Broadband Complex Permittivity Measurements of Microwave Interconnects and Bonding Materials

[1]Nahid Rahman, [1]Konstantin A. Korolev, [1]Mohammed N. Afsar, [2]Rudy Cheung and [2]Maurice Aghion
[1]*Department of Electrical and Computer Engineering, Tufts University*
161 College Avenue, Medford, MA 02155, USA
[2]*Microwave Engineering Corporation, 1551 Osgood Street, North Andover, MA 01845, USA*

***Abstract*— This paper presents a systematic study of the complex dielectric permittivity of two interconnect and bonding materials that are used in high frequency multi-chip modules. The materials are characterized in the Q-band, V-band and W-band frequency ranges using a broadband quasi-optical millimeter wave spectrometer with a backward wave oscillator (BWO) as a non-destructive high-power tunable source of coherent radiation. The real and imaginary parts of the dielectric permittivity and loss tangent have been accurately calculated from the transmittance spectra.**

I. INTRODUCTION

The process of interconnections is a major part of the semiconductor and microwave circuit assembly. Modern RFIC and MMIC devices often combine thin printed board circuits boards into multi-layered circuit boards via interconnects. Wire bonding has been widely used for this purpose so far, but the recent trend has been towards using thermoplastic polyethermide materials, that can retain their dielectric properties at very high frequencies [1]. In addition to interconnects, bonding materials, such as epoxy adhesives are also of particular interest when used in high frequency applications. In this regard, it often becomes necessary to characterize the electrical properties of these materials using standard and precise measurement techniques.

In this paper, we present for the first time, a wideband characterization of the dielectric permittivity and loss tangent of two such materials, Ultem and Insulbond, in the Q-band, V-band and W-band frequencies. Ultem is used as interconnect layers for Multi-chip modules and Rigid Insulbond is an epoxy adhesive used in high frequency pressure sensors.

For the dielectric measurements of these polymers, a free space quasi-optical spectrometer equipped with a backward wave oscillator (BWO) has been successfully employed [2]. Since Fourier Transform Spectroscopy (FTS), a standard reliable broadband method for the frequencies above 120 GHz cannot perform well enough at lower frequencies due to lower levels of output power of the thermal sources, quasi-optical spectroscopy method to determine accurate permittivity and loss tangent values for the polymers was considered the best approach for our purposes [3].

II. PROPOSED APPROACH

As our high power sources of millimeter wave coherent radiation, we have used BWO tubes that are tunable in the frequency range from 35 to 120 GHz. The specimens are prepared in the shape of flat parallel slabs and placed in the quasi-optical channel at a normal incidence to the waist of Gaussian beam for the measurements of transmittance spectra. In the quasi-optical measurement channel, two horn antennas, a set of focusing lenses, and a pair of free-standing wire grid polarizing attenuators are used.

A block diagram of the spectrometer is shown in Figure 1:

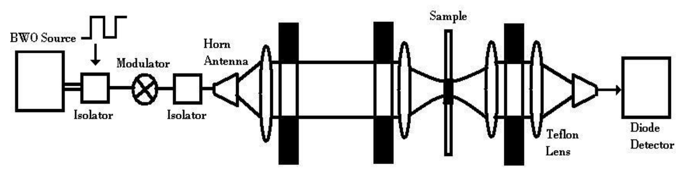


Fig. 1: Spectrometer with quasi-optical channel

The high power quasi-optical spectrometer enables us to perform dielectric measurements with great stability and accuracy. The basic optical parameters: the absorption coefficient (k) and the refractive index (n) are extracted from the attenuation and phase shift values through the comparison of transmittance spectra with and without the specimen in the quasi-optical channel. The transmittance interferogram in each band is a periodic function of frequency with pronounced maxima and minima. The evaluation of real and imaginary part of permittivity is achieved by fitting each maxima of the curve to a theoretical function parameterized with a pair of variables: refractive index (n) and absorption index (k).

Having determined the absorption index and the refractive index values, the real and imaginary parts of dielectric permittivity and loss tangent were computed from the following equations:

$$\epsilon' = n^2 - k^2 \quad (1)$$

$$\epsilon'' = 2 \times n \times k \quad (2)$$

$$\tan \delta = \epsilon'' / \epsilon' \quad (3)$$

Here, $k = (c \times \alpha) / 4\pi f$, where c is the speed of light, α is the absorption coefficient and f is the frequency in Hz [4].

This spectrometer is capable of incrementing voltage in steps as small as 90 mV over the voltage range of 0-1500 Volts. By using the smallest increase in the cathode input voltage, the frequency resolution can be achieved as accurately as 6 MHz.

There are, however, certain limitations to our approach. The DC voltage across the BWO varies from 300 V at the low frequencies to almost 1500 Volts at the highest frequencies in the W-band. The dissipated power changes 6 times during a full-band scan. The resulting variation of temperature causes the deviation of the generated frequency. To ensure the repeatability of the measurements, two scans should be performed so that the source and the power supply operate in the state of thermal equilibrium. The output power spectrum of the BWO is a fast changing function of frequency which implies that a small deviation of the output frequency of the

978-1-4244-2120-6/08/$25.00©IEEE.

two scans caused by the thermal instability can produce a large deviation of output power.

