A Series of Electromechanical Measurements for Determination of Piezoelectric, Dielectric and Elastic Tensor Components in Porous Polypropylene Electrets

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INTRODUCTION

The electromechanical properties of the Porous Polypropylene (p-PP) electrets by means of the precise dielectric measurements **including the nonlinear responses.**

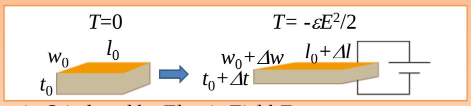
1. The dielectric resonance gives the piezoelectric and the elastic factors **without adding the Maxwell force**.
2. The second order and the third order nonlinear permittivity becomes a function of d_{33} and of the elastic compliance s_{33} **when the electrostriction generated by the Maxwell force** between electrodes of the sample were considered.

The piezoelectric and the elastic factors were determined by the nonlinear permittivity measured by various measurements and were compared with those given by the dielectric resonance measurements.

SAMPLE

Porous polypropylene sheet (provided by YUPO Corporation, JAPAN)
Thickness: 85 µm. Density: 470 kg / m³.
Aluminum electrodes were deposited on both surfaces of the sample.
Corona discharge was used to make electret of the sample.

NONLINEAR PERMITTIVITY AND ELECTROSTRICTION



Strain S_i induced by Electric Field E:

$S_1=\Delta l/l_0 = s_{13}T,\ S_2=\Delta w/w_0 = s_{23}T,\ S_3=\Delta t/t_0 = s_{33}T+d_{33}E$

Capacitance: $C^{ap} = \varepsilon lw/t = \varepsilon l_0(1+S_1)\, w_0(1+S_2)/t_0(1+S_3)$

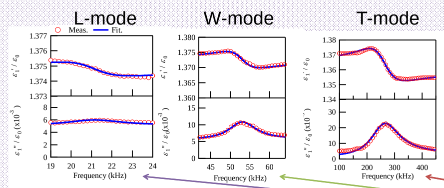
Measured Permittivity: $\varepsilon^{ap} = C^{ap}\, t_0/l_0w_0 = \varepsilon(1+S_1)(1+S_2)/(1+S_3)$

Electric Displacement: $D = \varepsilon_1 E + \varepsilon_2 E^2 + \varepsilon_3 E^3 + \ldots$

$$\varepsilon^{ap} = \varepsilon[1 - d_{33}E - 1/2\varepsilon(s_{13}+s_{23}-s_{33})E^2]$$

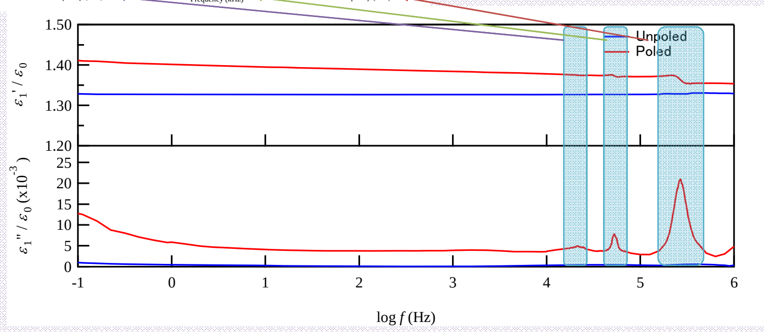
$$\varepsilon_2 = -d_{33}\varepsilon_1,\ \varepsilon_3 = -\varepsilon_1^2(s_{13}+s_{23}-s_{33})/2$$

DIELECTRIC RESONANCES OF THE SAMPLE



$\varepsilon^T = \varepsilon^S(1+k_w^2/(1-k_w^2)\tan b/b)$
$(1+k_l^2/(1-k_l^2)\tan c/c)/(1+k_t^2\tan a/a)$
$a = \omega h/2v_h,\ b = \omega w/2v_w,\ c = \omega l/2v_l$

ε^T and ε^S: permittivity of free and fixed conditions respectively
ω: angular frequency, h: thickness, w: width, l: length of the sample
v_h, v_w and v_l: the acoustic velocity of thickness, width and length directions
k_t, k_w and k_l: the electromechanical coupling factor of thickness, width and length directions



NONLINEAR PERMITTIVITY MEASUREMENTS

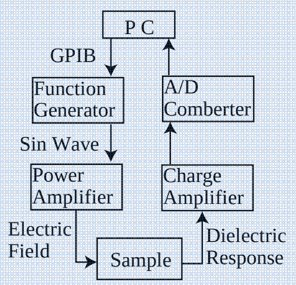
i) harmonic distortion of electric displacement against electric field

