Introduction to electrets: Principles, equations, experimental techniques

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Overview

Principles

Charges
Materials
Electret classes

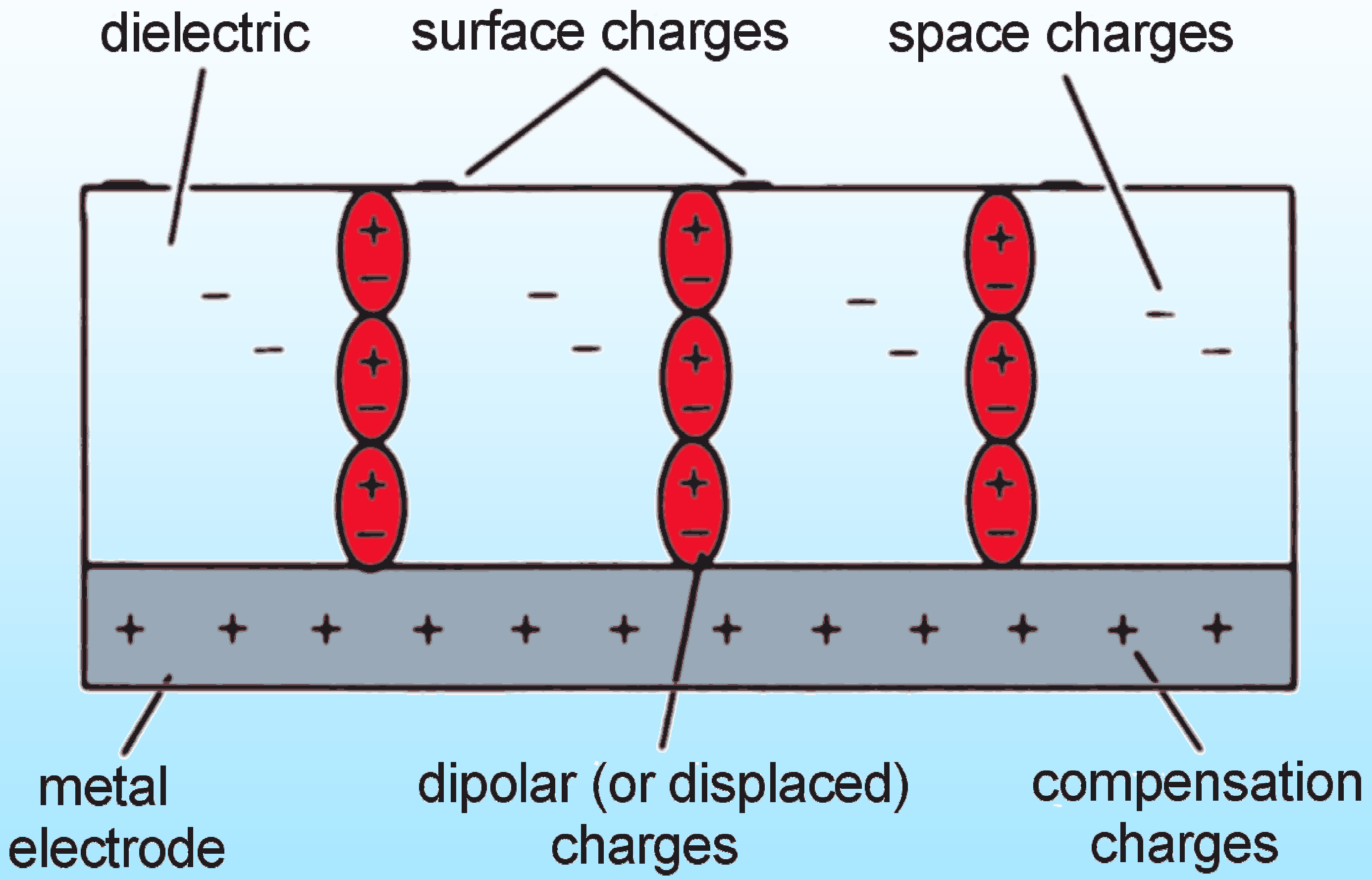
Equations

Fields
Forces
Currents
Charge transport

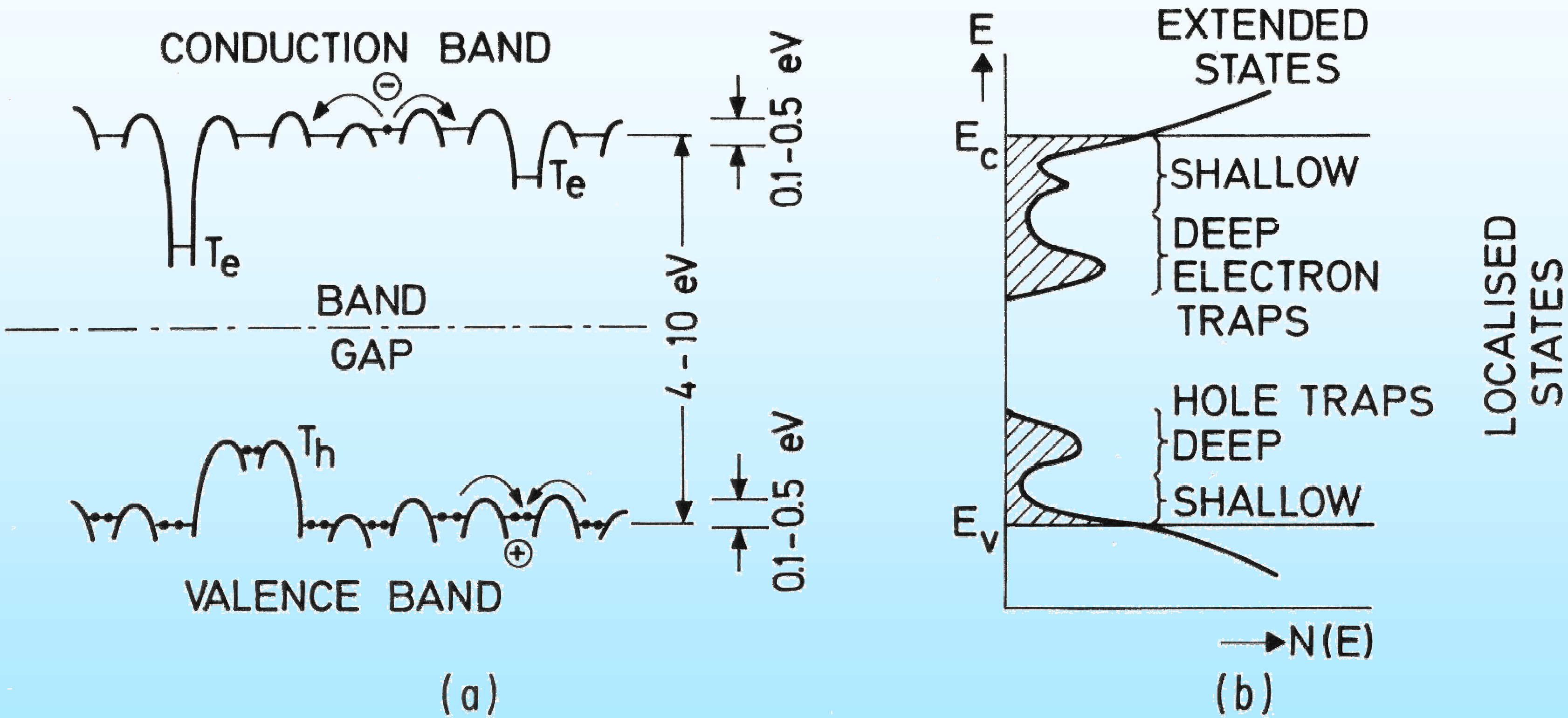
Experimental techniques

Charging
Surface potential
Thermally-stimulated discharge
Dielectric measurements
Charge distribution (surface)
Charge distribution (volume)

Electret charges



Energy diagram and density of states for a polymer



Electret materials

Polymers

Fluoropolymers (PTFE, FEP)
Polyethylene (HDPE, LDPE, XLPE)
Polypropylene (PP)
Polyethylene terephtalate (PET)
Polyimid (PI)
Polymethylmethacrylate (PMMA)
Polyvinylidenefluoride (PVDF)
Ethylene vinyl acetate (EVA)

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Anorganic materials

Silicon oxide (SiO_2)
Silicon nitride (Si_3N_4)
Aluminum oxide (Al_2O_3)
Glas (SiO_2 + Na, S, Se, B, ...)
Photorefractive materials

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•
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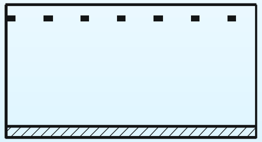
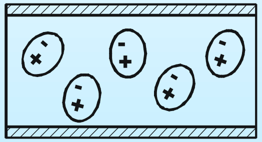
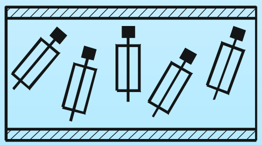
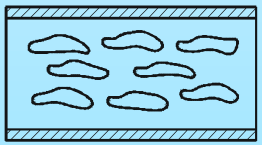
Cellular and porous polymers

Cellular PP
Porous PTFE

Charged or polarized dielectrics

Category	Materials	Charge or polarization		Properties	Applications
		Geometry	Density [mC/m^2]		
Real-charge electrets	FEP, SiO_2		0.1 - 1	External electric field and force	Electret microphones, head-phones, air filters, dosimeters, advanced engineering material.
NLO materials	PMMA / DR1, glasses		0.1 - 10	Electrooptic and NLO effects	EO switch, modulator, polarization converter, SHG - devices.
Ferroelectric materials	PVDF, PZT		10 - 100	Piezo- and pyroelectricity	Microphones, Hydrophones, accelerometers, infrared detectors, pyroelectric sensors, night-vision devices, actuators.
porous or cellular electrets	PP, PTFE		1	strong longitudinal piezoelectric effect	Loudspeakers, ultrasonic transducers, electromechanical transducers, hydrophones.

