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Measurement of Dielectric Constant of Waxes at Different Temperatures using Split Ring Resonator Structure

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***Abstract*—Dielectric constant variation with temperature for different wax samples is analysed with the help of split ring resonators (SRRs). The method employs a simple extraction procedure to obtain the unknown permittivity values from a calibration curve drawn between relative permittivity of standard samples and resonant frequency of SRR with each of the samples placed above it. The wax sample is placed on the SRR surface and its transmission characteristics are analysed using a vector network analyser (VNA) with its transmitting and receiving probes placed on either side of the SRR - sample system. The temperature is gradually increased from room temperature to 60°C with the help of a hot metal plate placed near the SRR. The dielectric constant of wax sample in contact with the SRR surface varies with the temperature, which in turn changes the capacitance of the SRR, resulting in a shift in its resonant frequency. The method has its advantages like simple experimental setup, direct measurement and ease of sample preparation.**

I. Introduction

Several industrial and household applications like lubricants, cosmetics, candles etc. utilizes the diverse properties of waxes. Like all dielectrics, structural and electrical properties of waxes are dependent upon temperature. There are several techniques existing for measurement of relative permittivity of dielectric samples at higher temperatures. Some of them are circular cavity method, open ended coaxial probe method and circular waveguide method. A broadband microwave system is presented by Li *et. al.*, that measure dielectric properties of low-loss materials at high temperatures using circular cavity method [1]. An open ended coaxial probe method for glass ceramic and porous alumina are done by Gershon *et. al* [2]. Measurement techniques using coaxial lines, wave guides and cavity perturbations are explained in the literature [3]. Many of these methods demand bulky experimental setup and detailed calculations.

Factors contributing to the temperature dependence of dielectric constants of materials are analysed by E. Havinga using some alkali halides and $BaTiO_3$ as samples [4]. Analysis of variations in dielectric constant with temperature of the material shellac is done by Srivastava *et. al.* [5]. A study on electric properties such as dielectric constant and dielectric loss is conducted in the p-band microwave frequencies for the solid samples of bees wax, paraffin wax and microcrystalline wax using Von Hippel method at room temperatures [6]. The analysis in the above referred work is done for wax samples after heat treatment also. But a detailed study on permittivity variation of wax samples under continuous variation of temperature is not found in the literature. In this paper we present the study of temperature dependence of dielectric constant of three wax samples (bees wax, bran wax and paraffin wax) by using split ring resonator (SRR).

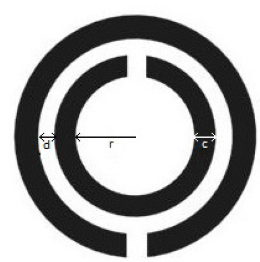

Fig. 1. Schematic representation of the Split Ring Resonator (SRR) with its structural parameters - inner radius (r), ring width (c) and spacing (d)

SRRs are artificial constituent molecules of metamaterials showing negative permeability and having a LC resonant nature. The sensitive nature of the resonant frequency of SRR arising due to small changes in the permittivity of the medium in contact with it is studied in some of the previous works [7]–[9]. When a dielectric sample is placed on the surface of SRR the resonant frequency gets redshifted due to an increase in the capacitance of the resonator. Fig. 1 shows the structural representation of SRR with its structural parameters - inner radius (r), ring width (c) and spacing (d) and the resonant frequency is given by

$$f = \frac{1}{2\pi\sqrt{LC_{(\epsilon_r)}}} \tag{1}$$

where L is the inductance and C is the capacitance of the resonator which is a function of relative permittivity (ϵ_r) of the sample.

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As SRRs are usually fabricated using conductors on dielectric substrates, they are very much prone to changes in the environmental conditions especially the temperature. Varadan *et. al.* had done a study on shift in the resonant frequency of SRR in terms of the temperature dependence of the metallic structure, substrate permittivity and electrical conductivity [10]. It is reported that the resonant frequency variation is primarily affected by the change of permittivity of the substrate.

Here we use an extraction procedure from the calibration curve of known dielectric samples and resonant frequencies corresponding to them. The detailed measurement technique to measure the permittivity of dielectric samples at different temperatures is explained in our former work [11]. This method is much easier and efficient than other existing methods especially at low temperature regions.

II. EXPERIMENTS AND MEASUREMENTS

SRR used for the measurement is fabricated on a glass epoxy board (ϵ_r = 3.7) using photochemical etching method. Dimensions of the SRR are r = 2 mm, d = 0.5 mm and c = 0.75 mm. A single SRR unit is used as a test probe which is placed between transmitting and receiving probes. These coaxial probes are connected to a Vector Network Analyzer (VNA). Resonant frequency of SRR at room temperature (29 °C) is found to be 3.469 GHz (f_{r0}). The only constraint for selecting the sample is that, its thickness should be at least equal to c+d/2 [11].

