Nanoscale thermometry utilizing thermal diffuse scattering in the scanning transmission electron microscope

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Electron microscope thermometry offers the possibility of mapping temperature with very high spatial resolution. To date, most temperature measurement techniques demonstrated in the transmission electron microscope (TEM) have fundamentally measured thermal expansion [1-3]. Since thermal expansion is a relatively small effect, the measured temperature coefficients are <30 ppm/K. However, much larger temperature coefficients are associated with the less-utilized mechanism of thermal diffuse scattering (TDS). Simple Debye-Waller theories describing how the electrons scatter off of the vibrating atoms predict the temperature coefficients of TDS are >1000 ppm/K, and comparable TDS temperature coefficients have been previously measured in the TEM [4].

Here, we demonstrate two techniques to measure the temperature dependent TDS in the scanning TEM. First, we measure the TDS in electron diffraction patterns of a gold film. We energy filter the diffraction patterns to isolate the TDS from other inelastic scattering mechanisms, and we separate the diffuse signal from the Bragg spots in post-processing. Comparing the diffuse counts averaged over many spatial locations at 300 K and 100 K, we obtain an average temperature coefficient of 1900±400 ppm/K, in reasonable agreement with the Debye-Waller prediction of 3000 ppm/K. This diffraction pattern technique, however, is most easily applied to single crystal materials. Our second technique, which is applicable even for polycrystalline and amorphous materials, utilizes the TDS contribution to annular dark field (ADF) images. We use a lock-in amplifier to measure the small changes in the ADF signal due to time-periodic Joule heating of a ceramic membrane. The lock-in technique improves the temperature sensitivity, but we sacrifice some spatial resolution because the beam must be continually scanned to avoid thermal expansion artifacts. Moving forward, we plan to use these two techniques to map temperature profiles at the nanoscale in the scanning TEM.

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