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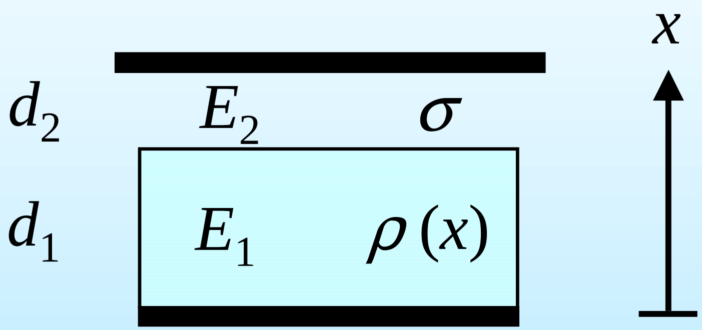
Equations 1: Fields of an electret

Surface charges only:

$$\sigma = \sigma_r + \Delta P_P$$



$$E_1 = -\frac{\sigma d_2}{\varepsilon_0(\varepsilon d_2 + d_1)} \qquad (1)$$

$$E_2 = \frac{\sigma d_1}{\varepsilon_0(\varepsilon d_2 + d_1)} \qquad (2)$$

Volume charges only:

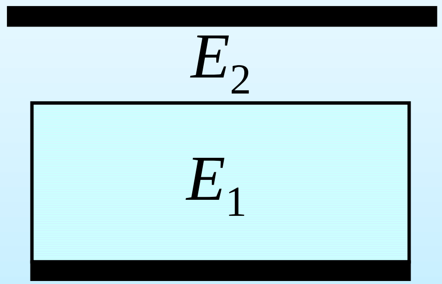
$$\rho(x) = \rho_r(x) + \rho_P(x)$$

$$\hat{\sigma} = \frac{1}{d_1}\int_0^{d_1} x\rho(x)dx$$

External field E_2 from

Eq. (2) with $\sigma = \hat{\sigma}$

Equations 2:
Force of an electret on an electrode



$$F = \frac{1}{2}\varepsilon_0 E_2^2$$

Equations 3: Currents in an electret

$$E(x,t) \quad P_\mathrm{p}(x,t) \quad i_\mathrm{c}(x,t)$$

Current density

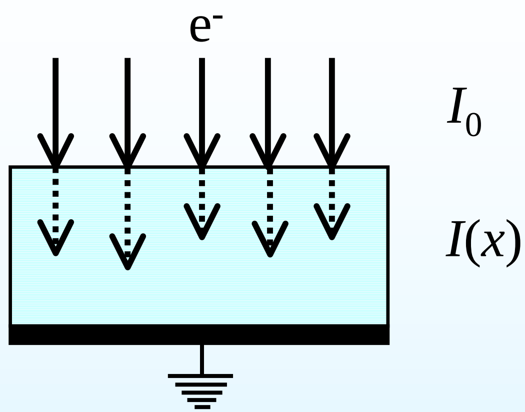
$$i(t) = \frac{\partial(\varepsilon_0 \varepsilon E + P_\mathrm{p})}{\partial t} + i_\mathrm{c}$$

$$i_c = (\mu_+ \rho_+ + \mu_- \rho_-) E$$

Equations 4: Charge transport equations

Current Equation:

$$\varepsilon \frac{\partial E(x,t)}{\partial t} + \mu \rho_{\mathrm{f}}(x,t) \cdot E(x,t) + I(x) = I_0 \quad (1)$$

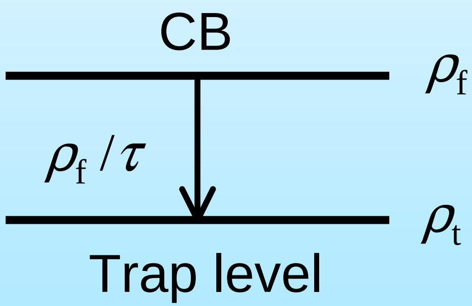


Poisson Equation:

$$\varepsilon \frac{\partial E(x,t)}{\partial t} = \rho_{\mathrm{f}}(x,t) + \rho_{\mathrm{t}}(x,t) \quad (2)$$

Poisson Equation:

$$\frac{\partial \rho_{\mathrm{t}}(x,t)}{\partial t} = \frac{\rho_{\mathrm{f}}(x,t)}{\tau} \cdot \left[1 - \frac{\rho_{\mathrm{t}}(x,t)}{\rho_{\mathrm{m}}}\right] \quad (3)$$



Parameters of Model:

$I(x)$: current

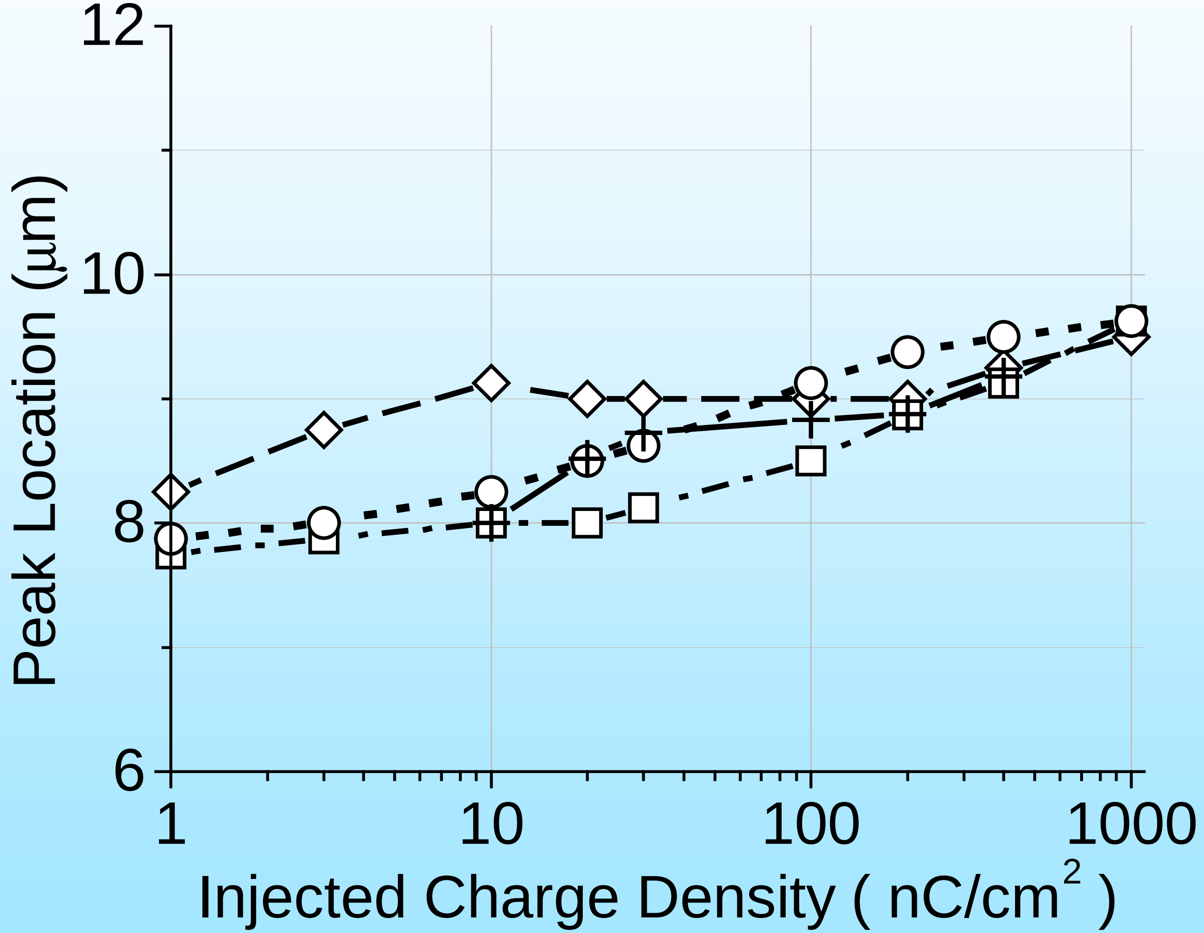
μ : free-carrier mobility

τ : free-carrier lifetime

ρ_{m} : trap density

Measured and calculated location of charge peak in electron-beam charged FEP

(Sessler 2004)



