ULTEM™ 1000

Datasheet

ULTEM™ 1000 Resin is an unreinforced amorphous polyetherimide (PEI) resin that offers excellent mechanical, electrical, and dimensional properties up to high temperatures. The material also offers very good chemical resistance for an amorphous material and is inherently flame-retardant offering UL94 V0 and 5V ratings and aerospace FAR 25.853 compliance. The material is RoHS compliant and the natural, uncolored, material is halogen-free according to standards IEC 61249-2-21, IPC 4101E, and JEDEC JS709B.

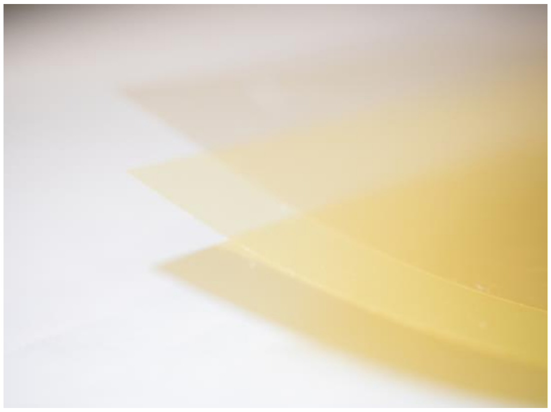

Figure 1: ULTEM™ 1000.

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Revision 0.2

Acknowledgement

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Disclaimer

NATIONAL ENERGY TECHNOLOGY LABORATORY

Insulation Reference Characteristics

The focus of this report is to measure the dielectric constant of ULTEM^{TM} 1000 at frequency and voltage ranges appropriate for power electronics applications. Dielectric constant is used to determine the ability of an insulator to store electrical energy. The relative dielectric constant is the ratio of the capacitance induced by two metallic plates with an insulator between them to the capacitance of the same plates with air or a vacuum between them. The manufacturer's data of ULTEM^{TM} 1000 is given in Table 1 and provides dielectric constant data at 1 MHz utilizing fixturing at low voltage. This report provides data at varied material thicknesses and appropriately higher voltages for applications in power electronics.

Table 1: Typical Electrical Properties of ULTEM^{TM} 1000

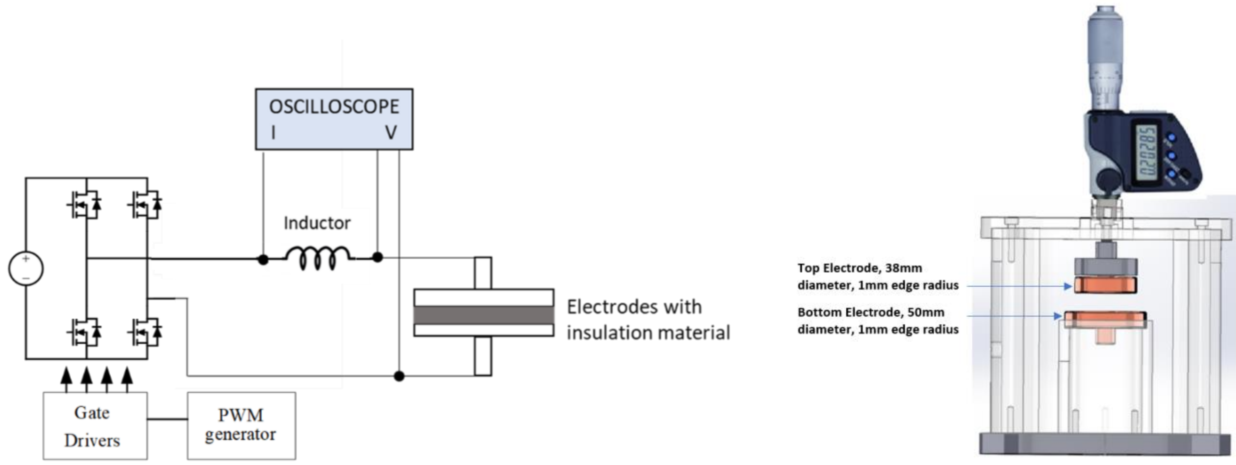
Property	1 MHz	Test Standard
Dielectric Constant	2.9	IEC 62631-2-1

Background

A square waveform Insulation Characterization System (ICS) was designed and built at NETL to characterize the insulation material under test (MUT). The testing performed at NETL characterizes the material between 10 and 100 V for material thicknesses between 0.05 and 0.25 mm.

Measurement Setup

Conceptual and lab setups are shown in Figures 2 and 3. An inductor is placed in a series with the capacitor created by the electrodes and MUT to enable a resonant circuit. Parameters from the resonant waveform are measured to extract the dielectric constant of the MUT.



