DECAY METHOD FOR MEASURING COMPLEX DIELECTRIC CONSTANTS DURING MICROWAVE PROCESSING

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ABSTRACT

We have developed a fast in-situ method for measuring the quality factor, Q, and resonant frequency, f_r, for an isolated microwave resonant mode. The mode resonant frequency was continuously monitored using a phase modulation frequency tracking technique, The quality factor was determined by periodically switching off the microwave power and fitting the decay curve to an exponential. The cavity perturbation method was used with small samples (ka << 1). Combining the Q and f_r data with a non-contact measurement of the sample temperature permits the calculation of the temperature dependence of the real (e') and imaginary (e") dielectric constants. Because of the speed of this technique (≈ 1 µsec), it can be used during processing to continuously measure the dielectric constants of the material without perturbing the sample temperature. Measurements were performed using an isolated TM 010 cylindrical cavity mode with f_r = 4.8 GHz. Care was taken to minimize the perturbing effects of the sample support. The accuracy of the frequency tracker was verified at room temperature from measurements on several alumina spherical samples that yielded ε' = 9.9 ± 0.05 in agreement with published values. The decay technique was also verified from measurements on several small spherical nylon samples that yielded ε' = 3.33* 0.02,&" = 0.040* 0.002.

INTRODUCTION

The ability to measure the dielectric constants of a material during microwave processing is extremely useful. A standard technique for measurement of dielectric constants is cavity perturbation. The technique requires knowledge of the resonant frequency and quality factor of a cavity with and without the sample to be measured. Using this technique at its purest form at high temperatures as a sample is processed poses some challenges. Ideally one wishes to utilize the measurement microwave signal to heat the sample to a desired temperature and then obtain the resonant frequency and quality factor of the cavity, The standard technique for obtaining the quality factor is to sweep the cavity. This may cause some problems if one is using the measurement fields to heat the sample since sweeping the cavity results in a dramatic power transfer change that may affect the sample temperature. Another practical problem in using the measurement field to heat the sample is that the dielectric constants change as the sample heats up and processes. Consequent y, the drive frequency needs to be constantly adjusted to obtain good control over the sample temperature. To overcome these difficulties, we developed a method for continuous and automatic tracking of the cavity resonant frequency and applied a decay technique to obtain the quality factor of the cavity.

PROCEDURE

Fig. 1 is a block diagram of the setup used to accomplish this measurement. The microwave sourcewas a sweep oscillator with FM and AM capability that was connected to a traveling wave tube (TWT) amplifier through a high speed microwave switch. A crystal detector monitored the reflected and transmitted power and an non-contact IR thermometer measured the temperature of the material.

