Polymer ferroelectrets: Novel materials with built-in functionality

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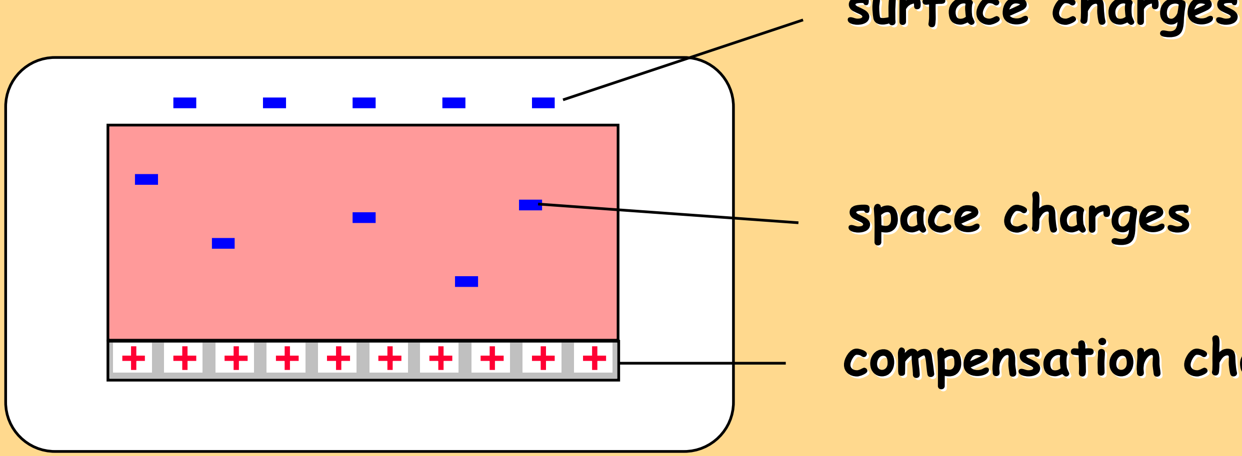
Traditional charge electrets

Electret: Dielectric material with quasi-permanent electrical charge

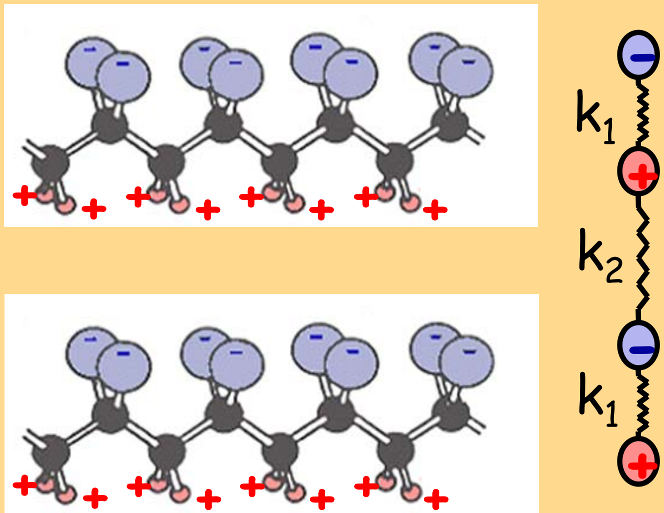


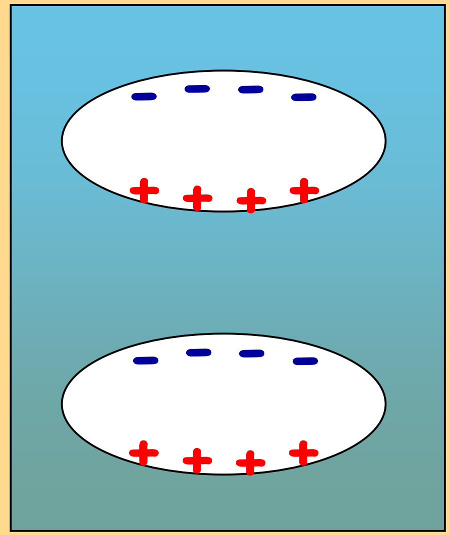
- Employed wherever large external fields are required
- Applications in acoustical transducers (microphones, headphones...)
- Nonpolar materials ⇨ no pyro-, piezoelectricity

Modern charge electrets: ferroelectrets

ferroelectric polymer

ferroelectretic polymer





ferroelectrets (cellular space-charge electrets)

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combine features of ferroelectrics and space-charge electrets

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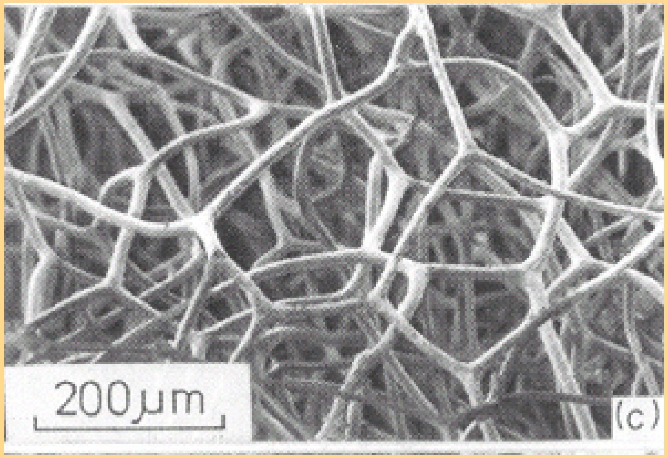
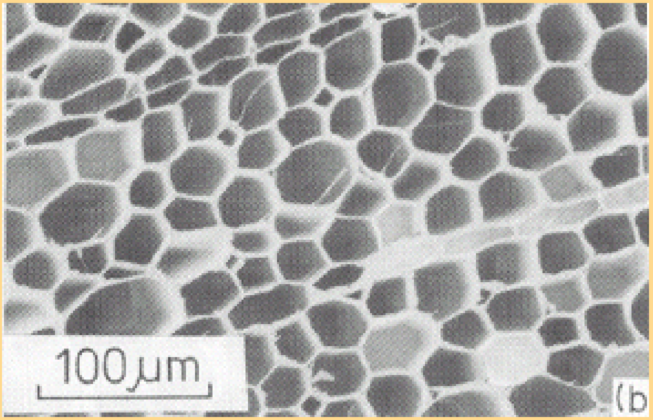
novel class of soft transducer materials

