Two Terminal Impedance Spectroscopy of Electrowetting on Dielectric Test Structures

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Electrowetting on dielectric is a phenomenon where the application of a voltage to a conducting liquid placed on a dielectric covered electrode causes the liquid to spread over the dielectric surface. [1] The apparent contact angle of the liquid decreases as the surface acts increasingly hydrophilic. There is considerable recent interest in electrowetting for microsystems applications as the surface tension forces can be significantly larger than electrostatic or magnetic forces.

Electrowetting devices are generally modeled as a first-order series RC circuit, where the resistance is determined by the liquid conductivity and geometry, and the capacitance per unit area is dominated by the dielectric properties (permittivity and thickness). We have made measurements on electrowetting samples which show the impedance to be a complicated function of frequency which is not accurately modeled by a first order RC circuit. Contributions from the dielectric/electrolyte double layers need to be included to accurately model the impedance.

Our electrowetting samples consist of electrolyte droplets (sodium sulfate or sodium chloride solutions) on a thermal SiO_2 dielectric layer. Contact to the droplet is made through either thin insulated gold wires (with a known exposed area) or Si wafers with evaporated Au films. The droplets were confined with nylon O-rings coated with vacuum grease to produce a well-defined and calibrated device area. Impedance was characterized using an HP 4192A impedance analyzer from 1 kHz to 13 MHz, with zero DC bias and a 10 mV AC perturbation. Multi-strand Litz wires were used to connect the sample to the instrument to reduce the parasitic resistance from the leads due to the skin effect.

The samples have equivalent circuits consisting of several lumped elements in series: the dielectric capacitance, the solution resistance, and elements characterizing the electrode double layers. Ideally, these latter elements exhibit capacitive behaviors in the absence of Faradaic processes. In our experiments, however, the double layer invariably behaves like a constant phase element (CPE), where the impedance is described by a power-law function of frequency: $Z(\omega) = A(j\omega)^{-\alpha}$. [2] Numerical values of the parameters in the equivalent circuit were found by fitting the model to the experimental impedance data using a multidimensional nonlinear minimization technique.

Typical results for Na_2SO_4 solution droplets (of various concentrations) connected through two 25 μm diameter Au wires are shown in Fig. 1. The steep falloff in impedance magnitude and phase at high frequencies is due to the stray capacitance of the test fixture, including the test leads. The impedance is dominated by the droplet resistance for midrange frequencies (the horizontal portion of the magnitude curves) and by the double layer capacitances at low frequencies.
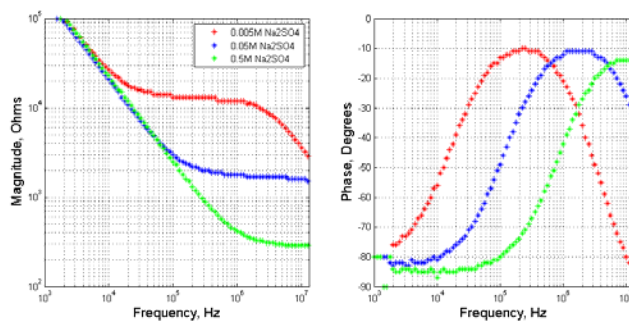

Fig.1 Impedance magnitude (left) and phase (right) spectra for two gold wires immersed in Na_2SO_4 solutions with concentrations 0.005 M (red), 0.05 M (blue), and 0.5 M (green).

This data can be fit using CPE models for the electrode double layers and a series resistance R_S. Fig. 2 illustrates the results of such data fitting.
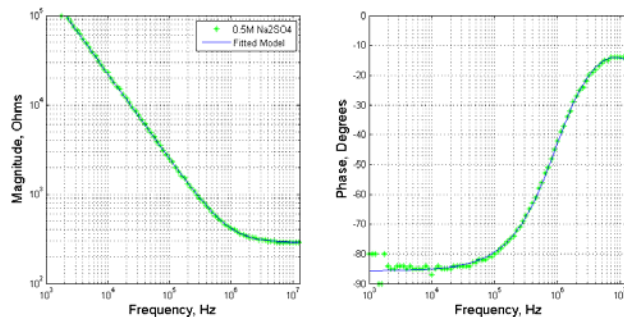

Fig.2 Parameter fitting for two gold wires immersed in 0.5 M Na_2SO_4 solution. Fitted parameters are: $\alpha = 0.95$, $A = 4.10 \times 10^8 \ \Omega(\frac{rad}{s})^\alpha$, $R_S = 293 \ \Omega$.

Our presentation will describe other electrode configurations and discuss equivalent circuit models useful for describing electrowetting on dielectric devices. In general, the impedance is typically dominated by contributions from the wire contact double layer.

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