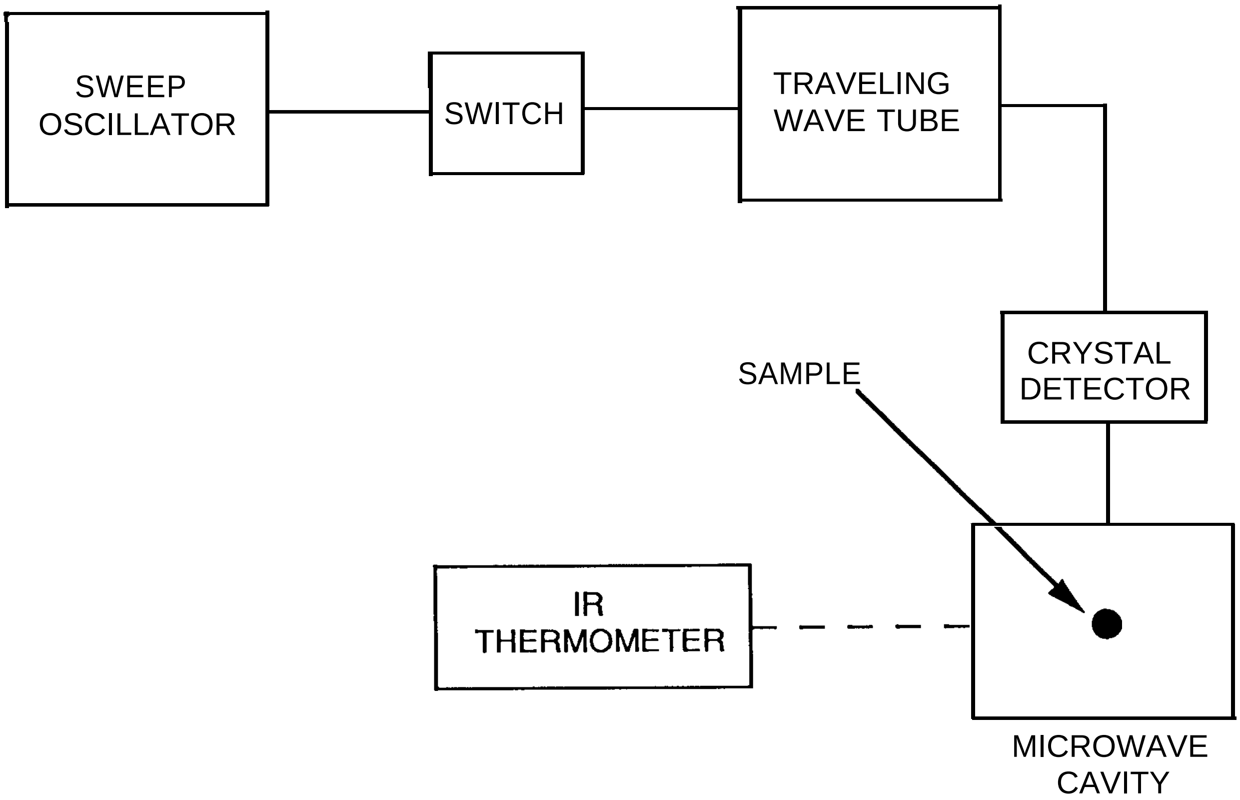

Fig. 1 Schematic of Experimental Arrangement

Fig. 2 is a block diagram of the electronic circuit used to track the resonant frequency of the microwave cavity. The microwave frequency from the oscillator was slightly modulated (± 2 KHz) at the rate of 20 KHz. This modulation resulted in a 20 KHz signal in the reflected or

