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Study on Dielectric Behaviour of Waxes in p-band region

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Abstract: A study on electric properties such as dielectric constant, dielectric loss, electric conductivity, and the penetration depth is conducted in the p-band microwave frequency range, of 12.4 GHz to 18.0 GHz for the solid samples of bees wax (BW), paraffin wax (PW) & microcrystalline wax (MW). The transmission line technique using vector network analyzer (VNA) is employed in the study. The dielectric properties of different waxes in their normal condition and after heat treatment are investigated. The study reveals that the conductivity and dielectric loss decreases after heat treatment with respect to frequency.

Keywords - Dielectric constant, Dielectric loss, penetration Depth, Conductivity, Beeswax, Paraffin wax, Micro-crystalline wax.

INTRODUCTION

Natural waxes are derived from animal sources such as beeswax. Natural waxes are also derived from petroleum like paraffin wax and microcrystalline wax. Chemically wax is a type of lipid that contains a wide variety of long chain alkanes, esters, alcohols and fatty acids.

Sanat Kumar, *et al*[1] studied composition and properties of some petroleum waxes. The thermal properties viz, phase transition temperature and the associated energy during phase transition was determined using Differential Scanning Calorimeter (DSC). Maria Peterson, *et al.*[2] has reported comparison of micro structural and physical properties of the petroleum waxes. They have worked on the inherent properties of waxes using IR, DSC & XRD. Kotb, *et al.*[3] studied thermal characteristics of paraffin wax for solar energy storage. They found that the instantaneous rate of heat storage decreases till it reaches a nearly constant value. Michael Matthal *et al.*[4] investigated the dependence of penetration on the temperature and composition of paraffin waxes. They have demonstrated that, in addition to crystallinity, the chain length of the n-alkanes also plays a decisive role in the penetration or temperature behavior. A review of literature indicates the information about thermal and structural properties of waxes. But no information is available on dielectric properties of waxes. Therefore, the objective of this study is to determine the dielectric properties of different waxes. Dielectric permittivity is one of the factors that determine how a material interacts with an applied electromagnetic field[5-6]. From the study of dielectric property one can get the knowledge on signal attenuation, phase change and presence of moisture in the material. Different methods are used to measure the dielectric constant and loss. The lumped circuit techniques are only suitable for low frequencies and high loss materials[7]. Depending on the dielectric material the measuring equipment and sample holder is designed. The fundamental concept of network analysis includes incident, reflected and transmitted waves travelling along transmission lines[8]. The Network analyzer has a broadband frequency range of 300 kHz to 325 GHz and is used to analyze the electrical networks properties associated with reflection and transmission of electrical signal known as scattering parameter. It consists of microwave signal source for stimulus, signal separation devices, receivers that detect incident, reflected, and transmitted signals and processor or display for calculating and receiving the results. When any material is exposed to microwave, part of energy is reflected while the remaining is transmitted through it. Again from this, part of energy which is absorbed in different proportion is defined as dielectric property. Many materials are mixture of different sized molecules. The permittivity of these mixtures will depend on interaction of these molecules, their mass charge and charge distribution.

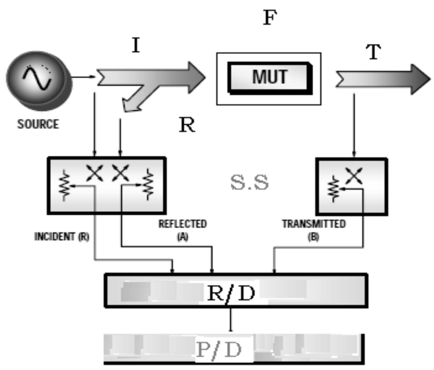

Fig.1: Generalized Network Analyzer Block Diagram. S- Source of microwave signal, I-incident wave, T- transmitted wave, R- reflected wave, F- fixture, S.S- signal separation, R/D- receiver/detector, P/D- processor/display

In network analyzer, there is need of devices for division of signals. Receiver is the device which detect downloads and converts the signals. The displayers or processors are the devices which show the result. A reflection measurement is the ratio of reflected signals detected over the incident signals detected by receiver or detector. A transmission measurement is the ratio of transmitted signal detected over the incident signal detected by receiver or detector[9,10].