Natural cellular materials

sponge



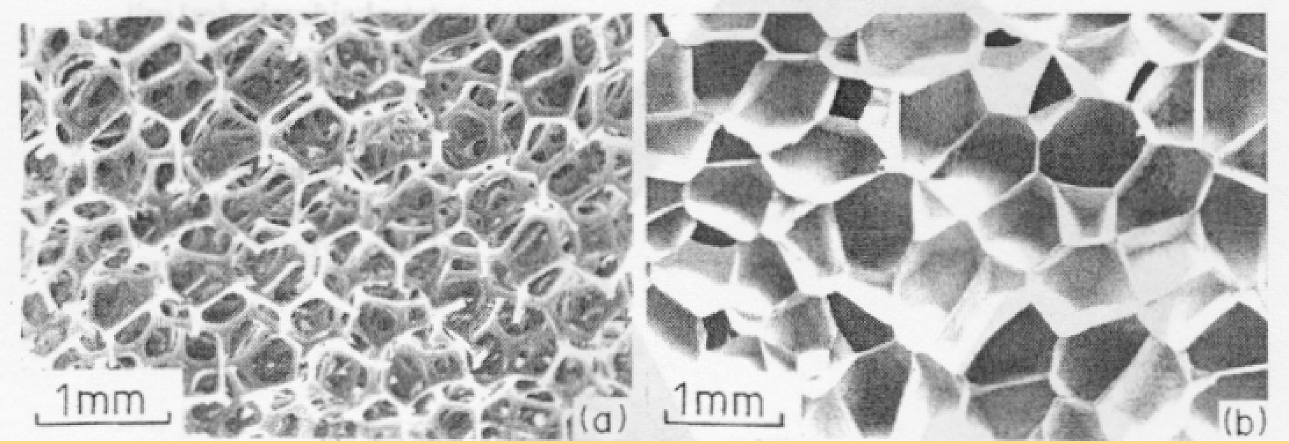
wood



Nature employs the concept of cellular materials for extending the property range of solid materials

Synthetic cellular materials

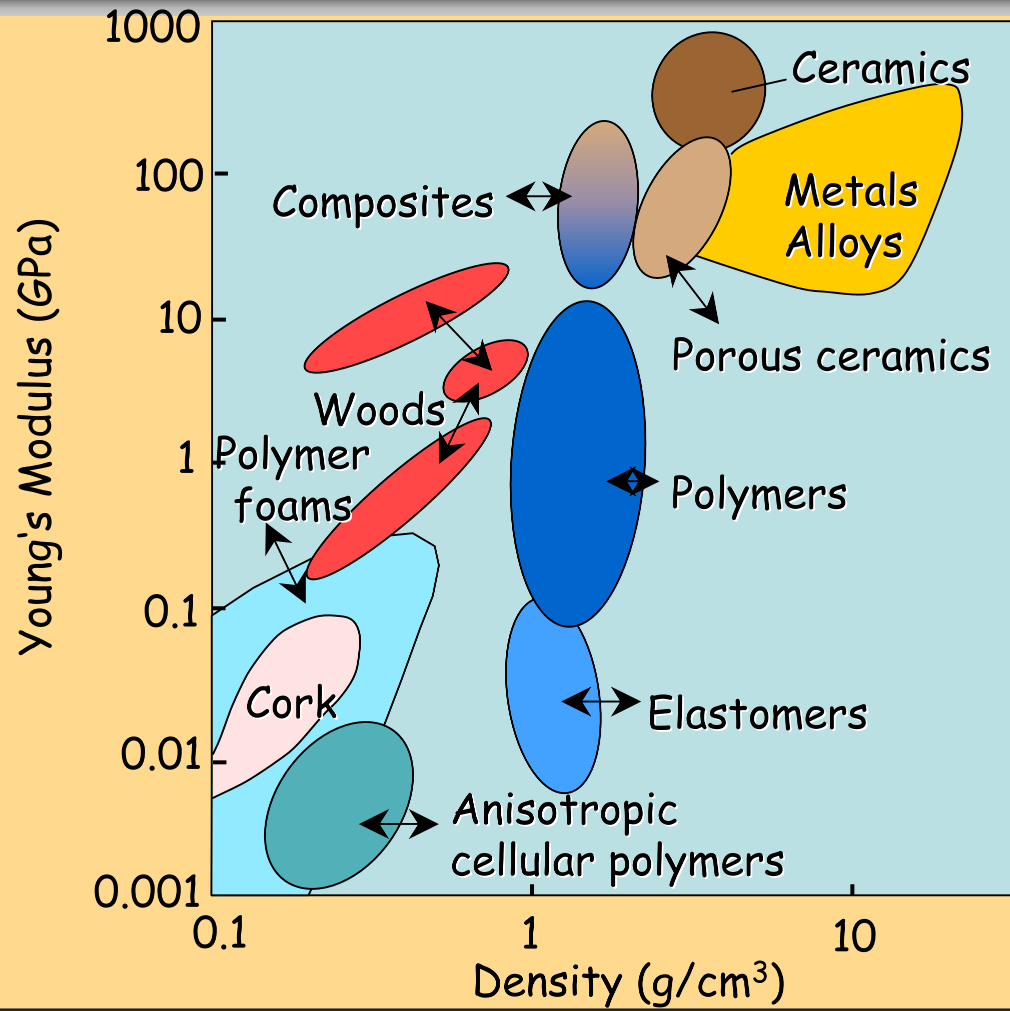
Open- and closed-cell polyurethane foams



Engineers benefit from the foam concept by extending the materials property range for applications in

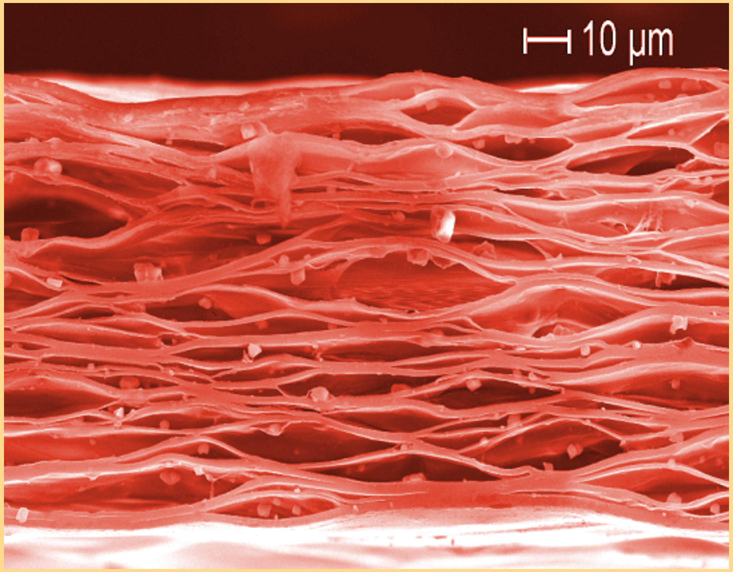
thermal insulation, packaging, mechanical energy absorption,...

