Luminescence Properties of Experimentally Grown Forsterite Chondrule: Implication for Astromineralogy.

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Introduction:

According to Weisberg et al. [1] barred-olivine (BO) chondrule has a unique solidification texture containing single or multiple groupings of elongated parallel olivine crystals (barred texture) with shell of olivine (rim). Crystal growth experiments have been tried to reproduce the barred-olivine texture, but its formation mechansim has been still not understood well [2,3]. Tsukamoto et al. [4,5] produced a rim structure in very rapid cooling experiments with forsterite melt droplets levitated aeroacustically. They observed a sudden temperature increase of hundreds kelvin during solidification of the droplet. This is due to a relesase of latent heat of crystallization and termed as recalescence. It implys that the recalescence played an important role for the formation of solidification textures of chondrules.

For the synthetic and meteoritic forsterite samples, the defect-related centers produced in various conditions during cooling and/or recalescence have been little investigated so far. Moreover, the crystal growth condition of forsterite as one of the first crystalline particles occurred in the Early Solar System is still controversial. In this study, CL imaging and spectroscopy have been performed to characterize luminescent centers of the forsterite in the chondrule experimentally grown under the super cooling and to discuss formation mechanism of the meteoritic forsterite.

Experimental Procedure:

Forsterite crystals with 1-2 mm in diameter were grown as a chondrule analogue by the aero-acoustic levitation floating method [4,5]. Levitated melt crystallizes via homogeneous nucleation under very high super cooling, because heterogeneous nucleation is suppressed due to container free.

Six thin sections (designated as FS004, FS005, FS008, FS010, FS013, and FS014) were selected for further systematic Optical Microscope (OM), Scanning Electron Microscope (SEM) and CL investigations CL color imaging was carried out using Luminoscope (ELM-3R). CL scanning (SEM-CL) images at high magnification were recorded by a Mini-CL detector (Gatan) consisting of multi-alkali photomultiplier tube installed in a JSM-5410LV SEM. CL spectroscopy was made by an SEM-CL system, which is comprised of SEM (JEOL: JSM-5410LV) combined with a grating monochromator (OXFORD: Mono CL2). Detailed construction of the equipment and analytical procedure can be followed from Ikenaga et al. and Kayama et al. [6,7].

Results and Discussion:

Red luminescent forsterite sample (FS004)

This sample exhibits nearly homogeneous red CL color in its Luminoscope image. The SEM-CL image at high magnification revealed that the core of the grain contains scattered star-type bright areas, which can be seen in the BSE image with their typical inverse relationship in the brightness indicating an occurrence of a different phase. CL spectrum of the red luminescent sample has an intense broad band centered at 643 nm (1.93 eV-Mn^{2+} impurity center), which is accompanied by a shoulder peak at 724 nm (1.71 eV- Cr^{3+} impurity center). An additional weak broad band appears at 394 nm (3.14 eV-intrinsic defect center) [8-13].

Blue luminescent forsterite sample (FS005)

Color CL image of this sample is dominated by irregular blue areas, which are arranged at the rim (thin, but with an intense intensity) and in a part divergent from the otherwise non-CL core area. The SEM-CL images show a well-developed branch system in the dendritic texture. The CL spectral features of the blue luminescent forsterite sample show a broad peak at 396 nm (3.13 eV-intrinsic center) with a shoulder band at around 460 nm (2.69 eV-defect center) and a hump centered at 628 nm (1.97 eV- Mn^{2+} impurity center). The peak intensity shows a systematic decrease toward to high wavenumbers [8-13].

Greenish blue luminescent forsterite sample (FS014)

This forsterite sample contains a combination of the linear and branch-type dendritic textures having blue and greenish blue CL patterns, which can be observed in both optical and CL images. On the basis of a comparison between the red and blue luminescent samples, this sample records only a few nucleation points with the highest crystal growth rate. CL spectra of the greenish blue luminescent forsterite samples from the FS014 show a broad band centered at around 401 nm (3.09 eV-intrinsic center) with weak shoulder bands at 480 nm (2.58 eV-defect center) and at 630 nm (1.97 eV- Mn^{2+} impurity center) [8-13].

In our study, a new broad band providing the greenish blue luminescent color ranging from 450–525 nm (2.75– 2.35 eV) was recognized, which would be an identical as a characteristic CL peak of the forsterite that was formed under the super cooling conditions. This broad band is associated with the microdefect-related center, which was formed by the rapid crystal growth in the dendritic branch of forsterite chondrule.

Conclusions:

A comparative spectroscopic investigation involving CL spectrometry and BSE as well as CL images, was performed on a variety of synthetic forsterite samples produced under super cooling. The results show distinct changes of the CL properties of synthetic forsterite samples with crystal growth rate and density of defect centers. Our results also give new insights to understand more about the crystallization processes of the first solid particles in the early Solar System.

References:

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