Electrical Property Characterization of SilcoTek Coatings

Background

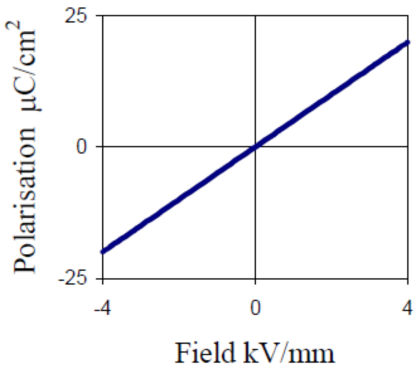
Recently there has been an increasing amount of inquiries from existing and potential customers on the electrical properties of SilcoTek coatings. Different customers require different electrical properties depending on their specific applications. Although our coatings are in general poor electrical conductors, we had not performed any systematic study to quantify the electrical properties in our coatings. Therefore to gain a better understanding of our coatings' electrical properties will not only help us provide better advice to our customers, but also provide us with an opportunity to expand into new markets.

Samples to be characterized include SilcoTek commercial coatings as well as experimental coatings. Measurements are carried out at the Electrical Characterization Lab of Penn State University. The goal of this study is to 1) identify the dielectric vs. resistor nature of the coatings (a resistor allows electric current to flow through it whereas a dielectric is an electrical insulator that gets polarized by an applied electric field and through the polarization stores electric energy); 2) if a coating exhibits low loss dielectric behavior, characterize its breakdown strength and permittivity values at room temperature; and 3) characterize these values as a function of temperature to understand the stability of our coatings with temperature elevation. This temperature stability will be important for our coatings to compete with polymer dielectric coatings that possess high breakdown strengths but cannot withstand elevated temperatures.[1]

The method used for study 1) above is the polarization vs. field measurement (P-E loops). This is done under low applied voltages and it serves as a quick screening method to check whether a coating's response to applied electric field is "capacitor-like" or "resistor-like". Study 2) and 3) are performed with a Cascade probe station and high voltage breakdown measurement tool, equipped with a temperature-controlled bath.

Introduction to P-E Measurement

A P-E loop for a device is a plot of the charge or polarization (P) developed, against the field (E) applied to that device at a given frequency. The P-E loop for an ideal linear capacitor is a straight line whose gradient is proportional to the capacitance (figure 1a). For an ideal resistor the current and voltage are in phase and so the P-E loop is a circle with the center at the origin (figure 1b). If these two components are combined in parallel we get the P-E loop in figure 1c which is in effect a lossy capacitor, meaning there is resistive leakage in the device, and the equivalent circuit would be a resistor with a linear capacitor in parallel. If we consider less ideal devices such as non-linear ferroelectric materials we would get a P-E loop such as in figure 1d.[2]



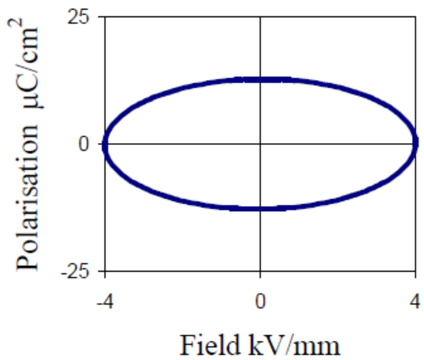
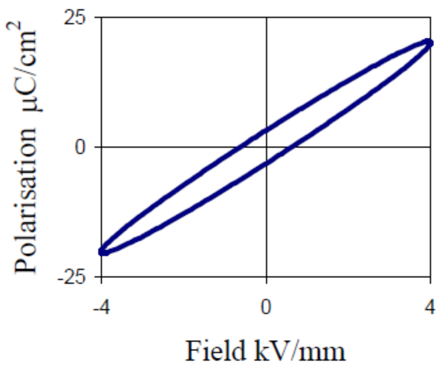


