§12. Dynamic Evolution of the Near UV Emission Spectrum during Microwave Iron Making

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The microwave-heating technology accumulated through the nuclear fusion research has contributed widely to the field of industrial microwave processing. An important innovation in this field was brought about by the discovery that even powdered metals could be sintered by the microwave irradiation.[1] Highly pure pig iron has been produced in a microwave test applicator from powdered iron ores with carbon as a reducing agent.[2] A fundamental chemical equation is given as $Fe_3O_4 + 2C \rightarrow 3Fe + 2CO_2 - 75.66$ kcal/mol. The energy required for the endothermic reaction is supplied from microwave energy; thus, microwave iron making has a great advantage to reduce the CO_2 emission by tens of percent from the level in the conventional blast furnaces, if the electric power for the microwave is generated by renewable energy, such as solar, hydro and nuclear power. In this report, we present that the experimental result that the continuous emission spectrum appears intensively in near UV range before completion of the oxygen-reduction in the process of the microwave iron making. The spectral intensity of the continuous spectrum is at least three orders of magnitude larger than that of black body emission from the sample for the temperature of 860 °C ~ 1070 °C measured simultaneously with the pyrometer, rather comparable with that of black body emission for 2200 ± 100 °C.

The continuous spectrum was obtained for the following condition. The prepared sample was powdered magnetite (54.0 g) with carbon (6.0 g), and was heated with microwave (cw 2.5 kW, 2.45 GHz) in nitrogen atmosphere of 1 atm in the multi-mode furnace. The evolution of the emission spectrum passes through three stages, of which time-regions are indicated as hutches shown in Fig. 1. The intense continuous spectrum appears continuously in the first stage (810 s ≤ t ≤ 1100 s, depicted as the hutch I), when the sample temperature rises from 860 °C to 1070 °C. The typical emission spectrum in this stage is shown in Fig. 2(a). Then, the continuous spectrum decays in the second stage for the temperature range of 1070 °C – 1260 °C. This temperature range overlaps with the range of high reduction rate for magnetite and wustite; therefore, the decay of the continuous spectrum implies the end-state of the reduction process. The intensity of the continuous spectrum takes its minimum at 1260 °C [t ~ 1300 s; see spectrum in Fig. 2(b)]. The iron atomic spectra develop gradually in the third stage, when the temperature rises from 1260 °C to 1390 °C. The sample melted entirely at the end of the third stage, which was seen through video image.

A possible origin for the intense continuous spectrum is electron free-bound transition achieved by recombination of atom such as C and O for reproducing molecules of CO/CO_2. In fact, it has been known that a molecular spectrum called carbon monoxide flame bands of CO_2 can appear in the wavelength range from ~ 310 nm up to 440 nm for the case of CO-burning with oxygen. This implies the observed continuous spectrum is emergence of the short wavelength part of those CO_2 molecular bands. The dynamic evolution of the emission spectrum indicates obviously remarkable characteristics of non-thermal equilibrium in microwave iron making process.

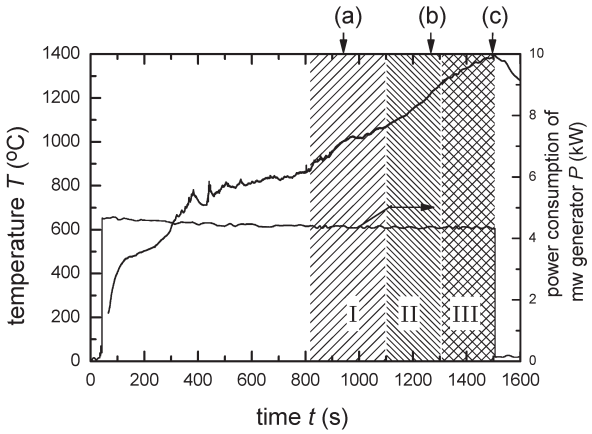

Fig. 1. Variation of temperature of sample and microwave power as a function of time. Three stages I, II, and III are indicated as hutch.

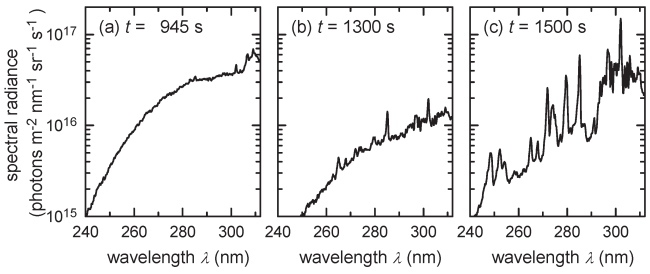

Fig.2. Evolution of the emission spectrum. The peaks around 308 nm in (a) are OH spectrum. Almost all the peaks in (c) are spectra of iron neutral.

1) Roy, R., et al., Nature **399**, 668 (1999).
2) Sato, M., et al., 11th *International Conference on Microwave and High Frequency Heating*, O-24, Sep.11-15, (2005).