SPECTANO 100 – Information Note

Considerations Regarding Sample Geometry and Test Setup

1. Introduction

This document describes general considerations which should be made if samples of solid dielectric materials are measured with SPECTANO 100. Special focus is put on the geometry of the sample but also general rules of the test setup are explained. This Application Note only considers solid samples of insulating materials.

2. Safety Instructions

Warning

Death or serve injury caused by high voltage or current

Before starting a measurement, read the safety rules, operation and connection instructions in the SPECTANO 100 User Manual to protect yourself from high-voltage hazards.

3. Sample Geometry

When a sample of an insulating dielectric material is put between electrodes, it exhibits a capacitance C which is dependent on the sample's relative permittivity ε_r, the vacuum permittivity ε_0 and the sample geometry.

Figure 1 and the equations (1) and (2) illustrate the interdependency of the sample geometry, its capacitance and its permittivity.

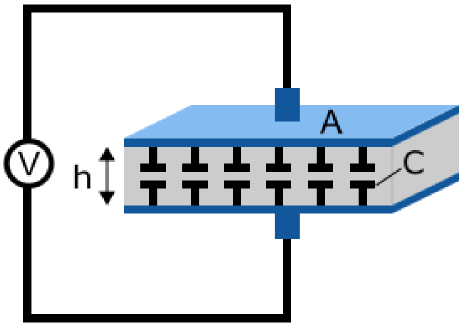

Figure 1 - Sample permittivity and geometry dependency of capacitance for parallel plate electrodes

$$C_0 = \varepsilon_0 \cdot \frac{A}{h} \quad (1)$$

$$C = \varepsilon_r \cdot C_0 \quad (2)$$

C_0	Vacuum capacitance
ε_0	Vacuum permittivity 8.8541878176 × 10^{-12} F/m
A	Area of electrodes
h	Sample height of examined dielectric material
ε_r	Relative permittivity
C	Sample capacitance

When a sinusoidal AC voltage V is applied to parallel plate electrodes as shown in Figure 2, a corresponding current I results which is dependent on the amplitude of V, the sample capacitance C and the frequency f of the applied voltage.

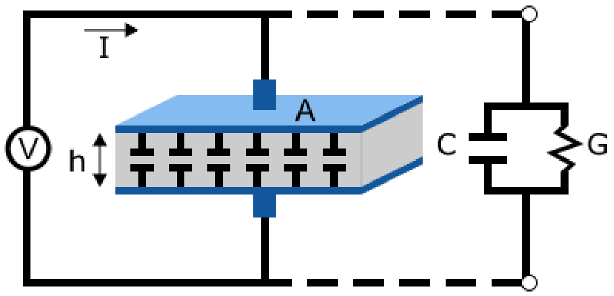

Figure 2 - Parallel plate electrodes, AC case

Formulae (3) - (6) describe the behavior when a sinusoidal AC voltage is applied to a dielectric material placed between parallel plate electrodes. The resulting current can be calculated in accordance to formula (3):

$$I = V \cdot (j\omega C_0 \varepsilon_r' + G) \tag{3}$$

The calculation of the current can be simplified by inserting formulae (2), (4) and (5):

$$G = \omega C_0 \varepsilon_r'' \tag{4}$$
$$\varepsilon_r = \varepsilon_r' - j\varepsilon_r'' \tag{5}$$

which results into the following formula:

$$I = V \cdot (j\omega C_0 \varepsilon_r) = V \cdot (j\omega C) \tag{6}$$

G Conductance
C_0 Vacuum capacitance
C Sample capacitance
ε_r Complex relative permittivity
ε'_r Real part of relative permittivity which represents the storage of energy in the examined material
ε''_r Imaginary part of relative permittivity which represents the losses occurring in the examined material

To illustrate the influence of the individual parameters and their relevance in practical measurements, the following typical values for the properties of the test system and the sample are used:

- Connected test voltage is 100 V_{peak}
- Relative permittivity ε_r of the sample material is assumed to be exactly 3 for the whole frequency range
- The sample is considered to have no losses ($\varepsilon''_r = 0$).

