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Planetology using high-power laser and X-ray free electron laser

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Meteorites, upon impact, often present unequivocal evidence of the compositions of their parent bodies in the solar system, as represented by dense polymorph minerals that must have recrystallized under shock compression. Olivine [α-$(Mg,Fe)_2SiO_4$] and its three dense high-pressure polymorphs found in shocked meteorites [1-3] are of particular interest because they are believed to quantitatively record the ancient history of impact-induced shock processes occurred in the early solar system. Based on their geochemical analysis, it was proposed that the shocks continued for seconds or longer durations, which requires mutual collision of kilometer-scale asteroids.

To evaluate the timescale of ancient planetary shock events and also their generated pressure scales, we experimentally observed the structure transformation process of ringwoodite [γ-Mg_2SiO_4] from α-Mg_2SiO_4 during shock compression. Ringwoodite is the most commonly-observed dense high-pressure polymorph mineral occurring in meteorites. Following the preestablished scheme of laser-driven shock experiments [4,5], we focused a high-power laser pulse into α-Mg_2SiO_4 to apply strong shock compression, where its recrystallization process was time-resolved by ultrafast diffractometry using SACLA x-ray free electron laser beam of femtosecond time width. The experiments were conducted at our experimental platform designed for time-resolving x-ray diffractometry coupled with laser-driven shock generation (Fig. 1). We found that a lattice-shear mechanism proceeded within several nanoseconds, which was much faster than any previous estimation of solid-state structure transformation mechanism of silicate minerals. The mechanism proceeded even during short-lived shocks equivalent to those induced by impacts of sub-kilometer bodies. The mechanism worked even during shock release, such that the peak shock pressures deduced from the existence of shear-induced olivine polymorphs could be substantially underestimated.

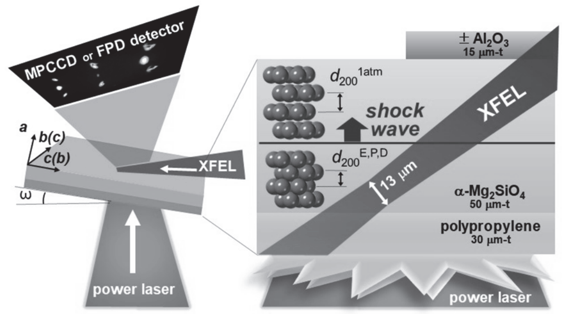

Fig. 1. The experimental setup at SACLA facility for simulating time-evolution of planetary materials after impact- induced shock-compression occurred in the early solar system

References

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