Insight — Application Note 2.07

Sensors, A/D Ratio and Base Capacitance

Introduction

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 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 shown in Figure 7-1. A rigid substrate supports the electrodes and resulting the planar structure does not change with pressure, or expansion and contraction of the MUT.

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 other factors and as a result can also act as the scaling factor between conductance and conductivity, and capacitance and permittivity.

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.

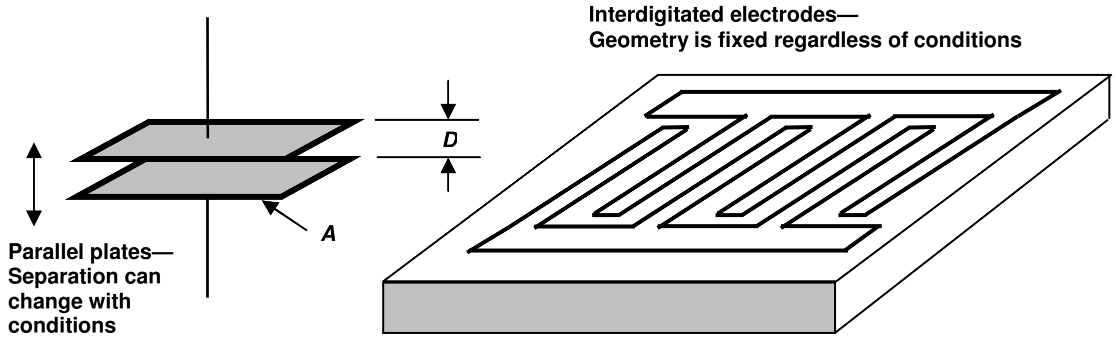

Figure 7-1
Comparison of parallel plate and interdigitated electrodes

Base capacitance

The substrate supporting interdigitated electrodes introduces an additional component into the system being measured. The cross section of Figure 7-2 shows that capacitance C_{tot} has a contribution C_{MUT} from the Material Under Test above electrodes. However, there is also a contribution C_{base} from the substrate beneath the electrodes. This second component is called the base capacitance.

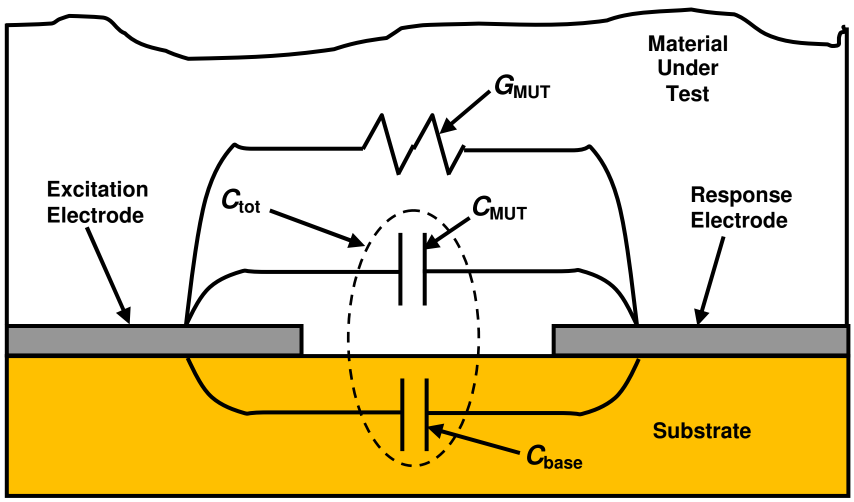

Figure 7-2
Cross section of interdigitated electrode structure

The total capacitance between the interdigitated electrodes is:

(eq. 7-1) $$C_{tot} = C_{MUT} + C_{base}$$

The capacitance of the MUT is:

(eq. 7-2) $$C_{MUT} = C_{tot} - C_{base} = \varepsilon_o \, \varepsilon'_{MUT} \, A/D$$

Finally, the conductivity, ion viscosity (*IV*) and permittivity of the MUT are:

(eq. 7-3) $$\sigma_{MUT} = G_{MUT} \, / \, (A/D)$$

(eq. 7-4) $$IV = \rho_{MUT} = (A/D) \, / \, G_{MUT}$$

(eq. 7-5) $$\varepsilon'_{MUT} = C_{MUT} \, / \, [\varepsilon_o \, (A/D)] = (C_{tot} - C_{base}) \, / \, [\varepsilon_o \, (A/D)]$$

Comparison of measurements with different sensors

To compare results from different sensors, a Ceramicomb-1″[1] sensor measured dielectric properties during cure on the surface of a graphite-epoxy prepreg and a Mini-Varicon[2] sensor measured dielectric properties between two layers of the same prepreg, as shown in Figure 7-4.

a. **b.**

Figure 7-3
Ceramicomb-1″ sensor (a.) and Mini-Varicon sensor (b.)

