Nondestructive Measurements of Thermal Transport and Elastic Properties in Nanostructured Metalattices

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In much the same way that a pier or sandbar disrupts the motion of ocean waves (wavelength ~ meters), far smaller features, appropriately designed, can disrupt the propagation of electrons, photons and even heat. By carefully engineering such scattering centers in materials, it is possible to achieve designer properties that are unattainable in bulk systems, with applications as diverse as nanoelectronics, thermoelectrics and next-generation energy efficient devices. Silicon metalattices, which consist of 3D periodic arrays of nanoscale voids or silica spheres embedded in a matrix material with periodicities in the sub-100nm range, are a promising route to achieve tunable functional properties via controlled nanostructuring. However, the complex geometry makes their material properties notoriously difficult to measure and model. Here, we use an ultrafast extreme ultraviolet (EUV) metrology technique to investigate three silicon metalattice samples with 14nm and 30nm sphere diameters, with and without the embedded silica spheres. The ~10fs pulse duration and ~30nm wavelength of our EUV source make it ideally suited to the length and time scales of the dynamics in these systems. We demonstrate the first-ever characterization of the structural and elastic properties of a <100nm diameter metalattice, which we corroborate with scanning electron microscopy and nanoindentation measurements. To investigate the thermal transport properties, we combine our experimental measurements with advanced non-equilibrium molecular dynamics simulations to gain insight into the ballistic phonon mechanisms underlying the metalattices' ultra-low thermal conductivity. This comprehensive investigation helps pave the way for predictive modeling of metalattice behavior to inform future sample synthesis and nanoengineered device applications.