(a) (b)

Figure 2: (a) Insulation characterization system conceptual setup, (b) Capacitance fixture with micrometer head.

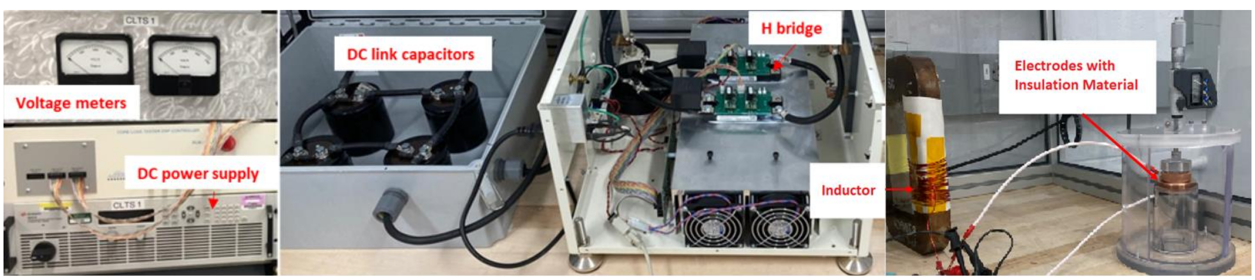
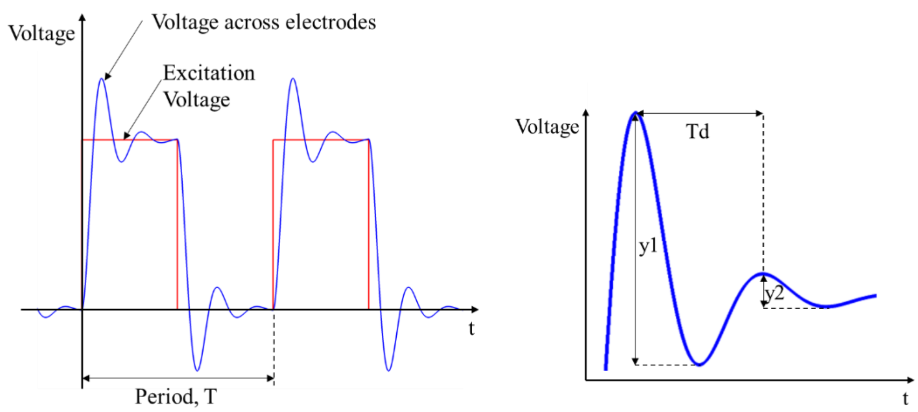


Figure 3: Insulation characterization system lab setup.

The insulation MUT is ULTEM^{TM} 1000 with varied thicknesses. The MUT is placed between two flat copper plates. The plates are designed with radiused edges to avoid the corona effect along with adequate thickness to dissipate heat generated during the test. In addition, a plexiglass fixture is designed to not only hold the electrodes, but also to provide a visual indication of measurement distance between the electrode surfaces utilizing a high-resolution micrometer head.

To extract the dielectric constant, an underdamped condition must be met so that the damping period can be measured. For this test, the series inductance has been selected to guarantee the underdamped condition. Figure 4 (a) illustrates the excitation voltage applied to the load and the measured voltage across the electrodes with the insulation material. Figure 4 (b) is the enlarged view of the voltage waveform across the electrodes.



(a) (b)

Figure 4: (a) Voltage waveforms with square wave excitation, (b) Underdamped voltage waveform across the electrodes.

The electrodes with insulation material can be considered as a capacitor with a resistor in a series and a resistor in parallel. Since the parallel resistance is in MΩ range, it is negligible compared with the capacitance at frequency in kHz range. Therefore, the load of the ICS system can be treated as a Resistor (R), Inductor (L), and Capacitor (C) in a series, resulting in a series RLC circuit.

For this special circuit, the damping factor is:

$$\zeta = \frac{R}{2}\sqrt{\frac{C}{L}} \tag{1}$$

For underdamped vibrations, the damping factor ζ is also related to the logarithmic decrement δ.

$$\zeta = \frac{\delta}{\sqrt{\delta^2 + (2\pi)^2}} \tag{2}$$

where:

$$\delta = ln\frac{y_1}{y_2} \tag{3}$$

and y_1, y_2 are the amplitudes between the positive peaks and their successive negative peaks as shown in Figure 4 (b).

The resonant frequency is:

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{4}$$

The damping frequency is:

$$\omega_\mathrm{d} = \sqrt{\omega_0^2 - \alpha^2} = \omega_0 \sqrt{1 - \zeta^2} \tag{5}$$

The damping period is:

$$T_d = \frac{2\pi}{\omega_d} \tag{6}$$

As shown in Figure 4 (b), the damping period is the time between two successive peaks.