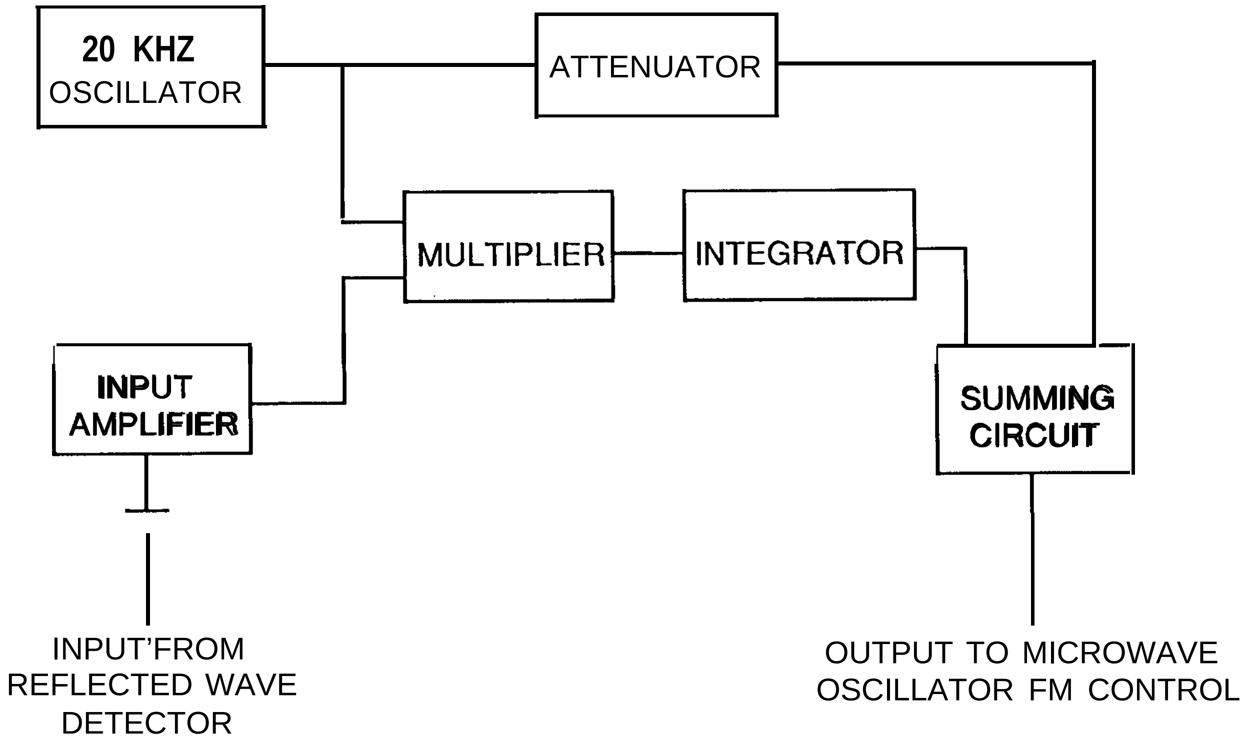

Fig. 2 Schematic of Cavity Resonant Peak Tracker

transmitted power. This detected signal was then amplified and multiplied by the initial modulating signal. If the microwave frequency was exactly at the resonant peak the resulting product will have no DC component. However, if the center frequency of the microwave oscillator is not at the peak of the cavity resonance, a proportional DC component is developed. The polarity of this component is determined by whether the frequency is above or below the resonant peak. This DC component was then integrated to produce an error signal that was summed and sent to the FM input of the microwave oscillator. This error signal shifted the oscillator frequency in the direction that reduced the error signal. Using a HP sweep oscillator we were able to track the cavity resonance over a range of 200 MHz. The response time of the tracker was only limited by the modulation frequency rate. The 20 KHz modulation rate used in this study resulted in an undetectable shift from resonance at any time.

The quality factor of the cavity was obtained by periodically turning off the microwave signal into the TWT through a high speed microwave switch attached to the output of the oscillator. The switch (≈ 15 nsec) was controlled by a voltage signal from a pulse generator. The rate at which the switch was turned off depended on the type of measurement needed. The length of time that the switch is off is under 1 µsec. During the "off" time the microwave power inside the cavity decays. This decay process obeys the usual exponential law. The decay was monitored by a high speed digitizing oscilloscope[1] from which the data may be downloaded to a computer. To extract the Q one needs to fit this data to an exponential line shape. Since typical decay times are about 100 nsec, care must be exercised when detecting this rapidly decaying signal. A load resistor (≈ 470 ohm) is placed on the output of the cavity power detector diode to prevent the inherent capacity of the diode, the coaxial line length, which should be minimized, and the measurement instrument from dominating the decay[2]. The major benefit of this method is the high speed at which the data is acquired which means that the sample temperature remains a constant and the resonant tracker is able to maintain the oscillator frequency at the resonance. Also, due to the speed one can average over many decays to improve accuracy.

MEASUREMENTS

To verify this technique we first compared a decay to a sweep measurement (Figs. 3 and 4) and obtained agreement to better then 1%. Next we measured the dielectric constants of alumina and nylon using a TMO1 O cylindrical cavity mode with a resonant frequency of 4.8 GHz. The samples used where all spherica, ranging in diameter from 0.085 to 0.20 inch. The samples where placed at the center of the cavity for measurement. They where supported on two thin (5 roil) quartz strings placed along the diameter of the cavity. This orientation is preferred since the TMO1 O mode doesn't have an electric field component along the radial direction. The small volume of the strings and their orientation results in a minimum perturbation to the field around the sample due to the support that is a fundamental requirement for cavity perturbation theory to be valid.