Material properties of solid and cellular materials

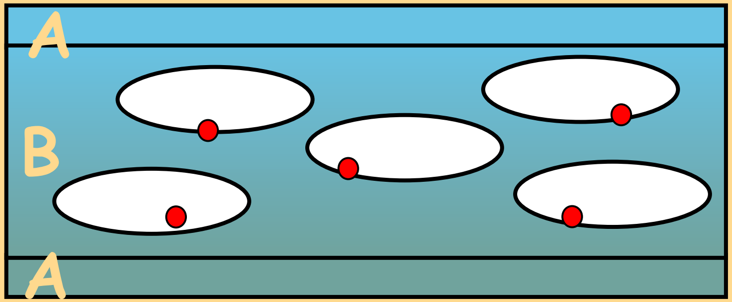


Synthetic functional foams

Cellular polymer with flat, lenselike voids



SEM picture



schematic view

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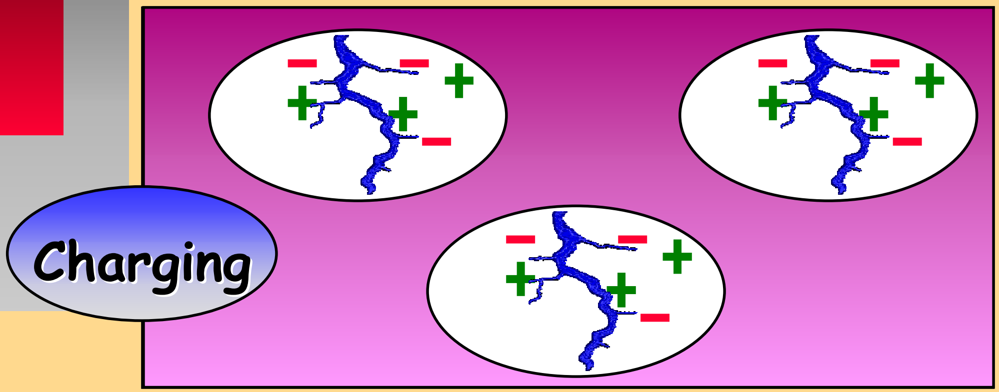
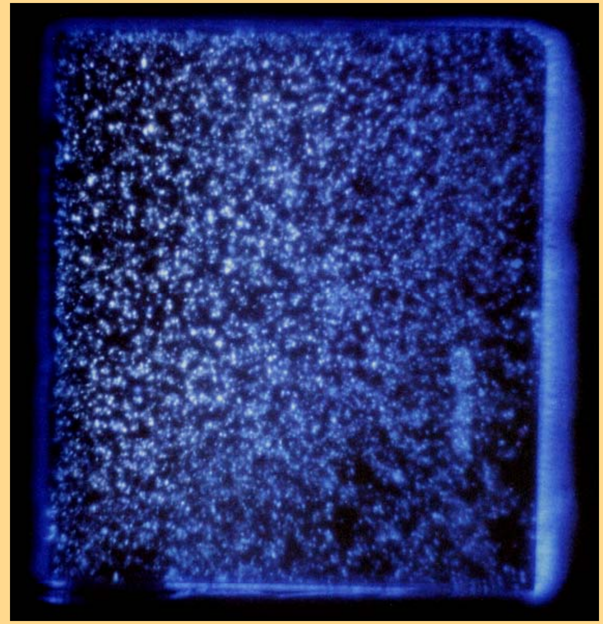
Functionalisation?

Microscopic origin of the internal charging of cellular materials

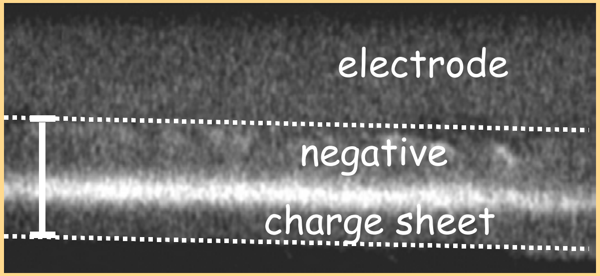


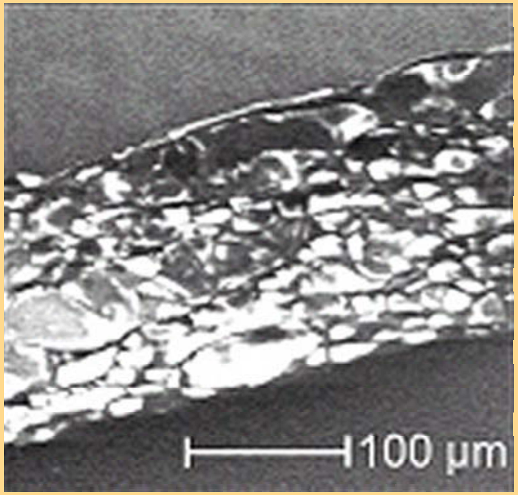
Dielectric barrier microdischarges
(partial discharges)

Light emisssion during charging



Direct visualization of the negative charges by SEM

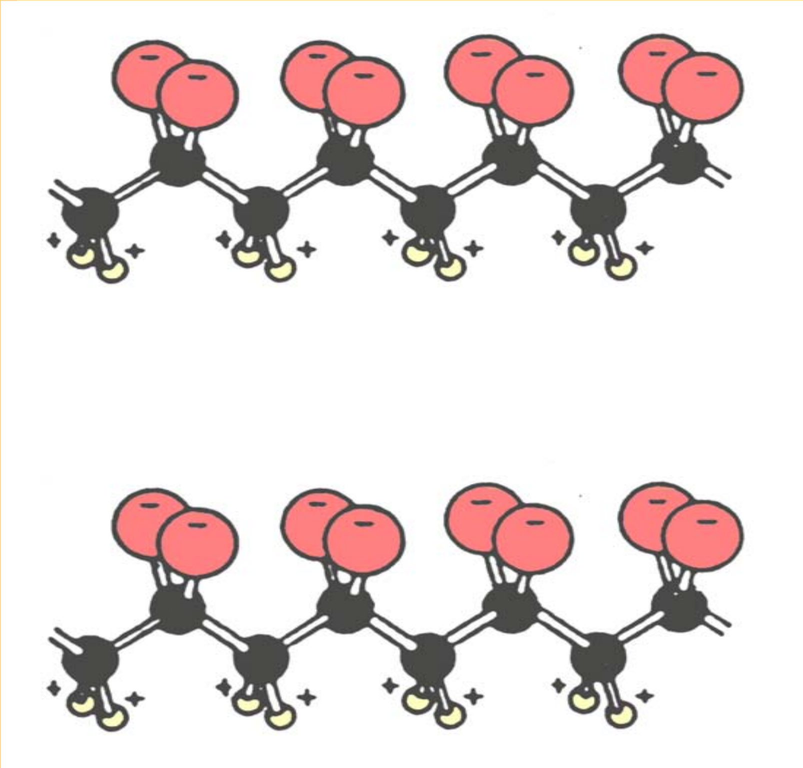




J. Hillenbrand and G. M. Sessler CEIDP (2000)

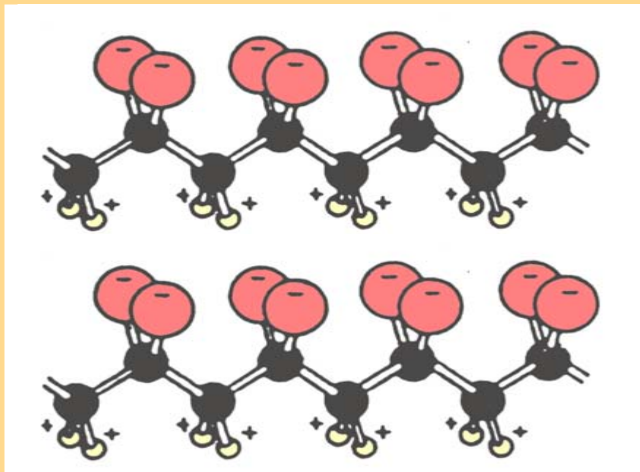
Piezoelectricity in ferroelectric polymers