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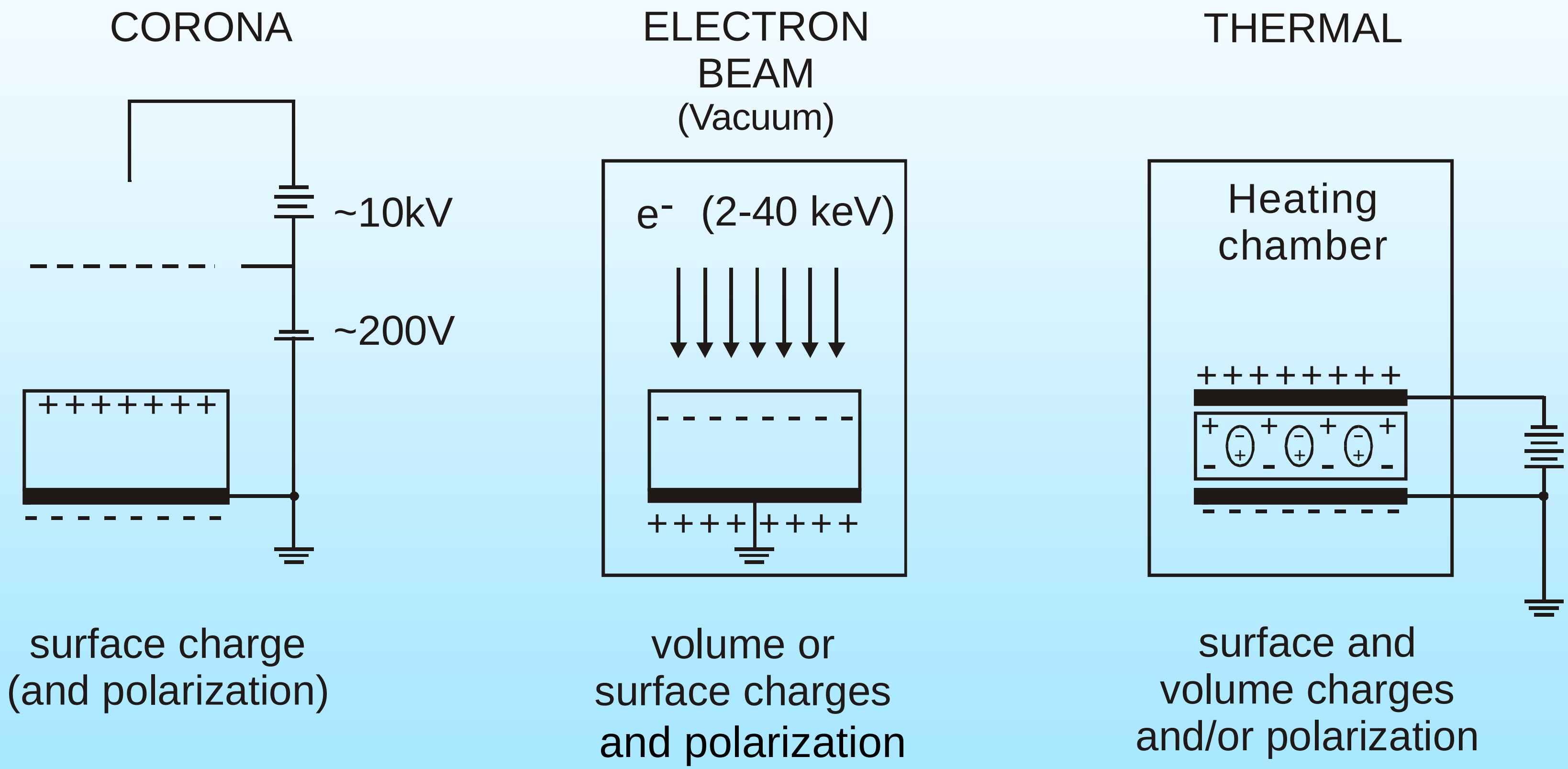
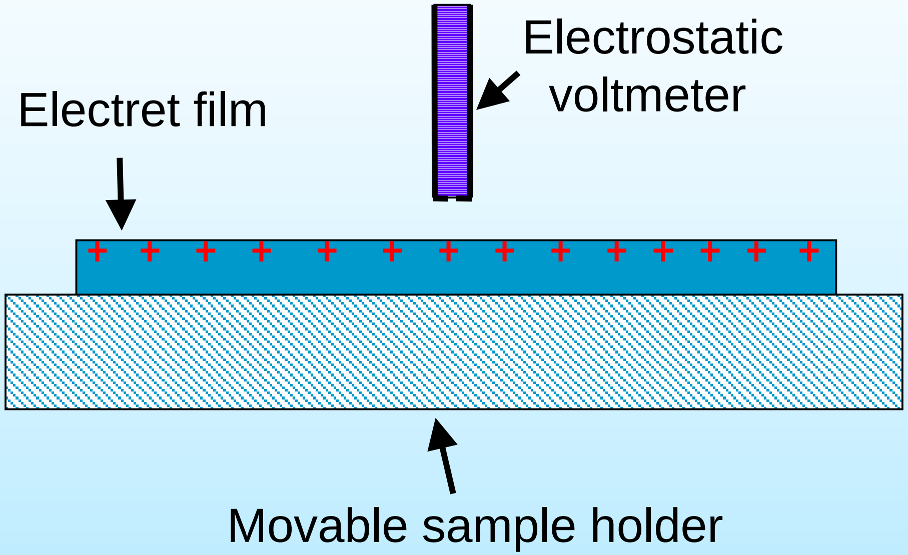
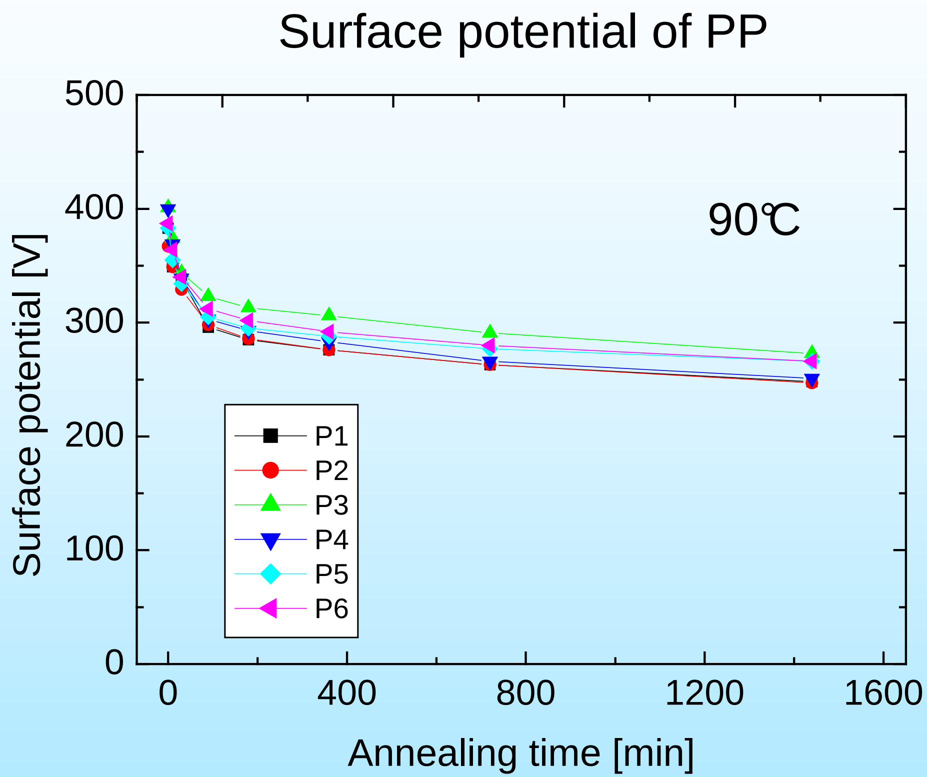
Charging methods