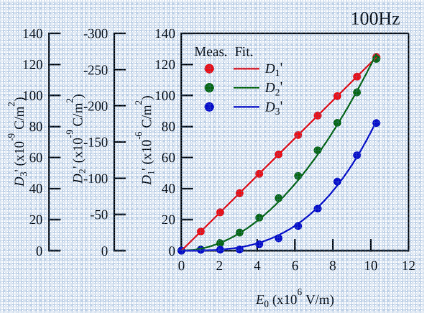
Applied Field: $E = E_0\cos\omega t$

Electric Displacement:

$$D = \varepsilon_1 E_0\cos\omega t + \varepsilon_2 E_0^2\cos^2\omega t + \varepsilon_3 E_0^2\cos^3\omega t + \cdots$$
$$= \varepsilon_1 E_0\cos\omega t + (1/2)\varepsilon_2 E_0^2\cos(2\omega t) + (1/4)\varepsilon_3 E_0^3\cos(3\omega t) + \cdots$$

$$D_1(\omega) = \varepsilon_1 E_0,\ D_2(2\omega) = (1/2)\varepsilon_2 E_0^2,\ D_3(3\omega) = (1/4)\varepsilon_3 E_0^3$$





Parameter	Result
ε_1' (pF/m)	12.1
ε_2' ($\times10^{-21}$F/V)	-5.12
ε_3' ($\times10^{-28}$Fm/V²)	2.93

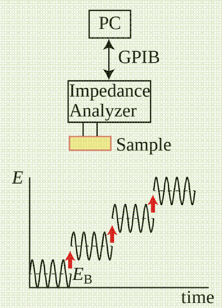
ii) linear permittivity against bias electric field

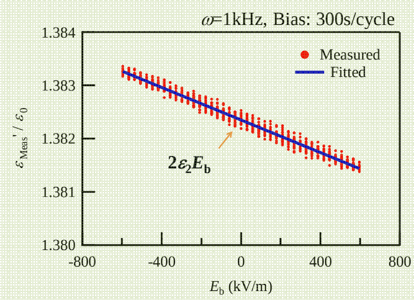
Applied Field: $E = E_b + E_0\cos\omega t$

Electric Displacement:

$$D = \varepsilon_1(E_b+E_0\cos\omega t) + \varepsilon_2(E_b+E_0\cos\omega t)^2 + \varepsilon_3(E_b+E_0\cos\omega t)^3$$
$$= (\varepsilon_1+\varepsilon_2E_b+\varepsilon_3E_b^2)E_b + (\varepsilon_1+2\varepsilon_2E_b+3\varepsilon_3E_b^2)E_0\cos\omega t + \cdots$$

$$D(\omega) = \varepsilon_{Meas}E_0\cos\omega t,\ \varepsilon_{Meas} = \varepsilon_1 + 2\varepsilon_2E_b + 3\varepsilon_3E_b^2$$





Parameter	Result
ε_1' (pF/m)	12.2
ε_2' ($\times10^{-21}$F/V)	-5.51

PIEZOELECTRIC AND ELASTIC COMPONENTS DETERMINED BY DIELECTRIC MEASUREMENTS

i) dielectric resonance (without applying Maxwell force)

Parameter	Result	Note
d_{31} (pC/N)	-0.75	
d_{32}(pC/N)	-1.47	
d_{33}(pC/N)	444	by e_{33}/c_{33}
e_{33} (µC/m²)	240	
k_{31}	0.011	
k_{32}	0.014	
k_t	0.094	

Parameter	Result	Note
s_{11} (nPa⁻¹)	0.357	
s_{22} (nPa⁻¹)	0.645	
c_{33} (kPa)	540	$1/c_{33}$ = 1.85(µPa⁻¹)
s_{12} (nPa⁻¹)	0.17	by s_w, and s_{22}
s_{13} (nPa⁻¹)	-3.125	by d_{31}/e_{33}
s_{23} (nPa⁻¹)	-6.125	by d_{32}/e_{33}

ii) nonlinear permittivty (with applying Maxwell force)

a) harmonic distortion measurements

Parameter	Result	Note
s_{33}(µPa⁻¹)	4.00	from ε_3'
d_{33}(pC/N)	423	from ε_2'

b) DC bias voltage measurements

Parameter	Result	Note
d_{33}(pC/N)	450	from ε_2'

SUMMARY

When the electrostriction is generated by the Maxwell force…
ε_2 depends on the piezoelectric constant d_{33}
ε_3 depends on the elastic compliance s_{33}

d_{33} determined by ε_2 showed a good agreement with the result of the dielectric resonance.

s_{33} determined by ε_3 was about two times larger than the result by the dielectric resonance. The result suggests an existence of frequency dependence of s_{33}.

The piezoelectric response of the p-PP electret
↓
Mainly induced by the size effect.

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