Researchers make an important step towards the quantum internet using diamond nanostructures

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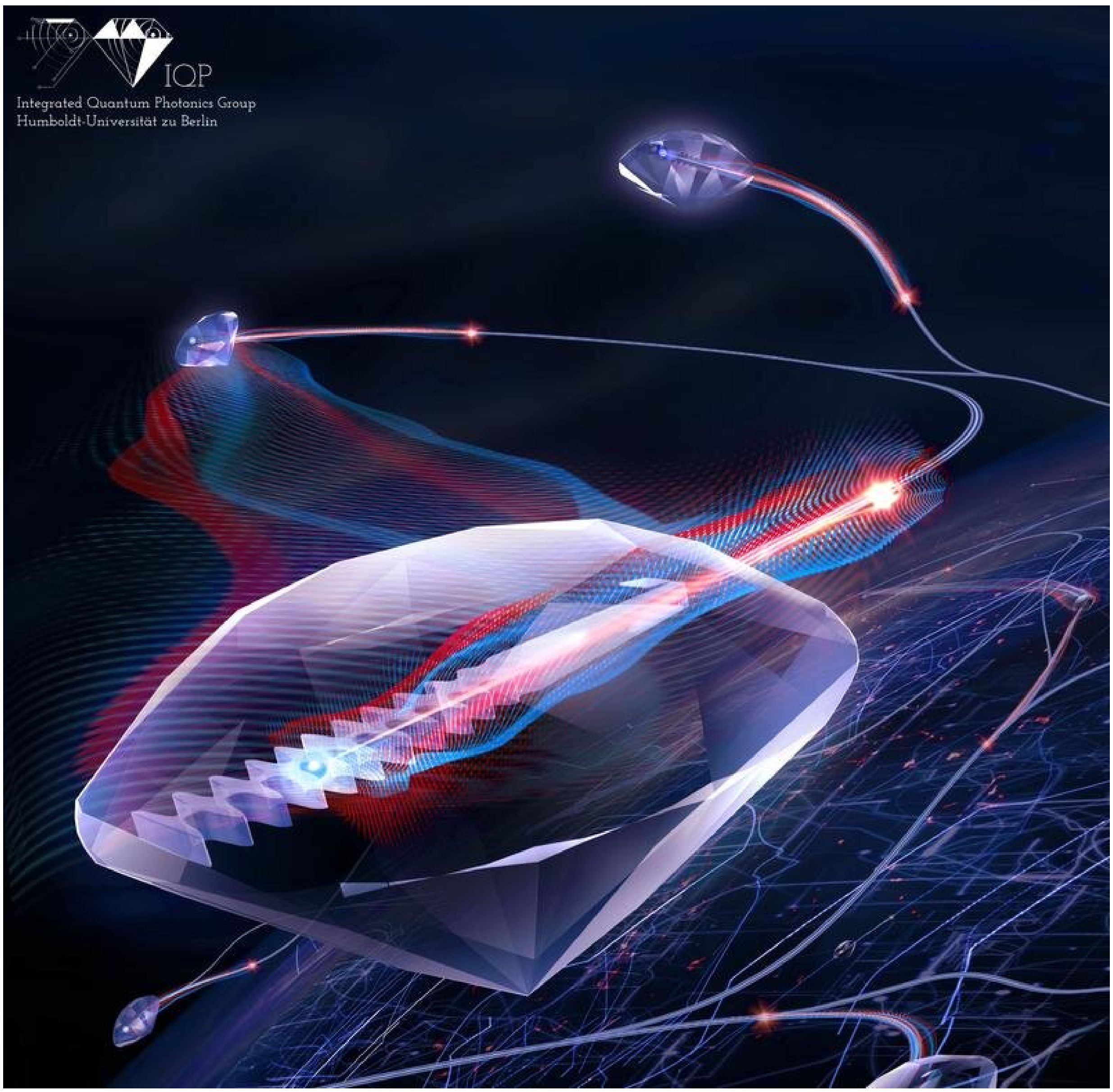


