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Micro-craters and phase transformations induced by supersonic microprojectile impacts

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Shock metamorphism, also called impact metamorphism, is the progressive breakdown and deformation of underlying rock layers and their constituent minerals during an impact event. It is caused by intense shock waves creating dynamic pressure and heat that originate at the point of impact, which occurs in natural impacts, nuclear explosions, and meteor airbursts. The shock metamorphic signatures are widely observed in impact craters on Earth, lunar rocks, meteorites, and many other types of asteroids.

The shock metamorphism of opal-A (SiO_2) and anatase (TiO_2) induced by supersonic microprojectile impacts in an advanced laser-induced projectile impact test (LIPIT) was investigated using synchrotron X-ray diffraction (XRD), SEM and transmission electron microscopy (TEM). The three-dimensional topography of impacted area is similar to the meteorite crater that has a circular outline with an uplifted rim. The post-impact synchrotron XRD and TEM analyses show the phase transformation of opal-A to coesite together with opal-CT, tridymite, and cristobalite. The results suggest that the transition pressure from opal-A to coesite is lower than the transition pressure of quartz to coesite (~2 GPa). The impact-induced phase transformation of opal-A to coesite at low pressure could be related to the local precursor structure (coesite domain) and water content (~6.7 wt.%) in the opal-A. The impacted anatase shows the phase transformation of anatase to rutile, brookite, srilankite, and amorphous TiO_2 phase. According to the impact calculation, the shocked regions experienced high pressure up to 2.1 GPa and high temperatures up to 986 °C. The shock waves created by impacts are attributed to shock-induced phase changes and lattice dynamic instability. The twinned rutile nanocrystals at the impact area have planar defects following {011} planes that formed under intense pressure or stress. The shearing on the rutile {011} planes can produce epitaxial nucleation of srilankite at the rutile twin boundary. The combined micron-scale ballistic test, impact simulation, and high-resolution characterization techniques will be useful to study the shock metamorphism of various minerals from macro-, micro-, to nanoscale, which will help understand the impact phenomena on Earth, Mars, and many other types of meteorites and asteroids.