The measurements where performed at low power using both the standard technique of sweeping and tuning the cavity and the tracking decay technique. In the case of the former technique the frequency was monitored with a standard frequency counter while the decay was

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1 It is not necessary to use a very high speed scope if one doesn't need to collect data at very high speed, a >1OOMHZ bandwidth scope that require many triggers to reconstruct the signal could be used.

2 Using a 470 ohm resistor in parallel to the diode with the diode placed directly at the input of the oscilloscope one obtains a decay time constant of about 10ns assuming an input capacity for the scope of 13pf. Note that had we used a length of coaxial cable from the diode output to the scope the time constant would have signifi cantly increased to a point where it may introduce significant errors into the decay of the cavity.

recorded using an HP54601 A digitizing scope.[1] The resultant dielectric constants compared well to each other and to published results for the materials at room temperature. A Quantitative demonstration was performed at high temperature with zeolite with good results. This demonstrated the ability of the setup to track the resonant frequency of a changing cavity while obtaining the quality factor using decays with accuracy.

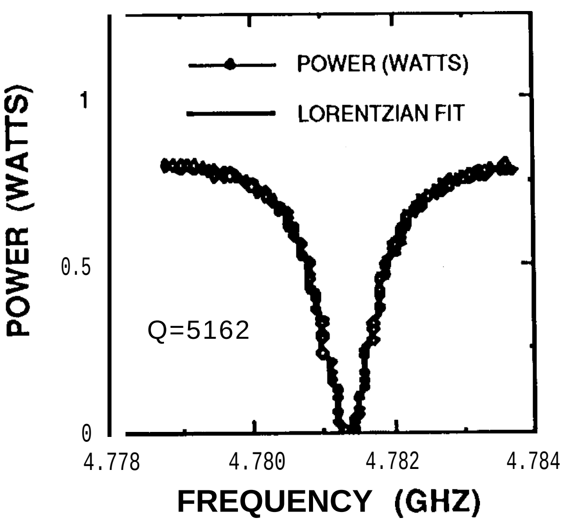

Fig. 3. Frequency sweep of the TM_{010} mode and fit to a Lorentzian line shape.

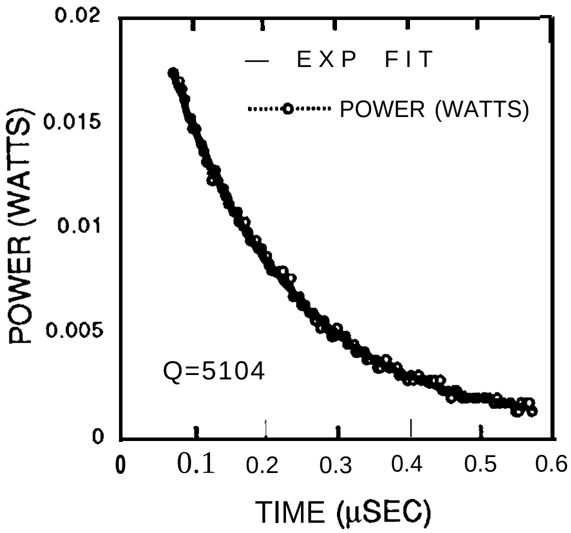

Fig. 4. Decay of the TM_{010} mode and fit to an exponential.

CONCLUSIONS

We demonstrated a simple technique for measuring the quality factor of a cavity and tracking its resonance under changing conditions. We established the accuracy of the setup by measuring several samples of materials at room temperature. We also established that with better automation as far as data gathering is concerned this technique could deliver a consistent low cost method for diagnosing microwave processing of materials.

ACKNOWLEDGMENT

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