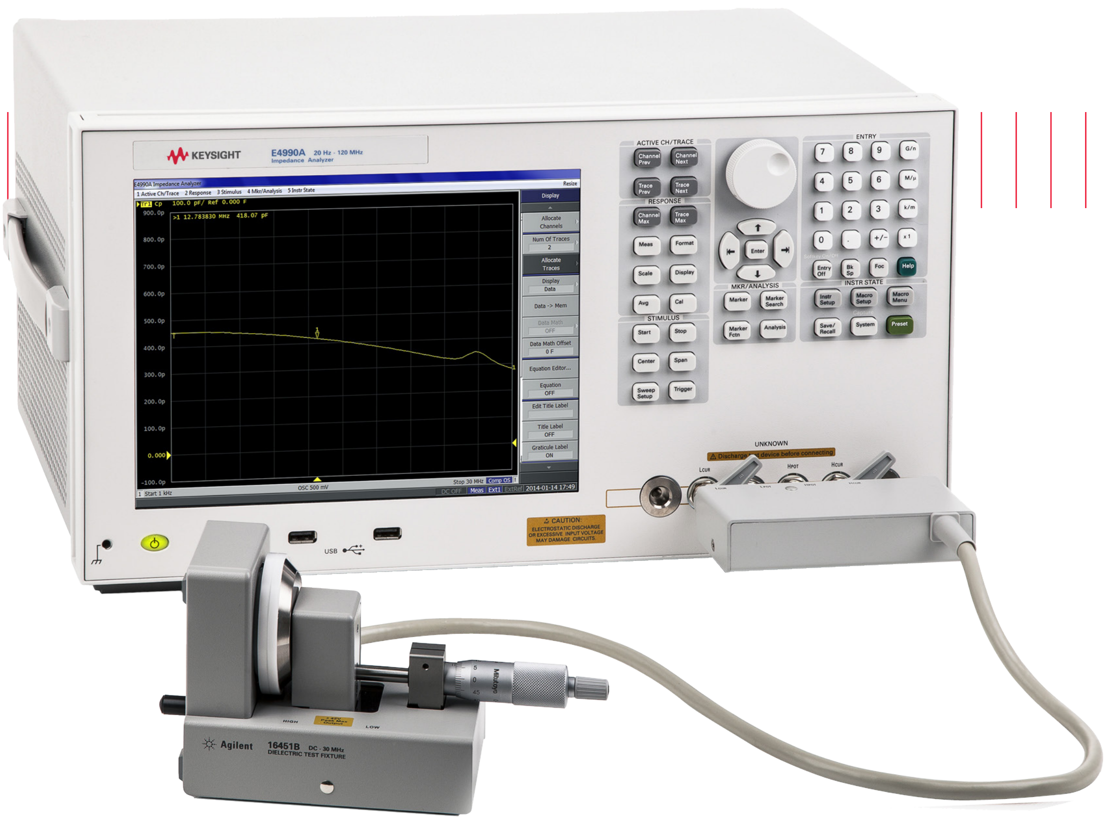
Keysight Technologies
Materials Measurement: Dielectric Materials

Application Brief



KEYSIGHT TECHNOLOGIES

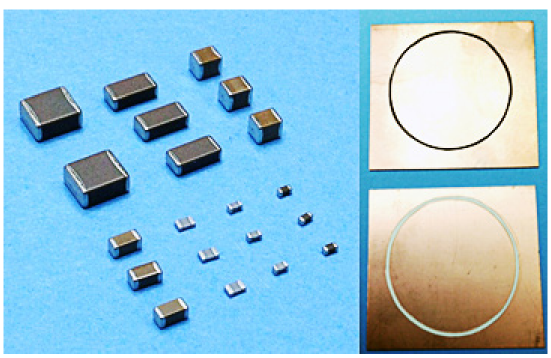
Overview

Increasing capability and performance of electronic equipment are supported by the development of new devices, which in turn is enabled by progress in material science and process technologies.

