§15. Development of the Thermographic Diagnostics Based on the Thermal Radiation Spectrum for Microwave Material Heating

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The microwave-heating technology accumulated through nuclear fusion researches contribute to the field of material processing based on microwave heating. One of the features of the microwave heating is so-called *selective heating*. When a composite material is heated with microwave, the temperature can be higher for the component of larger absorbance than that for component of lower absorbance. Selective microwave absorption has been believed to help to synthesize composite materials with desired functional properties[1]. However, clear-cut observation of the microscopic temperature distribution has been awaited for a long time. We present an observation of microscopic-temperature distribution with a novel thermographic diagnostics[2]. The thermography is based on the thermal radiation spectrum measured at an adequate number of points throughout the observation region on the surface of the material. The main reason why the thermal radiation spectrum is employed is to remove the influence of emissivity from the estimation of the surface temperature.

The employed spectroscopic system is the Integrated Microscopic Imaging System (IMIS) at NIFS. The main feature of the IMIS is integration of a microscope and an 2D-imaging spectrograph (see Fig.1). This allows us to observe emission spectrum two-dimensionally in parallel with checking the current position of the spectrum detection on the microscope image. In the 2D-spectroscopy mode, the scanning mirror is rotated while the spectral image is constantly captured. As a result, the direction of vertical axis in one image is directly associated to the vertical direction, and the direction of the stack of the spectral images is corresponding to the actual horizontal direction. For the present experiment, the duration of the mirror scanning was 10 s, and the period of exposure cycle for one spectral image was 0.1 s, so that 100 images were stored during the one scanning. The spatial extent of the scanning for one exposure period was 9.7 μm, and the total scanning extent was 0.97 mm. On the other hand, the vertical extent in a spectral image is 1.24 mm, which is associated to image size of the CCD (3.1 mm × 3.1 mm) of the camera attached on the spectrograph and the total optical magnification (1 : 2.5). For the microscope, 10 images were captured during the scanning duration.

A specimen was made of hematite Fe_2O_3 and magnetite Fe_3O_4 powders. Grain sizes of hematite and magnetite were 1.0 ± 0.2 mm and 0.5 ± 0.2 mm, respectively. The specimen of the composite material was shaped into a cylindrical rod (5-mm in diameter and 6-mm in length). The specimen was heated by H-field of microwave in the single mode cavity (TE_{103} at cw 2.450 GHz).

Fig.2(a) shows a video image captured by the microscope. This image shows the left upper quadrant of the side surface of the specimen. It is seen that the bright region with the scale length around 0.5 mm is smaller than dark region. As described above the grain size of magnetite is half of hematite, so that the bright region and dark region indicate magnetite and hematite, respectively. This situation suggests the selective heating of magnetite.

The white frame in Fig.2(a) means the observation area for the spectroscopic imaging. For thermography process, the temperature was drawn by fitting the function of thermal radiation based on a gray-model to all the spectrum measured throughout the scanning region. The resultant temperature distribution is presented in Fig.2(b). The pattern of the temperature distribution is similar to that of the microscope image. Typically, there is a high temperature (1250 °C ~ 1350 °C) region in the left side, but is a low temperature (~ 1000 °C) region in the right side. A mean scale length of the temperature difference between them is ~0.5 mm. In the high temperature region, the hot spot is found at (x, y) = (0.10 mm, 0.74 mm), which is also found in the microscope image in Fig. 2(a). The highest temperature at the peak is 1520 ± 120 °C. Above observation accelerates the research for understanding quantitatively the nature of selective microwave heating.

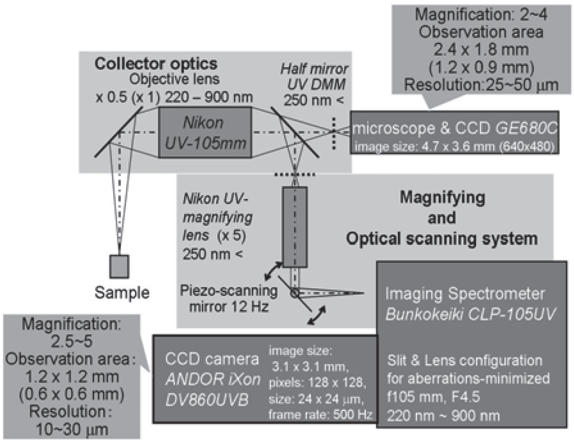

Fig. 1. Configuration of the Integrated Microscopic Imaging Spectrometer.

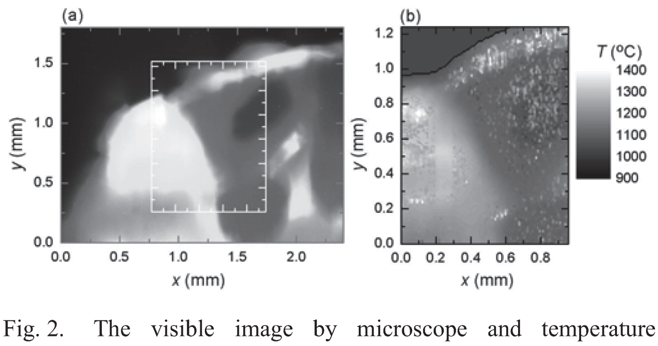

Fig. 2. The visible image by microscope and temperature distribution.

1) Bykov Y., et al., J. Phys. D: Appl. Phys. 34 (2001) R55.
2) Matsubara A., et al., J. J. Soc. Infrared Sci. Tech., Vol. 17, No.1 (2008) 23.