DuPont™ Nomex® 410

Datasheet

Nomex® 410 is a type of electrical insulation paper that can be found in a large variety of electrical applications. It exhibits a combination of good thermal stability, mechanical toughness, abrasion resistance, dielectric strength, broad chemical compatibility, and flame resistance. Nomex® 410 is a high-density variety of a broader class of Nomex insulation papers, which makes it suitable for applications where high mechanical resilience is more important than impregnability or saturability.

Figure 1: Nomex® 410.

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Acknowledgement

This technical effort was performed in support of the National Energy Technology Laboratory's (NETL) ongoing research in the U.S. Department of Energy's (DOE) Office of Electricity's (OE) Transformer Resilience and Advanced Components (TRAC) program. Testing was performed by NETL and North Carolina State University.

NATIONAL ENERGY TECHNOLOGY LABORATORY

Insulation Reference Characteristics

The focus of this report is to measure the dielectric constant of Nomex® 410 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 Nomex® 410 is given in Table 1 and provides dielectric constant data at frequencies at or below 1000 Hz and low voltage. This report provides data at appropriately higher voltages and frequencies for applications in power electronics.

Table 1: Typical Electrical Properties of DuPont™ Nomex® 410

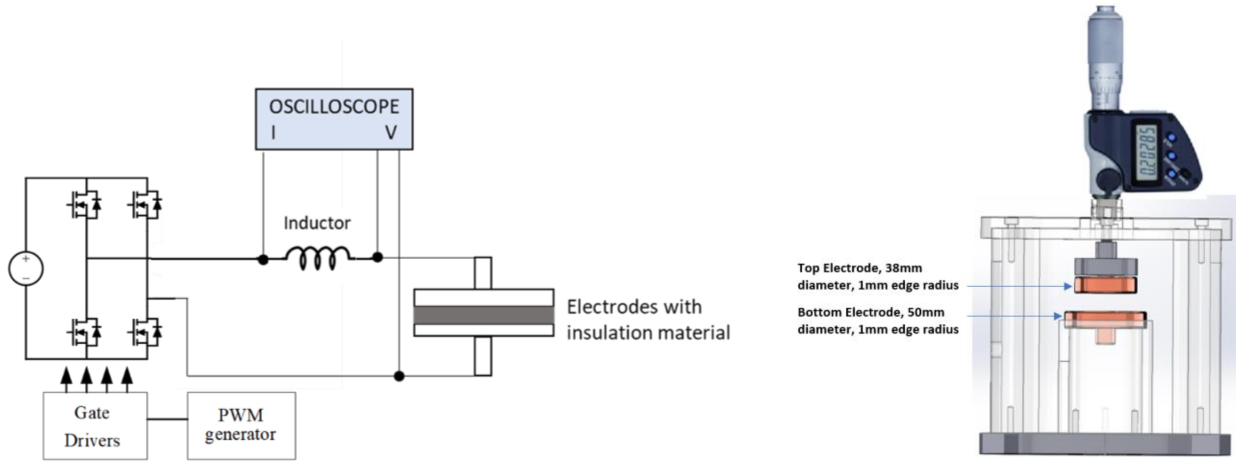
Property	Nominal Thickness, mm					Test Method
	0.05	0.08	0.13	0.18	0.25	
Dielectric Constant at 60 Hz (Ref. 1)	1.6	1.6	2.4	2.7	2.7	ASTM D150

Background

Square waveform Insulation Characterization Systems (ICS) were designed and built at NETL and North Carolina State University to characterize the insulation material under test (MUT). The characterization is divided into two parts. The testing performed at NETL characterizes the material between 10 and 100 V for material thicknesses between 0.05 and 0.25 mm, and the testing performed at North Carolina State characterizes the material at 400 V for material thicknesses between 0.25 and 0.75 mm.

NETL Measurement Setup

NETL 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.