PVDF



Piezoelectricity in ferroelectric polymers

compressive stress

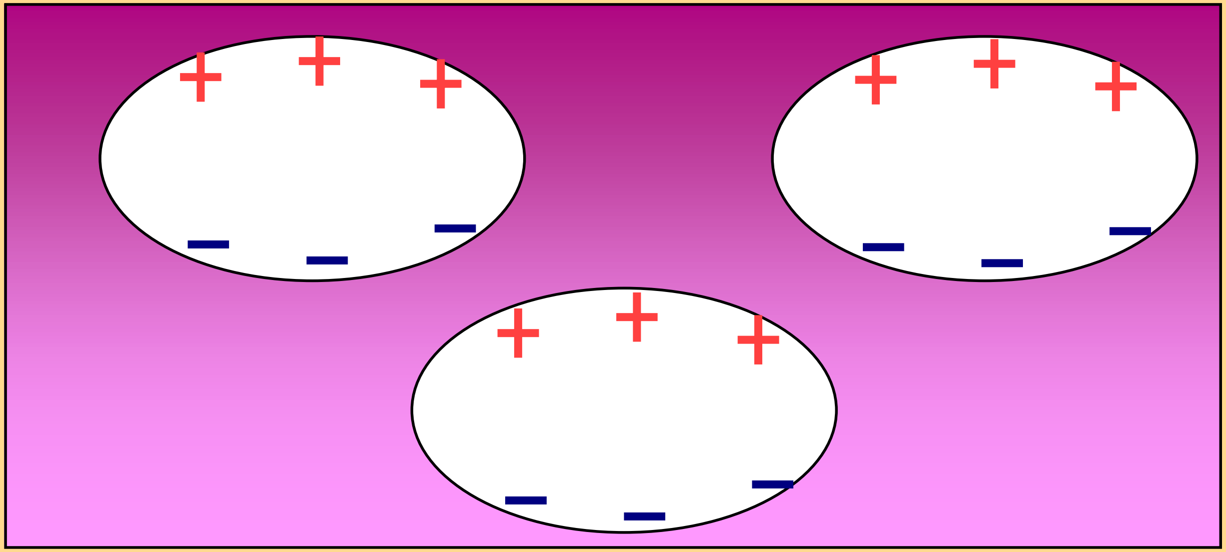


Dipole density piezoelectricity

$d_{33} = -30\ \mathrm{pC/N}$

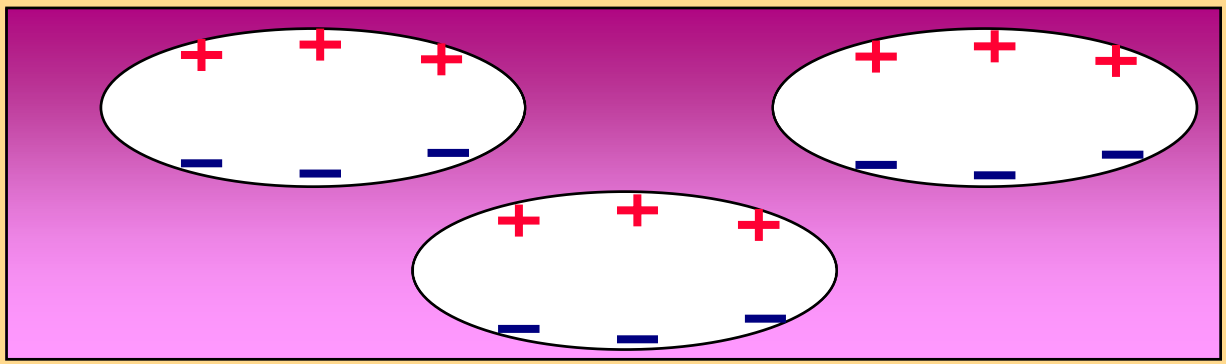
ferroelectrets → more sensitive piezoelectric polymers
polymers with intrinsic piezoelectricity

Piezoelectricity in ferroelectrets



Piezoelectricity in ferroelectrets

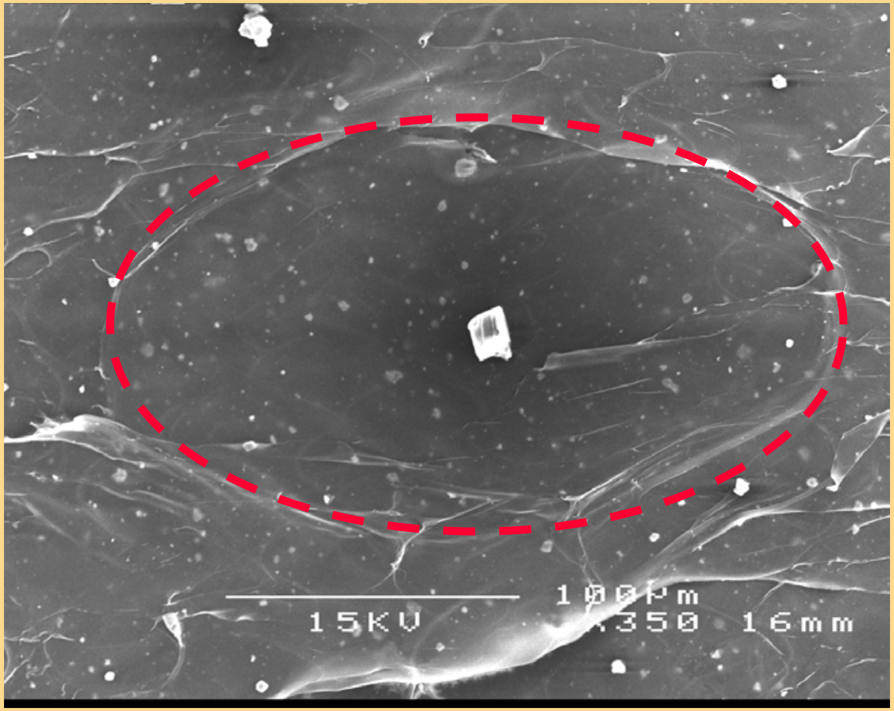
compressive stress



strong deformation of the macroscopic dipole

intrinsic piezoelectricity → $d_{333} \approx 50\ldots600$ pC/N

In-plane anisotropy of voids in polypropylene foams



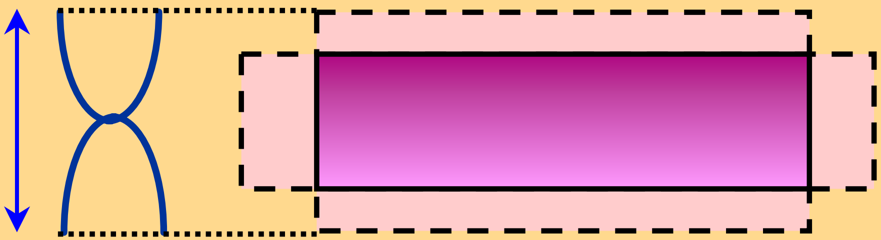
implications for piezoelectric properties ?

