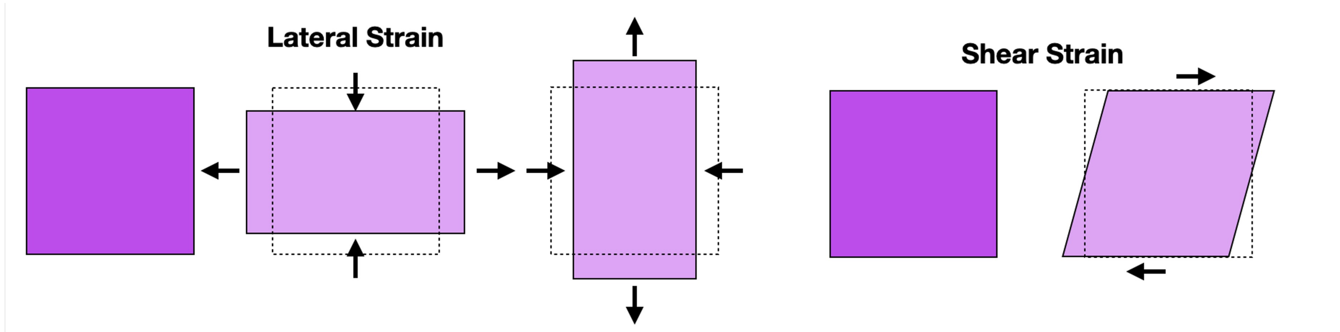
MODIFYING CRYSTAL SYMMETRIES VIA SHEAR DISTORTION

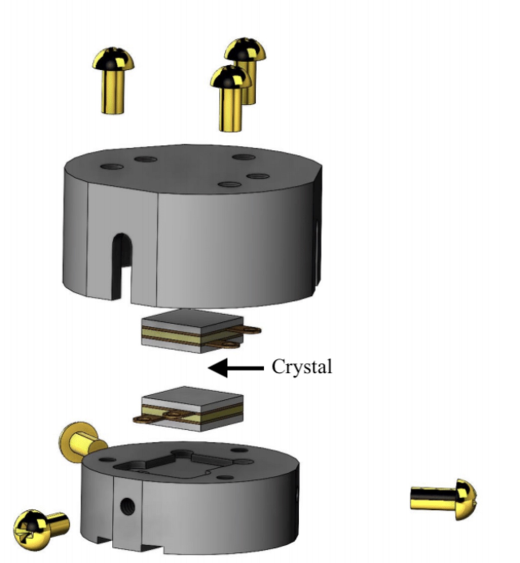
STUDENTS: SARAH EDWARDS AND QIXUAN LIN

Motivation and Outlook

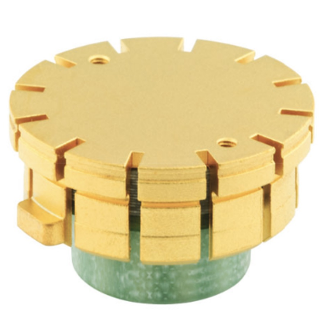
While lateral strain is a relatively common tool for probing atomic-level magnetic and electric phenomena, shear strain remains uncommon in condensed matter publications. Stacking order and magnetic phases coupled with spontaneous structural distortions are both properties that could be manipulated by a reliable source of shear stress, allowing us new degrees of freedom in the study of broken symmetries in complex solid-state systems. Once the effect of shear strain is better understood, altering the relative position of layers in a crystal has the potential to be a powerful tool for controlling properties with industrial and computing applications. This poster details the finalized design for a shear strain device which will be robust for low-temperature measurements under vacuum, including simulations of its various components and preliminary characterization of a material which we plan to measure the effect of shear strain on once all parts of the cell have been built.