There are two types of network analyzer:

1. VNA (vector network analyzer)
2. SNA (scalar network analyzer)

VNA is used to measure both magnitude and phase properties, while SNA measures amplitude property. To measure dielectric constant at higher frequency range above 1 GHz transmission line, resonant cavity and free space techniques are used[11-15]. The dielectric property can be measured in different ways i.e. reflection or transmission types using resonant and non resonant systems with closed or open structures. To study the property of closed structures wave guide and coaxial line, the closed transmission line method is used[16-20]. Similarly to study open structures and free space measurement open ended coaxial line transmission method is used. In reflection measurements one port device is used while for transmission measurements two ports devoice is used.

Transmission line system: In transmission line technique, the sample is kept in sample holder which is present in between two ports. It consists of sample holder, computer and software. This software converts the transmission co-efficient to dielectric properties. This technique is used for solid materials which are made to fit with the waveguide. The same can also be used for low loss materials. The results are more accurate compare to other techniques. The behavior of the material can be studied under the range of frequency 0.1 to 325 GHz. As the frequency decreases the size of the sample is increased. For higher frequency the size of the sample must be small compared to lower frequency sample. Transmission line technique can be used to measure magnetic properties of the material.

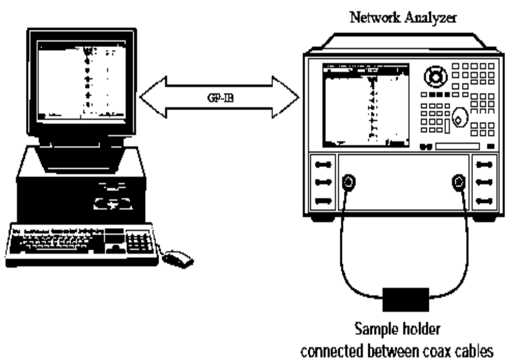

Fig.2: Transmission Line System

MATERIALS AND METHODS

The waxes were purchased from noted company SDFCL. The samples are prepared in rectangular cuboids shape of dimension of p- band using a die for both normal condition and after heating treatment to different waxes such as beeswax, paraffin wax and microcrystalline wax. For wax samples transmission line technique is used because wax is a low loss material. The advantage of using this method is due to wide availability of waveguide fixtures of broad frequency range. Von Hippel method requires measurement of the standing wave ratio (SWR) with and without sample. Depending on the length of the sample and the dimension of wave guide the shift of the SWR node changes. By using suitable computer programs one can calculate ε' and ε''. In network analyzer, the dielectric sample is placed in rectangular cross section sample holder which is connected between coaxial cables. In this, the phase shift and attenuation are the two parameters of the complex transmission coefficient and are measured. From these values, the dielectric constant and loss of the material are calculated using the program written for this purpose. The fundamental electrical property through which the interactions are described is the complex relative permittivity of the material ε *. It is mathematically expressed as

$$\varepsilon^* = \varepsilon' - j\,\varepsilon''$$

Where ε′= dielectric constant, ε"= dielectric loss factor, Penetration depth (d_p) of microwave is defined as the depth where the power is reduced to 1/e or 36.8% of its transmitted value of the power entering the surface. Sometimes penetration depth (d_p) is defined as the distance at which the microwave power has been attenuated to 50% of transmitted power. The penetration depth is a function of ε′ and ε".

$$d_p = \lambda_0 \sqrt{\varepsilon'} / 2\pi\,\varepsilon''$$

Where λ_0 = free space microwave wave length (for 12.4 GHz λ_0 =2* 1.5 cm)

The conductivity of the material is measured in terms of its resistivity. The conductivity of the crystalline materials can be measured by two methods i.e. dc and ac electrical conductivity. The dc electrical conductivity can be measured by using electrometer where as ac electrical conductivity is measured by using network Analyzer. The unit of conductivity is Siemen/cm or mhos/cm. AC electrical conductivity method is widely used, because there are some difficulties in DC electrical conductivity method. The AC conductivity is given by

$$\sigma = \omega\,\varepsilon_0\,\varepsilon''$$

Where ω = angular frequency, ε_0 = permittivity of free space, ε" = imaginary part of dielectric constant.

