§24. Thermodynamics of Microwave

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Introduction

Microwave heating is effective in the wide range of frequencies from 1 GHz to hundreds of GHz. It suggests that the resonance would not be fundamental mechanism of microwave heating, even if it exists. In this paper, we would take an approach following the non-resonant heating. It suggests that the 2nd law of thermodynamics is the key factor in which the energy can be carried over from lower temperature parts to the higher temperature parts by the works given to the systems externally. It suggests that the large temperature gradients, namely the strong thermally non-equilibrium states, are generated at the microscopic levels in the material. It is the fundamental mechanism of the so called "microwave effect". However, in the conventional heating, the mechanism is quite simple as the high temperature area supplies energy to the lower temperature regions dictated by the 1st law of thermodynamics (Energy conservation law).

In comparison of the classic heating process, the microwave heating is a radically new phenomenon in the 10000 years of the history to be called "new flame for humanity".

2nd law of thermodynamics

The key concepts are the external works, the collective ordered motions and the irreversible energy dissipations.

(1) External work: The alternating microwave field plays an identical role of the external works in the classic thermodynamic system.
(2) Collective motions: As the wavelength is much longer than the sizes of particles in the sample, the field will generate the ordered collective motions with huge numbers of electrons.
(3) Irreversible energy dissipation: The ordered motion transfes/carries the energy into the hot spots. The characteristic decay time is in the order of 10^{-12}~10^{-15} sec that is much shorter than the alternating period of the microwave fields.
(4) The electrons are accelerated to higher energy to pump up the energy into the hot spots.
(5) The electrons lose the energy in the hot spot and return to receive energy.

Energy Carriers or Media excited by the external works

The next question will arise "What is the medium to carry the energy to the hot spots?" The external work couples with the electrons in the material. Because, the electron is the matter to have mobility in response to the alternations of the field at the microwave frequency. The electrons get energy by several mechanisms depending on their mobility. The simplest is the electron current generated by the external electric field. It is blocked in the electron sheath on the surface of the particles and dissipates the kinetic energy on the surface. The irreversible process occurs in the sheath. If they are trapped on the surface, such as the itinerant electrons, more complicated matter will be considered. Electrostatic wave is a candidate to be excited. The frequency is much higher than the applied microwave. The spatial scales and partial density will give the conditions for coupling to Plasmon. If they are the crystals or molecules having unpaired spin, magnon will be the candidate. The frequency of the quantum wave and the coupling conditions depend on the kind and structures of materials. The waves carry energy from all around the hot spot and dissipate it in the spot.

Remarks

Microwave heating can be explained by the analogy to well known heat pump cycles. It works in the media of weakly trapped electrons. The alternated electric or magnetic fields play a role corresponding to "External Works". The hot spot and the surrounding are correspond to high and low temperature bathes.
I,e, when the microwave field going to the reverse direction at the next half phase, the concentrated kinetic energy remains at the spots. The kinetic energy in the hot spot is increasing until it balances to the radiation and conduction losses on the surface of hot spots.