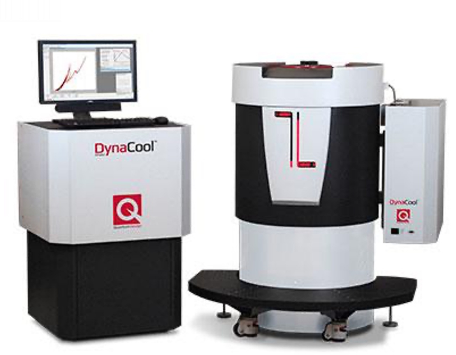
Strain Cell Construction

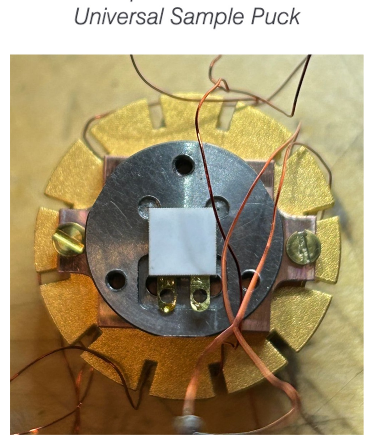


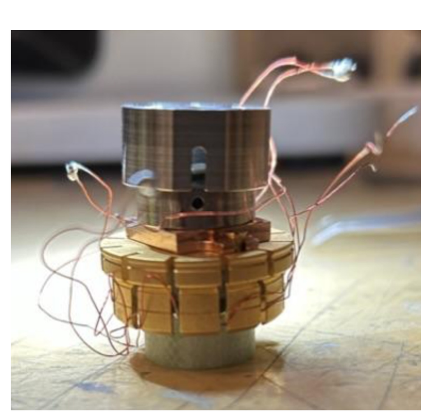
- Base and top shell are made of Titanium, chosen for its minimal thermal expansion
- A bulk crystal is held in place between two PZT chips by Loctite Stycast 2850FT epoxy
- As a voltage is run through the PZT chips, they undergo a shear piezoelectric deformation, displacing the faces of the crystal with respect to each other
- One of our main tasks has been to add a device to this cell in order to measure the in-situ strain experienced by the crystal



Optional P101 Universal Sample Puck







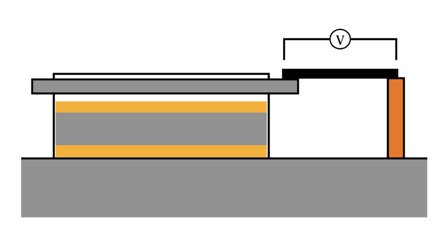
The strain cell is designed to work with QuantumDesign's Physical Property Measurement System (PPMS), which can apply magnetic fields up to 14 T and reach a base temperature of 1.9 K. This means building on top of one of their standard resistance pucks and designing elements to function under the extreme thermal and magnetic conditions.

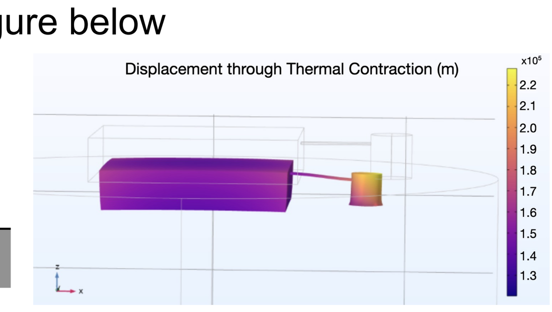
Designing a Precise Strain Gauge

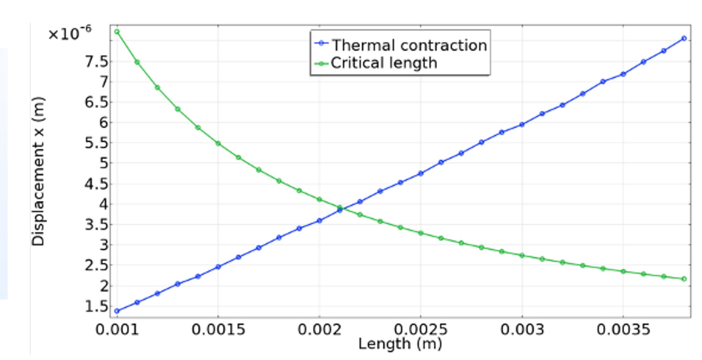
To better characterize the strain applied to the material, a small-scale, precise strain gauge is needed. We designed two kinds of strain gauge to measure the shear displacement using piezoresistive effect and capacitance change, respectively. For both, we have performed several COMSOL simulations to judge their accuracy and robustness under the conditions they will be subjected to.