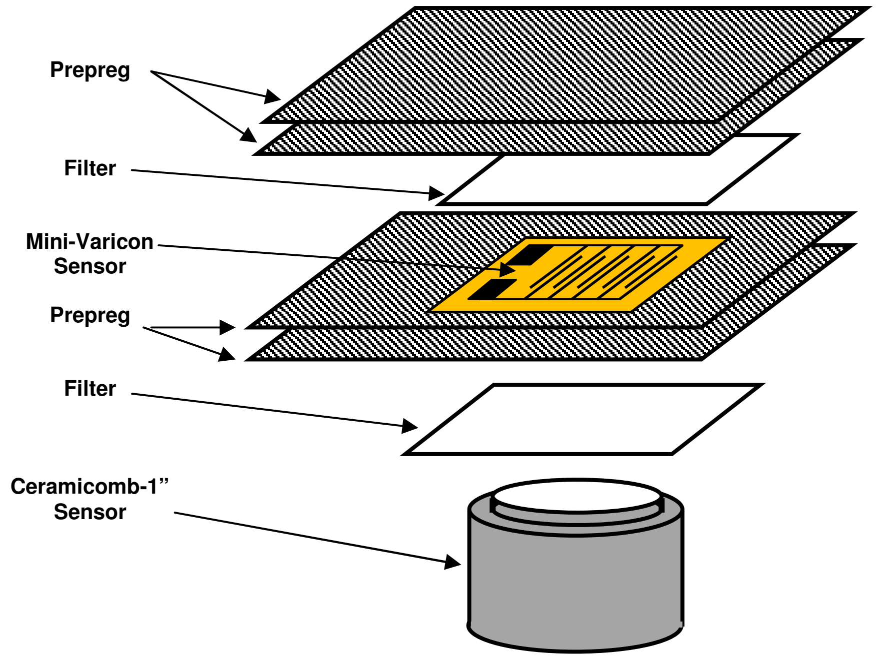

Figure 7-4
Lay-up of Ceramicomb-1" and Mini-Varicon sensors

The Ceramicomb-1" and Mini-Varicon sensors have very different constructions and geometries. In particular, the Ceramicomb-1" has an A/D = 10 cm and 1/8th the sensitivity of the Mini-Varicon, which has an A/D = 80 cm. Specifications of the Ceramicomb-1" and Mini-Varicon sensors are listed in Table 7-1:

Table 7-1
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

Figure 7-5 shows the log(ion viscosity) and slope of log(ion viscosity) data obtained with a frequency of 100 Hz from the two sensors during a single test. For brevity, log(ion viscosity) will be called *log(IV)* and the slope of log(ion viscosity) will simply be called *slope*.

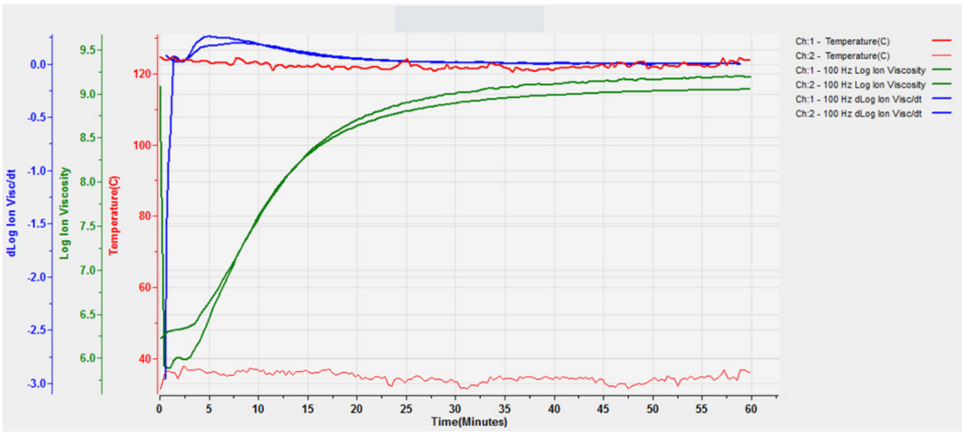

Figure 7-5
Cure of prepreg, two sensors simultaneously
(Ceramicomb-1" sensor on surface, Mini-Varicon sensor between plies)

The curves for slope overlap almost completely after the time of maximum slope (CP(3)), indicating that cure rates are essentially identical on the surface and within the laminate. For clarity, only the log(*IV*) curves are displayed in Figure 7-6 and only the slope curves are displayed in Figure 7-7.