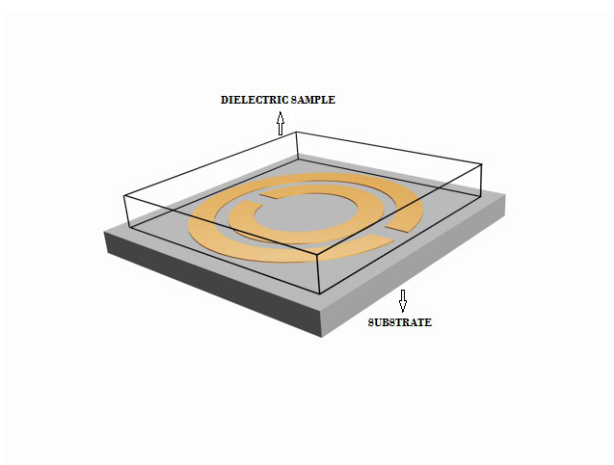

Fig. 2. Schematic diagram of the experimental setup with sample placed on the SRR fabricated on a substrate.

A. calibration curve

The calibration curve has been drawn between resonant frequency of SRR and relative permittivity of samples. For this we have selected four samples - glass, glass epoxy board, perspex and plastic. They are then placed on the surface of SRR (Fig. 2) and their resonant frequencies in GHz obtained are 2.48, 2.8797, 3.0398 and 3.1199 respectively. From the cavity perturbation method [12] we obtained the dielectric constants of these samples as 6.07, 3.58, 2.45 and 2.1 respectively. Fig. 3 is the calibration curve thus obtained. It is observed that resonant frequency decreases as the dielectric constant of the material increases. Relative permittivity of any unknown test sample in close contact with the surface of the SRR can be extracted from this calibration curve if corresponding resonant frequency of SRR - sample system lies on the curve.

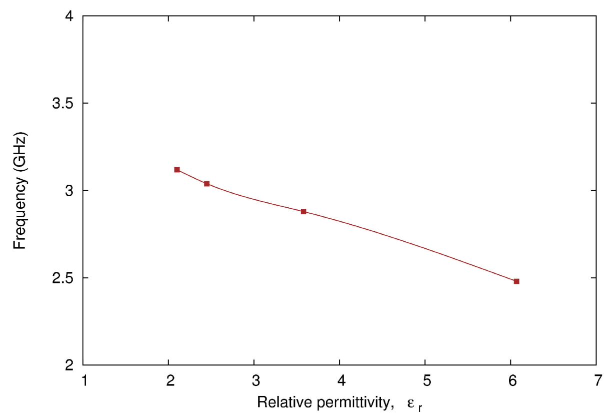

Fig. 3. Calibration curve between the resonant frequency and the relative permittivity of four standard samples.

B. Temperature dependence of SRR

When we measure the resonant frequency of SRR with sample placed on its surface and temperature is increased from the room temperature, the SRR also heats up with the whole system which also changes the resonant frequency. Hence to obtain accurate value of resonant frequency due to the increasing temperature of the wax sample a correction must be applied to the measured resonant frequency. For this the resonant frequency of SRR alone is measured at different temperatures and the values are represented as f_{t0} and are given in Table I.

TABLE I
RESONANT FREQUENCY OF SRR AT CORRESPONDING TEMPERATURES

Temperature(°C)	f_{t0} (GHz)
30	3.4578
35	3.4333
40	3.4184
45	3.4039
50	3.3898
55	3.3710
60	3.3518

C. Study of temperature dependence of wax samples

To study the temperature dependence of dielectric constants we have selected three samples of waxes *viz.* bees wax, paraffin wax and bran wax. The temperature of the test sample placed over the SRR is gradually increased using a heated metal sheet placed near the SRR - sample setup. An ordinary thermometer is used for the temperature measurements. Then different test samples are placed on the SRR and corresponding resonant frequencies are measured and are represented as f_{t1}. Transmission curves at different temperatures for paraffin wax placed over SRR is given in Fig. 4. From the figure we can see that as the temperature increases resonant frequecny decreases. The shift in resonant frequency $(f_{r0} - f_{t0})$ for each temperature is calculated as a correction factor and subtracted it from f_{t1}. The obtained resonant frequency f is the corrected resonant frequency.

