New Application of Cathodoluminescence to Earth and Planetary Sciences

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Introduction

Cathodoluminescence (CL) is the emission of visible light as the result of electron bombardment. CL can be used both in a purely descriptive way to detect and distinguish different minerals or mineral generations by their variable CL colors or as an effective method for spatially resolved analysis of point defects in solids by spectral CL measurements. During the past decade, there have been significant improvements in CL measurement instrumentation and analysis techniques. We have focused a new application of CL on geological and planetary materials. In this study we present the results of CL imaging and spectral analysis for thermal behaviour of clay minerals and shocked microdeformation recorded in quartz and feldspar.

Instrumentation and methods

Color CL images were obtained using a cold cathode type microscope (Luminoscope) with a micro-video lens and a cooled CCD camera under the electron beam condition of 15kV and 0.5 mA. High-magnitude CL images, together with SEM and BSE images, were recorded using a PMT (Gatan: Mini CL) built in a SEM (JEOL: JSM-5410). CL measurements were carried on in the range from 300 to 800 nm using a SEM-CL system, which is comprised of a SEM combined with a grating monochromator (OXFORD: Mono CL2), where the sample temperature can be automatically controlled over a wide range from -192 to 400 °C.

Results and discussion

Clay minerals

We have reported unusual thermal quenching of CL emission in kaolin group minerals [1]. Kaolinite and dickite show CL emission in the blue spectral region with a broad band peak at around 390 nm, which can be assigned to radiation induced defect centers (RID). Both minerals show almost same manner of the change in CL intensity against sample temperature. The intensity increased on heating above -50 °C, and up to its maximum at 60 °C, and then reduced with more heat. This behavior do not follow usual thermal CL reduction derived from a temperature quenching theory based on an increase in the probability of non-radiative transition with the rise of temperature. Arrhenius plot by assuming Mott-Seitz model results in an activation energy (E) in temperature quenching process, E: 0.39-0.43 eV in the increasing process of CL intensity from -50 to 40 °C and E: 0.43-0.49 eV in the diminishing process above 60 °C. The value of such energy is corresponding to that of O-H stretching vibration (3500-3700 cm-1) characteristic of kaolin group minerals. It suggests that the energy of non-radiative transition of the electrons from excited state to ground state might be transferred to lattice as phonon in temperature quenching process above 60 °C. To the contrary, same amount of energy in temperature sensitizing process below 60 °C was induced by the lattice vibration. Such phenomena have not been reported so far.

Shocked microdeformation in quartz and feldspar

Planar Deformation Features (PDFs) and Planar Fractures (PFs) were found from the optical microscope observations in the quartz grains from Mt. Oikeyama (Akaishi Mountains, Central Japan), of which ridge composes a semicircular topographic features suggesting a crater formed by an impact event. SEM-CL imaging of planar microstructures in the quartz grains reveals dark narrow lines indicating the destruction of its crystal structure, which was induced by shock metamorphism. Furthermore, SEM imaging of hydro-fluoride(HF)-etched sample clears up internal pillaring within glass-filled lamellae. Remarkable characteristics in such images correspond only to PDFs, which are limited to shocked quartz. Micro-Raman spectral features represent the low crystalline state of the planar microdeformations causing reduction of 464cm^{-1} Rama peak intensity and broadening of its peak shape. The 2-D Raman imaging of the PDFs shows a stripe pattern suggesting lamination layer comprised of high and low crystalline parts corresponding to the optical image of the PDFs. These facts unambiguously confirm impact origin of distinguishing planar microstructures, PDFs, in quartz from Mt. Oikeyama.

The shocked feldspar from Ries Crater shows PDFs with single or multiple sets under an optical observation. Such feature can be detected as dark narrow lines by CL imaging in the same manner of the case of quartz.

References

[1] Okumura, T., Nishido, H. and Ninagawa, k. (2006) Cathodoluminescence and thermoluminescence studies of clay minerals, Clay Science, *13*, 59-68.