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Enhancing Cryogenic Electro-Optic and Piezo-Electric Performance by Tuning Quantum Criticality

The Stanford team has dramatically enhanced materials properties crucial for low-temperature quantum photonic and phononic applications. By manipulating the oxygen isotope ratio in strontium titanate, they have demonstrated proof-of-concept devices with record-breaking performance at cryogenic temperatures. This establishes an flexible tuning mechanism for nonlinear materials.

Electro-optic tunability—a change in the refractive index upon the application of an electrical voltage—is a key requirement for tunable photonic elements and quantum technologies. However, at the cryogenic temperatures where many devices operate, there is a fundamental limitation: when cooled, leading electro-optic and piezo-electric materials lose their strong nonlinearity, becoming less efficient and preventing applications ranging from photonic quantum computing to microwave-to-optical transduction that could scale quantum computers.

The team discovered that $SrTiO_3$ (STO) is the most tunable electro-optic and piezoelectric material at cryogenic temperatures below 10 K. By approaching a quantum critical point through changing the ratio of Oxygen-16 to Oxygen-18 isotopes in strontium titanate, the electro-optic and piezoelectric nonlinearities are enhanced even further at cryogenic temperatures. This breakthrough will enable devices such as transducers, cryogenic piezoelectric positioners, and modular quantum computers.

Stage of Development: Proof of Concept

Applications

- **On-chip microwave-to-optical transducers** - based on the large electro-optic nonlinearity, necessary for creating modular quantum computers based on superconducting qubit processors. Efficiencies can now be orders of magnitude higher than the state of the art.
- **Cryogenic nanophotonic switches** - e.g. Mach-Zehnder interferometers, that are used for photonic qubit manipulation. Size, voltage, and loss can be reduced.
- **Cryogenic mechanical positioners** - for rocket fuel actuation, space applications, and nanopositioners used in cryostats for both academic and commercial applications.

Advantages

- **Higher tunability and more efficient** - than existing leading materials used for electro-optic and piezo-electric applications at cryogenic temperatures

Publications

- Christopher P. Anderson et al., Quantum critical electro-optic and piezo-electric nonlinearities. *Science* 390, 394-399 (2025).DOI:10.1126/science.adx8657
- Anderson, C. P., Scuri, G., et al. (2025), Quantum critical electro-optic and piezo-electric nonlinearities, arXiv:2502.15164v2

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