BL-11D/2020G130

Development of microscopic spectrometer for soft X-ray excited luminescence

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A new microscopic spectrometer has developed to obtain luminescence spectra of scintillators excited with soft X-rays in a small area. Using the developed spectrometer, a luminescence spectrum of Eu:GGG excited by the photon energy, 140 eV, has obtained with the wavelength resolution of 2 nm in the 4 μm diameter region.

1. Introduction

Some scintillators that show luminescence upon X-ray excitation exhibit the phenomenon of stimulated emission depletion (STED) upon simultaneous laser irradiation [1]. By applying the STED phenomenon to two-dimensional detectors, the pixel size of the two-dimensional sensor is expected to be reduced than that of commercially available image sensors [2]. Oxide scintillators using rare-earth ions as luminescent center exhibit emission levels that depend on the number of 4f electrons. The scintillators, Eu:GGG and Tb:LSO, show strong emission intensity in the soft X-ray region [3] and are hoped to show STED phenomenon but the optimum wavelengths for the luminescence and the depletion are unknown. Therefore, a new microscopic spectrometer is developed to measure luminescence spectra of the scintillators and investigate the optimum wavelengths of the STED phenomenon in soft X-ray excitation and visible light depletion.

2. Details of the spectrometer

The microscopic spectrometer was developed under the three requirement points; (1) easy confirmation of small emission points, (2) micro-spectroscopic measurements at the emission point confirmed in (1), and (3) portability of the instrument and easy adaptation to SR beamlines.

The microscopic spectrometer was developed as designated in Fig. 1. A sample is placed in the center of a cube-type nipple of the ICF70 that connected to a soft X-ray monochrometer. Soft X-rays monochromatized are introduced into the cube-type nipple and irradiate the sample. Emission from the sample is extracted and collimated by an objective lens placed into the cube-type nipple. The objective lens can only be replaced in the air. The objective lens also has a role of an illumination optics. After passing through the optical window, the emission light is separated from the laser beam reflected from the sample surface using a dichroic mirror. The optical path of the emission light is further switched by the filter wheel placed at a downstream point of the dichroic mirror 1. The emission light reflected by the dichroic mirror 2 is imaged on the camera sensor plane by the tube lens. The emission light passing through the filter wheel is focused on the pinhole by the other tube lens. The pinhole position is adjusted so that it matches the position of the laser spot in the camera image. The emission light passing through the pinhole is introduced through an optical fiber into a compact spectrometer (BLACK-Comet, StellarNet Inc.). These setups are assembled on a breadboard and can be easily installed into a beamline.

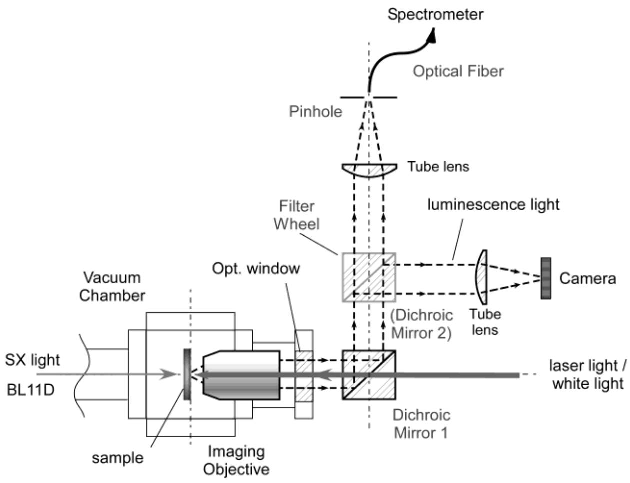

Fig. 1 : Layout of microscopic spectrometer for soft X-ray excited luminescence.

3. Evaluation and Demonstration

Figure 2 shows a 2 μm thick Eu:GGG irradiated with zeroth-order light and laser light at the same time. In this case, the irradiated zeroth-order light passed through the optical window installed at the downstream point of the monochrometer in BL11D, therefore the wavelength region of the irradiated light will be longer than the absorption edge of the optical window. The color of Figure 2 shows green because the dichroic mirror cut wavelengths shorter than 425 nm. A laser spot with a wavelength of 632 nm was located at the center of Fig. 2, and the beam diameter was about 1 μm. The laser beam was generated by a laser diode and attenuated by the ND filter. Using a pinhole spatial filter system, the shape of the laser beam was corrected, and a uniform Gaussian beam was generated. The beam diameter in Fig. 2 was evaluated by the FWHM value of the beam profile. The measurement area of the luminescence spectrum will be circular with a diameter of 4 μm, which is estimated from the incident pinhole. The positioning accuracy of the pinhole was measured as ±5 μm.