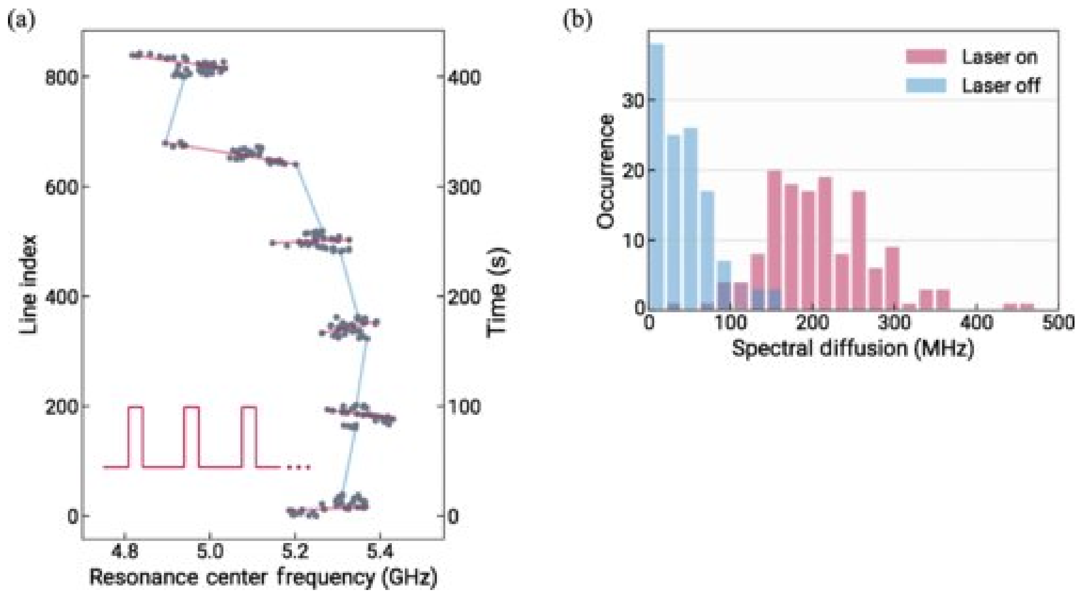
Defect centers in diamond nanostructures can be used as quantum bits. Via quantum operations (entanglement), quantum information can be stored in emitted single photons and transmitted in optical fibers in the future quantum internet. Credit: Humboldt-Universität zu Berlin

Diamond material is of great importance for future technologies such as the quantum internet. Special defect centers can be used as quantum bits (qubits) and emit single light particles that are referred to as single photons.

To enable data transmission with feasible communication rates over long distances in a quantum network, all photons must be collected in optical fibers and transmitted without being lost. It must also be ensured that these photons all have the same color, i.e., the same frequency. Fulfilling these requirements has been impossible until now.

Researchers in the "Integrated Quantum Photonics" group led by Prof. Dr. Tim Schröder at Humboldt-Universität zu Berlin have succeeded for the first time worldwide in generating and detecting photons with stable photon frequencies emitted from quantum light sources, or, more precisely, from nitrogen-vacancy defect centers in diamond nanostructures.

This was enabled by carefully choosing the diamond material; sophisticated nanofabrication methods carried out at the Joint Lab Diamond Nanophotonics of the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik; and specific experimental control protocols. By combining these methods, the noise of the electrons, which previously disturbed data transmission, can be significantly reduced, and the photons are emitted at a stable (communication) frequency.



NV in the dark (regime 3). (a) Shutter experiment in which we alternate between PLE scanning for 20 s and blocking the radiation for 60 s. When PLE scans are performed, the center frequency of the ZPL resonance is extracted from Voigt fits (gray dots). Here, a data set is exemplarily presented. (b) Occurrence of spectral shifts obtained from many data sets. The extracted spectral diffusion value for "Laser on" corresponds to the spanned frequency range recorded in a period of 20 s. The spectral diffusion for "Laser off" is extracted from the spectral difference of the last PLE scan before and the first scan after blocking the laser, as illustrated in panel (a). Credit: *Physical Review X* (2023). DOI: 10.1103/PhysRevX.13.011042

In addition, the Berlin researchers show that the current communication rates between spatially separated quantum systems can prospectively be increased more than 1,000-fold with the help of the developed methods—an important step closer to a future quantum internet.

The scientists have integrated individual qubits into optimized diamond nanostructures. These structures are 1,000 times thinner than a human hair and make it possible to transfer emitted photons in a directed manner into glass fibers.

However, during the fabrication of the nanostructures, the material surface is damaged at the atomic level, and free electrons create uncontrollable noise for the generated light particles. Noise, comparable to an unstable radio frequency, causes fluctuations in the photon frequency, preventing successful quantum operations such as entanglement.

A special feature of the diamond material used is its relatively high density of nitrogen impurity atoms in the crystal lattice. These possibly shield the quantum light source from electron noise at the surface of the nanostructure. "However, the exact physical processes need to be studied in more detail in the future," explains Laura Orphal-Kobin, who investigates quantum systems together with Prof. Dr. Tim Schröder.

The conclusions drawn from the experimental observations are supported by statistical models and simulations, which Dr. Gregor Pieplow from the same research group is developing and implementing together with the experimental physicists.

The paper is published in the journal *Physical Review X*.

More information: Laura Orphal-Kobin et al, Optically Coherent Nitrogen-Vacancy Defect Centers in Diamond Nanostructures, *Physical Review X* (2023). DOI: 10.1103/PhysRevX.13.011042

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