Surface potential measurement

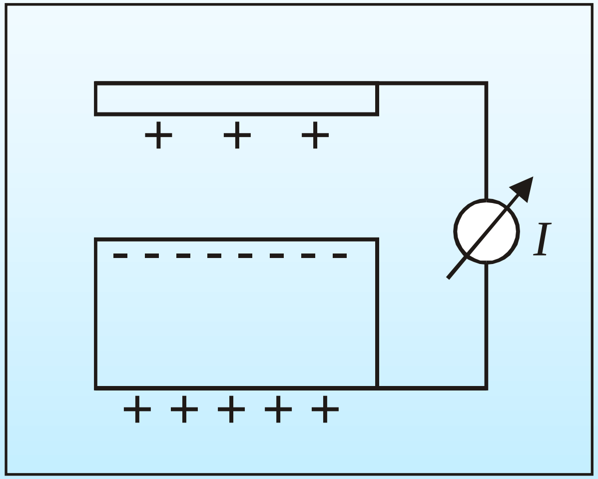




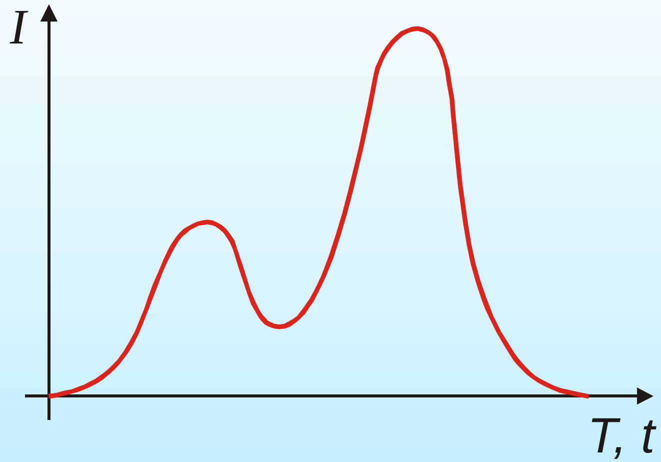
- Determination of charge stability of different electret materials by isothermal discharging at elevated temperatures

Thermally-stimulated discharge (TSD)

Heating chamber

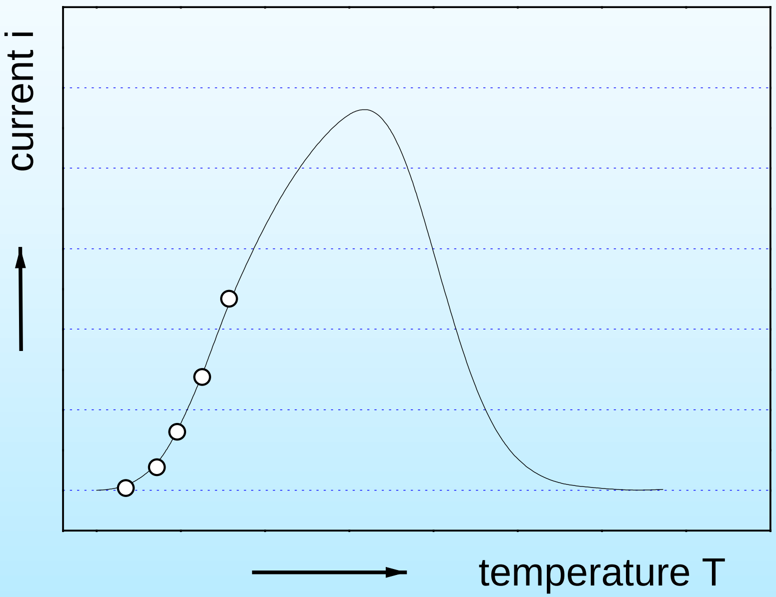


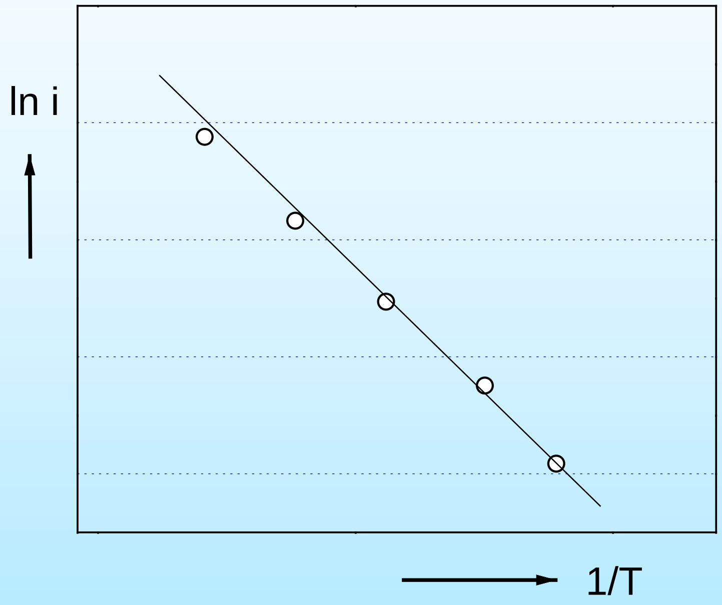
Linear temperature increase



Separation of surface and volume traps
Activation energies
Trap densities

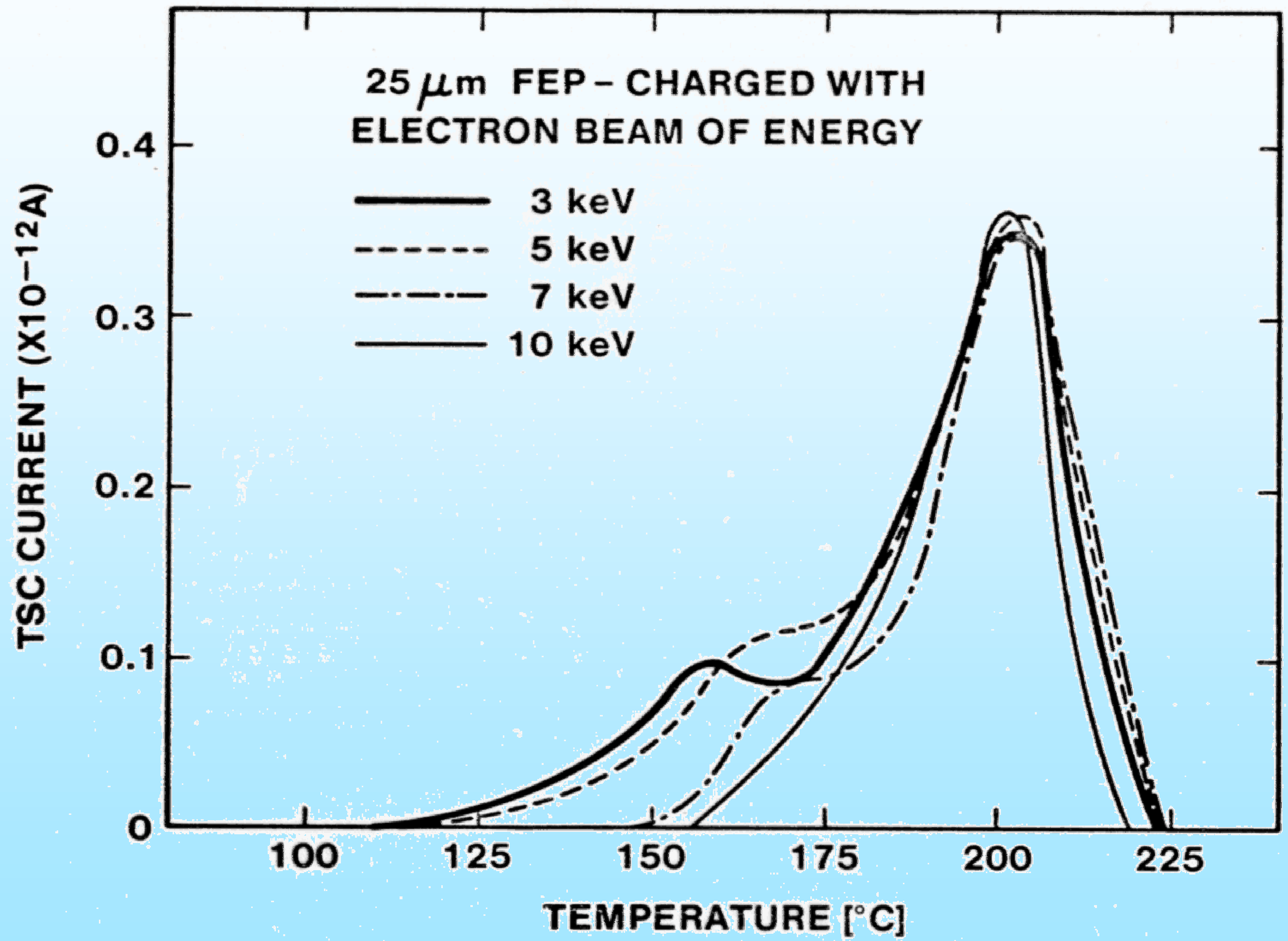
Measurement of activation energy A: Initial-rise-method





$$\frac{d(\ln i)}{d(1/T)} = -\frac{A}{k}$$

TSD for electron beam charged FEP
(v. Seggern 1981)