Dielectric materials play a key role in electronic circuits such as capacitors or insulators. Characterization of these materials in the early stage of development is essential to predict the performance of the final devices.

The electrical properties of a dielectric material are characterized by its complex permittivity. The real part of permittivity, also called dielectric constant, represents the material's ability to store energy when an external electric field is applied. Materials with a higher dielectric constant can store more energy in a small volume, while those with a lower value are preferred for signal transmission where minimum propagation delay is critical. The imaginary part of permittivity represents the loss dissipated in the material. Loss of material can lead to extra power consumption. It is possible to achieve various dielectric constants by controlling the micro structure of ceramics or nano composition of materials.

Impedance analyzers can be used with dielectric material test fixtures to provide a precise, repeatable, cost-effective and easy-to-operate measurement system over wide frequency range.



Problem

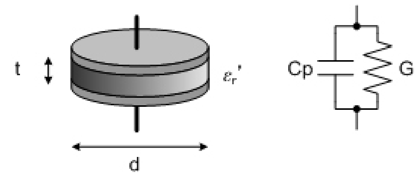
There are various ways of measuring dielectric constant, however it requires specialized knowledge of electromagnetic field theory.

The parallel plate capacitance method is generally used in low-frequency, which measures the capacitance of the material sandwiched between the two electrodes. Its principle is straightforward, but precise measurements are difficult due to the measurement errors, especially for low loss materials.

The complex permittivity is not a constant over a wide frequency range and must be evaluated at the frequency where the material is used, however, at higher frequencies, errors due to the measurement system become significant.

Solution

The parallel plate method uses two electrodes between which the material under test is sandwiched. The impedance of the material is measured and converted to the complex permittivity using the size of the material and the electrodes.



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

$$\varepsilon_r' = \frac{C_P}{\varepsilon_0}\frac{t}{A} = \frac{C_P \times t}{\varepsilon_0 \times \pi \times (d/2)^2}$$

$$\varepsilon_r'' = \varepsilon_r' \times \tan\delta$$

where ε^* : complex permittivity

ε_0 : permittivity of free space

C_P : measured capacitance

$\tan\delta$: measured loss tangent

A : Area of electrode

d: diameter of electrode

t: thickness of sample material

Figure 1. Parallel plate method

The Keysight 16451B dielectric material test fixture provides precise measurements up to 30 MHz when combined with the Keysight E4990A impedance analyzer. The 16451B, compliant to the ASTM D150 standard, has three electrodes, two of which form a capacitor and the remaining one provides a guard electrode. A part of the electrical field between the two electrodes flows outside of the dielectric material, which causes slightly large capacitance, i.e. "fringe capacitance." The guard electrode properly absorbs the current flowing through the fringe capacitance and provides accurate measurements.

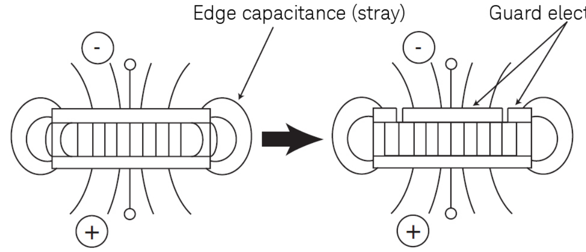


Figure 2. Effect of guard electrode

In preparation of the material, the flatness of the material surface is important to eliminate the air gap between the electrode and the material. To avoid the problem caused by the surface roughness, the following two methods can be used. One is to apply thin film electrodes on the surface of the dielectric material. Another method is the non-contacting electrode method, which derives the complex permittivity by comparing the two capacitances with and without the material between the electrodes. The 16451B supports both of these methods. View applications note 5980-2862EN for more details. Using this method, only real characteristic can be achieved with Keysight's Impedance analyzer solution, it provides 1) excellent phase accuracy enabling tanδ down to 0.006 and 2) takes into account of fringe effect of the test fixtures to extract true characteristics of MUT

The guard technique is effective at low frequencies, but at higher frequencies, the guard electrode gives an unfavorable effect to the electromagnetic field. The Keysight 16453A dielectric material fixture's state-of-the-art design with compact electrodes can extend the frequency range. The software eliminates the fringe capacitance when used with the Keysight E4991B impedance/material analyzer.

