Towards quantum networks with semiconductor quantum dots

Christian Schimpf, Institute of Semiconductor and Solid State Physics,
Johannes Kepler University, Linz, Altenbergerstr. 69, Austria

JOHANNES KEPLER UNIVERSITÄT LINZ

HFP Institut für Halbleiter- und Festkörperphysik

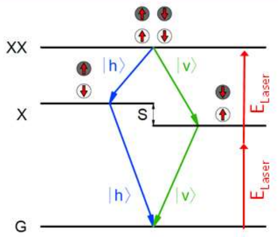
ÖAW Österreichische Akademie der Wissenschaften

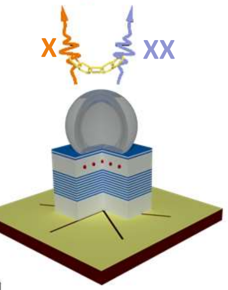
Picture: TU Delft

Emerging technologies demand the realization of quantum networks, allowing to share quantum information between different nodes [1]. Semiconductor quantum dots are promising candidates for this task as they can act as almost on-demand sources of entangled and indistinguishable photon-pairs [2,3,4] in a long-haul photon-based quantum network [5]. We report on the application of Photon Correlation Fourier Spectroscopy [6,7] - which greatly aids the improvement of the emission characteristics of the here used droplet-etched GaAs quantum dots [8,9]. Further, we demonstrate experimental entanglement swapping [10] and quantum key distribution [11,12] with GaAs quantum dots, representing two pivotal concepts for the realization of a practical quantum network.

Entangled and indistinguishable photon pairs from GaAs quantum dots [2,3,4]

Entangled photon pairs from GaAs quantum dots



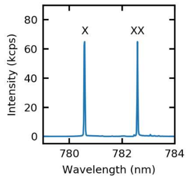


- Population of biexciton (XX) state by resonant two-photon excitation (TPE)
- Radiative decay by emitting two entangled photons (XX, X)

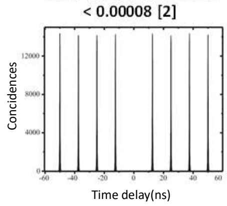
Potential tuning of the fine structure splitting by piezo-electric actuator [13]

Emission characteristics

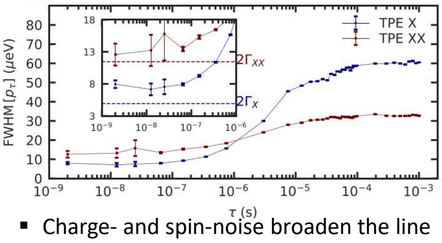
Spectrum



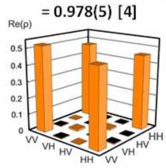
Multi-photon probability
< 0.00008 [2]



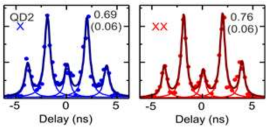
Time resolved line broadening, obtained by **Photon Correlation Fourier Spectroscopy [7]**



Fidelity to ϕ^+ Bell state = 0.978(5) [4]



Indistinguishability ~ 0.75 [3]



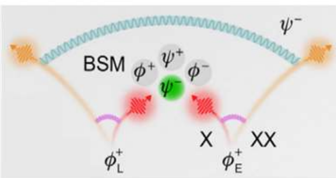
- Charge- and spin-noise broaden the line width beyond the Fourier limit (2Γ) [14]
- Decrease of indistinguishability when interconnecting multiple quantum dots
- Ongoing research to surpress dephasing mechanisms

Interconnection **Application**

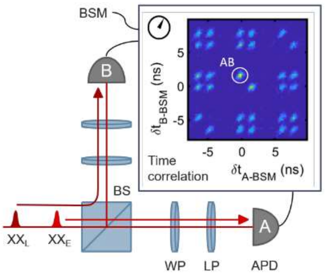
Entanglement Swapping [5]

Towards repeaters in a quantum network

Entanglement swapping via „Bell state measurement“ (BSM)