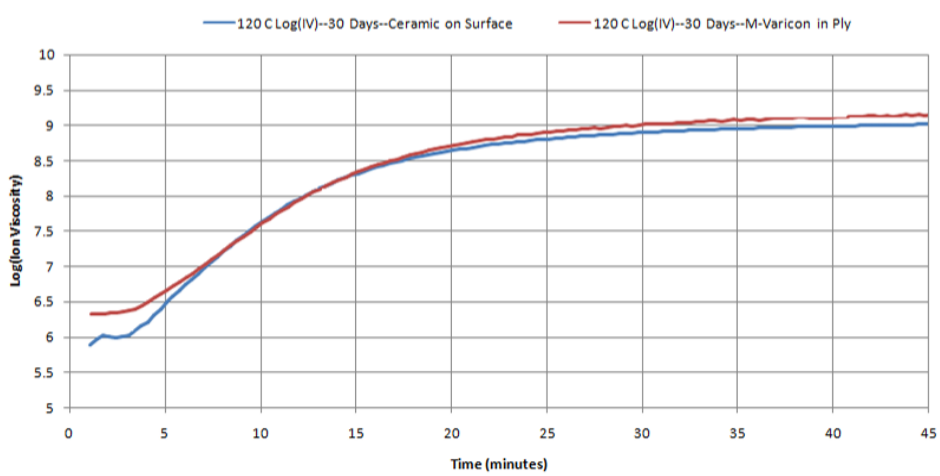

Figure 7-6
Log(*IV*) data for Ceramicomb-1" and Mini-Varicon sensors

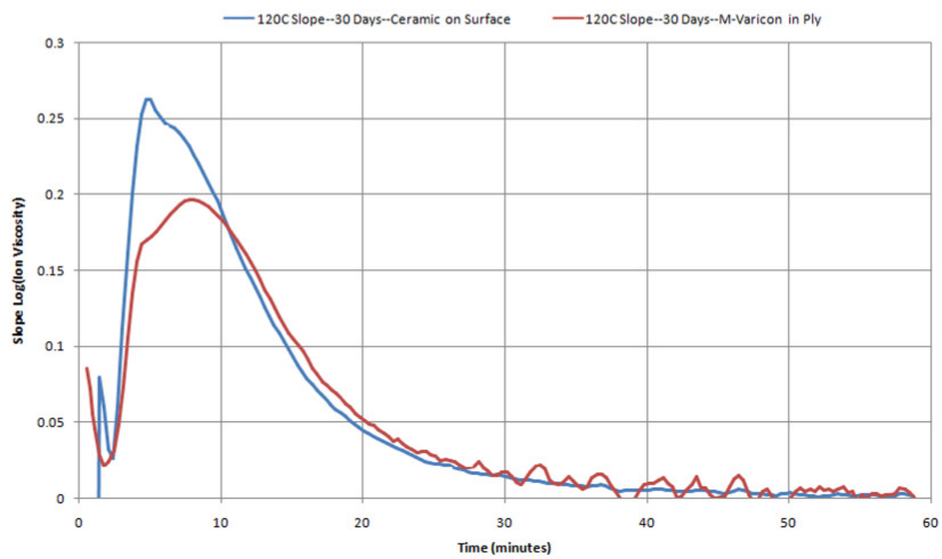

Figure 7-7
Slope data for Ceramicomb-1" and Mini-Varicon sensors

Figures 7-6 and 7-7 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 7-4 indicates that *only A/D ratio is used to obtain ion viscosity* from measurements of the conductance between the electrodes, G_{MUT}. Equation 7-5, however, shows that the base capacitance must be subtracted from measurements of the capacitance between the electrodes, C_{tot}, to obtain the capacitance of the Material Under Test, C_{MUT}.

References

1. P/N CCR-250-J-300-1 manufactured by Lambient Technologies, LLC, Cambridge, MA USA
2. P/N VC-400-X-40 manufactured by Lambient Technologies, LLC, Cambridge, MA USA

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