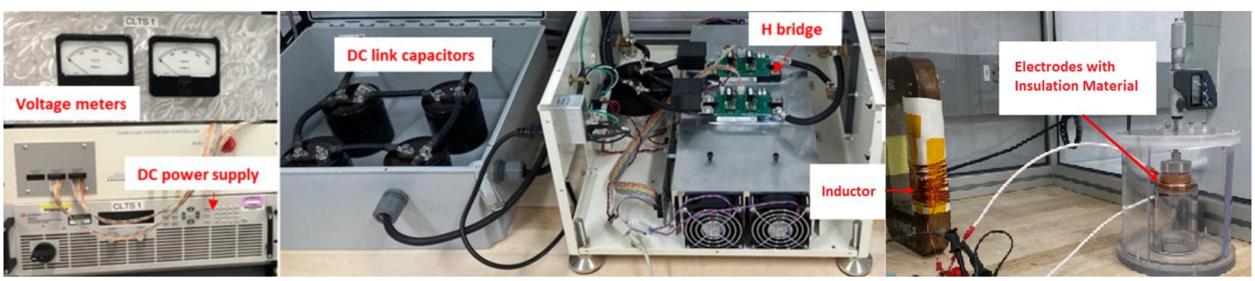
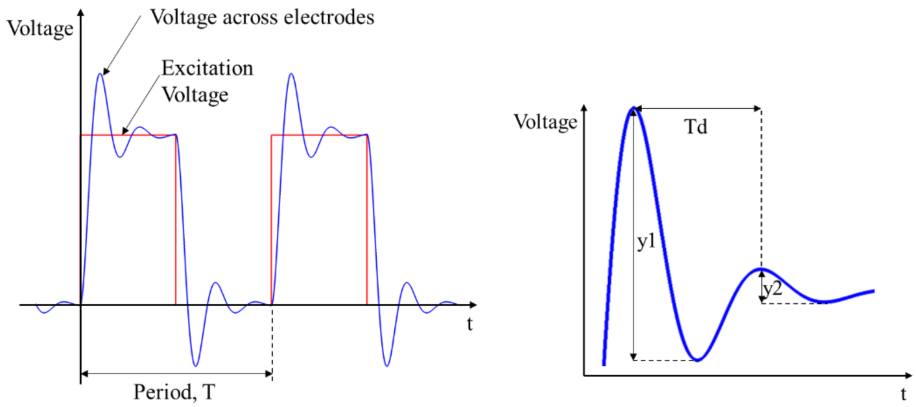


Figure 3: Insulation characterization system lab setup.

The insulation MUT is Nomex® 410 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:

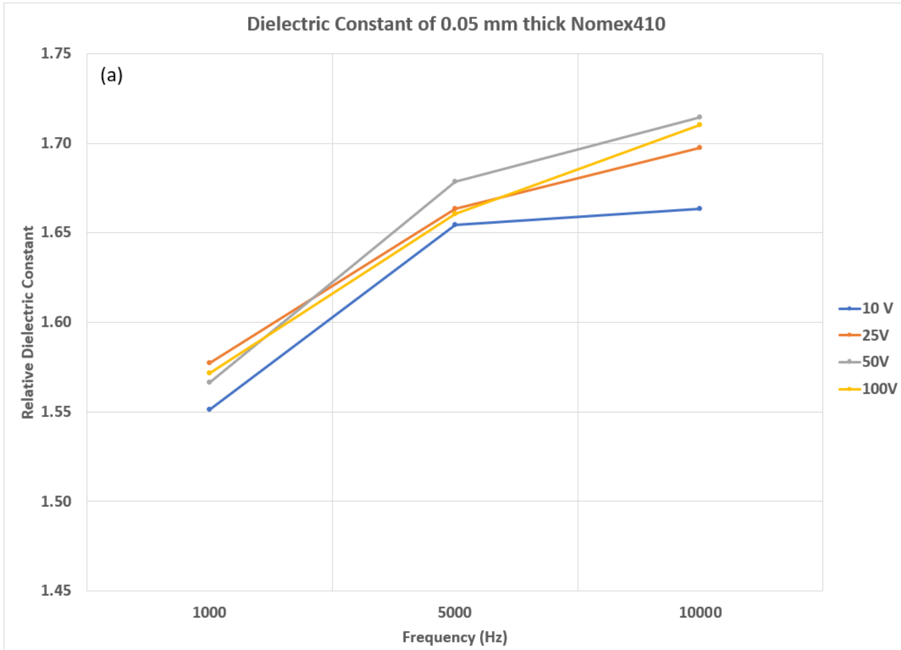
$$C = \frac{{T_d}^2(1 - \zeta^2)}{(2\pi)^2 L} \tag{7}$$