Dielectric resonance spectroscopy on ferroelectrets

thickness extension resonance (TE-Mode)

thickness $= \lambda/2$

λ : acoustic wavelength



length extension resonance (LE-Mode)

electric field → sample deformation (mechanical stress)

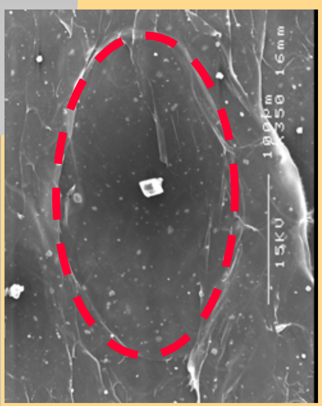
inverse piezo-effect

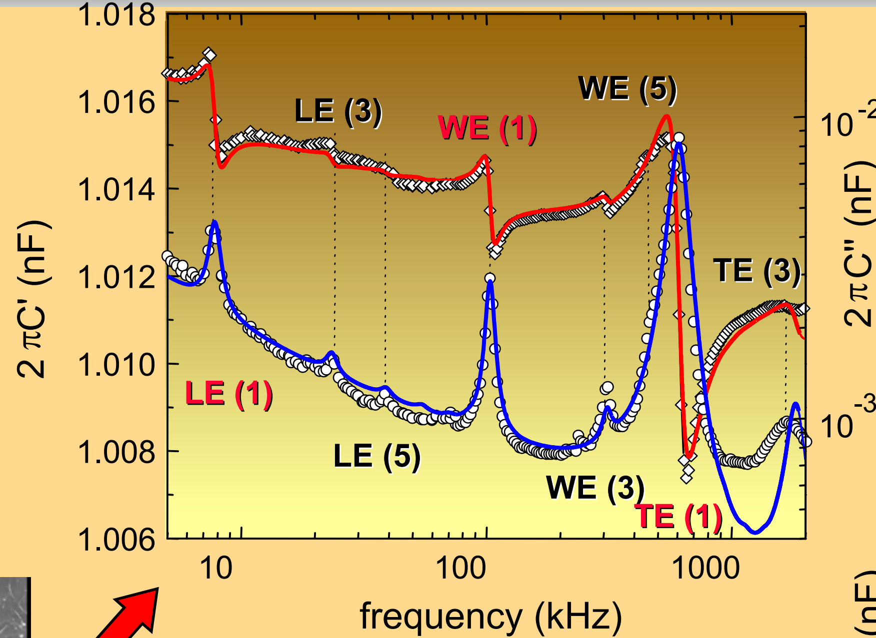
↓ direct piezo-effect

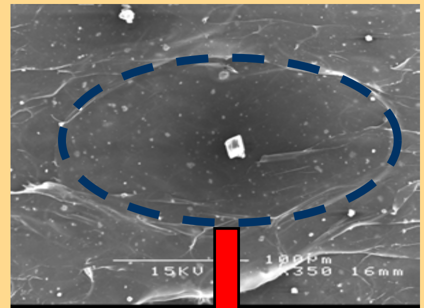
resonance in dielectric function

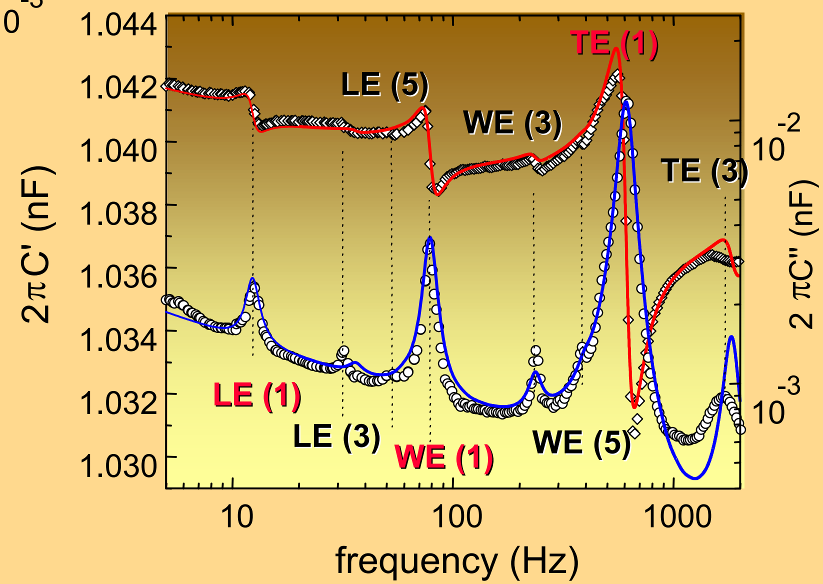
G. S. Neugschwandtner et al.
Appl. Phys. Lett. Vol. 77 (2000)

