Experimental Measurement of the Effective Electrical Conductivity of Thin Ferroelectric Polymer Films

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We have developed two methods of determining the effective conductivity of a ferroelectric polymer films. Experiments were performed on 11.5 μm-thick Kureha films of polyvinylidene fluoride (PVDF). The total current density j during repeated poling of an already completely polarized sample has three components, namely, the capacitive one j_c, the component related to the unstable reversible displacement j_{unst} and the conductivity component j_{cond}.

$$j=dD/dt=j_c+j_{unst}+j_{cond} \tag{1}$$

where D is the total ''apparent'' displacement containing in addition to the usual displacement the current density resulting from conduction. The capacitive component j_c is decreasing almost exponentially and approaches zero at times larger than about 5 R_sC_s=0.4 μs for a current limiting resistor of R_s=500 Ω_ and a sample capacitance of C_s=160 μF. The unstable part of polarization completely aligns or switches back in about 10 ms, so one can assume that $j_{unst}=0$ at $t>10$ ms. Therefore, the total current density j after a few seconds of voltage application to a completely poled sample contains only the conductivity component j_{cond}. Since j_{cond} depends on the conductivity g_o, its value can be determined experimentally either from the slope of the $D(t)$ curve for t> 10 ms, or from the residual charge on the measuring capacitor after short-circuiting of the sample, because this charge is accumulated due to conduction of the sample.

$D(t)$ is linearly increasing with time and g_o can be determined from $g_o=D(t)/E$. The conductivity obtained from the residual charge on the measuring capacitor amounts to $g_o = C_mV_{cond}/EAt_{ch}$ where V_{cond} is the voltage at the measuring capacitor C_m=0.2 μF, t_{ch}=150 s the charging time and A=0.2 cm^2 the sample area. There is a reasonable agreement between the two methods, and the average values are of the same order of magnitude (10^{-12} S/m).

Ohm's law is not valid, since the current-voltage dependence is non-linear. From our data $I=\gamma V^{1.6}$. The exponent of 1.6 indicates that the conductivity has a mixed origin with a quadratic dependence typical for the space charge limited injection currents superimposed with a linear Ohmic dependence caused by intrinsic conductivity of the sample. From the linear component the intrinsic conductivity of $g_{in}=0.63\cdot10^{-12}$ S/m has been derived and the quadratic component delivers a mobility of injected excess charge carriers of $\mu=9.3\cdot10^{-12}$ cm^2/V·s utilizing Child's law.