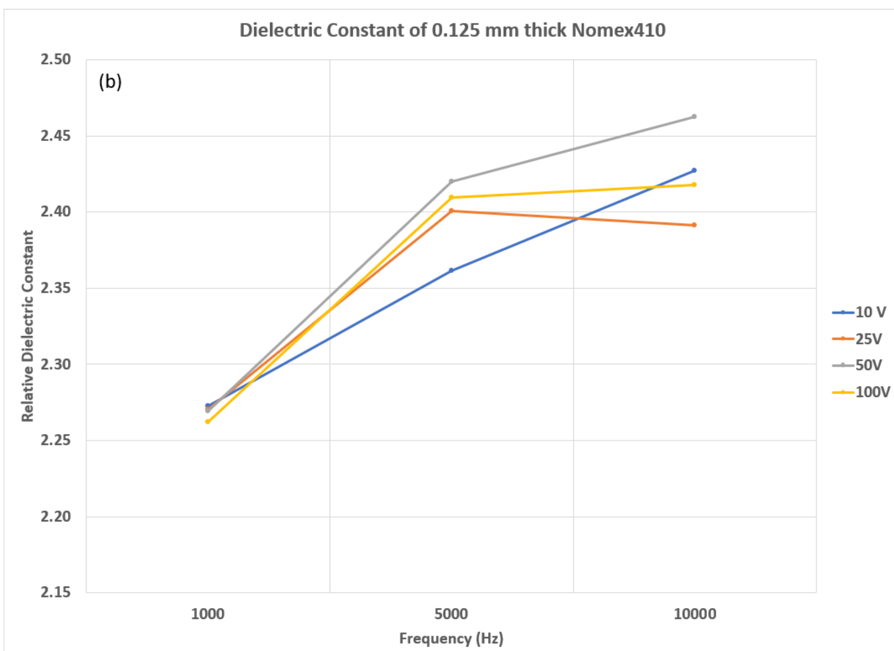
Then, the relative dielectric constant ε_r can be obtained using the following equation, in which *t* is the distance between the electrodes, *C* is the capacitance from Equation (7), *A* is the area of the top electrode, and ε_o is the permittivity in a vacuum.

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

NETL Dielectric Constant Measurements

Figure 5 illustrates the dielectric constants extracted from measured capacitances at different conditions. Three different thicknesses of Nomex® 410 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 Nomex410
(a)
Relative Dielectric Constant
1.75
1.70
1.65
1.60
1.55
1.50
1.45
1000
5000
10000
Frequency (Hz)
10 V
25V
50V
100V


Dielectric Constant of 0.125 mm thick Nomex410
(b)
Relative Dielectric Constant
2.50
2.45
2.40
2.35
2.30
2.25
2.20
2.15
1000
5000
10000
Frequency (Hz)
10 V
25V
50V
100V

