson,[2] Richard P. Leavitt,[2] Edo Waks[1,3,†]
[1]*Department of Electrical and Computer Engineering and Institute for Research in Electronics and Applied Physics, University of Maryland, College Park, Maryland 20742, United States*
[2]*Laboratory for Physical Sciences, University of Maryland, College Park, Maryland 20740, United States*
[3]*Joint Quantum Institute, University of Maryland and the National Institute of Standards and Technology, College Park, Maryland 20742 , United States*
*Author e-mail address: *jaykim@umd.edu, †edowaks@umd.edu*

Abstract: Quantum interference between indistinguishable photons are important for a broad range of applications in quantum communication and linear optical quantum computing. We demonstrate two-photon interference from chip-integrated quantum emitters, enabling scalable solid-state quantum photonic devices.

1. Introduction

Quantum networks require multiple identical emitters coupled to quantum memories. Achieving these requirement in a solid-state device is a challenging task, since inhomogeneous broadening and fabrication errors randomize the resonant frequencies of both the emitters and cavities. Here we demonstrate progress towards generating complex devices composed of multiple identical quantum dot emitters. To solve the problem of spectral mismatch between multiple cavities and emitters, we apply gas deposition and evaporation techniques [1] that control cavity resonance. We also integrate optical heaters to tune individual dots to the same resonance [2]. Combining these two tuning methods on cavity-coupled dots, we demonstrate two-photon interference from far-field emission of chip-integrated cavity-coupled emitters [3]. These results pave the way for integrated multiple quantum light sources on the same chip for developing quantum photonic circuits and distributing quantum information.

2. Experimental result

For the device fabrication we choose InAs/InP quantum dot system that emits single photons at telecom wavelengths [4, 5], and we fabricate photonic crystal structures by using electron beam lithography. The device consists of four L3 photonic crystal cavities with integrated optical heating pads shown in Figure 1(a). We couple multiple quantum dots to independent photonic crystal cavities fabricated on the same chip. To compensate spectral mismatch between multiple cavity resonances and dot emissions, we utilize combination of nitrogen gas deposition/ evaporation and thermal tuning techniques described in Figure 1(b) [3]. 500 nm-wide thin tethers suspend the photonic crystal membrane that thermally isolate each photonic crystal cavity and enable local control of individual cavity and dot emissions.

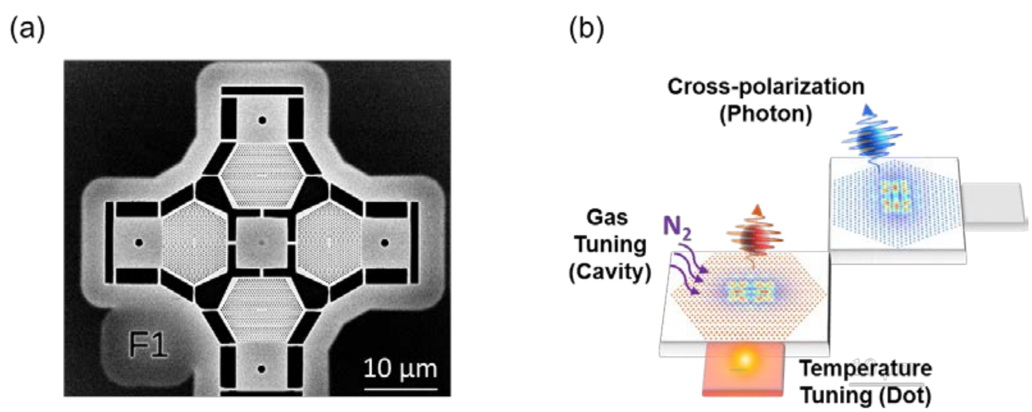

Fig. 1 (a) Scanning electron microscope image for photonic crystal devices. (b) Schematic image for gas tuning of cavities and temperature tuning of dot for multiple identical quantum emitters on a chip.

To obtain high off-chip out-coupling efficiency, we employ the high-order mode M3 that have a nearly Gaussian far-field profile and a well-defined linear polarization [4]. By using gas tuning and thermal tuning process, we compensate for the spectral mismatch of the resonant frequencies of independent quantum dots coupled to cavities on the same chip, and Figure 2(a) shows two cavity-coupled dot A and B have the same resonance with better than 3 μeV.