Piezoelectric resonances in the dielectric function of PP foams

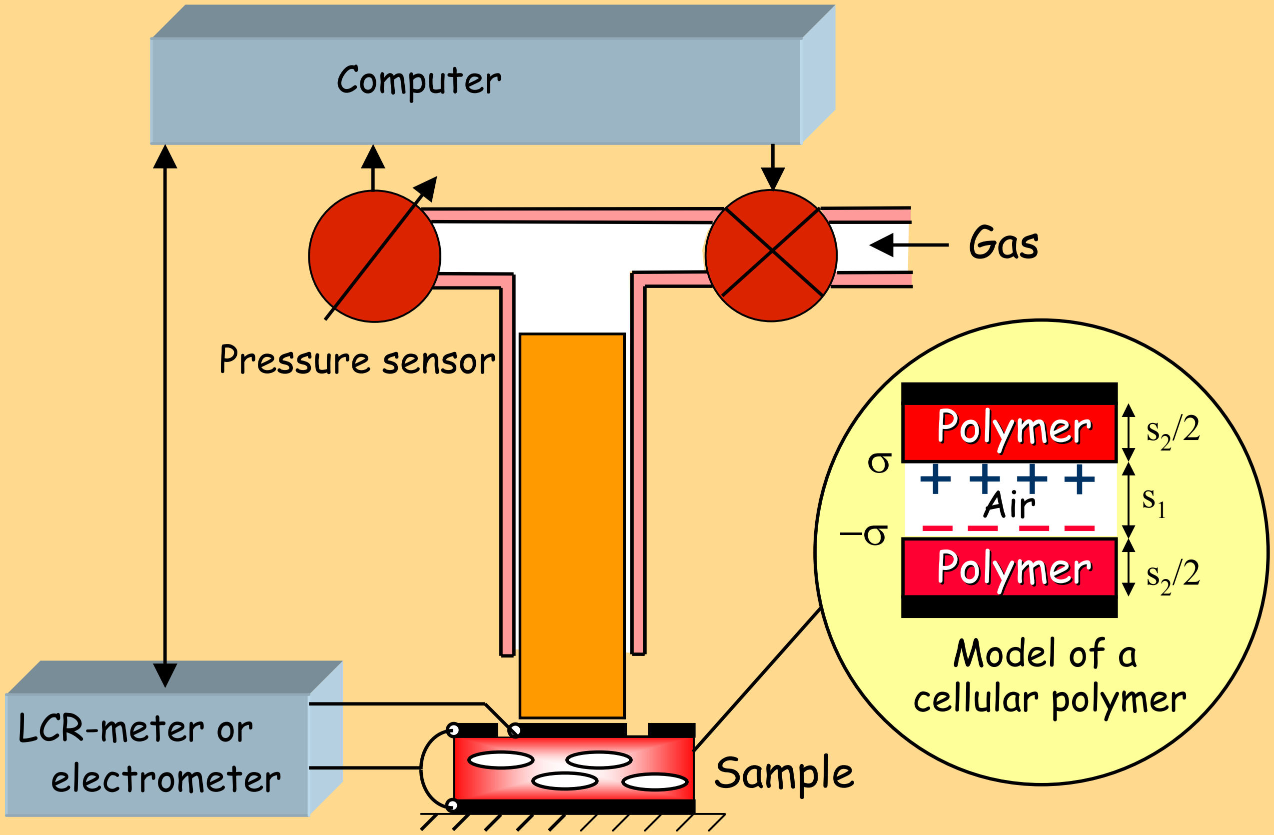






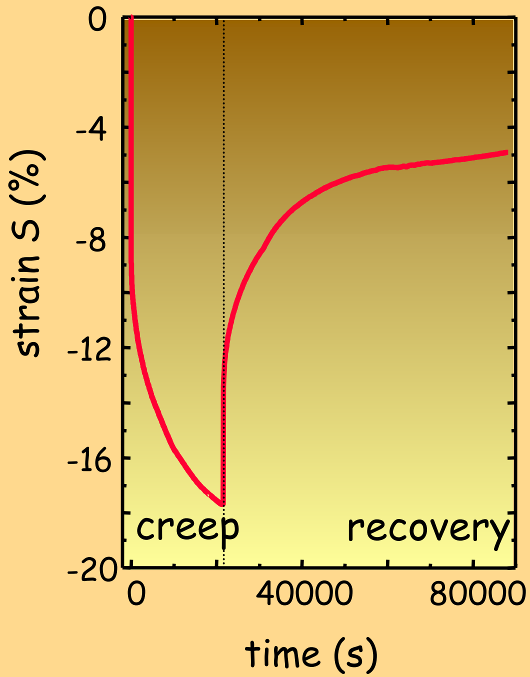


Measurement of elastic and piezoelectric properties of cellular polymers

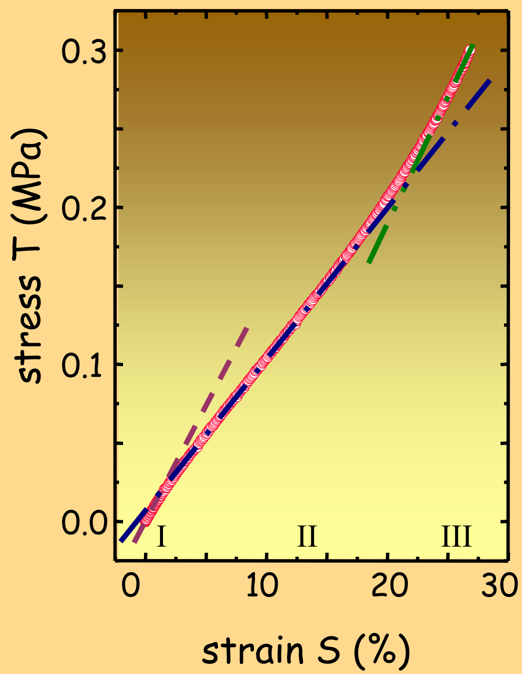


Elastic properties of cellular PP

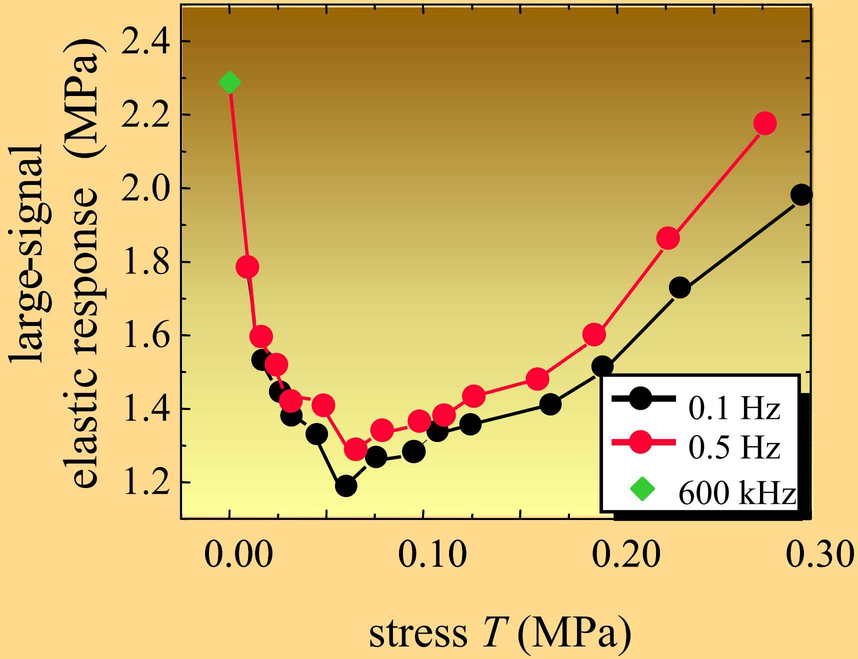
Creep and recovery with instantaneous elastic response, viscoelasticity and viscous flow

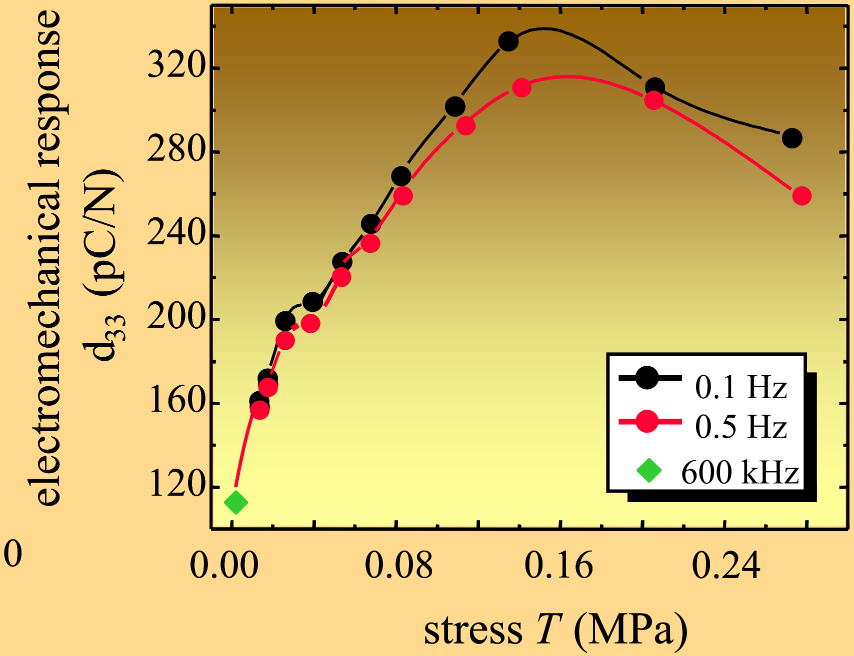


Nonlinear elastic response



Nonlinear elastic and piezoelectric responses of PP foams





Comparison of piezoelectric materials

piezoelectric material	Young modulus (GPa)	d_{33} (pC/N)
quartz	72	2 (d_{11})
PZT	50	360
PVDF	2	20
PP	0.002	200-600

