Insight — Application Note 3.06

Sensors, A/D Ratio and Base Capacitance

Sensors and A/D ratios

Measurements of dielectric properties often involve the use of simple parallel plate electrodes. However, their separation can change with pressure, or expansion and contraction of the material between them. The ratio of electrode area *A* and the distance *D* between them—the *A/D* ratio—therefore may not be well known. As the cell constant or scaling factor between conductance and conductivity, or capacitance and permittivity, uncertainty in *A/D* causes inaccuracies in determining dielectric material properties.

A common alternative is the interdigitated electrode like the one shown in Figure 6-1. A rigid substrate supports the electrodes and resulting the planar structure does not change with pressure, or expansion and contraction of the Material Under Test.

The *A/D* ratio of parallel plate electrodes may be generalized for application to interdigitated electrodes. In this case, *A* is not simply the area of the electrodes and *D* is not simply the distance between them. For interdigitated electrodes, the *A/D* ratio also accounts for fringing electric fields and as a result can also act as the scaling factor between conductance and conductivity, and capacitance and permittivity.

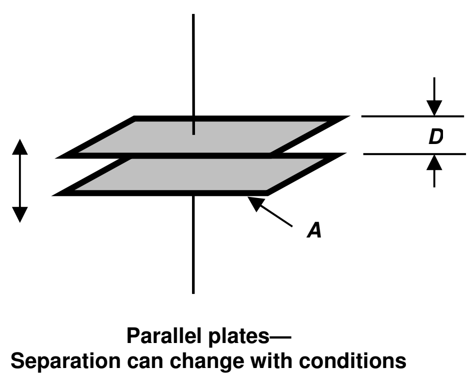

Figure 6-1
Comparison of parallel plate and interdigitated electrodes

Two-dimensional numerical simulations and experimental results have validated this generalization across a wide range of conductivity. The benefit of using interdigitated electrodes is an *A/D* ratio that is not affected by pressure, or expansion and contraction.

Base capacitance

The substrate supporting interdigitated electrodes introduces an additional component into the system being measured. The cross-section of Figure 6-2 shows capacitance C_{tot} has a contribution C_{MUT} from the Material Under Test (MUT) above electrodes. However, there is also a contribution C_{base} from the substrate beneath the electrodes. This second component is called the *base capacitance*.

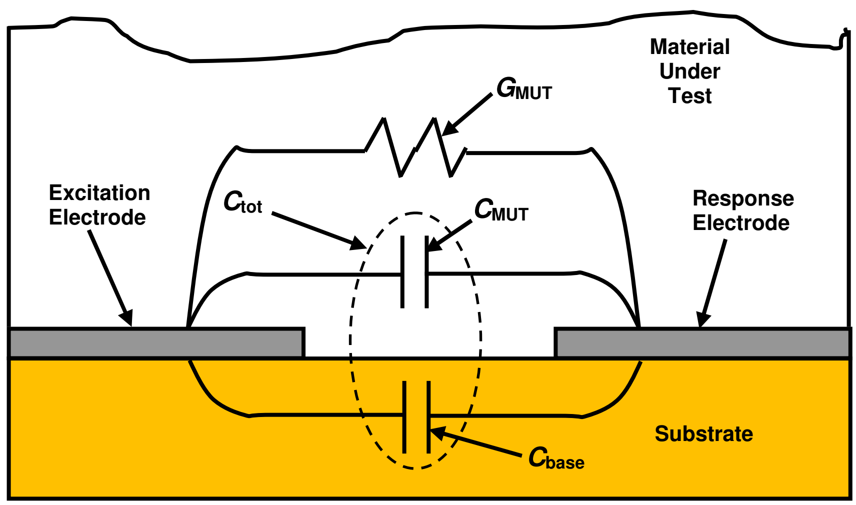

Figure 6-2
Cross section of interdigitated electrode structure

The total capacitance between the interdigitated electrodes is:

(eq. 6-1) $$C_{tot} = C_{MUT} + C_{base}$$

Therefore the capacitance of the MUT is:

(eq. 6-2) $$C_{MUT} = C_{tot} - C_{base} = \varepsilon_o\, \varepsilon'_{MUT}\, A/D$$

Where:

ε_0 = 8.85 x 10^{-14} F/cm
ε'_{MUT} = Relative permittivity of Material Under Test
A = Electrode area (cm^2)
D = Distance between electrodes (cm)

Finally, the conductivity (σ), ion viscosity (IV) and relative permittivity (ε'_{MUT}) of the MUT are:

(eq. 6-3) $$\sigma_{MUT} = G_{MUT} / (A/D)$$

(eq. 6-4) $$IV = \rho_{MUT} = (A/D) / G_{MUT}$$

(eq. 6-5) $$\varepsilon'_{MUT} = C_{MUT} / [\varepsilon_o (A/D)] = (C_{tot} - C_{base}) / [\varepsilon_o (A/D)]$$

Comparison of measurements with different sensors

If electrode geometry is properly factored into dielectric measurements, a material property like resistivity (ρ) will have the same value regardless of the sensor. For example, the Ceramicomb-1"[1] and Mini-Varicon[2] sensors of Figure 6-3, have very different constructions and electrode configurations. Specifications of these two sensors are listed in Table 6-1.

a. b.

Figure 6-3
Ceramicomb-1" sensor (a.) and Mini-Varicon sensor (b.)

Table 6-1
Comparison of Ceramicomb-1" and Mini-Varicon sensors

Sensor	Ceramicomb-1"	Mini-Varicon
Electrode Width	0.020"	0.004"
Electrode Spacing	0.020"	0.004"
Substrate	Alumina (ε_r = 9.8)	Polyimide (ε_r = 3.6)
A*/*D	10 cm	80 cm
Base Capacitance	≈25 pF	≈25 pF

The Ceramicomb-1" has an A/D ratio 1/8th that of the Mini-Varicon, and correspondingly has 1/8th the sensitivity. To compare results from different sensors, a Ceramicomb-1" measured dielectric properties during cure on the surface of a graphite-epoxy prepreg and a Mini-Varicon measured dielectric properties between two layers of the same prepreg, as shown in Figure 6-4.

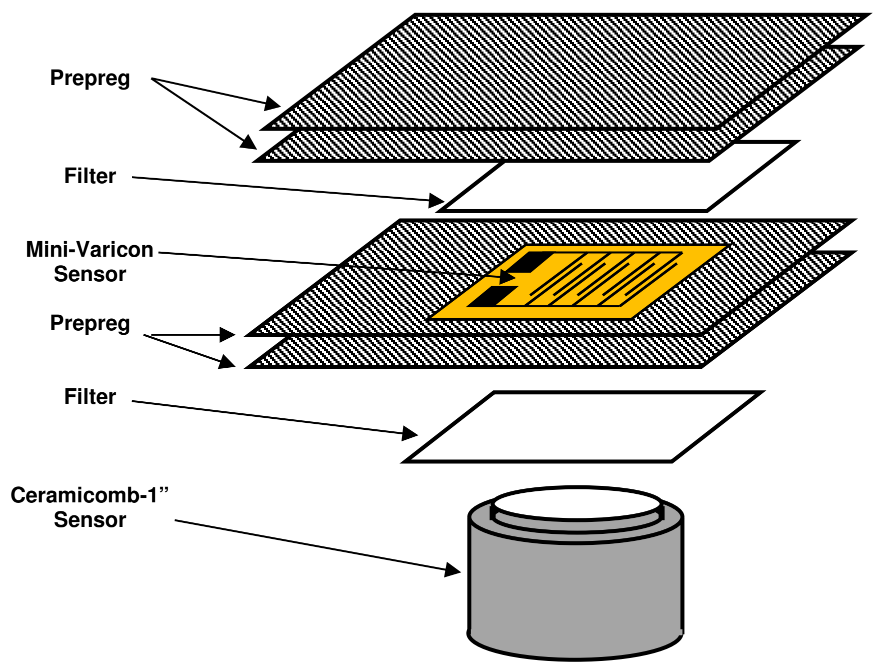

Figure 6-4
Lay-up of Ceramicomb-1" and Mini-Varicon sensors

Figure 6-5 shows the log(*ion viscosity*) and slope of log(*ion viscosity*) obtained with a frequency of 100 Hz from the two sensors during a single experiment. For brevity, log*(ion viscosity)* will be called log*(IV)* and the slope of log*(ion viscosity)* will simply be called *slope*.