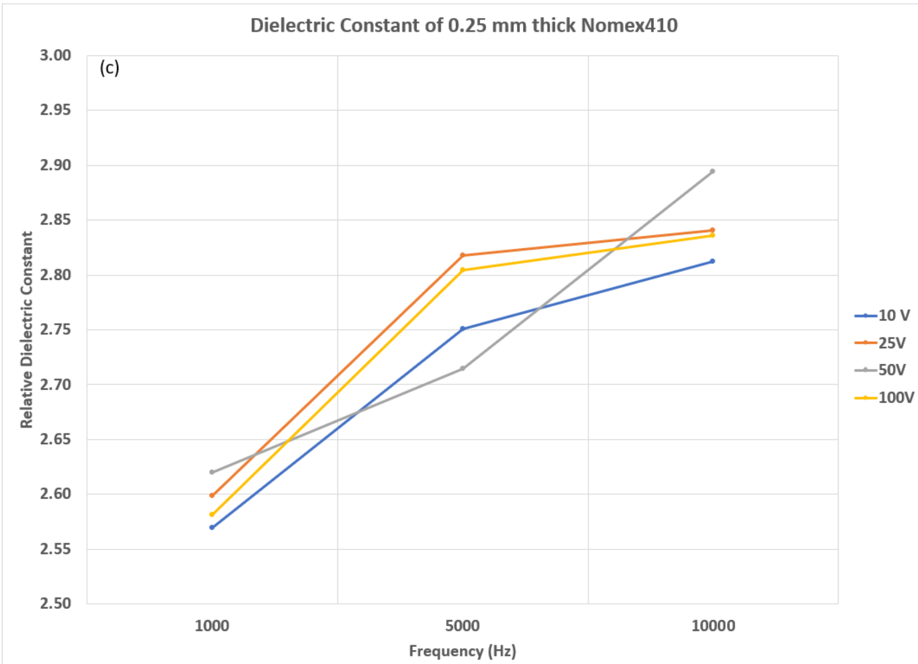


Figure 5: Dielectric constant at square waveform excitation with varied frequencies and voltages of the corresponding thickness (a) 0.05 mm, (b) 0.13 mm, and (c) 0.25 mm.

Table 2: Dielectric Constant

Variables		Thicknesses		
Voltage (V)	Frequency (kHz)	at 0.05 mm	at 0.125 mm	at 0.25 mm
10	1	1.55	2.27	2.57
	5	1.65	2.36	2.75
	10	1.66	2.43	2.81
25	1	1.58	2.27	2.60
	5	1.66	2.40	2.82
	10	1.70	2.39	2.84
50	1	1.57	2.27	2.62
	5	1.68	2.42	2.71
	10	1.71	2.46	2.89
100	1	1.57	2.27	2.58
	5	1.66	2.41	2.80
	10	1.71	2.42	2.84

Table 2 lists the dielectric constant of Nomex® 410 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 which correlates well with existing data. 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.

North Carolina State Measurement Setup

North Carolina State conceptual and lab setups are shown in Figures 6 and 7. Material characterization was performed by inserting the Nomex insulation paper between two 51 mm electrodes to form a capacitor which is inserted into a resonant circuit to achieve sinusoidal voltage excitation of the Nomex paper sample.

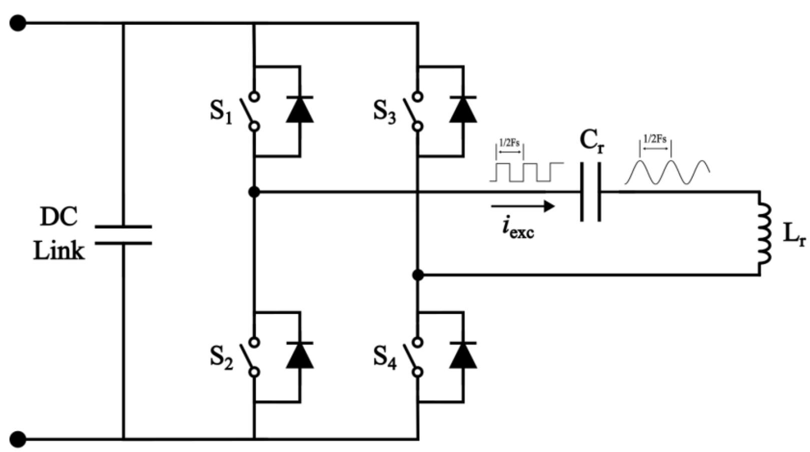


Figure 6: Dielectric material test system electrical diagram.

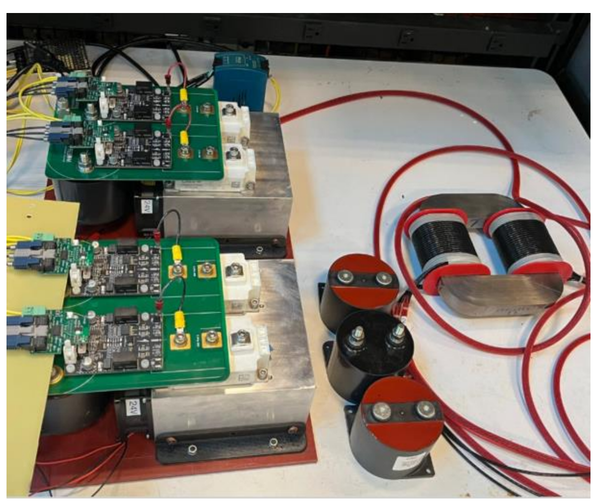


Figure 7: Dielectric test system hardware.