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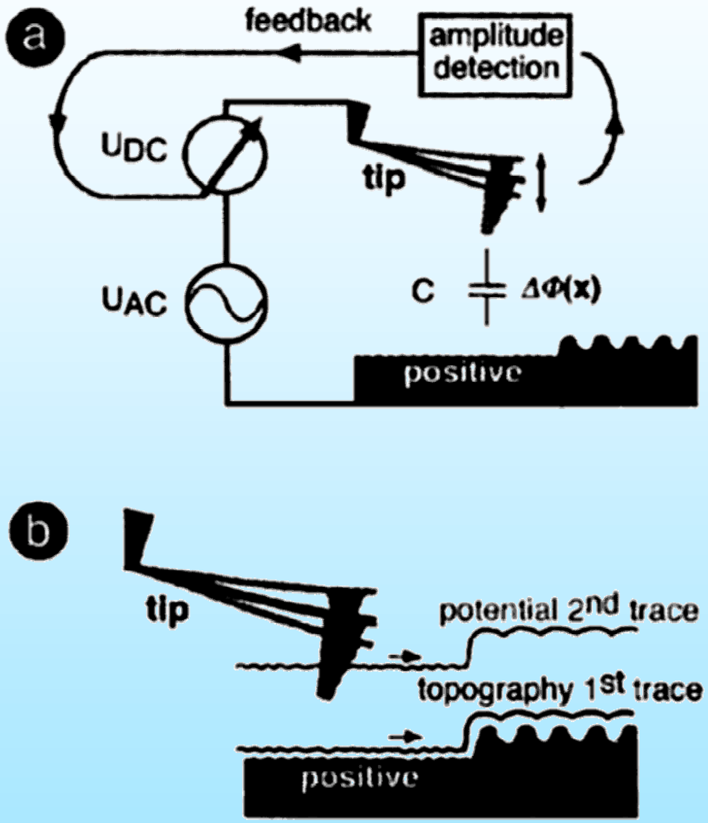
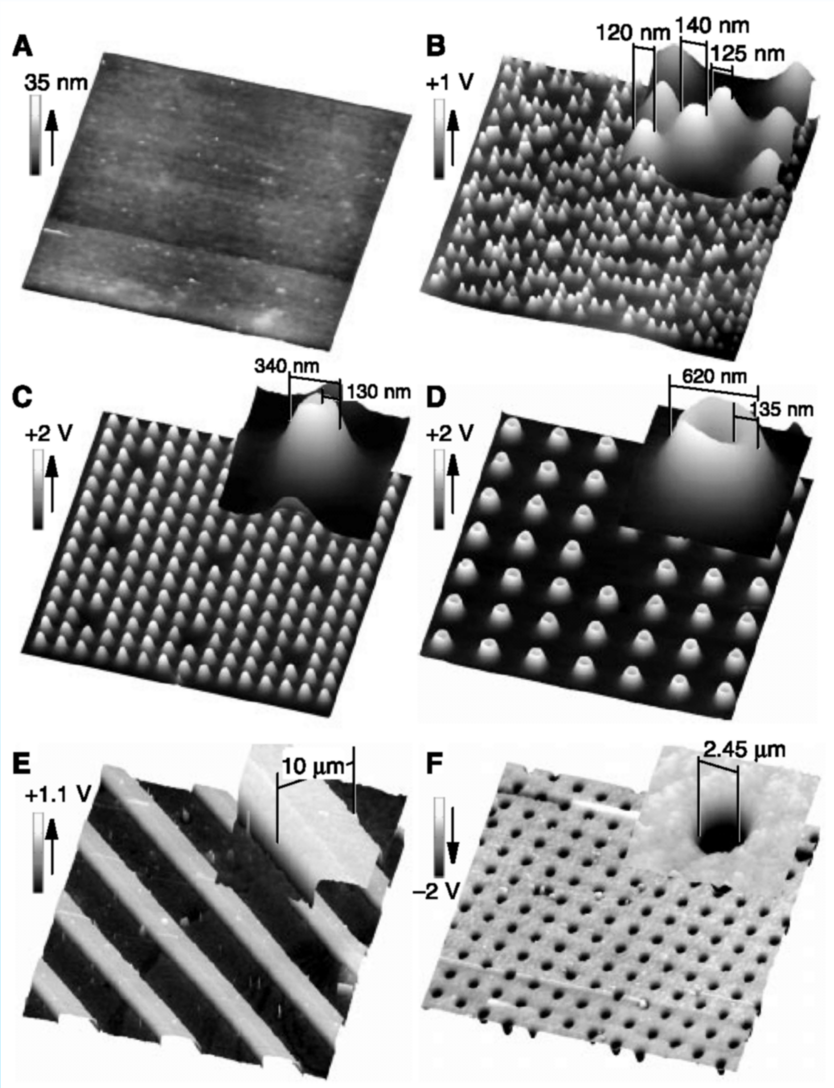
Kelvin probe force microscope (KFM)
(Jacobs et al 1997)

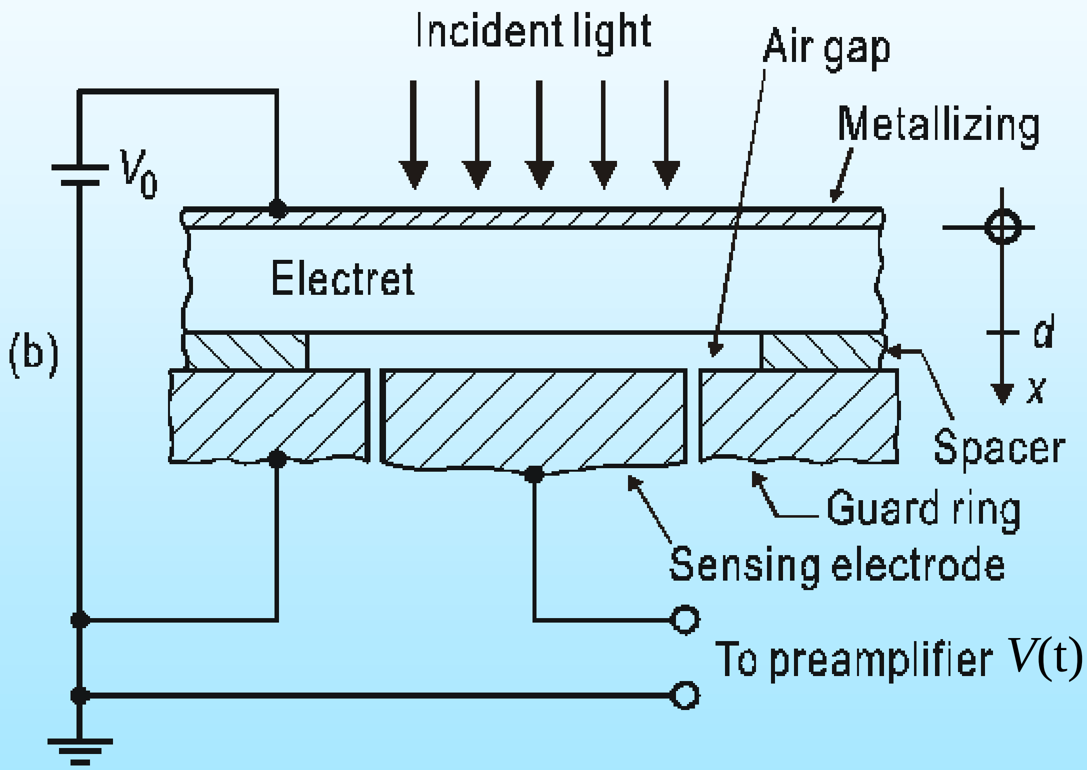


Measures lateral potential distribution

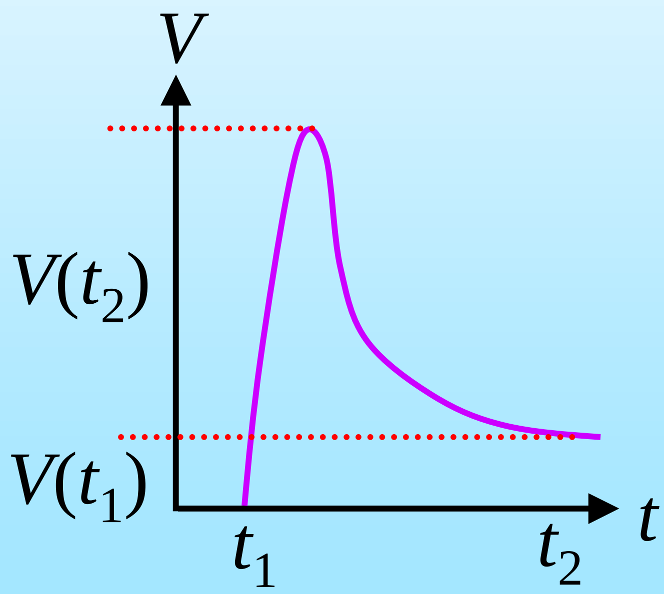
KFM images of charge distribution on PMMA
(Jacobs et al 2001)



