A Quasi-Optical Free-Space Method for Dielectric Constant Characterization of Polymer Materials in mm-wave Band

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Abstract: Polymers attract more and more attention as low loss dielectric materials in RF and millimeter wave field, because of their interest properties at high frequencies. In this work, we report a Quasi-Optical free-space method to derive W-band dielectric constant of some common-used polymers including Polymethylmethacrylate, polyvinylchloride, Nylon66, Mylar, polytetra-fluorethylene, polypropylene, high and low density polyethylene, kapton and polyethersulfone. Free-space transmission/ reflection coefficients of the aforementioned materials are measured with a millimeter wave network analyzer. Genetic algorithm (GA) is employed to compute the complex dielectric constant. The results are compared with those in other previously published works.

Introduction

Polymers are materials of interest to a wide range of applications including the millimeter-wave package. Their excellent electrical insulation properties and high temperature resistance, make them excellent candidates as low dielectric materials for millimeter wave applications such as lenses, windows, power supplies, connectors, industrial controls and dielectric waveguides [1]. The use of polymeric, rather than glass offers number of advantages: polymeric devices can be produced from a master template, thus improving device-to-device reproducibility; the wide range of polymeric materials available means that devices can be produced which have specific physical and chemical properties tailored to meet the requirements of a particular separation technique. Processes such as injection moulding or hot embossing can be used to produce large numbers of polymeric devices at a low cost [2].

The knowledge of dielectric properties is necessary to know if the material is suitable for a specific application. These properties include the complex permittivity and the dissipation factor. Many publications have reported the dielectric constant of polymers (examples [3] and [4]), however in which majority of the data are in frequency range lower than w-band. In millimeter frequency range a few methods are recently proposed: Afsar uses broad-band technique based on Fourier transform, in [1] and [5], to compute the permittivity data of polymers in frequency range 40-300 GHz. It is well known that this method exhibits sufficient accuracy only above 100 GHz [6]. Therefore [6] uses the same technique but in the range of 75-95 GHz for some nonpolar polymers.

In this paper we use the Quasi-optical free space technique in the frequency range 70-110 GHz. Transmission/Reflection method is employed with baseline calibration. The complex permittivity is computed from the measured S_{11}, S_{21} using Genetic algorithm (GA). We study two different classifications of polymers; on the one hand polar polymers, such as polymethylmethacrylate (PMMA), polyvinylchloride (PVC) and wavon Nylon66 (ZBF AG, CH-8803 Ruschlikon); and on the other hand non-polar polymers such as Mylar, polytetrafluorethylene (PTFE), polypropylene (PP), high density polyethylene (HDPE), low density polyethylene (LDPE), kapton and polyethersulfone (PES).

Measurement method

An AB Millimêtre MVNA-8-350-2 vector network analyzer is used to measure the reflection and transmission coefficients S_{11} and S_{21}. The network is shown schematically in Fig.1. It consists of two ports; a Harmonic Generator HG (the source), and a Harmonic Mixer HM (the detector). The beam generated by HG is reshaped and redirected using a conical horn and four mirrors, positioned with the surface at an angle of 45^o to the optical axis. In order to minimize the standing waves effects, the ports are equipped with a full band isolator.

