New temperature quenching model of cathodoluminescence in quartz

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During the past decade, CL of quartz has been extensively investigated by many researchers. A quantitative analysis of quartz CL, however, has been scarcely performed by the reason of complicating features of diverse defect and impurity centers, or weak CL intensity at room temperature. The CL intensity of quartz is significantly enhanced at low temperature [1]. In this study a sample temperature effect on the quartz CL is quantitatively evaluated by a two-step quenching model on the basis of a temperature quenching theory, and the mechanism in this quenching process is discussed.

Various natural quartz (hydrothermal, plutonic, volcanic and high-pressure metamorphic quartz) were used for CL measurements.

Spectral measurements were carried out on a JEOL JSM-5410LV scanning electron microscope (SEM) combined with a grating monochromator (OXFORD MonoCL2) in wavelength range of 300 to 800 nm, where the operated condition was at 15 kV acceleration voltage and a beam current of 0.03-0.05 nA. The sample temperature was controlled in the range from -192 to 25 ^{o}C.

Every sample exhibited a doublet peak in blue region at around 450 and 500 nm below -50 ^{o}C while no obvious peak was observed above -30 ^{o}C. Temperature quenching of the luminescence arises at high temperature because of the increased probability of non-radiative transition from the excited state to ground state. An activation energy of CL temperature quenching process was quantitatively evaluated by assuming Mott-Seitz model. Arrhenius plots provide activation energy of 0.03 and 0.23 eV in two step processes for hydrothermal and plutonic quartz, 0.05 and 0.08 eV for volcanic quartz, and 0.03 and 0.15 eV for high-pressure metamorphic quartz. Therefore, the dependence of CL efficiency in quartz on temperature reveals two temperature quenching processes. To interpret temperature quenching mechanism in terms of configuration diagram together with individual process, we introduce a new temperature quenching model derived from MQW (multiple-quantum-well structures), which can be applied to quantitatively estimate thermal quenching and retrapping effects in the photoluminescence of semiconductor. An energy level (E2) is assumed below the excited state level (E1), where electrons at this level can be tapped from or detrapped to excited state. An Arrhenius analysis leads to sufficient fitting of this model for two step processes on temperature quenching.

Each quartz has a broad band peak at around 450 nm at low temperature, whereas activation energies of temperature quenching processes differs among the samples. The fact indicates that the energy level (E1) of the excited state varies with the individual sample, where E2 is kept at an even level. The results suggest that the energy level (E1) might be affected by the alteration in the crystal field around defect center or the state of exciton, which is likely influence by the geological environment of quartz formation and metamorphic process after its formation. Therefore, the activation energy of quartz CL in temperature quenching process could be applied as an indicator for geothermometer or geobarometer.

Reference:

[1] Okumura, T., Nishido, H. and Ninagawa, K. (2004) 32nd Internat. Geol. Cong., Abs. #114-24.