Resistance-Based Strain Gauge

- We use a Si strip with one end mounted at one edge of the piezo chip and the other end at a fixed Cu brick
- The piezoresistive effect, a change in the resistance of the material under the applied strain, is usually more sensitive than the change induced by the geometry alone
- Calibrating to the known electrical properties of Si under low temperature, we can measure the applied strain by measuring the resistance change of the Si strip
- 2mm-long Si strips and Cu as the material for the supporting post are chosen to avoid buckling, as calculated in the figure below



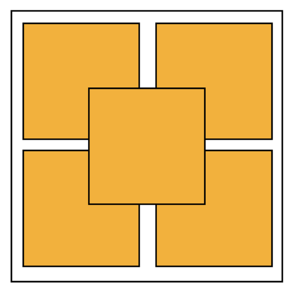


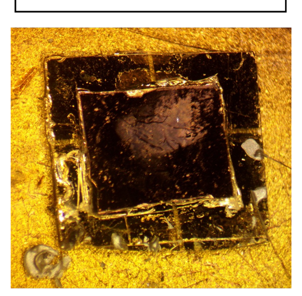


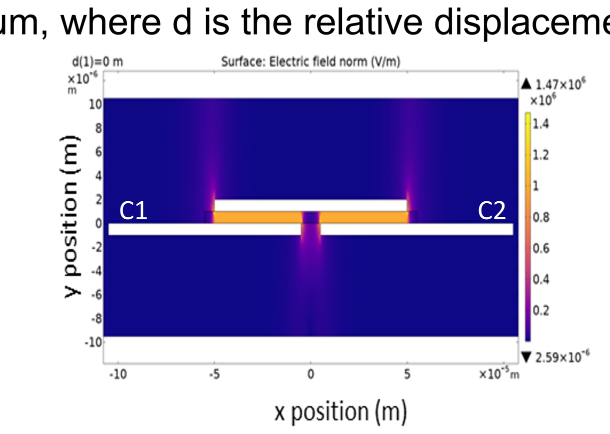
Left: an illustration of the resistance-based strain gauge.
Middle: A COMSOL simulation showing the displacement of each element as it thermally contracts from 300 K to 100 mK
Right: The thermal contraction of a strip of silicon vs. its length, plotted alongside the critical length

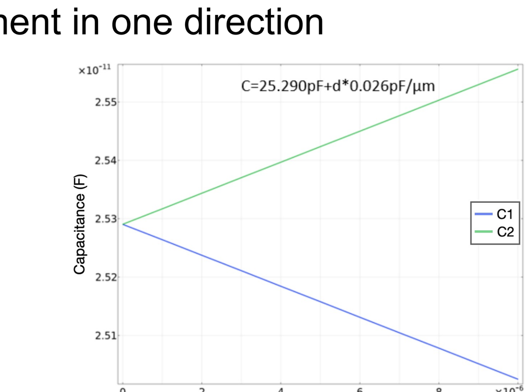
Capacitance-Based Strain Gauge

- The capacitive sensor consists of four square coplanar electrodes underneath one floating electrode, separated by a layer of polymethyl methacrylate (PMMA)
- As the surface of the piezoelectric moves and applies strain to the sample, the floating electrode will move alongside it, changing the area it covers on each lower electrode and therefore changing the capacitance of the parallel-plate capacitor it forms with each
- From a measurement of that capacitance through a very high-resolution capacitance bridge, the distance travelled by the face of the piezoelectric chip shearing the crystal can be calculated
- The simulated capacitance between a bottom electrode with the top electrode is 25.29pF+d*0.026pF/μm, where d is the relative displacement in one direction





