Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp693-694

Indistinguishable quantum-dot single-photon-sources on a reconfigurable photonic integrated circuit

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Abstract

The combination of integrated photonic circuits and solid-state single-photon-sources offers the promise of miniature, stable and scalable quantum photonic devices. We will discuss some schemes that have been proposed to combine III-V semiconductor quantum dots with low-loss optical circuits, and present our scheme to integrate an array of tunable single photon sources on a low-loss silicon oxy-nitride photonic integrated circuit.

1. Introduction

Semiconductor quantum dots are a promising resource for optical quantum algorithms [1]. They can be engineered to emit single, entangled or indistinguishable photons with near unity efficiency across a wide range of the optical and near-infra-red spectrum. Using processing techniques from the semiconductor industry electrically operated devices based on this technology can be manufactured in volume. Combining these solid state light sources with Photonic Integrated Circuits (PICs) is a target for many research groups. The small size, robustness, interferometric stability, configurability, manufacturability, scalability of this technology allows complex optical systems to be reduced to the size of a single chip.

2. General Instructions

PICs have been employed in many quantum applications including logic gates [2], higher order path entanglement [3], quantum walks [4], Boson Sampling [5,6] and on-chip quantum teleportation [7]. These PICs can support optical qubits encoded in path, time bin, polarization or mode which can be interconverted. All of these experiments have relied upon photons generated externally and delivered to the PICs through fiber. We have used this experimental arrangement with pairs of indistinguishable photons from a single quantum dot guided to a PIC to demonstrate an optical controlled-NOT gate [8] and generation of path-entangled *N00N* states that display phase super-resolution [9].

The major challenge in integrating quantum dots and PICs is in optimizing the optical coupling from the III-V semiconductor to the waveguide circuit. There are many architectures being investigated for this, but we have chosen to use a direct bonding method where the quantum dot device is physically attached to the end of the waveguide. This gives a coupling efficiency that is determined by the numerical aperture of the waveguide. In our initial demonstration [10] we integrated a single photon source, reconfigurable PIC and fiber-optic v-groove array on a simple device.

Semiconductor quantum dots display significant inhomogeneous broadening, which means any two dots are unlikely to emit photons at the same energy. We have recently tackled this problem with by integrating an array of quantum-dot-tunable diodes onto a reconfigurable PIC [11]. Using an optimized heterostructure [12] in the diode we are able to achieve tens of meV tuning of individual quantum dot transitions in separated channels on the PIC. This tuning range is sufficient to make transitions in separated dots, located at separate channels of the PIC, indistinguishable. We will discuss our latest results showing two photon interference between dots on this quantum dot-PIC device [11].

3. Conclusions

In conclusion, we have demonstrated a compact, packaged device that integrates a reconfigurable loss-loss photonic circuit with an array of independently controlled single quantum dot light sources. Choosing a diode design that allows substantial changes to the energy of transitions in the single quantum dots, we are able to show that photons from separate quantum dots can be made indistinguishable. This is a key requirement of linear optical quantum computing schemes.

Acknowledgements

We thank E. Murray and T. Meany for assistance at an early stage of this project, R. M. Stevenson for assistance with the superconducting detectors and Kevin and Trevor for hardware support. We acknowledge funding from the EPSRC for MBE the system used for the growth of the LED. C.D. acknowledges support from the Marie Curie Actions within the Seventh Framework Programme for Research of the European Commission, under Network PICQUE (Grant No. 608062). P.S. acknowledges support from the EPSRC Quantum Communications Hub (Grant No EP/M013472/1).

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