$\varepsilon'' = \varepsilon' \tan\delta$, where tanδ is the loss tangent

$\tan\delta = 1/\tan\theta$, where θ is the phase angle

$\varepsilon' = C\,d / A\,\varepsilon_0$, where C is the capacitance; d = Thickness ; A = Area of the sample

Then $\sigma = 2\pi\nu\varepsilon_0\varepsilon \tan\delta = 2\pi\nu\varepsilon_0\varepsilon''$, Where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m.

$\sigma = 2\pi\nu\varepsilon_0\varepsilon''$

RESULTS AND DISCUSSION

A comparison of dielectric constant (ε′), dielectric loss (ε"), penetration depth (d_p), and conductivity (σ) of different waxes in different conditions like normal and after heat treatment is measured at the frequency of 12.4 and 17.9GHz presented in Table 1 & 2 respectively.

Table-1: Dielectric data on waxes at 12.4 GHz

S. No.	Sample	Frequency ν (GHz)	ε′	ε "	Penetration depth, dp(cm)	Conductivity, σ ($\times 10^{-3}$ mho/cm)
1	Beeswax (n)	12.4	2.99	0.80	7.81	55.20
2	Beeswax (h & c)	12.4	2.84	0.09	7.17	61.89
3	Paraffin wax (n)	12.4	3.24	0.01	22.98	08.82
4	Paraffin wax (h & c)	12.4	2.98	0.02	15.59	11.58
5	Microcrystalline wax (n)	12.4	3.07	0.06	5.59	81.06
6	Microcrystalline wax (h & c)	12.4	2.90	0.04	10.87	30.32

Table-2: Dielectric data on waxes at 17.9 GHz

S. No.	Sample	Frequency ν (GHz)	ε′	ε″	Penetration depth, dp(cm)	Conductivity, σ ($x10^{-3}$ mho/cm)
1	Beeswax (n)	17.9	2.75	0.02	14.97	19.10
2	Beeswax (h & c)	17.9	2.60	0.01	20.59	08.85
3	Paraffin wax (n)	17.9	3.00	0.02	15.64	15.62
4	Paraffin wax (h & c)	17.9	2.75	0.08	07.49	75.31
5	Microcrystalline wax (n)	17.9	2.85	0.05	9.64	51.04
6	Microcrystalline wax (h & c)	17.9	2.67	0.03	12.05	26.16

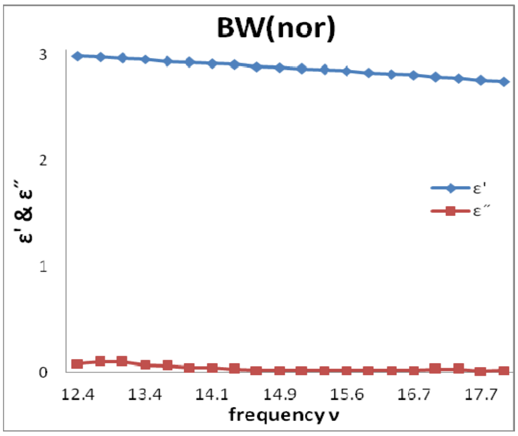

Fig. 3: Variation of (ε′) and (ε″) with υ

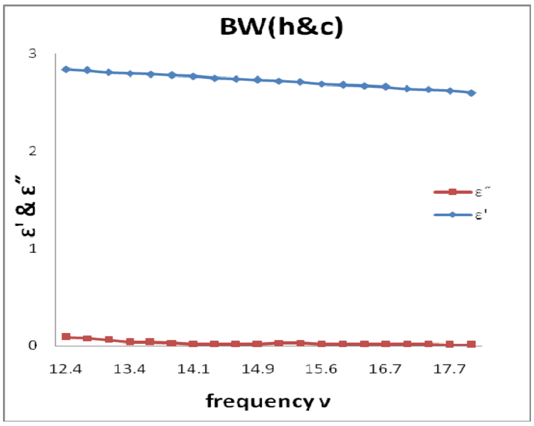

Fig. 4: Variation of (ε′) and (ε″) with υ

Fig. 3 and 4 represent the variation of the dielectric constant (ε′) and dielectric loss (ε″) with frequency (ν) for beeswax in normal and after heat treatment.

