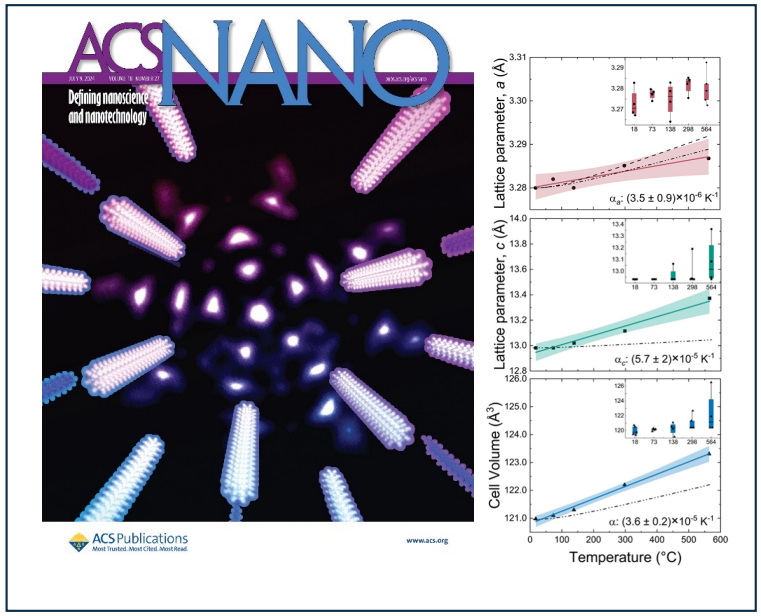
Patterned Electron Probes Enable Direct Measurement of the Thermal Expansion Coefficient of an Atomically Thin Semiconductor



(left) Exaggerated depiction of scattering from the complex-shaped electron probe and (right) experimental changes in lattice parameters with temperature used to obtain the TEC of 2D WSe_2.

Scientific Achievement

Discovery that patterned electron probes yield an extra level of precision in measuring lattice parameters enabling direct measurement of the thermal expansion coefficient (TEC) of a 2D material, WSe_2, which is promising as it falls within the value of conventional materials used in microelectronics.

Significance and Impact

Our discovery establishes that the in-plane TEC of large-scale polycrystalline monolayer WSe_2 [$(3.5\pm0.9)\times10^{-6}$ K^{-1}] is indeed more in line with the bulk TEC, while the out-of-plane TEC [$(57\pm20)\times10^{-6}$ K^{-1}] is an order of magnitude larger than bulk.

Research Details

- Heating experiments were performed on wafer-scale polycrystalline monolayer WSe_2 transferred onto TEM grids with 2 μm diameter holes, and heated in a furnace-style sample holder.
- 4D-STEM was performed at 60 keV from room temperature up to ~550 °C, and detailed computational processing performed to obtain the evolution in lattice parameter statistics as the sample was heated. This was compared against density functional theory calculations.

Kucinski, T.;Dhall, R.; Savitzky, B.; Ophus, C.; Karkee, R.; Mishra, A.; E. Dervishi, E.; Kang, J.H.; Lee, C.-H.; Yoo, J.; Pettes, M.T. "Direct Measurement of the Thermal Expansion Coefficient of Epitaxial Wse2 by Four-Dimensional Scanning Transmission Electron Microscopy," *ACS Nano* 2024, *18*, 17725–17734, DOI: 10.1021/acsnano.4c02996.

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