→ **Ferroelectrets**: extremely soft and sensitive transducer materials

Cellular materials: Ferro*electrets*

Close analogies to ferroelectric materials

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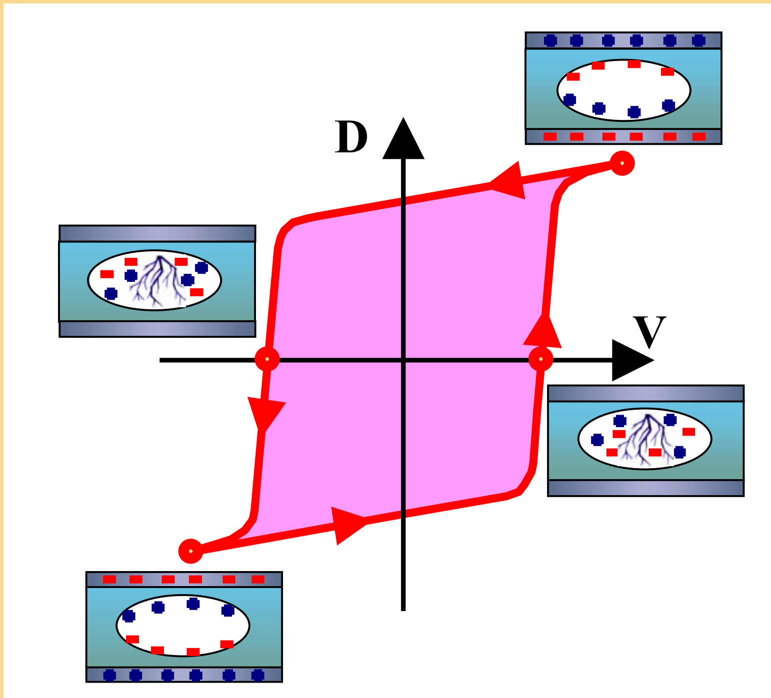
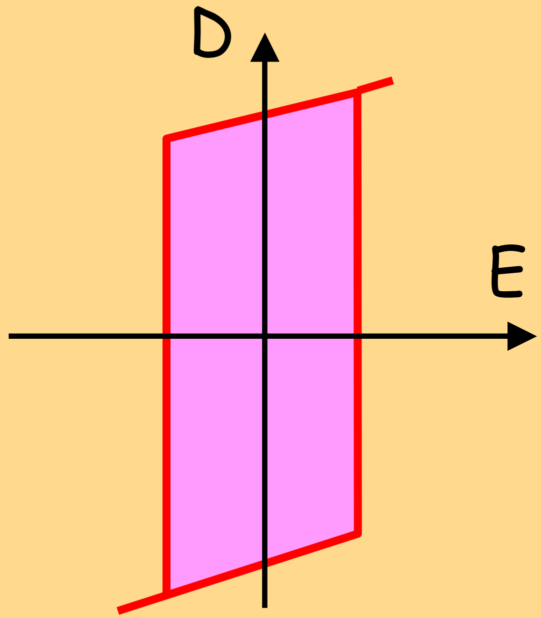
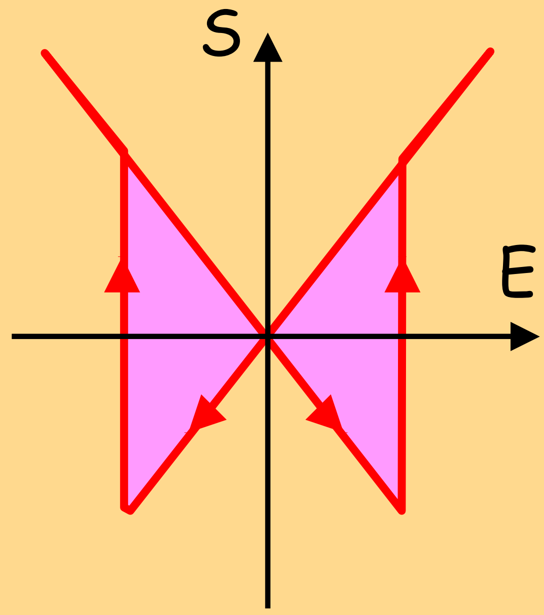
FERRO*ELECTRETS*



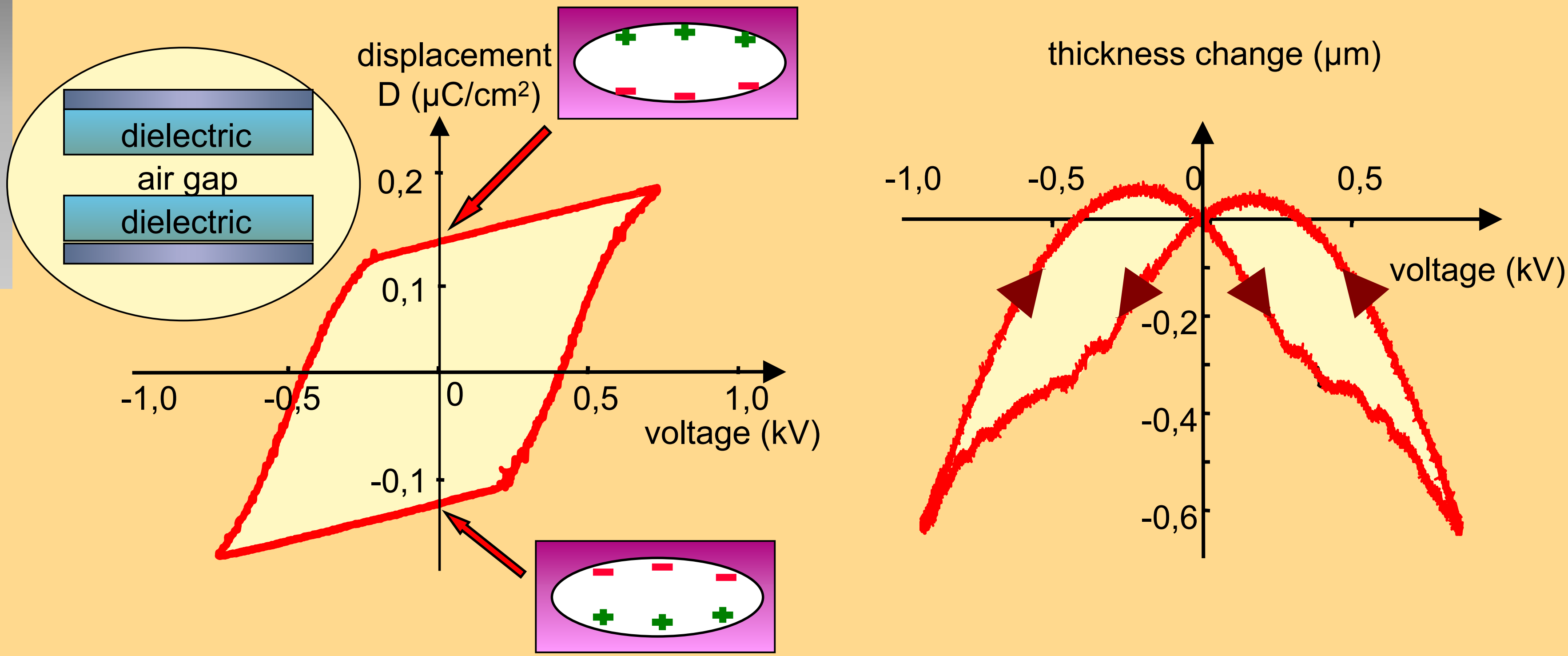
Hysteresis phenomena in ferroelectric materials

