Ultrafast laser induced irreversible phase transformations

D.R. Rittman[1], A.E. Gleason[1], B. Torralva[2], W.L. Mao[1], S.M. Yalisove[2], R.C. Ewing[1]

[1] Stanford University, Stanford, California, United States
[2] University of Michigan, Ann Arbor, Michigan, United States

Ultrafast laser irradiation induces highly non-equilibrium conditions in materials. Intense electronic excitations on ultrafast timescales leads to electronic effects that persist for <1 ps. Heating occurs as electrons recombine and couple to phonon modes from 1-10 ps. Expansion of the laser-excited region drives a shock wave through the material from 20-100 ps. Resolidification of heated material occurs from 1-10 ns.

Here, we show irreversible ultrafast laser driven phase transformations in simple oxides: ZrO_2, Ln_2O_3, and SiO_2 (α-quartz). These materials have been shown to undergo different types of phase transformations following irradiation by an ultrafast laser with $10^{14}<I<10^{15}$ W/cm^2. ZrO_2 undergoes a monoclinic-to-tetragonal transformation (a high temperature phase). Ln_2O_3 undergoes a cubic-to-monoclinic transformation (a high pressure phase). SiO_2 undergoes amorphization.

Interestingly, all three of these materials have a multitude of high temperature, high pressure, and amorphous phases in their pressure/temperature phase diagrams. So why do they all transform to different types of phases under identical irradiation conditions? Is there one unifying mechanism or do different mechanisms dominate different types of transformations? To answer these questions, we propose use of the LCLS to study the dynamical process induced by the ultrafast laser.