The emission spectrum of Eu:GGG excited with a SX light, 140 eV, was measured in the wavelength range of 300 nm ~ 900 nm at 0.5 nm steps. The spectra measured with an exposure time of 3 s were integrated for 350 times to improve the signal-to-noise ratio. The background was measured before and after the measurement and subtracted from the measurement result. The obtained result is shown in Figure 3. The wavelengths of the observed peaks are written in the peak positions. The peaks at 591.5 nm and 594.5 nm, which are originated from the $^5D_0 \rightarrow {}^7F_1$ transition of Eu^{3+} ion [4], can be separated, and the difference between the peak positions is 3 nm. The FWHM value of each peak was 2 nm. Based on the results, the wavelength resolution $\lambda\delta$ was estimated to be 2 nm or less. This is in agreement with the specifications of the compact spectrometer used ($\lambda\delta = 1.5$ nm).

4. Summary

The wavelength resolution of the developed microscopic spectrometer is 2 nm or less therefore the value is limited by the incident slit of the compact spectrometer used. The spatial resolution will be limited by the size of the incident pinhole of the fiber optics, then the measurement area is estimated as a circular shape with a diameter of about 4 μm. The positioning accuracy of the incident pinhole was ±5 μm that is larger than a value estimated from the radius of the pinhole. The positioning accuracy should be improved to measure exact STED effect of scintillators.

Acknowledgments

I am particularly grateful to Prof. K. Mase and Mr. T. Kikuchi for their assistance in beamline preparation, and to Mr. R. Kaneda, Mr. Y. Nakayama, and Ms. J. Ogawa for their assistance in the measurements, and to Prof. T. Wakayama and Prof. T. Higashiguchi for long collaboration of this work. This work was supported by JSPS KAKENHI (grant numbers 19H04391).

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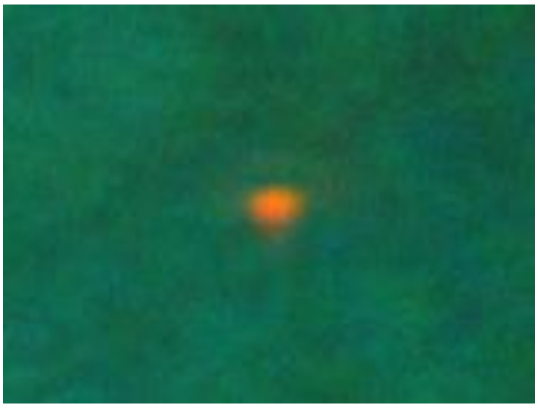

Fig. 2 : Simultaneous irradiation of the light from the laser and the 0th order light from BL11D beamline. The irradiation intensity of the laser light was decreased to 1/35 of the laser intensity by a ND filter, and the exposure

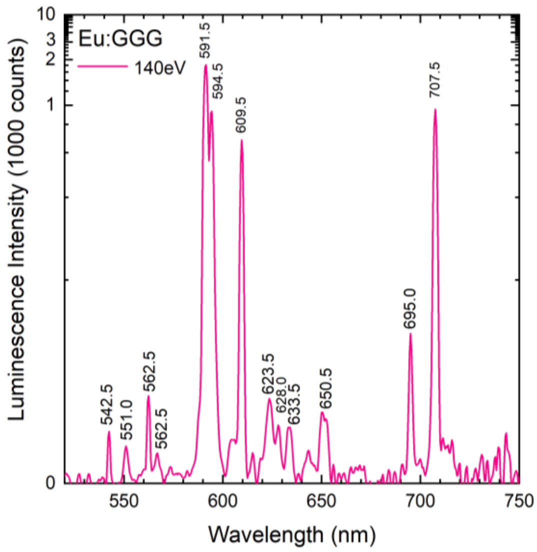

Fig. 3 : Soft X-ray excited luminescence spectrum of Eu:GGG. Photon energy of the SX was 140 eV.

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