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Hugoniot and released state of calcite: Implications for planetary impact

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Introduction

Protoplanets formed by repeated collisions of interplanetary dust and asteroids have firstly a primitive atmosphere consisting of mainly hydrogen and helium, called as a "primary" atmosphere. Such an atmosphere was dissipated soon into the outer space by the solar wind due to light molecules. Later, secondary components such as H_2O, CO_2, and N_2 were added into the atmosphere as originated by the degassing of planetary minerals. Carbonate minerals like calcite ($CaCO_3$) are considered to have been the major source of the CO_2 component. However, the shock-compressed calcite behaviors have been investigated only up to 100 GPa pressure, corresponding to an 8 km/s impact velocity. In this study, the Hugoniot pressure-density-temperature (P-d-T) relation of calcite was precisely determined to 1000 GPa using the decaying shock method, allowing us to predict the post-impact residual temperatures and the degassed greenhouse gas species.

Materials and Methods

The laser shock experiments on calcite were conducted with GEKKO XII laser facility at Osaka University. The total energy and intensity of laser were 300–800 J and 10^{12}–10^{13} W/cm^2 on the target in the present study, respectively. We used ~1 cm natural single crystals of calcite $CaCO_3$ (density: 2.71 g/cm^3). The crystals were polished to be 4 mm square plates (500 µm thick). The target assemblage used in the present study is shown in Fig. 1. All materials of the target were glued with an ultraviolet curing resin. Shock velocity and the thermal emission at the shock wave front of samples were measured by using the Velocity Interferometer System for Any Reflector (VISAR)[1] and Streak Optical Pyrometer (SOP)[2], respectively. The refractive index used in the present study is 1.66 and 1.55 for calcite and quartz, respectively. Velocity sensitivities [velocity per fringe (VPF)] of two line-imaging VISARs (line-VISARs) in this study were 7.39 and 4.47 km/s in vacuum.

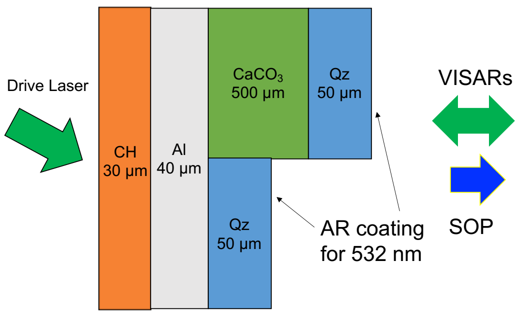

Fig. 1 Schematic setup in laser shock experiments.

Results and Discussions

Above 200 GPa, our result indicates that shock pressure had been overestimated by over 10% at same particle velocity or impact velocity in the case of using the previous U_s-u_p relationship by SESAME model[3]. The precise shock measurements elucidate the shape of the calcite Hugoniot curve continuously passing through the melting and metallization states up to a pressure of 1000 GPa (= 10-million atmospheres) or a corresponding impact velocity of 30 km/s, allowing us to predict the post-shock residual temperatures and the dominant carbon oxide species in the impact aftermath. These predictions suggest that CO emission is much more dominant than CO_2 at the impact velocities of ~10 km/s and above, affecting greenhouse processes and environmental changes during planetary evolution.

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