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Microwave Techniques for Physical Property Measurements

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Abstract

Industrial processing of metals and ceramics is now being streamlined by the development of theoretical models. High temperature thermophysical properties of these materials are required to successfully apply these theories. Unfortunately, there is insufficient experimental data available for many of these properties, particularly in the molten state. Microwave fields can be used to measure specific heat, thermal diffusivity, thermal conductivity and dielectric constants at high temperatures. We propose to develop (1) a microwave flash method (analogous to the laser flash technique) that can simultaneously measure the thermal diffusivity and specific heat of insulators and semiconductors at high temperatures, (2) an appropriate theory and experimental apparatus to demonstrate the measurement of the specific heat of a metal using a new microwave ac specific heat technique, and (3) experimental methods for noncontact measurement of the real and imaginary dielectric constants.

In the microwave flash method, a pulse of microwave power is applied to a spherical sample supported within a microwave cavity. The cavity mode and sample and cavity dimensions are chosen to produce an isotropic electromagnetic field about the sphere. This symmetry condition implies symmetric microwave absorption by the sample (i.e., absorption will only depend on distance from the sphere center, which will lead to considerable simplification in the determination of physical parameters). An advantage of microwaves over other heating methods is that the microwave power absorbed by the sample may be experimentally measured (as well as theoretically calculated given the sample complex dielectric constant). Our calculations indicate that in the case of most non-metallic samples it will be possible to determine the sample specific heat by combining the measured sample absorption with the measurement of the resultant sample temperature rise (see Fig. 3). We have already developed a microwave absorption model that can predict the volumetric heating of an isolated sphere. By combining the results of this model with the thermal behavior of the sample, we can also accurately predict the time-temperature response of the sample surface (see Fig. 4). From a comparison of the experimental and theoretical response curves we can then determine the thermal diffusivity. The sample thermal conductivity can be determined if one knows the specific heat and diffusivity.

In case of metallic samples, we propose to obtain a relative measurement of the specific heat using the ac method (see Fig. 5). For this technique the isolated sample is symmetrically heated within the skin depth by a sinusoidally varying microwave field and the associated maximum ac temperature rise is measured by a fast non-contact pyrometer. If the thermal equilibrium time constant of the sample is small compared to the time for heat transfer to the surroundings, then the specific heat is inversely proportional to the ac temperature rise.

Microwaves can also be used to perform noncontact dielectric measurements on non-metallic materials at high temperatures. We have developed and tested several dielectric measurement techniques using the cavity perturbation technique see Fig. 6). In this approach, one measures the microwave cavity resonant frequency and quality factor, with and without the sample present. From the temperature dependence of these measurements, the real and imaginary dielectric constants can be determined as a function of temperature. This method is valid for a small sample. These dielectric measurements are important input parameters to our microwave absorption models discussed above.

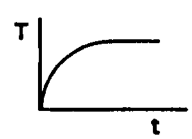
PHYSICAL PROPERTY MEASUREMENTS

- SPECIFIC HEAT, C (NONCONTACT)

  - MICROWAVE PULSE METHOD (INSULATORS, SEMICONDUCTORS)
    - MEASURE ENERGY, ΔE, ABSORBED BY SAMPLE
    - MEASURE SAMPLE TEMPERATURE RISE, ΔT
    - $C = \Delta E / \Delta T$, ΔE (G, Qc, ε', ε'')
    - $\delta E / E \leq 5 - 10$ % FOR INSULATORS, SEMICONDUCTORS

PHYSICAL PROPERTY MEASUREMENTS

- THERMAL DIFFUSIVITY, D (NONCONTACT)
  - THE TEMPERATURE, T, VERSUS TIME, t, CURVE DEPENDS ON D
    - T(t,C,D)



    - GIVEN C AND T(t), CAN BACK OUT DIFFUSIVITY D

- THERMAL CONDUCTIVITY, K
  - $D = K / C$, $K = D\,C$

PHYSICAL PROPERTY MEASUREMENTS

- AC METHOD (METALS, SEMICONDUCTORS)
  - ASSUME SAMPLE THERMAL EQUILIBRIUM TIME CONSTANT IS MUCH FASTER THAN HEAT TRANSFER TO SURROUNDINGS
- APPROACH
  - SINUSOIDAL (AC) MICROWAVE HEATING
  - MEASURE MAXIMUM TEMPERATURE RISE ΔTac
  - $C = A / \Delta Tac$, $A(\Delta E, G)$
  - IDEAL FOR PHASE TRANSITIONS

PHYSICAL PROPERTY MEASUREMENTS

- DIELECTRIC CONSTANTS (NONCONTACT)
  - PERTURBATION METHOD
    - CAVITY RESONANT FREQUENCY,f , AND QUALITY FACTOR, Q
    - Δf , ΔQ BETWEEN EMPTY AND LOADED CAVITY
    - EXTRACT REAL (ε') AND IMAGINARY (ε'') DIELECTRIC CONSTANTS
  - TECHNIQUES
    - HOT WALL FURNACE (LOW MICROWAVE POWER)
    - COLD WALL FURNACE (HIGH MICROWAVE POWER)