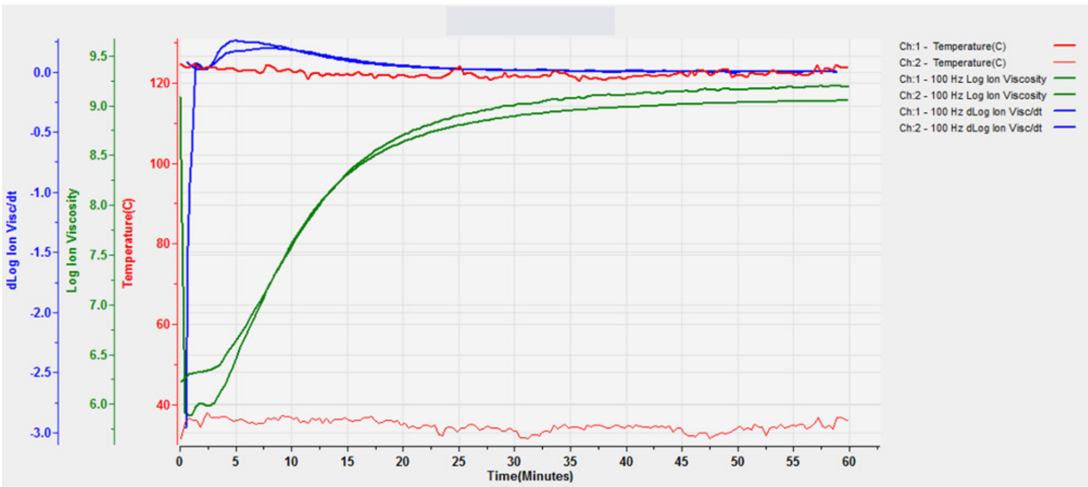

Figure 6-5
Cure of prepreg, two sensors simultaneously
(Ceramicomb-1" sensor on surface, Mini-Varicon sensor between plies)

Both the log*(IV)* and *slope* curves overlap very well, demonstrating measurement of a material property independent of the amount of sample or the geometry of the sensor. After 10 minutes the curves for *slope* overlap almost completely, indicating that cure rates at the end are essentially identical on the surface and within the laminate. For clarity, only the log(*IV*) curves are displayed in Figure 6-6 and only the *slope* curves are displayed in Figure 6-7.

Figures 6-6 and 6-7 illustrate that with the correct *A/D* ratio, different sensors provide the same cure data and are interchangeable for measuring ion viscosity. Note that equation 6-4 indicates *only A/D ratio is used to calculate ion viscosity* from the conductance between electrodes, G_{MUT}. Equation 6-5, however, shows that the base capacitance must be subtracted from the capacitance between electrodes, C_{tot}, to obtain the capacitance of the Material Under Test, C_{MUT}.