Table 3: Test System General Specification

Description	Symbol	Typical Value	Unit
Maximum Voltage	V_{max}	1,200	V
Maximum Current	$I_{rms,max}$	250	A_{rms}
DC Link Capacitance	C_{bus}	320	μF
Frequency Range	F_s	1–80	kHz
Resonant Inductor	L_r	20–200	mH

The electrodes design is per ASTM-D149 Type 1. Two opposing brass electrodes are used with 51-mm diameter, 25-mm thickness, and 6.4-mm edge radius.

(a) (b)

Figure 8: Dielectric material test electrodes.

North Carolina State Dielectric Constant Measurements

All dielectric constant measurements are made at a 400 V_{rms} excitation level and 25 °C. For practical reasons the resonant inductances are available in discrete increments so the measurement frequencies for each sample thickness are not the same.

Table 4: Resonant Frequencies for Dielectric Constant Tests

		Resonant Inductance (mH)									
		20	40	60	80	100	120	140	160	180	200
Nomex Thickness (mil)	10	71.02	50.68	41.70	36.40	32.82	30.21	28.20	26.60	25.21	23.99
	20	-	64.05	52.49	45.80	41.28	38.13	35.43	33.41	31.84	30.46
	30	-	-	60.91	53.11	47.82	43.96	40.98	38.52	36.58	34.95

The corresponding dielectric constants for the resonant frequencies in Table 4 are given in Table 5.

Table 5: Measured Dielectric Constants

		Resonant Inductance (mH)									
		20	40	60	80	100	120	140	160	180	200
Nomex Thickness (mil)	10	3.31	3.25	3.2	3.15	3.1	3.05	3	2.95	2.92	2.9
	20	4.1	4.07	4.04	3.98	3.92	3.82	3.8	3.74	3.66	3.6
	30	4.64	4.56	4.5	4.44	4.38	4.32	4.26	4.22	4.16	4.1

The resulting frequency-dielectric constant characteristic is given in Figure 9.

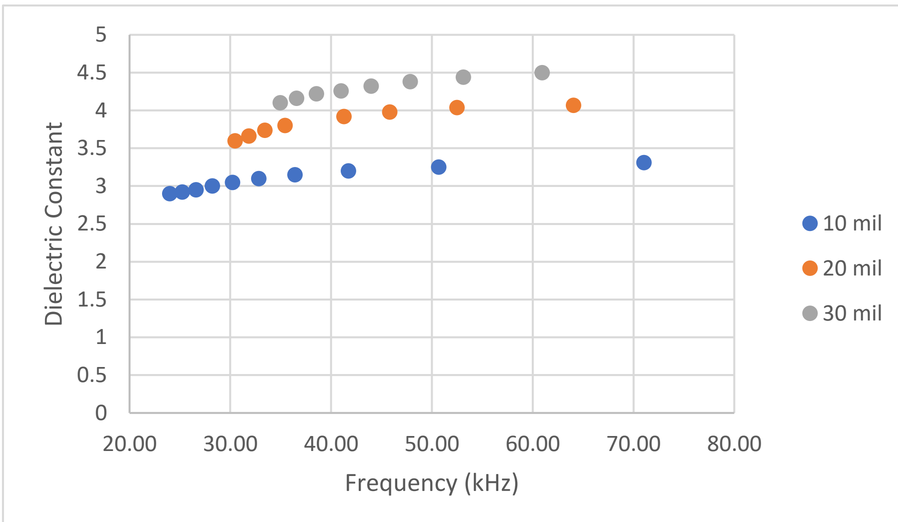


Figure 9: Frequency-dielectric constant characteristic for 10 mil, 20 mil, and 30 mil Nomex® 410.

The dielectric constant shows a distinct relationship with material thickness which also correlates well with existing data. 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.

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. https://www.dupont.com/content/dam/dupont/amer/us/en/safety/public/documents/en/DPT16_21668_Nomex_410_Tech_Data_Sheet_me03_REFERENCE.pdf