Unlocking Quantum behaviour with extreme strain of Nanometre thick oxide membranes

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In the mid-20th century, $SrTiO_3$ was explored as a potential alternative to diamond and valued for its optical brilliance. But its promise faded quickly: $SrTiO_3$ is extraordinarily brittle, and even slight strain causes it to crack. From a materials perspective, $SrTiO_3$ is also a quantum paraelectric poised on the edge of exotic electronic behaviour, but its inherent fragility prevented researchers from probing how strain might be used to unlock its hidden quantum phases. That barrier has now been overcome. By fabricating ultrathin, freestanding $SrTiO_3$ membranes, the material becomes remarkably flexible. These nanomembranes withstand more than 1% tensile strain, a tenfold improvement over bulk crystals, turning mechanical deformation into a precise and reversible tuning parameter for functional exploitation.

Using membranes, we repeatedly drove the material into and out of its ferroelectric state. Understanding how the lattice and electronic structure responded under strain required the combined capabilities of several synchrotron beamlines and a Razorbill strain cell. High-resolution X-ray diffraction and titanium K-edge spectroscopy at XMaS (Figure CS3) provided the sensitivity needed to track lattice coherence, strain-induced distortions, and changes in the Ti–O electronic environment. Collaboration between XMaS and APS beamlines allowed us to connect macroscopic structural response with atomic-scale electronic signatures in a way no single instrument could achieve alone. These measurements resolved a long-standing debate: the ferroelectric transition in strained $SrTiO_3$ is displacive, involving a coordinated shift of atoms rather than the alignment of pre-existing polar nanodomains. They also revealed a striking classical-to-quantum crossover which was tracked using X-ray linear dichroism. A crossover from a classical transition at high temperatures to a quantum paraelectric regime at low temperatures is seen in the evolution of the critical exponent, which moves from ~0.5 near 100 K to ~1.5 below 40 K. At high temperatures, the transition behaves classically, driven by thermal fluctuations. Below 100 K, however, thermal motion fades and persistent quantum fluctuations dominate, suppressing any spontaneous ferroelectric order. Mechanical strain provides the critical additional energy needed to overcome these fluctuations and stabilise low-temperature ferroelectricity. Crucially, stretching the membranes allows the ferroelectric state to be switched on mechanically as pulling the lattice apart displaces oxygen and titanium ions relative to one another, generating a spontaneous electric polarization.

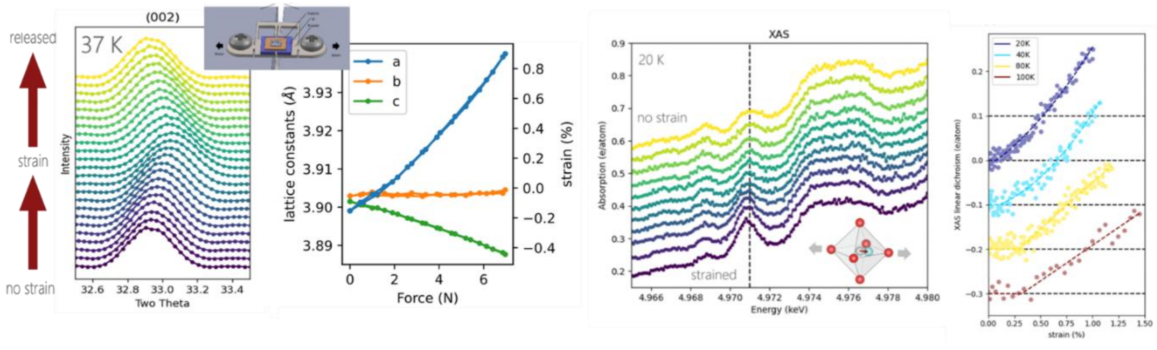

Figure CS3: By combining strain and X-ray techniques on XMaS, the ferroelectric phase transition in $SrTiO_3$ membranes was explored with the temperature-strain phase diagram followed using diffraction (left) and spectroscopy (right).

The ability to toggle the ferroelectric state mechanically, rather than through chemical doping or fixed epitaxial growth, offers a transformative roadmap for microelectronics where non-volatile data storage and high-efficiency switches are controlled by the subtle, reversible stretching of a membrane. The work marks an important step toward technologies in which flexible oxide nanomembranes act as mechanically tuneable quantum materials. Early results from other perovskite membranes indicate that this strategy could extend across a wide family of complex oxides. Integrated onto stretchable or biocompatible platforms, these materials could enable applications ranging from wearable quantum sensors to implantable microelectronics and lattice-based memory devices. More broadly, the findings suggest that many seemingly ordinary materials may hide remarkable functional properties, only waiting only for the right experimental tools, and, in this case, the right amount of tension to reveal them.