In order to investigate the indistinguishable property of the emitted single photons from independent cavity-coupled dots, we perform two-photon interference measurements. We choose two dots in two adjacent cavities with orthogonal orientation so these dots produce cross-polarized emission, enabling us to separate the emission from two resonant dots using a polarizing beamsplitter and merge them again on a 50:50 beamsplitter for two-photon interference. Figure 2(b) shows obtained coincidence histograms for indistinguishable (parallel polarization) and distinguishable (orthogonal polarization) two photons from dots A and B. When two photons are distinguishable the graph shows the expected anti-bunching behavior with a second order correlation at zero time delay of $g_{\perp}^{(2)}(0)$= 0.72±0.01, which is higher than the ideal value of 0.5 due to the limited time resolution, detector dark counts and background emission from the heating laser. In contrast, parallel-polarized photons show a sharp peak near zero delay time, which is a clear sign of two-photon interference, where $g_{\parallel}^{(2)}(0)$=0.96±0.02. The post-selected visibility of the two-photon interference effect at delay time zero is given by $V= (g_{\parallel}^{(2)}(0)-g_{\perp}^{(2)}(0))/g_{\perp}^{(2)}(0)$=0.33±0.01. The narrow peak width in the indistinguishable two-photon correlation measurement indicates the presence of dephasing. The extracted coherence time of the quantum dot is 115±5 ps, which is consistent with previous measurements performed with a single dot [4]. Therefore, we attribute the dominant dephasing mechanism in our system to timing jitter in the dot emission as a result of above-band excitation.

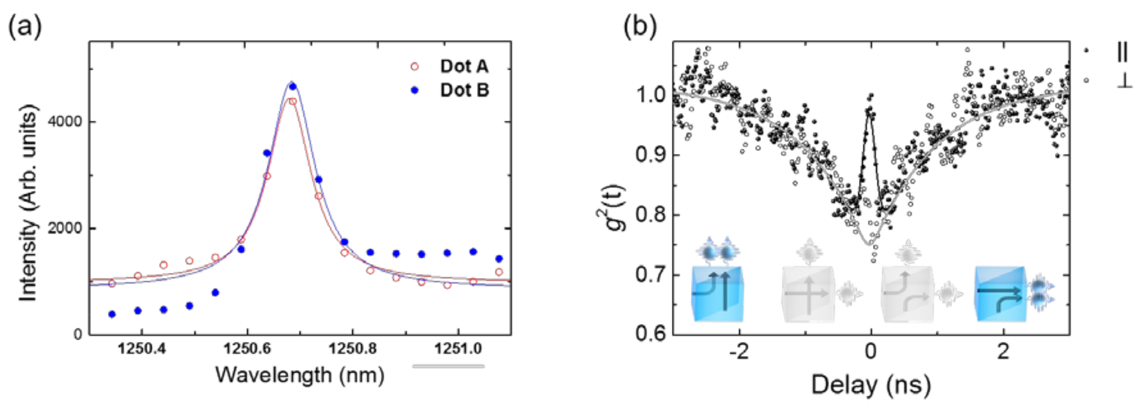

Fig. 2 (a) Emission spectra of cavity-coupled dots A and B after gas tuning and thermal tuning process. (b) Two-photon interference histogram for parallel and orthogonal polarized two photons from dots A and B.

3. Conclusion

We demonstrated two-photon interference from far-field emission of chip-integrated cavity-coupled emitters. We combined gas tuning of cavities with thermal tuning of quantum dots to match the resonances of both cavities and dots. Using this approach we attained a two-photon interference from independent cavity-coupled dots on the same chip, which is a crucial requirement for scalable quantum photonics applications. These results represent an important step towards scalable quantum integrated photonic devices composed of multiple sources for photonic quantum information processing.

4. References

[1] S. Mosor, J. Hendrickson, B. Richards, J. Sweet, G. Khitrova, H. Gibbs, T. Yoshie, A. Scherer, O. Shchekin, and D. Deppe, "Scanning a photonic crystal slab nanocavity by condensation of xenon," Appl. Phys. Lett. **87**, 141105 (2005).

[2] A. Faraon, D. Englund, I. Fushman, J. Vučković, N. Stoltz, and P. Petroff, "Local quantum dot tuning on photonic crystal chips," Appl. Phys. Lett. **90**, 213110 (2007).

[3] J.-H. Kim, C. J. K. Richardson, R. P. Leavitt, and E. Waks, "Two-Photon Interference from the Far-Field Emission of Chip-Integrated Cavity-Coupled Emitters," Nano lett. **16**, 7061-7066 (2016).

[4] J.-H. Kim, T. Cai, C. J. K. Richardson, R. P. Leavitt, and E. Waks, "Two-photon interference from a bright single-photon source at telecom wavelengths," Optica **3**, 577-584 (2016).

[5] R. P. Leavitt, and C. J. K. Richardson, "Pathway to achieving circular InAs quantum dots directly on (100) InP and to tuning their emission wavelengths toward 1.55 μm," J. Vac. Sci. Technol., B **33**, 051202 (2015).