Realization of miniaturized PMN-PT piezo actuators by femtosecond laser processing for compensation of fine structure splitting of entangled photon quantum emitters

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Strain influences the band structure and optical properties of semiconductors. In the case of GaAs quantum dots (QD), which can serve as sources of entangled photons, the specific introduction of strain can influence the emission characteristics in a way to optimize the entangled state by compensation of the fine structure splitting. Since the QD emitters are operated at cryogenic temperatures, an actuator platform is required that delivers strain values high enough to achieve full compensation under these conditions. Single crystal PMN-PT shows a giant piezoelectric response and is therefore one of the most promising materials for this application. The possibility of using this material with high innovation potential depends essentially on the extent to which it can be processed with the necessary precision and quality. The manufacturing options for this very fragile and temperature-sensitive material are severely limited and have disadvantages like the long processing time, the introduction of too much damage to the substrate material or the limited flexibility. We show the completely laser-based realization of different actuator designs and their application for entangled photon quantum emitters. The actuators enable a full control of the in-plane strain tensor in a semiconductor nanomembrane with GaAs QDs, bonded directly on the actuator surface [1-4]. The experiments were done using a femtosecond laser with a pulse duration of 350 fs. The laser was operated at its second or third harmonic wavelength of 520 nm and 345 nm, respectively, depending on the actuator design.

References: [1] Rota, M.B.; Krieger, T.M., A source of entangled photons based on a cavity-enhanced and strain-tuned GaAs quantum dot, preprint Arxiv.org, 2022, arXiv:2212.12506; [2] Lehner, B.U.; Seidelmann, T., Beyond the four-level model: Dark and hot states in quantum dots degrade photonic entanglement, Nano Lett. 2023, 23 ,4 , 1409,1415; [3] Lettner, T.; Gyger, S., Strain-Controlled Quantum Dot Fine Structure for Entangled Photon Generation at 1550 nm, Nano Lett. 2021, 21, 24, 10501–10506; [4] Martín-Sánchez, J.; Trotta, R., Reversible Control of In-Plane Elastic Stress Tensor in Nanomembranes, Adv. Optical Mater. 2016, 4, 682-687.Trotta, R.; Martín-Sánchez, J., Energy-Tunable Sources of Entangled Photons: A Viable Concept for Solid-State-Based Quantum Relays, Phys. Rev. Lett. 2015, 114, 150502.