In order to ensure repeatability of our experimental results, we calibrated the system by performing two consecutive reference scans for each band and compared the transmittance values. The transmittance ratio for the two reference scans, which is theoretically expected to be identical, showed that the repeatability of the experiments is better than 0.1%. It means that random errors caused by instability of source of radiation to the final transmittance spectrum do not exceed 0.001. An example calibration plot is included in figure 2. It shows the ratio of transmittances with a mean value of 1.012 and standard deviation of 0.015 in the V-band over the frequency range 42 GHz to 77 GHz.

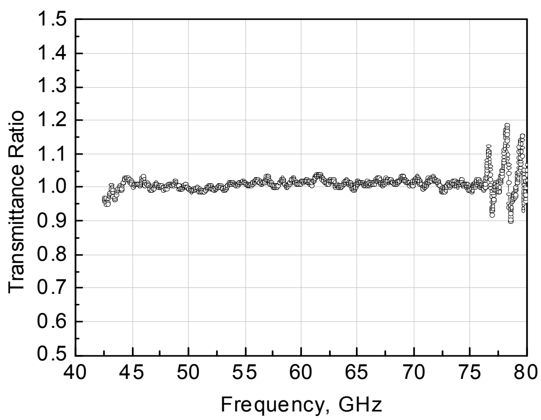
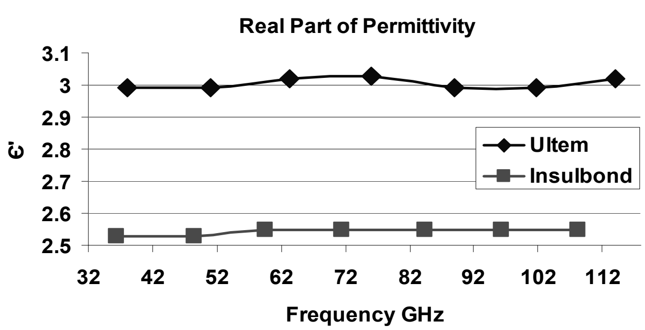
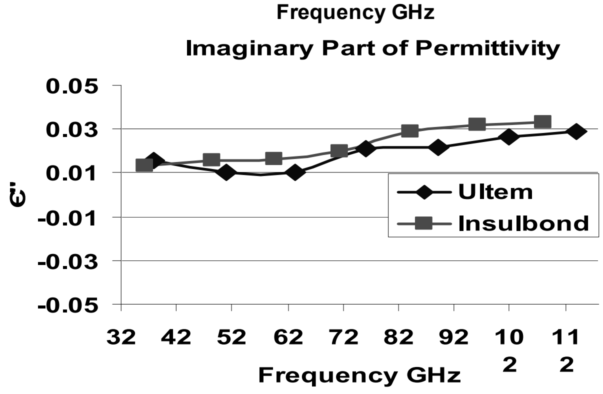


Fig. 2. System calibration showing transmittance ratio in the V-band

III. RESULTS

Fig. 2 shows the plots for the real and imaginary parts of the dielectric constants for Ultem and Insulbond:





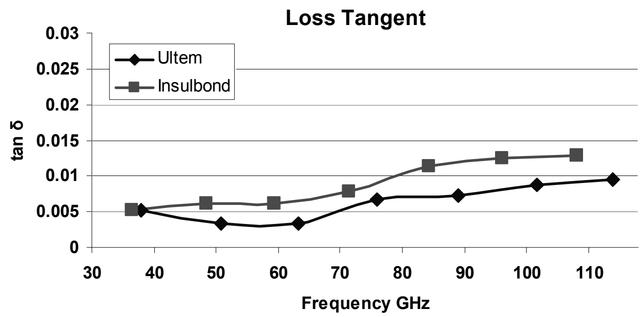


Fig. 2. Real and imaginary parts of dielectric permittivity of Ultem and Insulbond at millimeter wave frequencies

The curves show that the real and imaginary parts of permittivity for both samples remain fairly constant in the whole millimeter frequency range: 34 – 120 GHz. The specimens in our experiment are well-prepared and the thickness uncertainty is well within 20 µm or .3%.

IV. CONCLUSION

Complex dielectric permittivity of Ultem and rigid Insulbond has been accurately measured in the entire Q-, V- and W- band frequencies. For our purposes, we have used a fast and high efficiency, non-contact instrumentation that seems to be a very promising technique for characterizing new materials that are being used in today's emerging technology.

REFERENCES

[1]A. Pham, et al., "Ultra Low Loss Millimeter Wave MCM Interconnects", *IEEE Transactions on components, packaging, and manufacturing Technology – Part B, Vol. 21, No. 3 August 1998.*

[2] M. N. Afsar et al., "A Novel W-band Spectrometer for Dielectric Measurements", *IEEE Transactions on Microwave Theory and Techniques, Vol. 48, No. 12, pp. 2637-2643, 2000.*

[3] K. A. Korolev, L. Subramanian, I. I. Tkachov and M. N. Afsar, "Complex Dielectric Measurements of Materials at Q-band, V-band and W-band Frequencies with High Power Sources", *Proceedings of IMTC 2005 – Instrumentation and Measurement Technology Conference, Ottawa, Canada, 17-19 May, 2005.*

[4] S. Chen, J Kuperschidt, K. A. Korolev and M. N. Afsar, "A High Resolution Quasi Optical Spectrometer for Complex Permittivity and Loss Tangent Measurements at Millimeter Wavelengths", *Proceedings of IMTC 2007 – Instrumentation and Measurement Technology Conference, Warsaw, Poland, May 1-3, 2007.*

978-1-4244-2120-6/08/$25.00©IEEE.