Displacement and mechanical strain vs. field



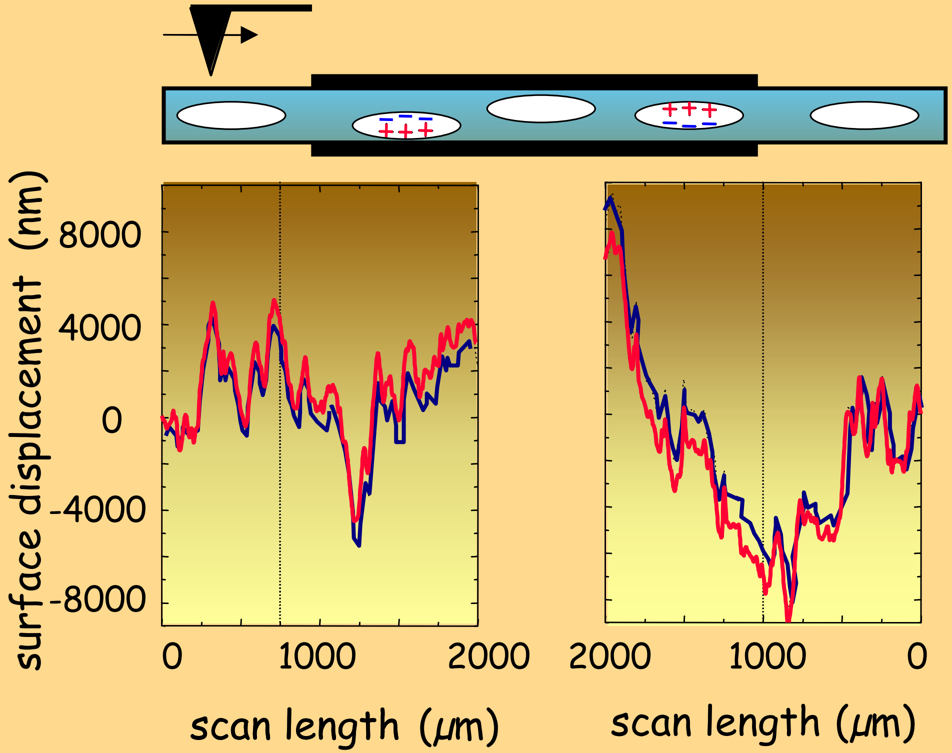


Ferroelectric-like properties: Dielectric and electromechanical hysteresis



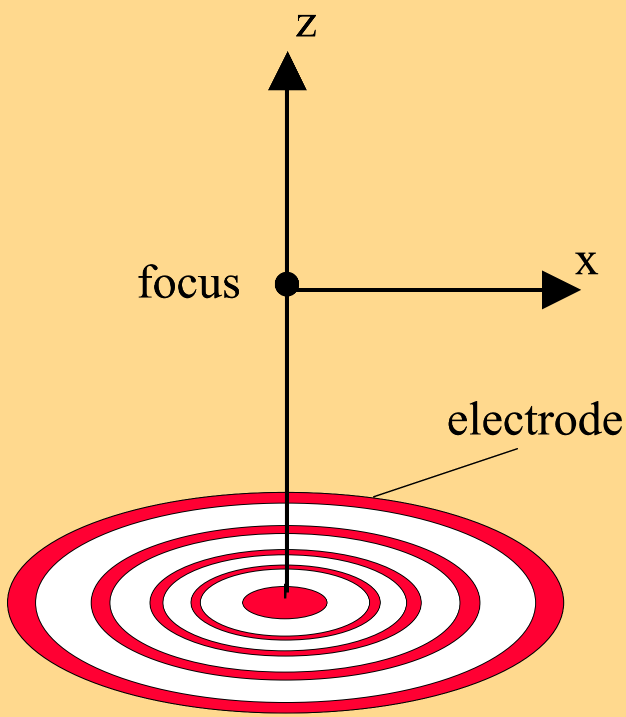
Poster: I. Graz et al.: *A Fairytale of ferroelectricity*

Patterned charging and converse piezoelectricity of ferroelectrets



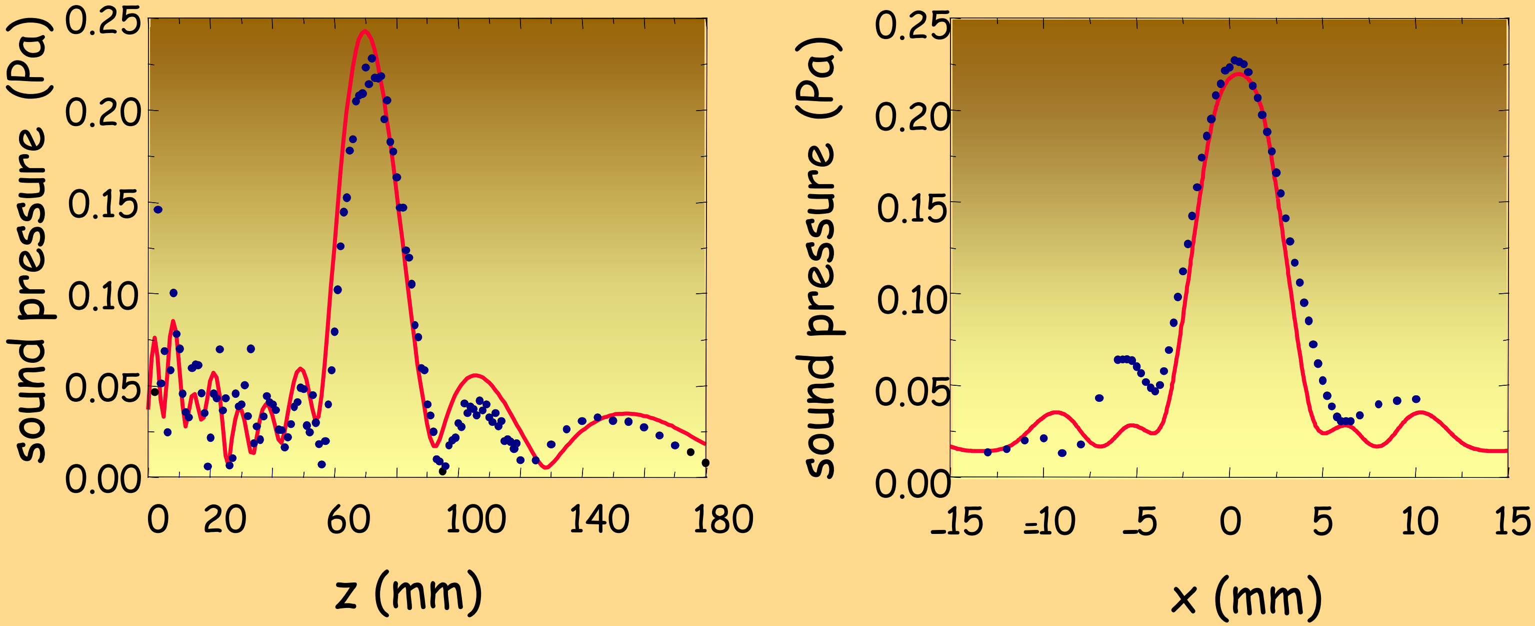
➡ Patterned charging ⇨ switching of the piezoelectric response

Focussing ultrasound with an acoustical Fresnel zone plate



electrode pattern of an acoustical Fresnel lens

Sound pressure of a five-element acoustical Fresnel zone plate



ultrasound foci along the main axis and in the focal plane

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with present materials air-borne ultrasound up to 600kHz possible

Summary

Ferroelectrets

- Combine features of ferroelectrics and electrets
- New material class for electromechanical energy conversion
- Attractive for large area transducers and air-borne ultrasound

Acknowledgments