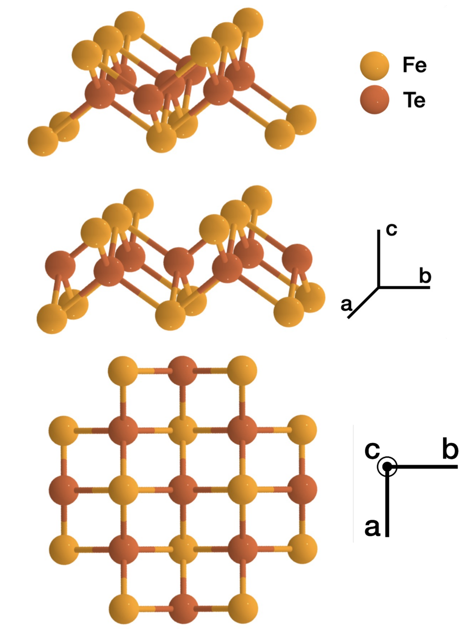




Top left: An illustration of electrodes forming capacitors in parallel
Bottom left: An initial prototype of the strain gauge
Top right: Electric field and capacitance of two electrodes as the top electrode moves away from one and towards the other

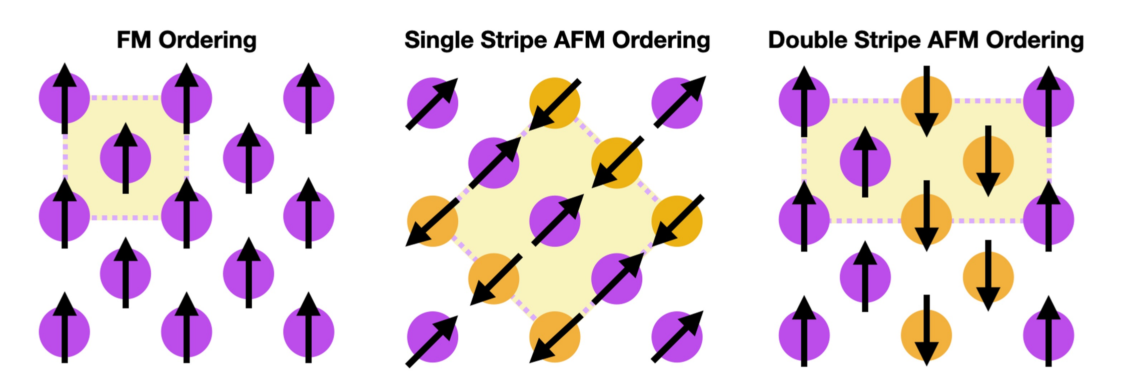
Shear Strain and FeTe

The first bulk crystal we plan to measure in the pilot test of this strain cell is FeTe. This material undergoes a strong monoclinic structural distortion as it enters its antiferromagnetic phase [5], indicating that it will have a significant response to shear strain.