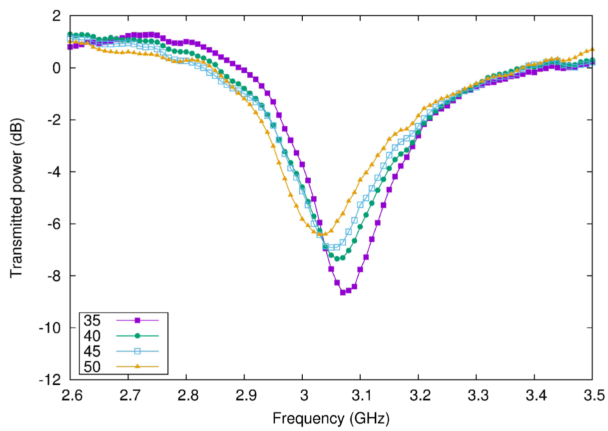

Fig. 4. Transmission curves of SRR at temperatures 35°C, 40°C, 45°C and 50°C with paraffin wax placed over it.

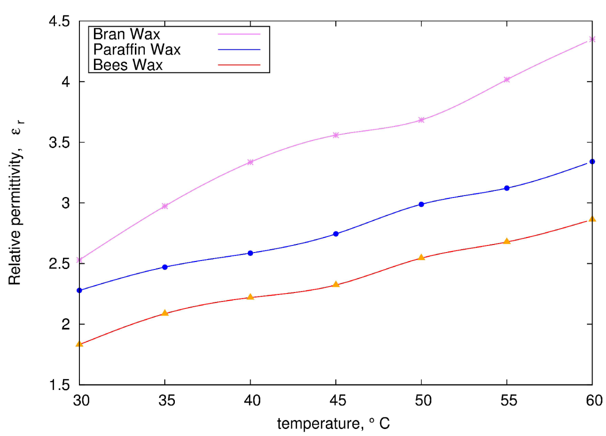

Fig. 5. Relative permittivty variation with temperature for bran wax, paraffin wax and bees wax samples

The permittivity values corresponding to each of the resonant frequencies (f) is found out from the calibration curve. The values of resonant frequencies and relative permittivity values are given in the Table II. Fig. 5 shows the variation of relative permittivity of the three wax samples with increasing temperature.

III. Results and Discussion

Fig. 4 shows that the resonant frequency of SRR decreases as the temperature of the sample in contact with it increases.

TABLE II
RESONANT FREQUENCY AND RELATIVE PERMITTIVITY OF WAX SAMPLES CORRESPONDING TO DIFFERENT TEMPERATURES

Sample	Temperature (°C)	f_{t1} (GHz)	$f = f_{t1} - (f_{r0} - f_{t0})$ (GHz)	Relative permittivity from the graph (ϵ_r)
Bran Wax	30	3.044	3.032	2.5298
	35	2.989	2.953	2.9737
	40	2.960	2.908	3.3361
	45	2.950	2.884	3.5582
	50	2.939	2.859	3.6840
	55	2.919	2.821	4.0166
	60	2.889	2.771	4.3496
Paraffin Wax	30	3.090	3.077	2.2785
	35	3.070	3.033	2.4708
	40	3.06	3.008	2.5859
	45	3.05	2.984	2.7444
	50	3.03	2.949	2.9886
	55	3.03	2.931	3.1218
	60	3.03	2.911	3.3410
Bees Wax	30	3.168	3.156	1.8321
	35	3.160	3.124	2.0864
	40	3.146	3.094	2.2192
	45	3.131	3.065	2.3229
	50	3.100	3.019	2.5447
	55	3.099	3.000	2.6779
	60	3.087	2.968	2.8628

This is due to an increase in relative permittivity with increase in temperature. By analysing Fig. 5 and Table II we can conclude that the relative permittivity varies linearly with temperature for wax samples. The variation for paraffin and bees waxes are observed to be showing similar characteristics. For an increase of 30°C in temperaure, the bran wax showed a larger increase in relative permittivity (1.8198). For the same increase in temperature, bees wax and paraffin wax showed an increase by 1.0307 and 1.0625 respectively.

IV. Conclusion

We have analysed the temperature dependence of relative permittivities of three wax samples - bees wax, bran wax and paraffin wax - using SRR method. The technique employed resonant frequency measurement using a single metamaterial SRR structure as a test probe. Sample taken are of sizes comparable to the size of the SRR. The method has many advantages over existing techniques like simple and compact experimental setup, direct measurement technique and ease of sample preparation. The measurement does not involve any detailed calculations. The measurement method is intended to be improved by using more precise temperature measurement setup and heating techniques in future.

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