Variable values are the test frequency and the sample geometry.

3.1. Material Example: Cube of 1cm Length

In the first step, we analyze a cube-shaped material sample with a side length of 1 cm. This sample geometry results in a capacitance C of:

$$C = \varepsilon_r \cdot C_0 = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{h} \tag{7}$$
$$= 8.88541878176 \times 10^{-12} \frac{F}{m} \cdot 3 \cdot \frac{(0.01m)^2}{0.01m}$$
$$= 0.266pF$$

At a test voltage of 100 V_{peak} and a frequency of 1 kHz, the resulting peak current according to formula (6) is 1.67 nA which still can be measured with SPECTANO 100 if the setup is good[1].

[1] More information about the optimization of a test setup for dielectric measurements can be found in chapter 3.3.

At a frequency of 1 mHz, the resulting current is only 1.7 fA which is far beyond the measurement limit of any dielectric analyzer, even more as typically the phase shift should also be measured. Formula (9) describes the electrical field strength E for the sample cube with a side length of 1 cm and an applied test voltage V of 100 V_{peak}:

$$E = \frac{V}{h} = \frac{100\,V_{peak}}{10mm} = 10\ \frac{V}{mm} \qquad (9)$$

The resulting electric field strength inside the sample is 10 V/mm for this geometry.

It is obvious that a small sample capacity results in a very low current at low frequencies. Therefore, it is advisable to increase the sample capacitance since other factors like the applied voltage can only be varied within certain limits.

3.2. Increasing the Sample Capacitance & The Myth of High Voltages

The simplest way to increase the sample capacitance is to increase the area *A* of the sample that is covered by the electrodes. For a square sample, a side length of 10 cm instead of 1 cm increases the area A and therefore also the capacitance by the factor of 100. Combined with a reduction of the sample height from 1 cm to 0.1 mm, the capacitance is increased by a factor of 10 000. Referring to formula (8) the capacitance of the optimized sample geometry is:

$$C = 0.266\,pF \cdot 10000 = \ 2.66\text{ nF} \qquad (10)$$

The resulting current according to formula (6) increases with the same factor. Thus at 1 kHz it is 16.7 µA and at 1 mHz it is 16.7 µA. These currents can be easily measured with SPECTANO 100 if the setup is performed correctly. Due to the reduction of the sample height h to 0.1mm, the electrical field strength E inside the sample increases to 1000 V/mm according to formula (9). Thus, a high field strength can be achieved <u>without applying high voltage</u> by simply reducing the sample thickness. If the results achieved in 3.1 and 3.2are compared it is obvious that it is advisable to use thin samples with a large sample area to increase the current especially at lower frequencies. However, even when the sample geometry is optimized, the resulting current is very low at low frequencies. Therefore, the whole measurement setup must be shielded against interferences and other external influences as described in 3.3.

3.3. Setup Optimization

The following measures should be considered to avoid distortions during the measurement:

- Only shielded, low-noise cables should be used. Do not use any unshielded connections or bare cables (pins).
- Keep adapter cables and connection cables as short as possible.
- Avoid vibrations since they can generate piezo-currents in cables and the setup.
- Fix the cables to avoid movements.
- Put the sample test cell in a shielded metal chamber for measuring.
- Avoid temperature changes.
- Avoid interferences by electric devices nearby such as wireless transmitters, fans, motors etc.
- If possible, separate guard from ground.
- Always ground the SPECTANO housing. This doesn't influence the measurement in any negative way but provides additional safety for the user. The measurement circuit inside SPECTANO 100 is always separated of ground potential.

4. Summary

By choosing the right sample geometry high field strengths inside the sample as well as higher sample currents and capacitances can be achieved without the need of increasing the applied voltage. In addition, a proper measurement set-up will further improve the reproducibility and accuracy of the results.

Further information on the SPECTANO 100 and its applications can be found on our website at www.omicron-lab.com.

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