Therefore, given the inductance, the capacitance can be calculated using the following equation:

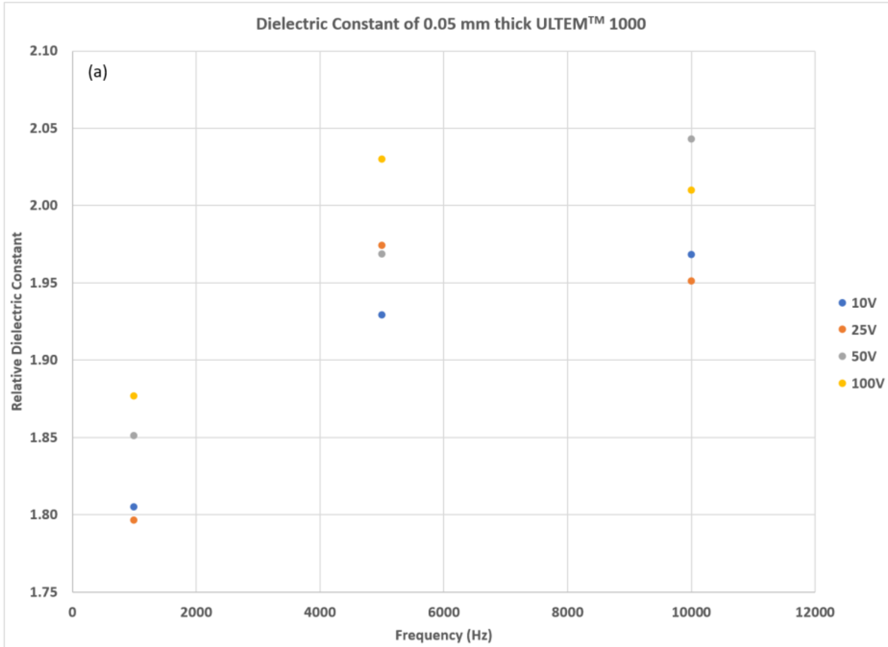
$$C = \frac{{T_d}^2(1 - \zeta^2)}{(2\pi)^2 L} \tag{7}$$

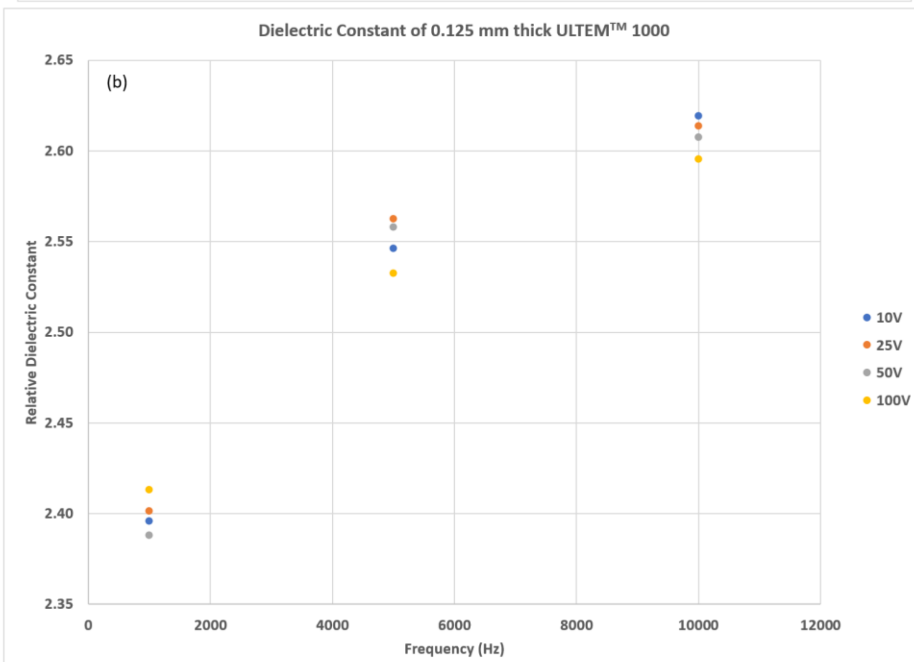
Then, the relative dielectric constant ε_r can be obtained using the following equation, in which t is the distance between the electrodes, C is the capacitance from Equation (7), A is the area of the top electrode, and ε_o is the permittivity in a vacuum.

$$\varepsilon_r = \frac{tC}{\varepsilon_0 A} \tag{8}$$

Dielectric Constant Measurements

Figure 5 illustrates the dielectric constants extracted from measured capacitances at different conditions. Three different thicknesses of ULTEM^{TM} 1000 were tested, which are 0.05 mm, 0.125 mm, and 0.25 mm. The testing was performed under square waveforms with frequencies of 1, 5, and 10 kHz, and the voltage in the range 10–100 V. The measured capacitance in this test fixture is very small in value (pF range) and sensitive to several factors including distance between the electrodes, the flatness of the insulation material, dust, etc.