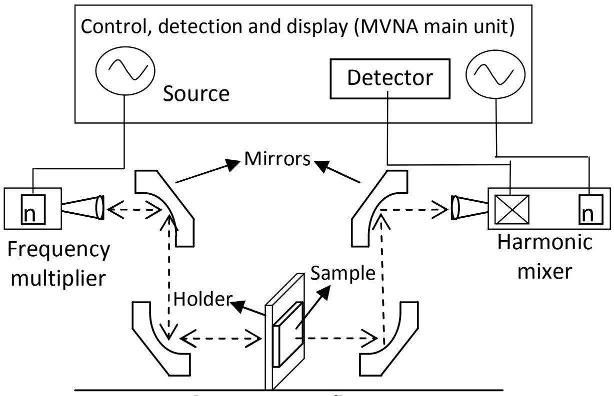

Fig. 1. Quasi-optical mm-wave reflection/transmission setup

For normally incident beam, before reflection and transmission coefficients are measured, the system is first calibrated using the baseline calibration method to remove the effects of mismatches. The transmission is calibrated using an open or empty sample holder fixture while the reflection is calibrated using a metal mirror plate placed at the sample plane. This is a very simple and costless calibration method. After calibration has been performed, the DUT is positioned on the holder. S_{21} and S_{11} are simultaneously measured. The illumination frequency is swept from 70 to 110 GHz with step of a 43 MHz. All samples are shaped in a flat format; also all measurements are performed at room temperature. The relative complex permittivity is computed from the measured S_{11}, S_{21} by using GA algorithm. To know how S_{11}, S_{21} are related to the dielectric permittivity see [7] and [8]. The accuracy of the achieved values depends mostly on the measurements of the vector analyzer and the uncertainty in dimensions of the dielectric samples. In the case of thin samples, the measured S_{21} suffers from many spikes which affect the computation process, thus the measured data are fitted into polynomial curves before using them. The thicknesses of the samples were measured using Mitutoyo corp. with a resolution of 1 μm and a range of 50.8–0.001 mm and an accuracy of 0.006 mm.

Results and Discussion

The reflection and transmission coefficients of a set of polymers are measured in W-band frequency range. GA was able to compute precisely the complex permittivity, although the accuracy of the imaginary part is slightly lower than the accuracy of the real part. The results are shown in Figs. 2-7. They are in very good agreement with the previously published data ([1], [5] and [9]). A comparison of our results with earlier published work at different frequencies is reported in Table 1. It can be seen that accurate values for the permittivity are obtained. The polymer PES exhibits a noticeable change in its imaginary part with respect to the frequency. Moreover the computed imaginary part of the permittivity of Mylar at 100 GHz is 0.0055; this value is close to the result obtained by [9], whereas [10] gives higher value (0.032). Furthermore both LDPE and HDPE show an increasing of absorption towards high frequencies (>90 GHz).

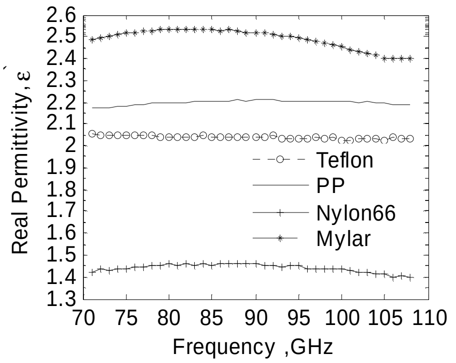

Fig.2. The real part of dielectric permittivity for Teflon, PP, Nylon66 and Mylar.

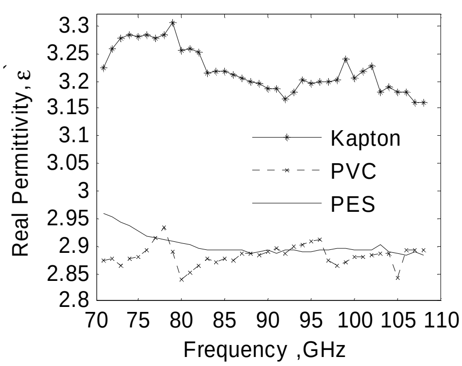

Fig.3. The real part of dielectric permittivity for Kapton, PVC and PES.

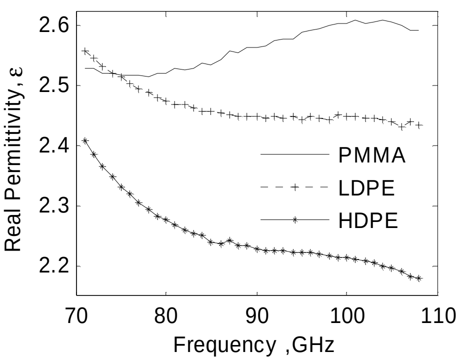

Fig.4. The real part of dielectric permittivity for PMMA, LDPE and HDPE.