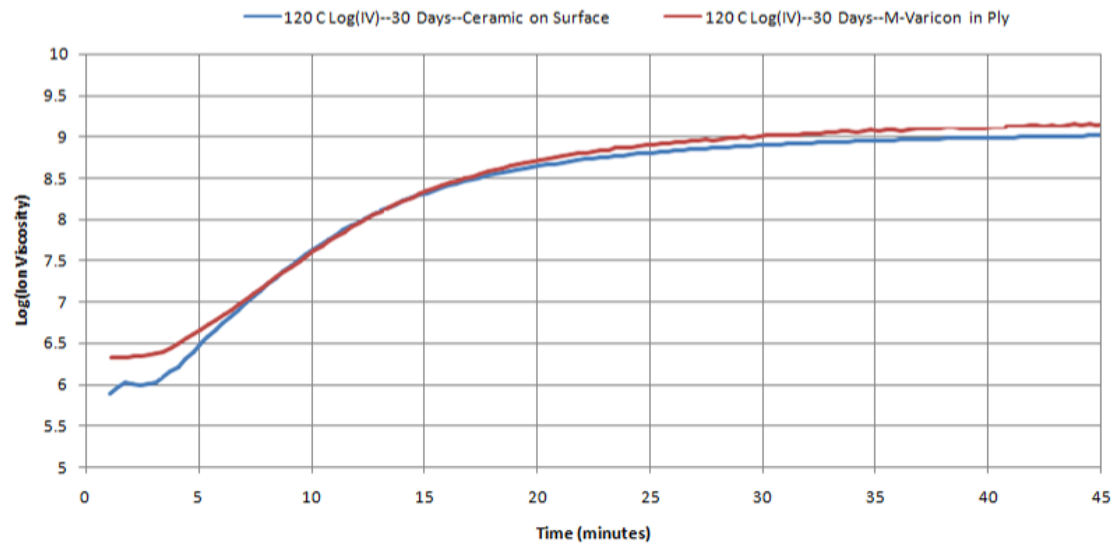

Figure 6-6
Log(*IV*) for Ceramicomb-1" and Mini-Varicon sensors

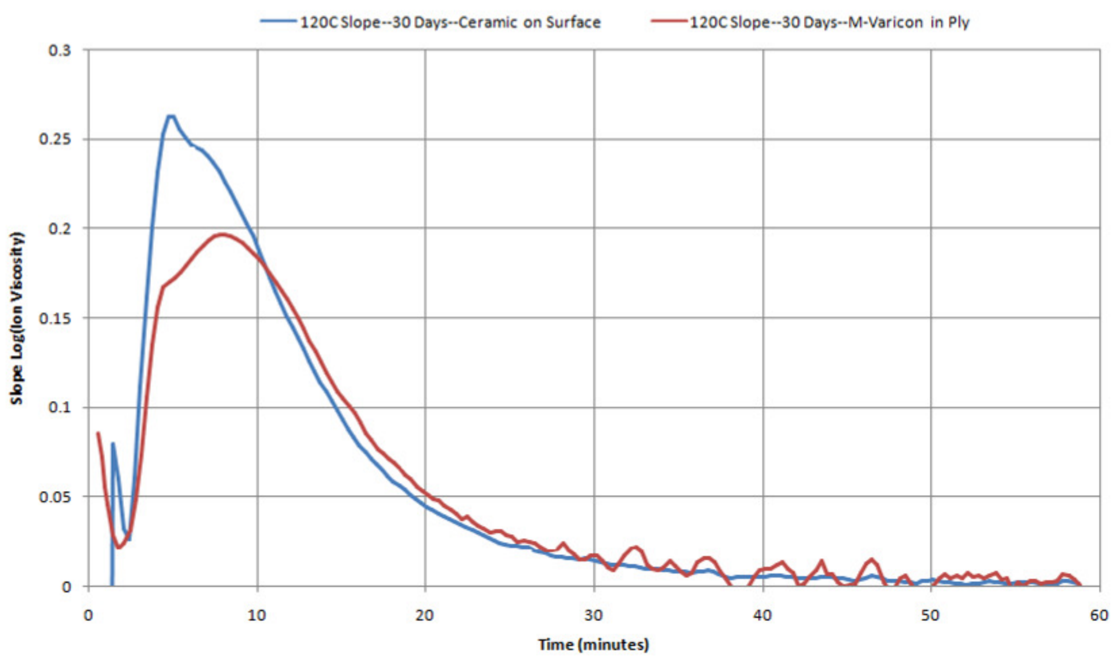

Figure 6-7
***Slope* for Ceramicomb-1" and Mini-Varicon sensors**

References

1. Ceramicomb-1″ sensor, manufactured by Lambient Technologies, Cambridge, MA USA. https://lambient.com

2. Mini-Varicon sensor, manufactured by Lambient Technologies, Cambridge, MA USA

Lambient Technologies, LLC
649 Massachusetts Ave., Cambridge MA 02139, USA
(857) 242-3963
https://lambient.com
info@lambient.com