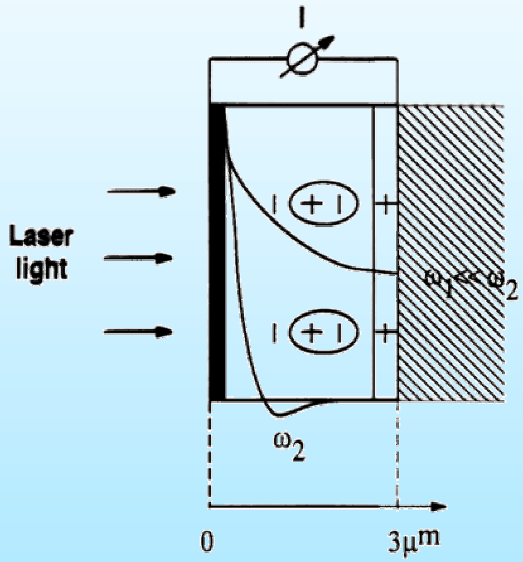
Thermal pulse method
(Collins 1975)



$$\frac{\bar{r}}{d} = \frac{V(t_2)}{V(t_1)}$$



Thermal wave method
(Bauer 1996)

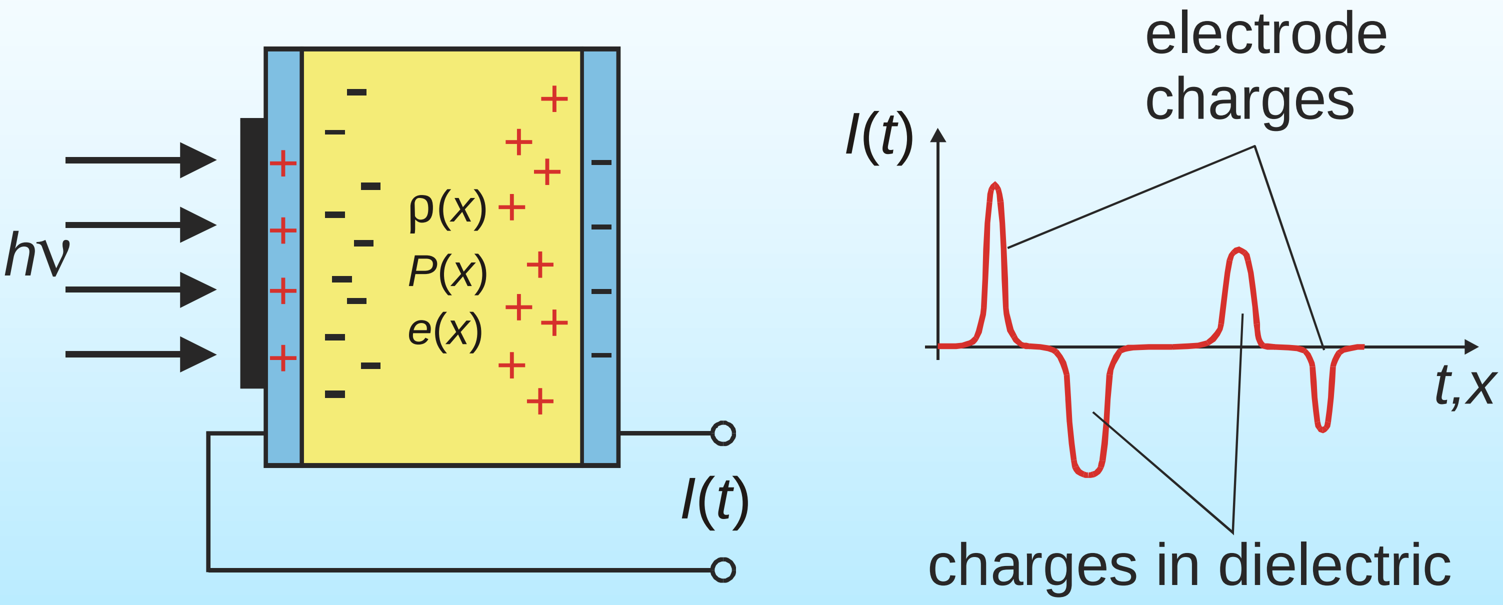


penetration depth

$$1/k = \sqrt{2D/\omega}$$

Measures charge distribution close to surface

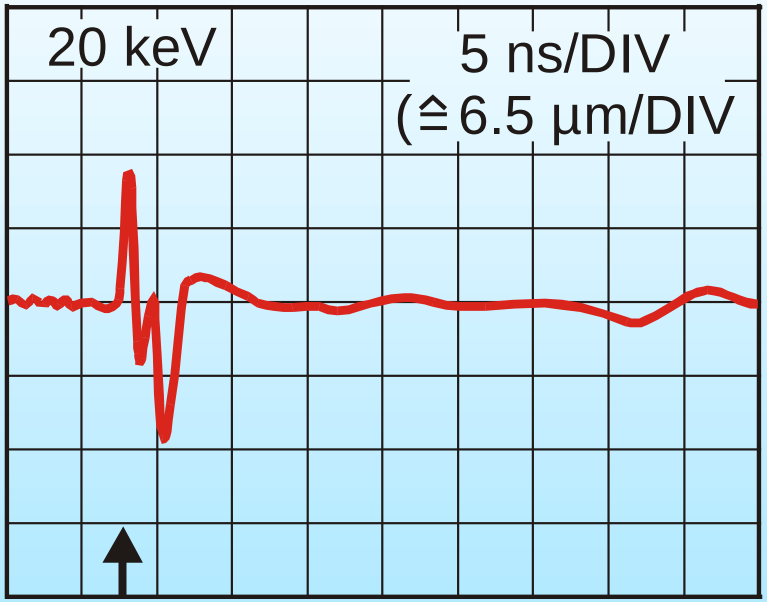
Laser-Induced Pressure Pulse (LIPP) method

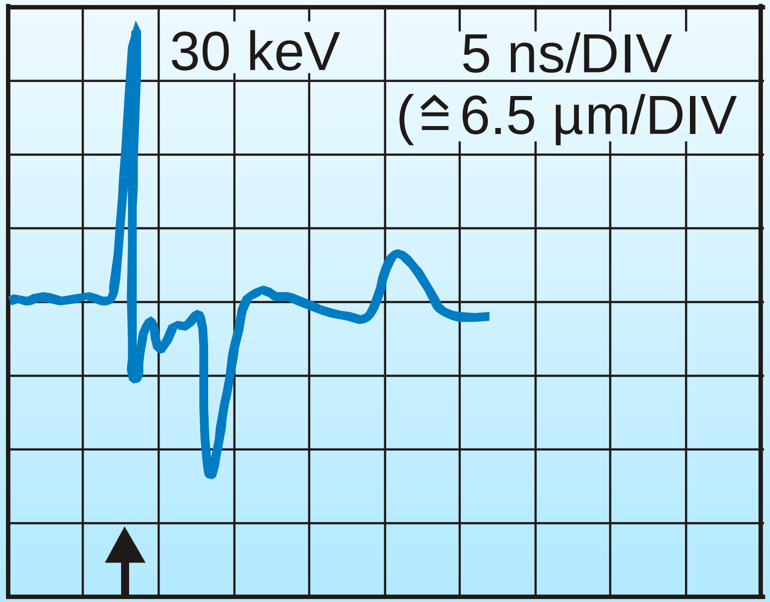


$$I(t) \propto (\gamma+1)\left(\rho - \frac{dP}{dx}\right) - \frac{de}{dx}\,, \quad x=ct$$

