§25. Interactions of Magnetic Spins with Alternating Magnetic Field at GHz Frequency

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Microwave irradiation to materials is a newcomer for our civilization with a history of only half century. The temperatures of the surroundings are colder than that of targets, that can easily be imagined by a home microwave oven. It clearly suggests that the energy transfer mechanism in microwave heating is quite different from the traditional heating process.

In the heating by infrared to ultraviolet light, the photon energy is large enough to excite the electrons to the higher orbit and to ionization stage directly. If the photon energy is much lower than the band gaps in the atomic shells, the different mechanism must be required. The wavelength is much larger than the dimensions of heated objects at the low frequency in GHz range. It suggest that vectors of magnetic or electric field is equal all over in atomic, molecules and crystal in the materials. As the photon energy is very low, the energy carried by each cycle of the wave is only a few Gauss in the wave propagating with 100 watts/cm^3 at 2.45 GHz. The two characters of field uniformity and low energy in the wave vectors suggest that small collective electron motions generate coupled with the wave. If the ordered motions were scattered by some mechanism, the collective (kinetic) motions of electrons would dissipate and accumulate into the materials. The histolysis heating is the typical example that can be explained by the ordered motion of magnetic walls and energy dissipation caused by delay of magnetic moments in the opposite phases. The experiment shows that the heating continues beyond the Curie temperature *(Tc)*.

Tnaka and coauthors predicted theoretically that such heating is caused by non-resonant response of electron spins in the unfilled 3d shell to the wave magnetic field [1]. Small spin reorientation thus generated leads to a large internal energy change through the exchange interactions between spins, which becomes maximal around Tc for magnetite Fe_3O_4. The dissipative spin dynamics simulation yields the imaginary part of the magnetic susceptibility, which becomes largest around *Tc* and for the microwave frequency around 2 GHz. Experiment has done for proof of the theories to the heating beyond Tc.

High frequency alternated magnetic field applied to a sample placed on the H-field node in the TE103 single mode cavity with the cross-section of 27.2mm x 85 mm. The generator supplied microwave to the cavity at the frequency 2.45 GHz. The microwave power varied from 50 to 1500 watts controlling by the DC power supply consisted of AC-DC inverter. The waveguide was evacuated to 10^{-4} Pa by turbo molecular pump with 100 *l*/s pumping speed. The infrared pyrometer measured the temperature of the sample through the 6mm hole drilled through the end plunger of cavity. The cavity has thin sidewall of aluminum to get enough transparency of the neutron particles for the diffraction measurement. The cavity was installed in the split magnet to apply static magnetic field up to one Tesla. The cavity heating equipments was installed on the beam line on JRR-3 neutron radiation sources.

The sample composed of one micron under Fe_3O_4 powders packed by static press up to 60% of the theoretical density. The size of the sample was 8mm diameter and 4 mm thick pellet that was small enough not to disturb the criterion for fundamental resonance in the cavity. It was put in the H field maxima in the cavity supported by thermal insulator made of a lightweight alumina silica fiber board. It was evacuated in one hour before the microwave application.

The neutron diffractions spectrum was measured under H-field of microwave. Figure 1 shown the polarized neutron scattering profile of Magnetite (111) Bragg reflection at 600℃ with one Tesla. On *Tc* temperature, the neutron scattering intensity was additional polarization independent, i.e. non-magnetic. When the static magnetic field of one Tesla was applied to the cavity, the heating could never observe beyond *Tc*. The direction of the static magnetic field and high frequency magnetic filed were crossed perpendicularly in the cavity. Without external static magnetic field, the temporal evolution of temperature of the sample reached to 1200℃ in 10 second at 100 (W) injection of microwave.

It suggests that the static magnetic filed pined the electron spins so strongly, so that the collective motions could not be excited by microwave beyond the curie temperature where the electron spins can move more freely.

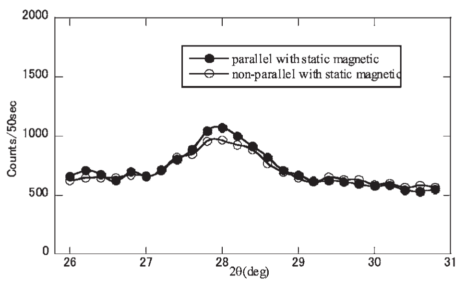

Figure 1: The polarized neutron scattering profile at 600℃

[1] M. Tanaka H. Kono, K. Maruyama, Physical Review B **79**, 104420 (2009)