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Pressure dependence of cathodoluminescence spectra of shocked quartz.

CHANG, Yu[1*] ; KAYAMA, Masahiro[2] ; TAJIKA, Eiichi[3] ; SEKINE, Yasuhito[1] ; SEKINE, Toshimori[4] ; NISHIDO, Hirotsugu[5] ; KOBAYASHI, Takamichi[6]

[1]Earth & Planetary Sci., Univ. of Tokyo, [2]Earth & Planetary Sci., Kobe Univ., [3]Complexity Sci. & Eng., Univ. of Tokyo, [4]Earth & Planetary Sci., Hiroshima Univ., [5]Research Institute of Natural Science, Okayama Univ. of Science., [6]National Institute for Material Science (NIMS)

Impact cratering is a ubiquitous process on both terrestrial planets and small bodies in the solar system. Study on impact craters on the Earth provides a unique opportunity to constrain planetary-scale impact phenomena. In particular, reconstruction of distribution and shock pressure recorded on the shock-metamorphosed minerals would provide vital information on partition of the impact energy and cratering mechanism on Earth.

Quartz, which is one of the most abundant and widely distributed rock-forming minerals on the Earth, has been conventionally used to evaluate shock pressure on the minerals. However, the precious shock estimations using quartz, such as PDFs, are rather qualitative, hence it is required for more detailed evaluation of shock pressure to develop new advanced method. Recently, cathodoluminescence (CL), emissions of photon from materials in ultraviolet to infrared wavelength regions, especially CL of quartz is expected to be used as shock barometer because of change of luminescent properties with shock metamorphism, but systematic study focused on pressure dependence of CL spectra have never been reported. In this study, we conducted a series of systematic shock recovery experiments of impact on quartz crystals and analyzed recovered samples to evaluate the CL spectral features and their dependence on shock pressure.

The shock recovery experiments were performed on natural and synthesis quartz crystals in the National Institute for Material Science (NIMS) using a one stage propellant gun. The velocity range of flyer plate was 0.5 to 1.8 km/s, which produces peak shock pressure from 5 to 40 GPa. Recovered samples were polished to make thin sections, and then are coated by carbon for CL analysis. CL measurements of grain by grain were conducted at Okayama University of Science using a SEM-CL (SEM combined with a grating monochromator) instrument.

Based on CL measurements of over a hundred shock-recovered quartz grains, we found drastic change in spectral pattern with an increase in shock pressure. The starting material of synthetic and natural quartz has only one broad emission peak around 630 nm, but another broad peak around 450-460 nm (blue emission) appears from the shock-recovered samples at 10 to 20 GPa. At higher pressure, the CL intensity of blue emission of shocked quartz increases drastically up to 100 times as large as that of the starting materials. On the other hand, CL emission intensity around 630 nm changes less than 3 times in spite of the pressure increase.

CL spectra of quartz with β-form (e.g., quartz from Goroku, Sendai) show extremely intense blue emission and unique luminescent properties depending on temperature (e.g. activation energy) similar to quartz from terrestrial impact craters, suggesting probably relationship of the blue CL with defects associated with Daufine twins formed as a result of α-β transition. On the other hand, Daufine twins are also confirmed in the experimentally shocked quartz under TEM observation. Therefore, the rise of blue emission intensity in our measurements suggests generation and density increase of defects related to Daufine twins with ascending shock pressure. Quantitative evaluation of this relationship presumably enables us to construct a new quantitative pressure barometer or thermometer for shocked quartz grains.

Keywords: shock metamorphism, shocked quartz, cathodoluminescence