Charge distribution in e-beam irradiated FEP

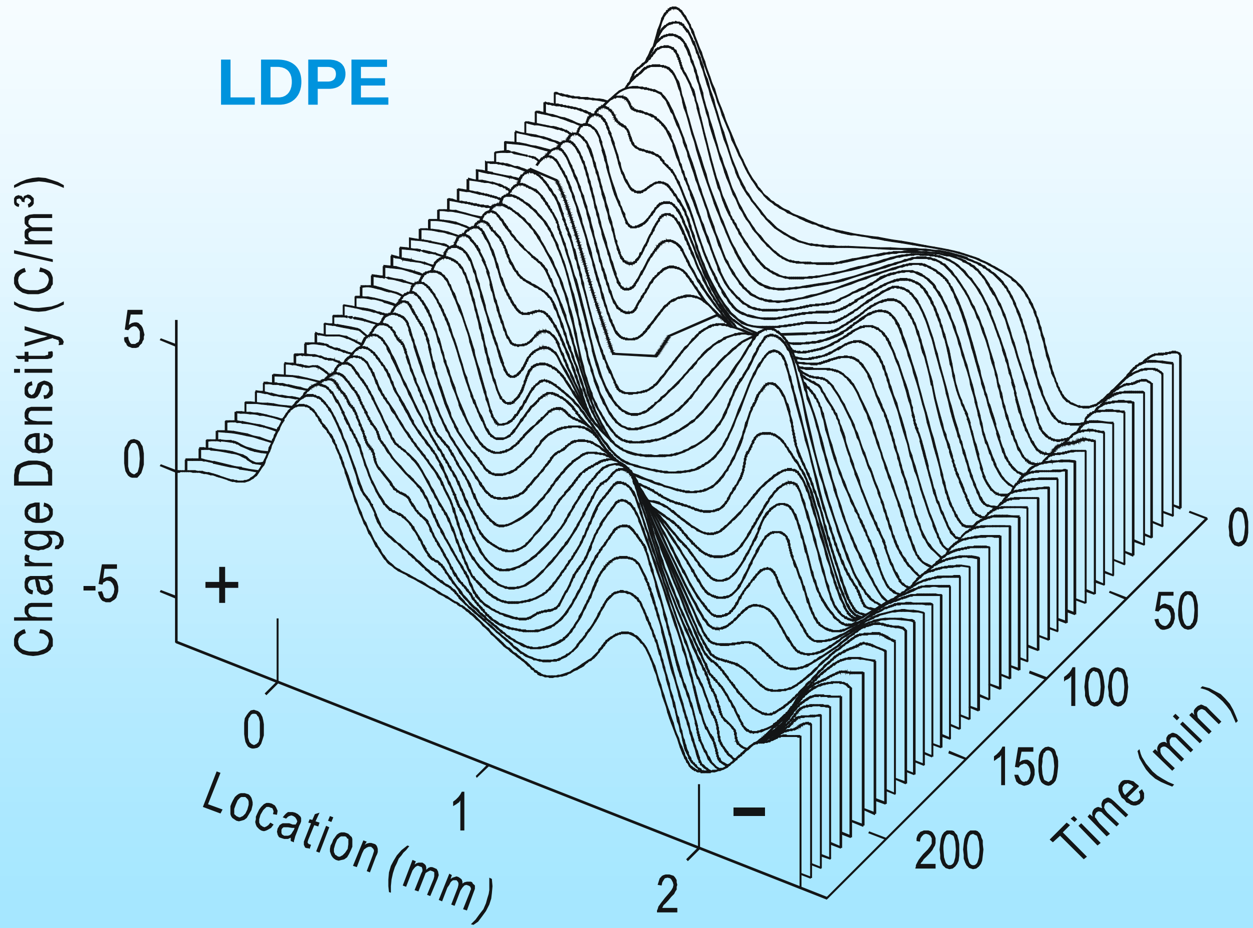
(Sessler et al 1983)



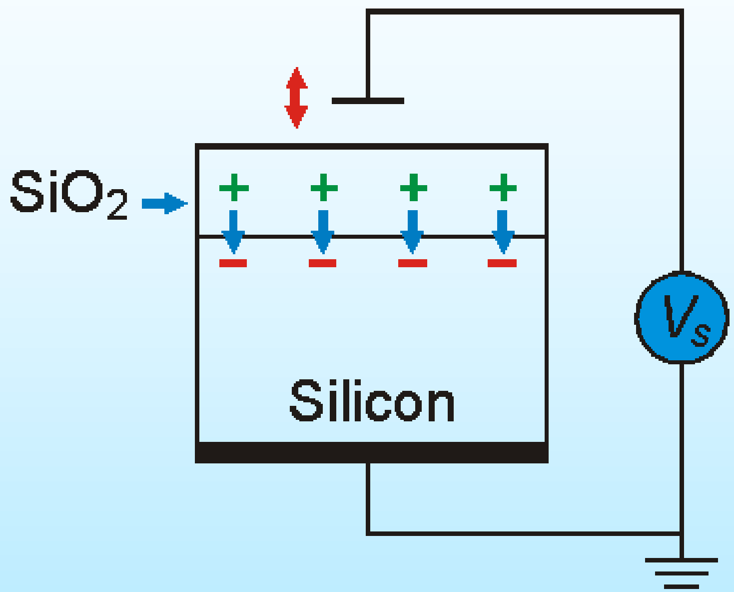


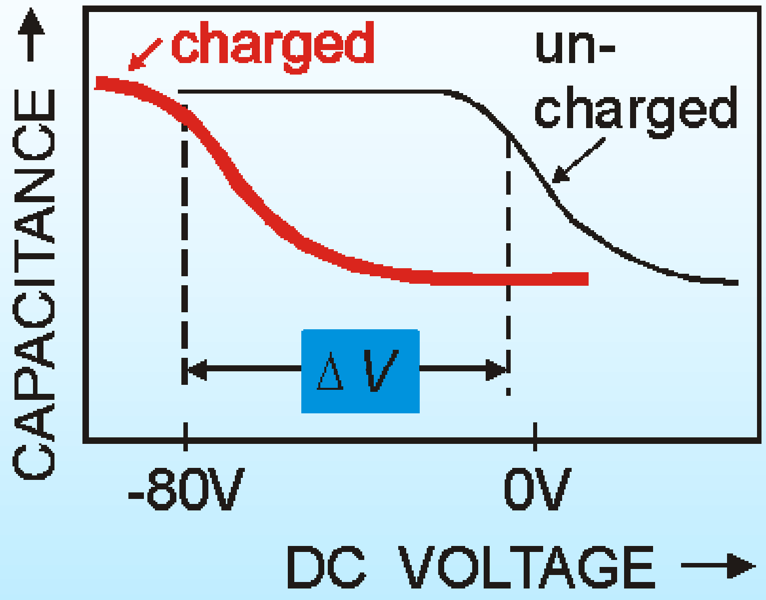
Evolution of charge distribution in LDPE measured with Pulsed ElectroAcoustic (PEA) method

(Hozumi et al 1998)



CV-method for measuring charge centroid location





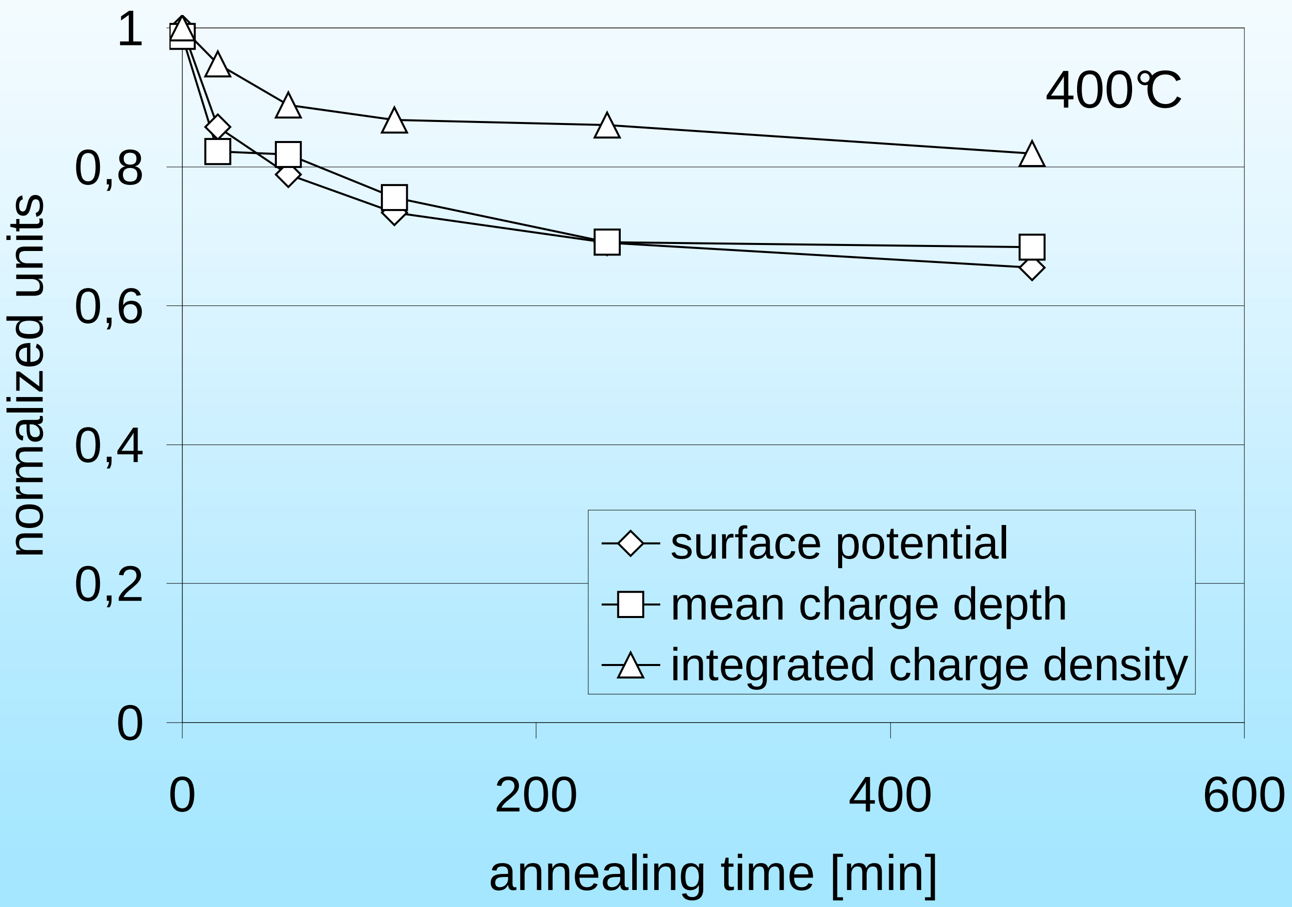
Electrostatic Voltmeter
(field compensation principle)