Figure 1a): Ideal linear capacitor response

Figure 1b) Ideal resistor response



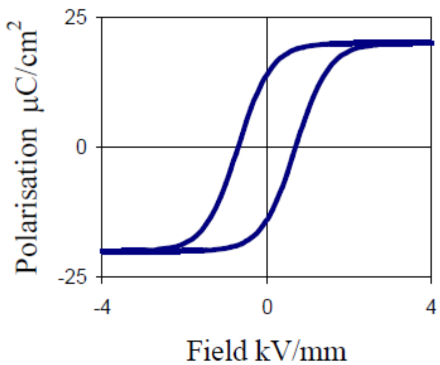


Figure 1c): Lossy capacitor response

Figure 1d): Non-linear ferroelectric response

In a good dielectric material with low loss, we want to see a P-E response of linear line as shown in figure 1a.

Characterization of Coatings

P-E measurements are performed on SilcoTek commercial as well as experimental coatings. Results are shown below. As this document is a work-in-progress, it will get updated when new data comes in with the progress of developmental work.

Two of our silicon-based coatings (Silcolloy and SilcoNert 2000) were characterized and their P-E responses are shown below in figures 2a and 2b, respectively. These measurements indicate that our silicon-based coatings exhibit large resistive leakage and are more “resistor-like” than “capacitor-like”. This may be expected as silicon is a semiconductor and known to be a lossy material.[3] Our other two silicon-based coatings SilcoKlean and SilcoGuard were not measured, but are expected to possess similar properties due to similar chemistry.

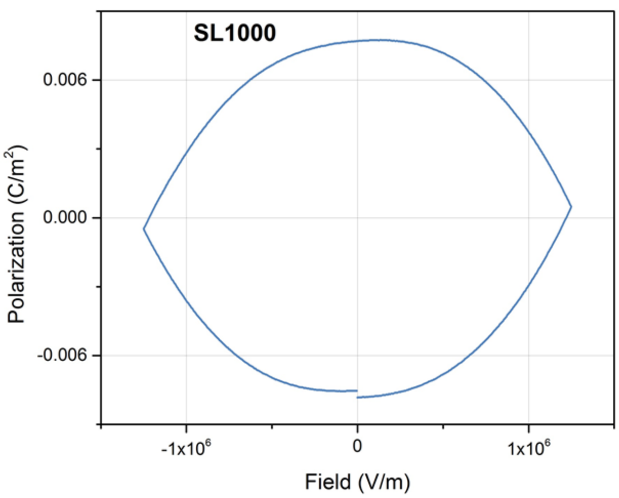


Figure 2a): P-E response of Silcolloy 1000 coating

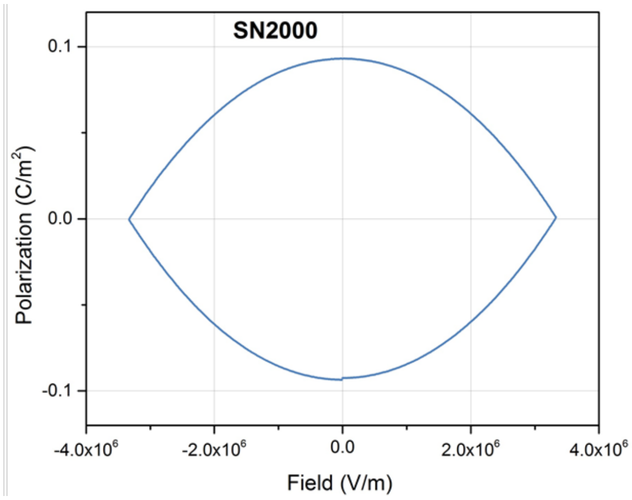


Figure 2b): P-E response of SilcoNert 2000 coating

The P-E response of an outdated version of Dursan coating is shown in figure 3, and it represents what's described as a "lossy capacitor". Compared to figures 2a and 2b, the loop is much narrower, indicating resistive leakage at a much reduced level. The area within the P-E loop is proportional to the loss tangent of the device, and the slope proportional to the capacitance. The improvement on the loss factor of this old Dursan compared to silicon-based coatings is due to the oxidized nature of Dursan. Silicon dioxide (SiO_2) is a good dielectric material with low loss and high breakdown strength on the order of 10MV/cm.[4,5] Dursan, however, contains carbon and is not a pure SiO_2 film.

