Deterministic sources for quantum networks

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Abstract

We present the work towards the realization of deterministic sources for quantum networks using quantum dots embedded in photonic crystal. It consists in the realization of single photon sources at 1.55µm operating at 77K as well as theoretical and experimental results towards deterministic sources of entangled photons and finally deterministic growth of single quantum dots for efficient coupling with photonic crystals.

Introduction

Quantum communications have evolved from ideas [1,2], to in-the lab experiences [4] and finally out of the lab demonstrations [3] or even commercially available products [5]. Almost all demonstrations have been obtained by the use of non ideal sources, creating non deterministic states due to the Poissonian distribution of the emission. Although ideal sources are not always necessary, for example in short distance quantum cryptography, they still present an important tool for quantum relays and quantum repeaters [6,7] as well as long distance quantum cryptography. Hence the development of such sources, as well as novel single photon detectors, should not be neglected. Deterministic single photon sources have already been demonstrated but not only their quantum efficiency was quite low, but their emission wavelength was not in the C-band telecomunication window, or their repetition rate was to low. In this paper we present our work towards single photon and entangled photon sources at telecom wavelength using quantum dots in photonic crystals.

Toward 1.55µm quantum dot sources

An interesting candidate for single photon or entangled photon source are quantum dots. Standard InAs quantum dots grown on GaAs emit below 1.3µm and due to the important lattice mismatch it impossible to create higher quantum dots, emitting at higher wavelengths. Our work is oriented towards the realization of single InAs quantum dots grown on InP with a smaller lattice mismatch. We realized and characterized such quantum dots emitting at 1.55µm. Temperature dependant lifetime measurements show that grown quantum dots are of excellent optical quality, and maybe be operated at temperatures above 77K [9]

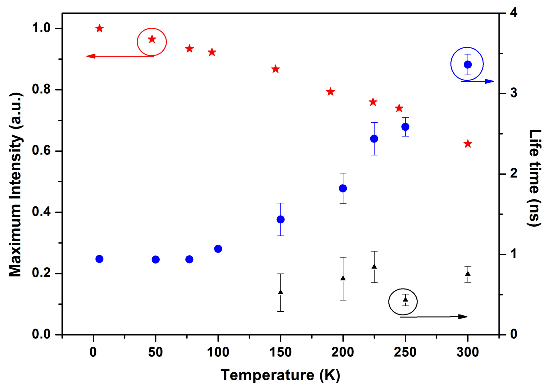

Figure 1 : Temperature dependent lifetime measurments for quantum dots emitting at 1.55µm

Toward Deterministic Entangled Photon sources

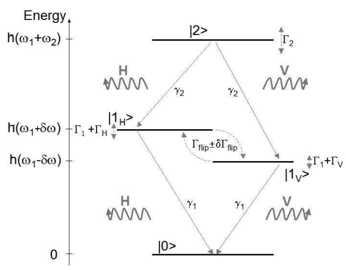

Figure 1 : Biexciton cascade of a real single quantum.

Using the biexciton cascade of single quantum dots, it is possible to create polarization entangled photon pairs [8] when the two decay paths are indistinguishable. However in the case of non ideal quantum dots, the excitonic relay level is splitted in energy, leading to two distinguishable paths destroying the entanglement. We analytically derived the CHSH inequality showing that entanglement can be restored by accelerating the exciton emission, if the energy splitting is lower than 5 µeV [10].

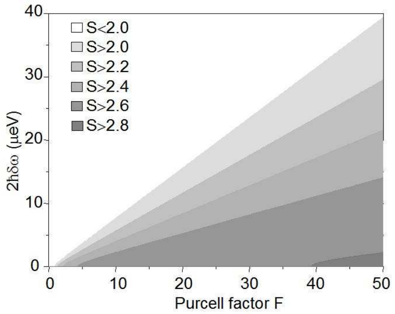

Figure 2 : Bell inequality as a function of the Purcell effect (acceleration of spontaneous emission) and the energy splitting of the exciton levels.

Coupling quantum dots with photonic crystals

Both high repetition rate single photon source as well as entangled photon source demand a short lifetime of the excitonic state. The emission lifetime of a single dipole is governed by Fermi's golden rule, linking the dipole to it's electromagnetic environment. Hence by modifying the environment, ie inserting the quantum dot inside a photonic crystal cavity, one is able to accelerate it's emission dynamic using the Purcell effect. We are actively developing high quality factor photonic crystal cavities and demonstrated cavities with an quality factor of up to Q=60000. On the other hand quantum dots are generally randomly grown on the substrate, leaving almost no possibility to deterministically couple a single dot with a cavity. In this paper we shall present our work towards the deterministic growth of single quantum dots and their coupling with photonic crystals.

Conclusion

In conclusion, we presented in this paper the work toward the realization of deterministic single photon and entangled photon source using single quantum dots coupled to photonic crystal cavities.

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