§8. Nano-Structure Formations by Microwave Irradiations

Sato, M., Tanaka, M., Takayama, S., Matsubara, A., Nishi, N. (Institute for Molecular Science),
Agrawal, D. (Material Research Institute of Pennsylvania State Univ.)

INTRODUCTION

Microwave heating is "the New Flame for Humanity". The process of energy transfer is different principally to the conventional heating. The electromagnetic field couples directly to the electrons in the atoms, molecules and crystals or cluster structures of the materials. The ultimate structures at nano-scales were observed by TEM forming nano-domains consisting of small magnetic domains of 5~20 nanometers with random orientation of the axis

FORMATION OF NANO-DOMAINS

The microwave H and E fields selectively radiated the testing material (sample) that are set either in the H field or E field maximum in the TE103 mode in 2.45 GHz dominant mode rectangular. The testing materials (Fe_3O_4 10micron powder) pressed to a small cylindrical pellet with 6 mm diameter and 3 mm height.

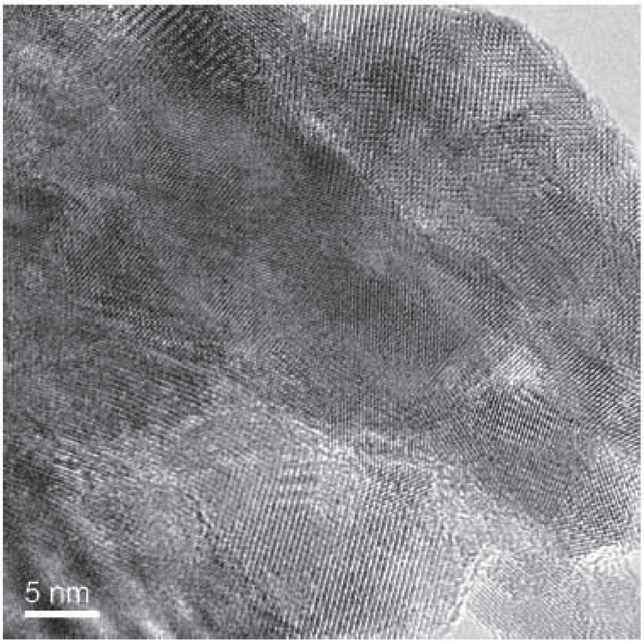

Figure-1 The ultimate structures at nano-scales were observed by TEM forming nano-domains consisting of small magnetic domains of 5~20 nanometers with random orientation of the axis

The temperature increase in the sample is accelerated at a temperature close to the Curie point when the sample set in the H field maximum and never is raised above 1370 K, but it is below the melting point of 1810K. Thus this high temperature state never liquefies the sample but maintains. The applied field energy could be spent for the rotational of the magnetic domains with negligible inter-domain interaction at the temperatures higher than the Curie point. The sudden removal of the field at 1370K is expected to cause the rapid deceleration of the domain rotations that causes the binding of the domains. However, the temperature of 1370K is so higher than the Curie temperature that one cannot expect any strong force for the lattice alignment of the nano-domains. The nano-domain formation with the random crystalline orientation is expected to result in the appearance of glassy morphology in the micron-scale. On the other hand, the heating in the maximum E field did not show any Curie point effect and the temperature increases monotonically up to 1500 K. We could not expect the rotational excitation of magnetic domains so that the cooling the sample should produce larger micro-crystals as observed in TEM images.

THE PHYSICS VIEW

The frequency of the microwave is much lower than the phonon energy. For example, phonon energy at 1100 degree K is 10^{-1} eV, and the photon energy at 2.45GHz is 10^{-5} eV. What is the mechanism that the cold photons accumulate the energy up to the hot phonon levels. Such an irreversible process is strongly related to the second low of thermodynamics. To apply the mechanism in the framework of thermodynamics, the hollowing must be considered carefully.

The first is the numbers of particles to apply the statistical mechanics. Nano is the marginal scale to apply the concept.

The second is the time scales. The quantum mechanics suggest that the relaxation time is the order of picoseconds. While the electric and magnetic fields alternate the direction in the scale of 10~1000 picoseconds. i.e., 200 picoseconds at 2.45 GHz. The time scale of alternation is long enough to establish the equilibrium.

Following model proposed; the directions of electron spins ordered to the direction to magnetic field on each half cycle of applying microwave, the reputations of the ordered motion considered to kinetic works and finally the relaxation processes change the entropy of the system. From the viewpoint of thermodynamics, the microwave field gives the work to the system and the lower entropy state relax to the higher entropy. The analogy the reciprocal engine will help to understand the model in which the motion of piston corresponds to the alternate magnetic field and the adiabatic expansion correspond to the quantum relaxation.