

Shock barometer using cathodoluminescence and synchrotron angle-dispersive x-ray diffraction analyses of minerals

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A part of meteorites record collisional history of asteroidal and cometary impacts. Impactites were created in impact craters by the shock event on the Earth. These materials provide vital information on collision and accumulation processes of asteroid and planet and ejection process from the parent body. The shock pressure is one of the most important parameters to interpret these impact history. Various techniques such as optical and electron microscopy and infrared adsorption and Raman spectrometry have been applied for minerals (e.g., feldspar and silica minerals) in meteorites and impactites to estimate the shock pressure that occurs on the Earth, Moon, and Mars. Although there are many works to evaluate the shock pressure using these techniques, quantitative estimation of a wider dynamic range of shock pressure has not been possible for a micrometer-sized grain to date. Here, cathodoluminescence (CL) and synchrotron angle-dispersive x-ray diffraction (SR-XRD) of experimentally shocked feldspars and quartz and these minerals in meteorite and impactite have been investigated to establish a new shock barometer.

Shock experiments were performed for single crystals of synthetic and terrestrial quartz and terrestrial feldspars at the National Institute for Material Science using a one stage propellant gun. Quartz in an impactite from the Chicxulub crater and alkali feldspar and plagioclase in martian meteorites (NWA 2975, Shergotty, Dhofar 019, and Zagami) were selected here. CL spectroscopy of these samples was conducted at Okayama University of Science. SR-XRD was measured for the powder samples at KEK Photon Factory (PF; beam line: PF BL-4B2).

CL spectra of unshocked feldspars (starting material for the shock recovery experiments) consist of blue, yellow, and/or red emission bands in the wavelength range from 300 to 800 nm. The ultraviolet (UV) to blue emission bands at 330 and 380 nm were obtained from CL spectra of only experimentally shocked feldspars at 20 to 40 GPa. The intensities of all UV-blue emissions correlate positively with the shock pressure. Similar UV-blue emission bands were recognized in CL spectra of the shock-induced feldspar glasses in the martian meteorites and impactites.

CL spectra of unshocked synthetic and terrestrial quartz show an extremely weak blue emission band at 400 nm. The blue emission band was also detected in CL spectra of the experimentally shock recovered samples at 5 to 40 GPa and quartz in the impactite, whereas their blue emission intensities are obviously higher than those of the unshocked quartz. The blue emission intensities increase with the pressure due to shock experiments gradually from 5 to 15 GPa and drastically from 20 to 40 GPa. These correlations obtained from CL spectra of experimentally shocked feldspar and quartz would give quantitative values of the shock pressures that the minerals in martian meteorites and impactite have experienced. Therefore, the CL intensity of feldspar has a potential for a shock barometer with high spatial resolution.

SR-XRD analyses of experimentally shocked quartz demonstrated that the diffraction peaks increase in the intensity and become broader with increasing the shock pressure in the range from 5 to 30 GPa. At the shock pressure above 35 GPa, diffraction peak of quartz was no longer undetectable from the pattern, implying its complete amorphization. Moreover, several crystal planes exhibit peak shifts with the pressure in the pressure range from 15 to 30 GPa. Furthermore, the shock experiments enhance micro strain and

reduce crystallite size. This fact indicates that the shock-induced amorphization was initiated by lattice distortion and structural defects induced by shock compression. The SR-XRD response to the shock pressure suggests the possibility of shock barometer using SR-XRD method, at least in the range from 15 to 30 GPa.

Keywords: Shock impact, Feldspar, Quartz, Cathodoluminescence, Synchrotron angle-dispersive x-ray diffraction