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Telecom-Wavelength Quantum Relay Using a Semiconductor Quantum Dot

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Abstract: One promising technology expected to enable long-haul quantum communication networks with untrusted nodes are quantum relays. Their most practical implementation requires an entanglement source with operation at telecom wavelength and intrinsic single photon character. Here, we use a semiconductor quantum dot emitting in the O-band to demonstrate for the first time a system fulfilling both of these criteria. For implementation of a standard 4-state QKD-protocol with weak coherent input states, the system achieves mean fidelities above 88%. Further characterization of the relay with process tomography reveals teleportation for arbitrary input states. The results represent a significant advance in demonstrating feasibility of semiconductor light sources for the development of infrastructure-compatible quantum-communication technology for multi-node networks.

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1. Introduction

Quantum relays [1] are a key technology to extend the range of present quantum cryptography systems and future general purpose optical quantum networks. The underlying physical principle is to perform teleportation of photonic input quantum bits, which can effectively reduce noise in long-distance photon-transmission scenarios. Most interesting for cryptography applications is that the security of the quantum channel is unconditionally guaranteed, even if the entanglement resource or the relay itself are located at untrusted nodes of the network.

Photon sources based on non-linear processes have a long history in photonic teleportation experiments, enabling pioneering work, most recently even over metropolitan distances [2,3]. However, the number statistics of these sources follow a Poissonian distribution, typically increasing error rates and requiring operation at very low intensities and implementation of sophisticated security protocols.

Semiconductor quantum dots (QD) have proven to be a promising alternative entangled photon source, with true single-photon emission enabling intrinsically secure implementations of quantum relays [4]. Here, we demonstrate for the first time a semiconductor-based quantum relay which is operating at standard telecom wavelength, therefore being compatible with existing telecom-fiber infrastructure.

2. Experiments

Figure 1 a) shows the experimental setup. Alice sends a stream of weak coherent input qubits in different polarization bases. Charlie uses an InAs/GaAs QD emitting at telecom wavelength [5] (Figure 1 b)) and generating entangled photon pairs on the Bi-Exciton (2X) - Exciton (X) spectral emission lines. A projective Bell-state measurement is performed with the input and 2X photons, heralding teleportation of the input qubit to Bob after coincidence detection of detectors 1 and 2. The target state is analyzed at Bob using detectors 3 and 4.

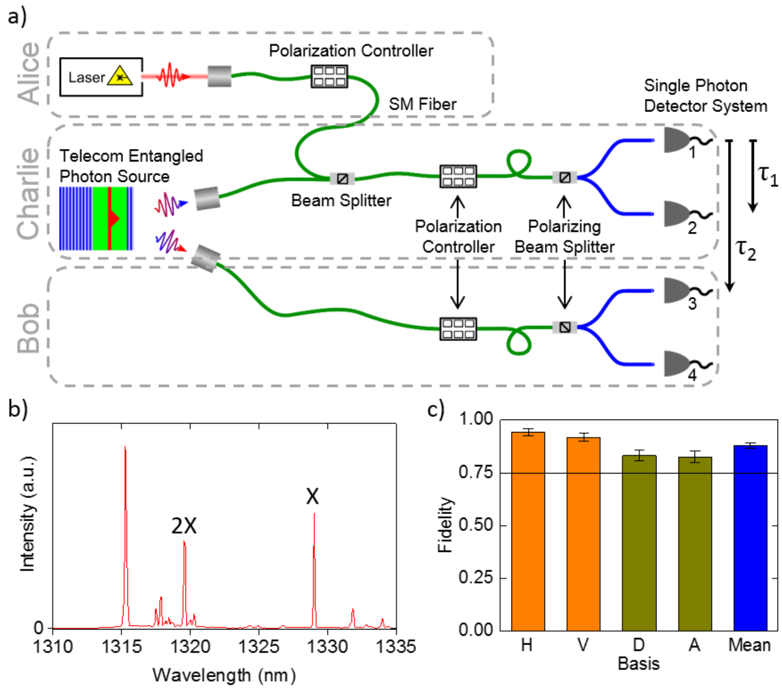

Figure 1: a) Schematic representation of quantum relay components. The system is implemented in standard single-mode fiber. b) Spectrum of quantum dot emitting in the telecom O-band. Entangled photons are extracted from the indicated X and 2X telecom emission line. c) Measured quantum relay fidelity when teleporting the states H, V, D, and A. The straight line indicates the classical limit for the implemented protocol.

One of the standard communication protocols in QKD (BB84) makes use of 4 polarization states, such as H, V, D, and A. Figure 1 c) shows the resulting measured teleportation fidelities for a bin size of $\Delta\tau_1 \times \Delta\tau_2 = 88$ ps × 120 ps in the recorded two dimensional 3-photon coincidence space, with an average fidelity of 87.9 ± 1.1 %. This exceeds the classical limit of 75 % by more than 11 standard deviations and is above the 80 % error correction threshold for secure quantum key distribution [6]. When further reducing the size of the time window at the sacrifice of the total number of recorded 3-photon coincidences, we obtain a maximum average fidelity of 94.5 ± 2.2 %.

With process tomography, we determine an average gate fidelity of 83.6 ± 1.1 %, showing that the capability of the system is not limited to the previously chosen four states, but enables teleportation of arbitrary input states, important for the implementation of different communication protocols or for general purpose quantum communication channels.

3. Conclusions

To conclude, we have implemented a telecom-wavelength quantum relay using a quantum-dot entangled photon source. The combination of sub-Poissonian photon-pair statistics and operation at standard telecom wavelength of such a system has not been demonstrated before and has potential advantages for the development of secure and network-compatible quantum relay technology for the future. The results show that quantum-dot entangled photon sources are a serious alternative to the existing well-established approaches for generation of photon entanglement at telecom wavelength.

4. References

[1] B. C. Jacobs *et al.*, "Quantum relays and noise suppression using linear optics", Phys. Rev. A **66**, 52307 (2002).
[2] R. Valivarthi *et al.*, "Quantum teleportation across a metropolitan fibre network", Nat. Phot. **10**, 676 (2016).
[3] Q. Sun *et al.*, "Quantum teleportation with independent sources and prior entanglement distribution over a network", Nat. Phot. **10**, 671 (2016).
[4] C. Varnava *et al.*, "An entangled-LED-driven quantum relay over 1 km", npj Quantum Information **2**, 16006 (2016).
[5] M. B. Ward *et al.*,"Coherent dynamics of a telecom-wavelength entangled photon source", Nat. Commun. **5**, 3316 (2014).
[6] H. F. Chau, “Practical scheme to share a secret key through a quantum channel with a 27.6% bit error rate”, Phys. Rev. **66**, 060302 (2002).