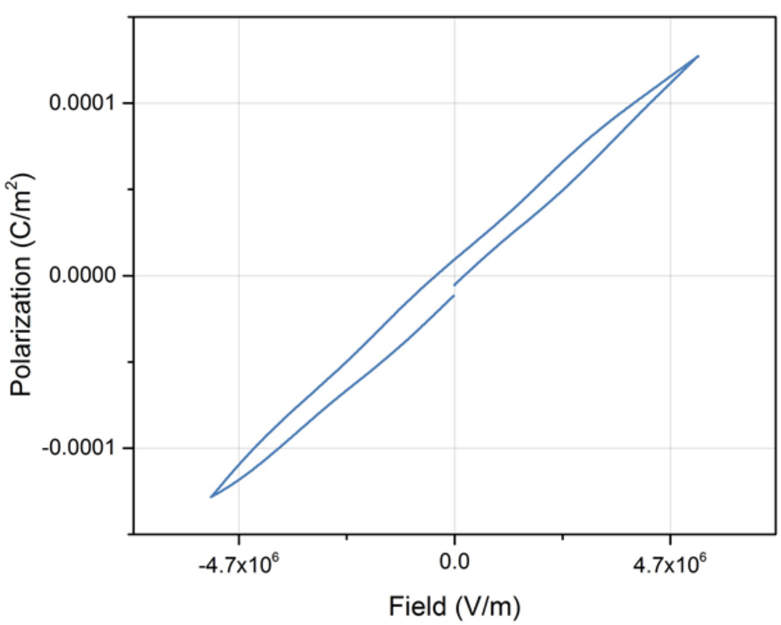


Figure 3): P-E response of outdated Dursan coating

One January 1st, 2015, SilcoTek enacted an improvement to the deposition process of Dursan which has improved its dielectric properties (i.e. better electrical insulating properties with minimized loss), in addition to better inertness and corrosion resistance. The process optimization has led to a modified Dursan coating that shows improved dielectric properties. The P-E response of the current Dursan coating is shown in figure 4 below. The linear P-E response is characteristic of a low loss capacitor.

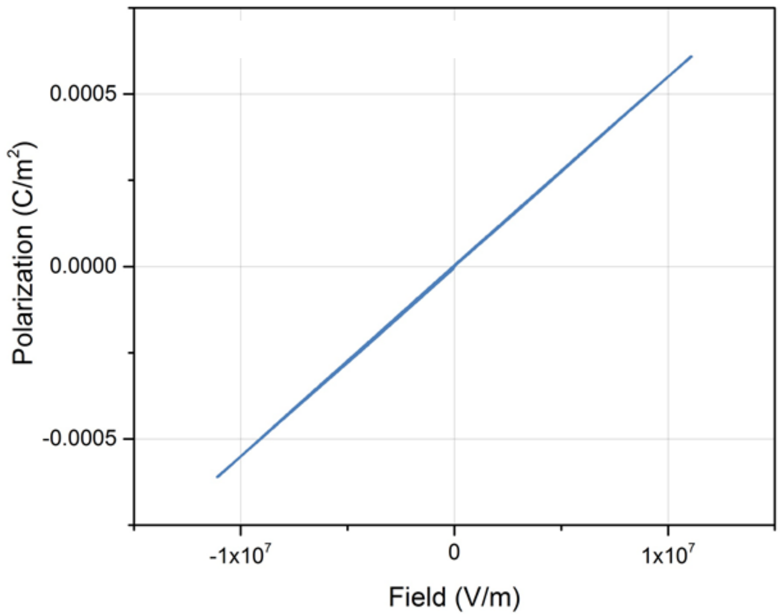


Figure 4): P-E response of the current Dursan coating

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