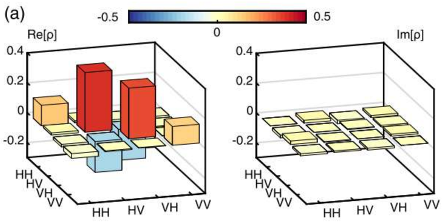


„Early“ (E) and „Late“ (L) entangled photon pairs



- Two entangled photon pairs from one quantum dot (time shifted)
- Bell state measurement between the two X photons
- Full state tomography on remaining XX photons
- XX photons now entangled → **Quantum repeater in a network**

Density matrix of „swapped“ entangled state (early and late XX)

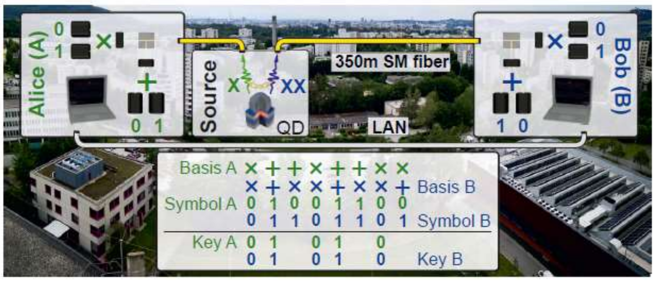


- Fidelity to expected Bell state: **0.58(4)** (Classical limit: 0.25) [5]

Quantum Key Distribution [11,12]

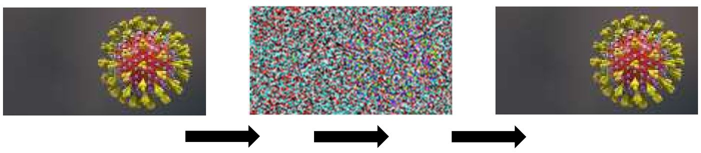
Secure communication in a quantum network

BBM92 protocol [11] with entangled photons



- Quantum key distribution between two buildings, connected by a 350 m fiber
- Automatic synchronization and polarization stabilization

One-Time-Pad Encryption/Decryption



encryption transmission decryption

Resulting qubit error rate and key rate [12]

- Raw qubit error rate (QBER): **1.91%**
  (due to non-unity entanglement and imperfect optical setup)
- Key rate before error correction: **135 bits/s**
- Key rate after error correction: **85 bits/s**

Acknowledgements and references:

Christian Schimpf is a recipient of a DOC Fellowship of the Austrian Academy of Sciences.
We want to thank J. Handsteiner and Richard Küng for the fruitful discussions.

[1] Kimble, H. J., Nature 453, 1023-1030 (2008)
[2] Schweickert, L., et al., Appl. Phys. Lett. 112, 093106 (2018)
[3] Huber, D., et al., Nat. Commun. 8, 15506 (2016)
[4] Huber, D., et al., Phys. Rev. Lett. 121, 033902 (2019)
[5] Reindl., M., et al., Sci. Adv. 4, eaau1255 (2018)
[6] Brokmann, X., et. al., Opt. Express 14, 6333-6341 (2006)
[7] Schimpf, C., et al., Opt. Express 27, 35290-35307 (2019)
[8] Heyn, C., et al., Nanoscale Res. Lett. 5, 1633-1636 (2010)
[9] Huo, Y. H., et al., Appl. Phys. Lett. 102, 152105 (2013)
[10] Basso Basset, F., et al., Phys. Rev. Lett. 123, 160501 (2019)
[11] Bennet, C., et at. Phys. Rev. Lett. 68, 557-559 (1992)
[12] Schimpf, C., et al., in preparation (arXiv:2007.12726)
[13] Trotta, R., et al., Phys. Rev. Lett 114, 15502 (2015)
[14] Kuhlmann, A., et al., Nat. Phys. 9, 570-575 (2013)

JKU LINZ INSTITUTE OF TECHNOLOGY

erc European Research Council Established by the European Commission

FWF Der Wissenschaftsfonds.

CEITEC Central European Institute of Technology BRNO | CZECH REPUBLIC

DFG Deutsche Forschungsgemeinschaft

EMPIR EURAMET

QUANTERA ERA-NET Cofund in Quantum Technologies