Dielectric strength

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In physics, the term **dielectric strength** has the following meanings:

- Of an insulating material, the maximum electric field strength that it can withstand intrinsically without breaking down, *i.e.*, without experiencing failure of its insulating properties.
- For a given configuration of dielectric material and electrodes, the minimum electric field that produces breakdown.
- the maximum electric stress the dielectric material can withstand without breakdown.

The theoretical dielectric strength of a material is an intrinsic property of the bulk material and is dependent on the configuration of the material or the electrodes with which the field is applied. At breakdown, the electric field frees bound electrons. If the applied electric field is sufficiently high, free electrons from background radiation may become accelerated to velocities that can liberate additional electrons during collisions with neutral atoms or molecules in a process called avalanche breakdown. Breakdown occurs quite abruptly (typically in nanoseconds), resulting in the formation of an electrically conductive path and a disruptive discharge through the material. For solid materials, a breakdown event severely degrades, or even destroys, its insulating capability.

Factors affecting apparent dielectric strength

- it decreases slightly with increased sample thickness. (see "defects" below)
- it decreases with increased operating temperature.
- it decreases with increased frequency.
- for gases (e.g. nitrogen, sulfur hexafluoride) it normally decreases with increased humidity.
- for air, dielectric strength increases slightly as humidity increases

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[edit] Breakdown field strength

The field strength at which breakdown occurs depends on the respective geometries of the dielectric (insulator) and the electrodes with which the electric field is applied, as well as the rate of increase at which the electric field is applied. Because dielectric materials usually contain minute defects, the practical dielectric strength will be a fraction of the intrinsic dielectric strength of an ideal, defect-free, material. Dielectric films tend to exhibit greater dielectric strength than thicker samples of the same material. For instance, the dielectric strength of silicon dioxide films of a few hundred nm to a few μm thick is approximately 0.5GV/m.[1] However very thin layers (below, say, 100 nm) become partially conductive because of electron tunneling. Multiple layers of thin dielectric films are used where maximum practical dielectric strength is required, such as high voltage capacitors and pulse transformers. Since the dielectric strength of gases varies depending on the shape and configuration of the electrodes, it is usually measured as a fraction of the dielectric strength of Nitrogen gas.

Dielectric strength (in MV/m, or 10^6 Volt/meter) of various common materials:

Substance	Dielectric Strength (MV/m)
Helium (relative to nitrogen)[2]	0.15
Air [3]	3.0
Alumina[2]	13.4
Window glass[2]	9.8 - 13.8
Silicone oil, Mineral oil[2][4]	10 - 15
Benzene[2]	163
Polystyrene[2]	19.7
Polyethylene[5]	18.9 - 21.7
Neoprene rubber[2]	15.7 - 26.7
Distilled Water[2]	65 - 70
High Vacuum (field emission limited)[6]	20 - 40 (depends on electrode shape)
Fused silica[7]	25–40 at 20 °C
Waxed paper[8]	40 - 60
PTFE (Teflon, Extruded)[2]	19.7
PTFE (Teflon, Insulating Film)[2][9]	60 - 173
Mica[2]	118

[edit] Units

In SI, the unit of dielectric strength is volts per meter (V/m). It is also common to see related units such as volts per centimeter (V/cm), megavolts per meter (MV/m), and so on.

In United States customary units, dielectric strength is often specified in volts per mil (a mil is 1/1000 inch).[10] The conversion is:

$$1\ \mathrm{V/m} = 2.54 \times 10^{-5}\ \mathrm{V/mil}$$
$$1\ \mathrm{V/mil} = 3.94 \times 10^{4}\ \mathrm{V/m}$$

[edit] See also

- Breakdown voltage
- Relative permittivity
- Rotational Brownian motion

[edit] References

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10. ^ For one of many examples, see *Polyimides: materials, processing and applications*, by A.J. Kirby, google books link

[edit] External links

Calculating the Dielectric Strength

The dielectric strength is the maximum working voltage a material can withstand without breaking down.

It is normally expressed in Volts/mm. The material manufacturer should be able to supply this information but if not an approximate value can be found using a Holiday Detector.

Calculating the Dielectric Strength

1. Obtain a sample of material with a uniform thickness of about 1mm applied to a sheet of metal.
2. Connect the Holiday Detector to the sample with the earth lead connected to the metal and the high voltage probe (via a pointed probe) to the surface of the material.
3. Starting with the output voltage set to minimum, slowly increase the volts until the material breaks down and the alarm on the Holiday Detector sounds.
4. Lift the HV electrode off the surface of the material and note the output voltage.

5. Repeat this test a number of times on a new area of the sample at least 20mm from where any previous breakdowns have occurred, noting the breakdown voltage each time.
6. Take an average of the voltages and then 75% of that is approximately the dielectric strength of the material.

So now you have a value for the dielectric strength we can look at how this relates to the test voltage calculated previously.

It is important to check, before you start testing, that the test voltage you have selected is not so high that it will actually create faults in a coating. This would rather defeat the object of holiday detection. To demonstrate this let's look at a worked example.

Example

Say we have a coating 2mm thick which has a dielectric strength of 8400 V/mm. Using the NACE formula the test voltage is:

We know the dielectric strength is 8400 V /mm so for 2mm the maximum voltage before breakdown occurs is 2 x 8400 = 16,800 V. In this example then the test voltage of 11,180 V can be used since it is less than the breakdown voltage of the material (16,800V).

So what if the dielectric strength is below the calculated test voltage. Let's look at the same example as was shown above, a coating 2mm thick but this time it has a dielectric strength of 5000 V /mm. Again the test voltage is calculated to be 11,180 V but now the breakdown voltage of the material is 10,000 Volts (2 x 5000). This is clearly less than our test voltage and attempting to use 11,180V to test this coating would result in the creation of more holes.

In this instance high voltage holiday detection may still be used to locate flaws in the coating, but some further testing is required to ensure that this method is valid.

Referring to the example above of a 2mm coating with a dielectric strength of 5000 V / mm, the validation test would be as follows:

1. Make a small hole in a test piece.
2. With the electrode over the hole slowly increase the voltage until the spark jumps the gap. Note the voltage (which in this instance, on a 2mm coating, would be ~ 5000 V).
3. To determine the test voltage, use a value midway between the test voltage calculated using the NACE formula (in this case 11,180 V) and the minimum voltage determined from the above test (~5000V). This works out to be 8090 V. ((11,180 – 5000) / 2) +5000).
4. Now make some more holes in the test piece (making sure there is more than 20mm between each hole), this time at angles, and using your test voltage (in our example 8090V) ensure that it is possible to locate the faults.

This method of finding the test voltage is fine if all you are looking for is cracks in the coating (that is complete faults that go all the way through the coating to the substrate). Indeed, many standards only require this type of fault to be detected. However, with careful selection of the test voltage, it is possible to find a variety of different flaws. See A guide to using DC Holiday detectors for more information.