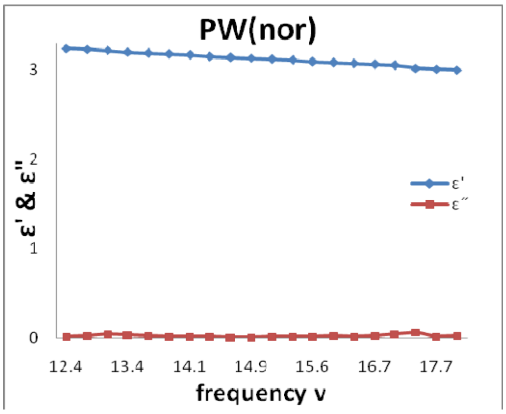

Fig. 5: Variation of (ε′) and (ε″) with υ

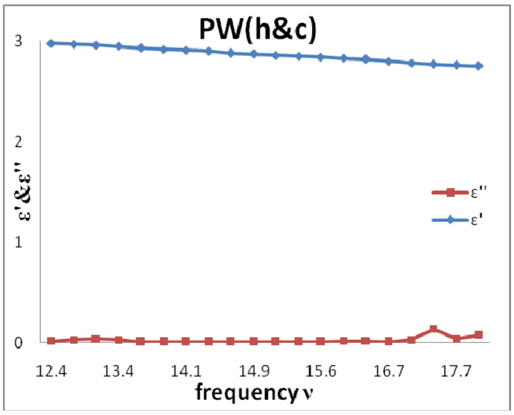

Fig. 6: Variation of (ε′) and (ε″) with υ

Fig. 5 and 6 represent the variation of the dielectric constant (ε′) and dielectric loss (ε″) with frequency (ν) for paraffin wax in normal and after heat treatment.

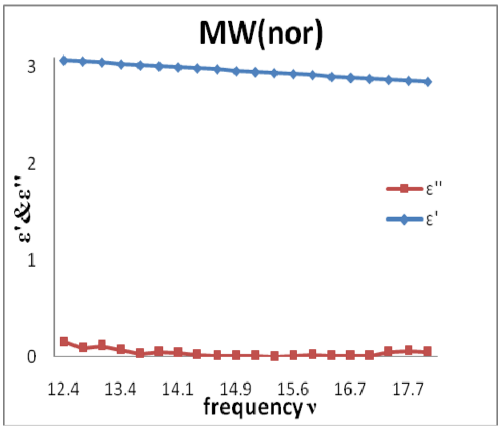

Fig. 7: Variation of (ε′) and (ε") with υ

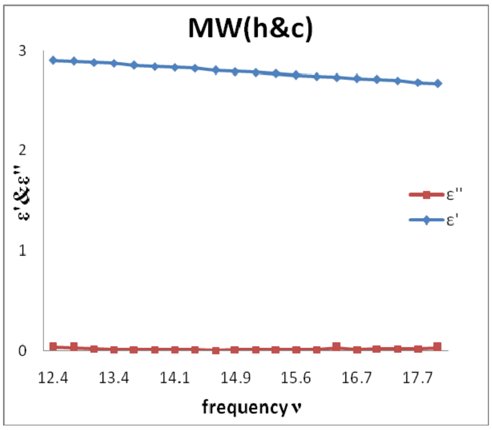

Fig. 8: Variation of (ε′) and (ε") with υ

Fig. 7 and 8 represent the variation of the dielectric constant (ε′) and dielectric loss (ε") with frequency (ν) for microcrystalline wax in normal and after heat treatment.

In all above cases the study represents a decrease in dielectric constant (ε′) and changes on dielectric loss (ε") with the increase in frequency as shown in Fig 3 to 8.

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