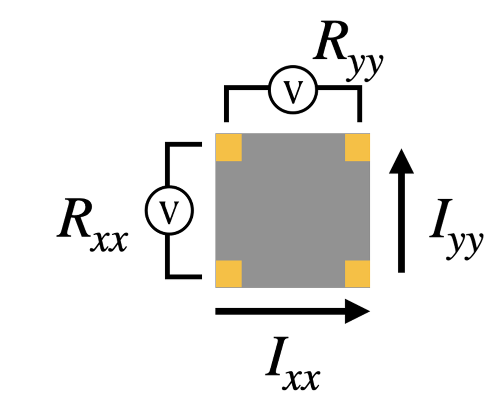


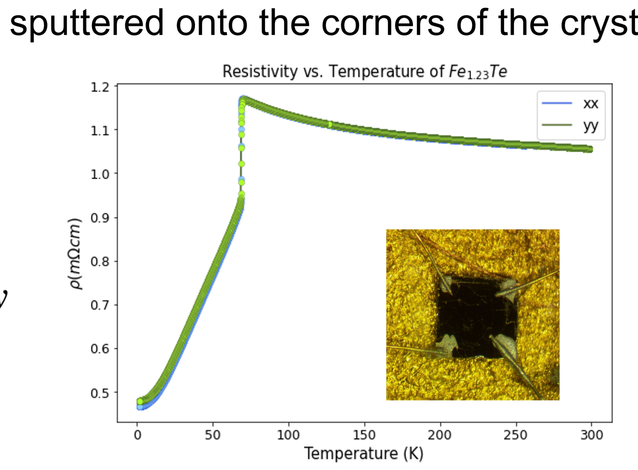
- FeTe is a tetragonal material in the same family as more famous superconductors such as FeSe and $FeTe_{1-x}Se_x$
- Bulk crystals were grown via the self-flux method and formed, as FeTe almost always does, with extra iron around some small percentage of iron sites in the lattice
- In its ground state it enters a double-stripe antiferromagnetic (AFM) phase at a temperature of 65 K [1]
- Becomes a bulk ferromagnet under a pressure of 2 GPa [1]
- Theoretical predictions [1] and experiments [3] on thin film FeTe indicate that it can enter a single stripe AFM ordering under tensile strain, an ordering which may be connected to an emergent superconducting phase

Above: Lattice diagram of FeTe provided by The Materials Project [2]
Below: Possible magnetic orderings of FeTe. Magnetic unit cell is highlighted in yellow.



Early measurements to prepare for strain cell tests include performing energy-dispersive X-ray spectroscopy (EDX) to measure excess iron and recording the resistivity along the a and b axes down to 2 K. Results can be seen in the figure below, alongside a picture of the sample measured. Current is applied and voltage measured through gold wires attached with silver paste to gold pads sputtered onto the corners of the crystal.





Resistivity vs Temperature of a sample of FeTe with excess iron. Measured using the Montgomery method [4]. The flow of current and points of measurement in this method are shown to the left.

References and Acknowledgements

Many thanks to Dr. Arthur Barnard, our mentor for this project, the AQET program and especially Dr. Sara Mouradian for organizing the capstone project framework, Dr. Jiun-Haw Chu for insight on materials, Morgan Sherer for creating the first prototype of the capacitive strain gauge, Dr. Qianni Jiang for growing FeTe crystals we used.

[1] A.Ciechan, M.J.Winiarski, and M.Samsel-Czekała,"Magnetic phase transitions and superconductivity in strained fete,"Journal of Physics: Condensed Matter 26, 025702 (2013).
[2] The Materials Project. Materials Data on FeSe by Materials Project. United States. doi:https://doi.org/10.17188/1195438
[3] Y. Han, W.Y. Li, L.X. Cao, X.Y. Wang, B. Xu, B.R. Zhao, Y.Q. Guo, and J.L. Yang,"Superconductivity in iron telluride thin films under tensile stress," Phys. Rev. Lett. 104, 017003 (2010).
[4] C.A.M. dos Santos, A. deCampos, M.S. daLuz, B.D. White, J.J. Neumeier, B.S. deLima, and C.Y. Shigue,"Procedure for measuring electrical resistivity of anisotropic materials: A revision of the Montgomery method," Journal of Applied Physics 110 (2011), 10.1063/1.3652905, 083703.
[5] J.Warmuth, M. Bremholm, P. Hofmann, J. Wiebe, and R. Wiesendanger, "Domain imaging across the magneto-structural phase transitions in fe1+yte," npj Quantum Materials 3, 21 (2018).

ELECTRICAL & COMPUTER ENGINEERING
UNIVERSITY *of* WASHINGTON

ADVISERS: ARTHUR BARNARD

SPONSOR: UNIVERSITY OF WASHINGTON, AQET PROGRAM