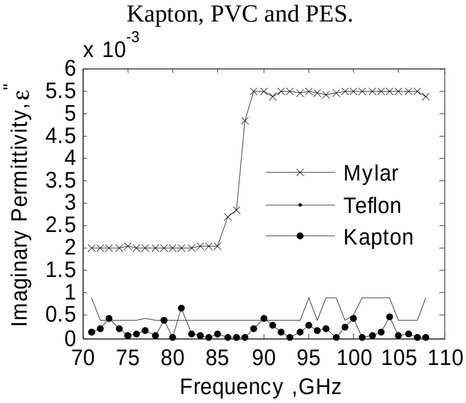

Fig.5. The imaginary part of the permittivity for Mylar, Teflon and Kapton.

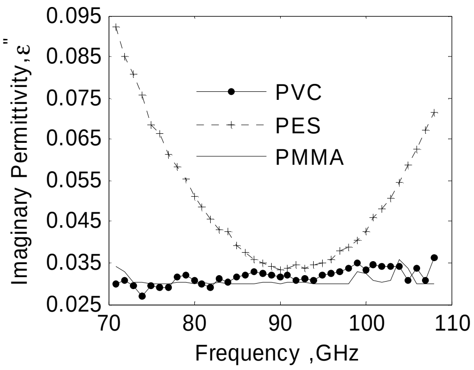

Fig.6. The imaginary part of the permittivity for PVC, PES and PMMA.

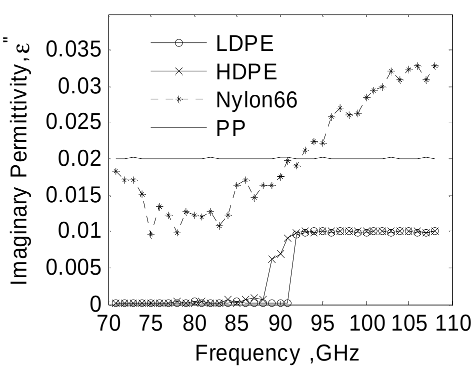

Fig.7. The imaginary part of the permittivity for LDPE, HDPE, Wavon-Nylon66 and PP.

Conclusion

We have developed a Quai-optical free-space technique, in which S_{11} and S_{21} are measured with MVNA, calibrated afterwards and fed to Genetic Algorithm to derive complex permittivity of dielectrics. With this technique we successfully obtained complex permittivity of various polar/non-polar polymers over the whole w-band. Results of Teflon, Mylar, PP, HDPE LDPE, and PCV are in a good agreement with those in other publications in the same frequency range. The permittivity of wavon Nylon66, Kapton, PES, and PMMA in W-band is reported for the first time, according to the author's knowledge.

Table 1. Real and imaginary part of dielectric permittivity for some materials

Specimen	Frequency GHz	ε' this work	ε" this work	ε' previously published	ε" previously published
Mylar	100	2.4519	0.0055	2.48 [10]	0.032 [10]
Teflon	85	2.0437	0.0004	2.057±0.004 [6]	0.0016 [6]
	94	2.0318	0.0004	2.057±0.004 [6]	0.0015 [6]
	100	2.0303	0.0004	2.02 [10]	0.0004 [10]
PP	85	2.2038	0.0200	2.258±0.002 [6]	0.0013 [6]
	94	2.2081	0.0200	2.258±0.002 [6]	0.0013 [6]
	100	2.2032	0.0201	2.17 [10]	0.0054 [10]
HDPE	85	2.2505	0.0005	2.306±0.002 [6]	0.0012 [6]
	94	2.2230	0.0099	2.306±0.002 [6]	0.0012 [6]
	100	2.2129	0.00998	2.29 [10]	0.02 [10]
LDPE	100	2.4490	0.0099		
PVC	85	2.8782	0.0316	2.738±0.004 [6]	0.0260 [6]
	94	2.9011	0.0307	2.738±0.005 [6]	0.0262 [6]
Nylon66	100	1.4405	0.0285		
Kapton	100	3.2048	0.0004		
PES	100	2.8933	0.0427		
PMMA	100	2.6016	0.0325		

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