Capacitance - Voltage
measurements

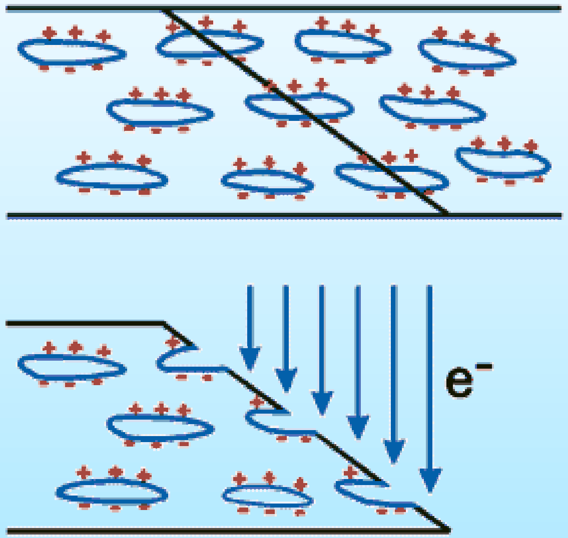
Measures location of charge centroid and total charge

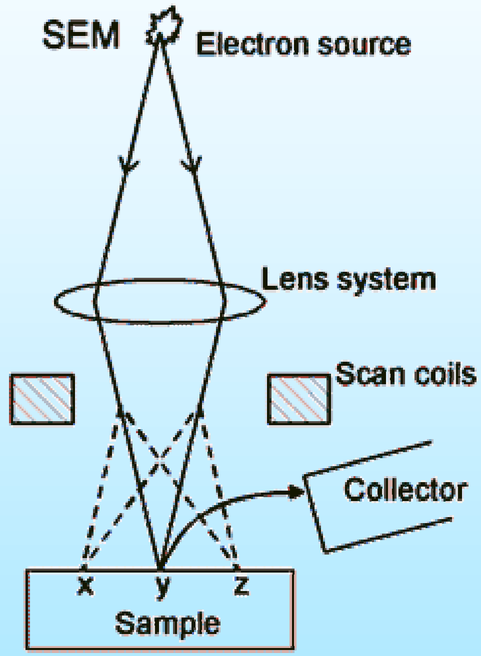
Charge drift in double layers of SiO_2 (300 nm) and Si_3N_4 (150 nm)

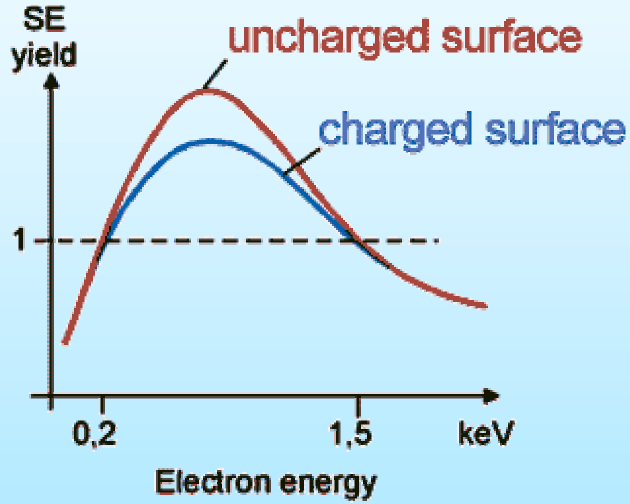
(Zhang et al 2002)



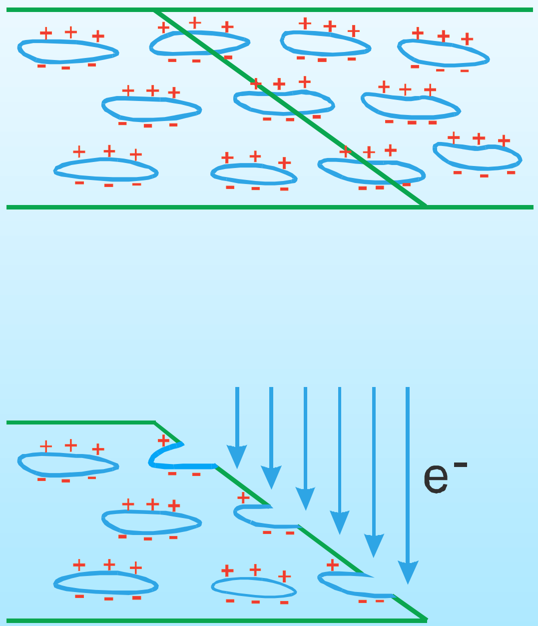
Scanning Electron Microscope (SEM) method

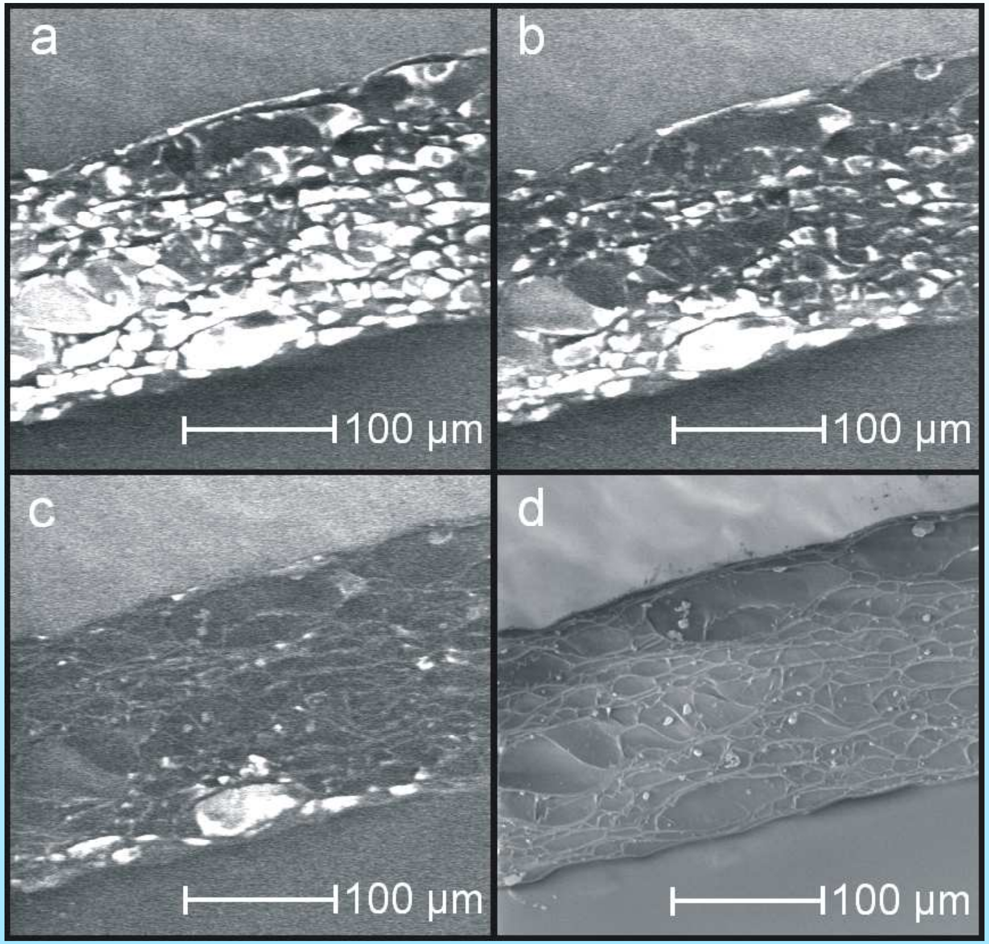






SEM pictures of cross section of charged cellular PP
(Hillenbrand et al 2000)





Summary:
New aspects of electret research

Electret materials

NLO materials
Cellular polymers
Tailored polymers
Silicon materials

Theoretical approaches

Charge transport models with
- dispersive transport
- generation-recombination models
- radiation effects

Experimental methods

Pressure pulse and thermal methods
Atomic force microscopy
Scanning electron microscopy
CV-method
Dielectric method

Better understanding of

Charging and charge transport in irradiated polymers, cellular polymers, etc.