Dielectric Constant of 0.05 mm thick ULTEM™ 1000
(a)
Relative Dielectric Constant
Frequency (Hz)
2.10
2.05
2.00
1.95
1.90
1.85
1.80
1.75
0
2000
4000
6000
8000
10000
12000
10V
25V
50V
100V


Dielectric Constant of 0.125 mm thick ULTEM™ 1000
(b)
Relative Dielectric Constant
Frequency (Hz)
2.65
2.60
2.55
2.50
2.45
2.40
2.35
0
2000
4000
6000
8000
10000
12000
10V
25V
50V
100V

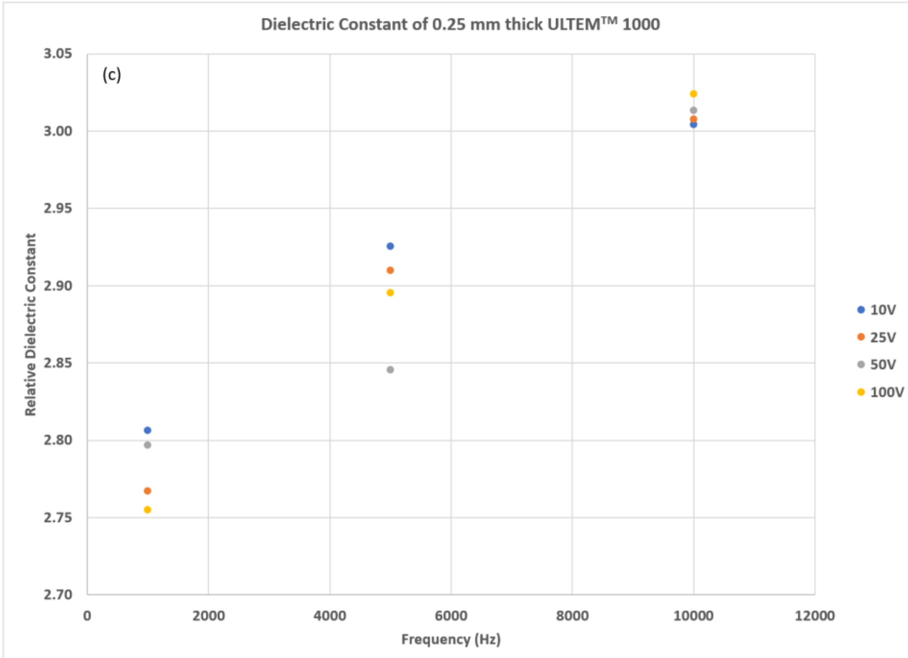


Figure 5: Dielectric constant at square waveform excitation with varied frequencies and voltages of the corresponding thickness (a) 0.05 mm, (b) 0.13 mm, and (c) 0.25 mm.

Table 2: Dielectric Constant

Variables		Thicknesses		
Voltage (V)	Frequency (kHz)	at 0.05 mm	at 0.125 mm	at 0.25 mm
10	1	1.81	2.40	2.81
	5	1.93	2.55	2.93
	10	1.97	2.62	3.00
25	1	1.80	2.40	2.77
	5	1.97	2.56	2.91
	10	1.95	2.61	3.01
50	1	1.85	2.39	2.80
	5	1.97	2.56	2.85
	10	2.04	2.61	3.01
100	1	1.88	2.41	2.76
	5	2.03	2.53	2.90
	10	2.01	2.60	3.02

Table 2 lists the dielectric constant of ULTEM^{TM} 1000 at different thickesses, voltages, and frequencies. The relationship of these variables is obtained from Figure 5 and Table 2. The dielectric constant shows a distinct relationship with material thickness. A trend in increasing dielectric constant with frequency in the selected operation range is also noted to be above the measurement error of the system. However, there is not a significant relationship between relative dielectric constant and applied voltage, or if it exists, it is within measurement error.

Summary

Given the increasing demand for insulation materials in the high voltage/high frequency power electronics industries, knowledge of the dielectric constant characteristics at relevant voltage and frequency ranges is critical for a given thickness of material. Insulation material manufacturers typically provide dielectric constant data for a very narrow range of material thickness, applied voltage, or frequency. This datasheet provides dielectric constant information at voltage and frequency ranges of interest to high voltage and power electronics industries for a candidate insulation material.

Reference

1. Material Datasheet (campusplastics.com)