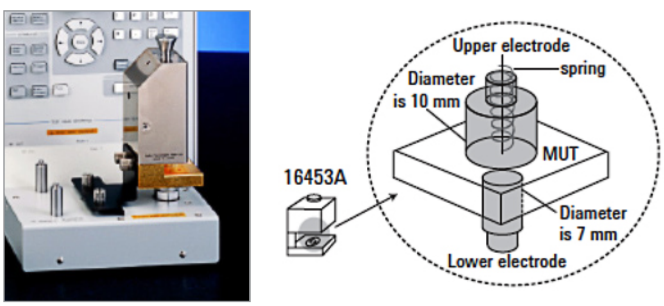


Figure 3. Structure of the 16453A

In both systems, residual error due to the fixture and the analyzer can be removed by open/short/load compensation. The Keysight impedance analyzer has the compensation function as a standard feature, which enables accurate measurements over a wide frequency range.

These systems provide an accurate and efficient way to evaluate the dielectric property of the material without knowledge of electromagnetic theory or calibration techniques. All the calibration, correction and calculations are done by the analyzer and the results are directly obtained.

The graph below shows a permittivity example of different dielectric materials measured using the E4990A with the 16451B and the E4991B with the 16453A fixture.

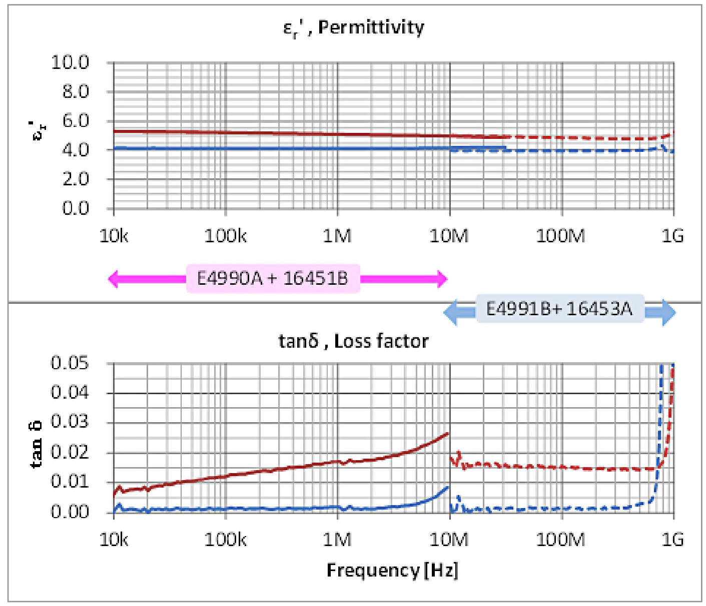


Figure 4. Measurement result example

For the evaluation of temperature characteristics of dielectric materials, a temperature chamber and heat resistant cables are required. Keysight supplies a program for chamber control and data analysis along with the heat resistant cable kit as an option for the E4991B.

Conclusion

Advances in material science and process technologies have allowed for new devices through the development of new materials. Measurement systems with accuracy and stability are desired for time and cost effective evaluation.

The Parallel plate capacitance method is a standard technique for the evaluation of dielectric material. Fringe capacitance is a major source of errors and can be eliminated by using the appropriate fixture and/or software correction, which enables simple and repeatable measurements over a wide frequency range.

Keysight Technologies provides impedance analyzers, fixtures, calibration technique, software for data analysis, and temperature characteristic evaluation.

For more information, application notes and papers are available under references.

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