POF

- compared to GOF
  - flexible ~ workable
  - larger diameter ~ connectable, dispersion (→ low bandwidth, slow)
  - high loss ~ short-range
- core/cladding/jacket
  - core ~ PMMA popular
    - clearer than PC, more ductile than PS
  - cladding ~ lower RI ~ fluoropolymers
  - jacket ~ PE, nylon, --
- for high bandwidth POF
  - double-step index, graded-index
- for low-loss POF
  - low RI, heavy elements
  - PMMA-d8 or fluoropolymers ~ expensive

bandwidth [bps]
loss [dB/km]

Fig 5.35

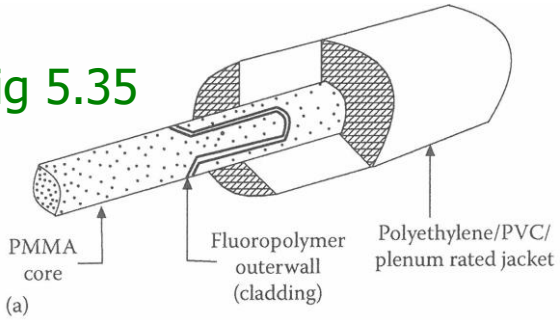
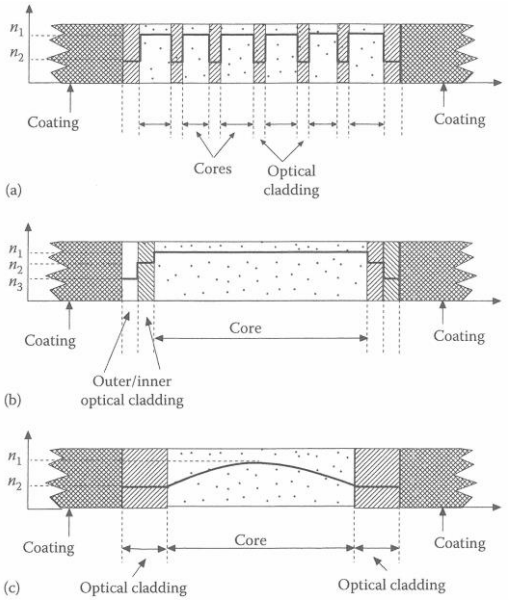


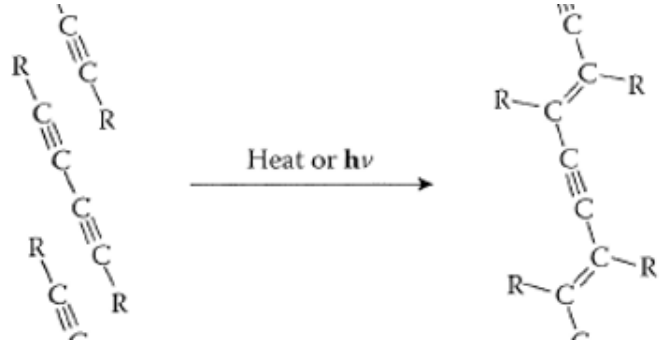
Fig 5.36



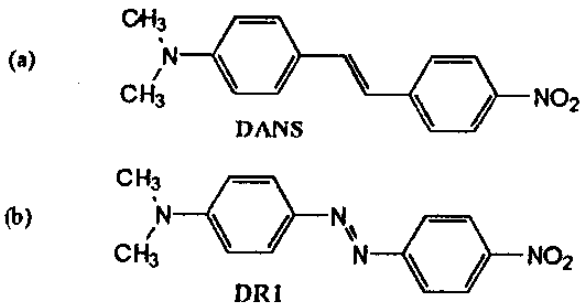
Polymers for NLO

- polarization [P] of material by electric field [E]

$$\Delta P = \chi^{(1)} E + \chi^{(2)} EE + \chi^{(3)} EEE + \cdots$$



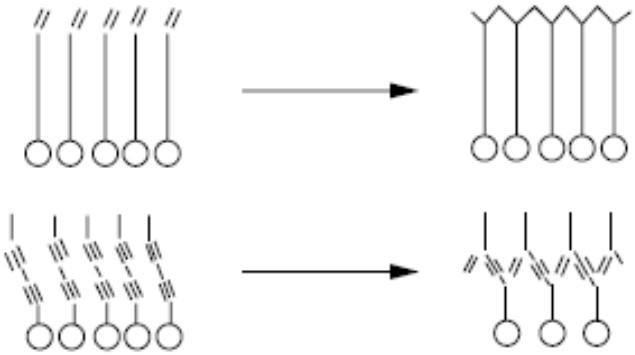
  - linear ~ change in RI
    - transportation, waveguide
  - (2nd) non-linear
    - 2nd harmonic generation = change in freq
    - freq doubler, amplification, optical mixing, hologram
    - need asymmetric structure

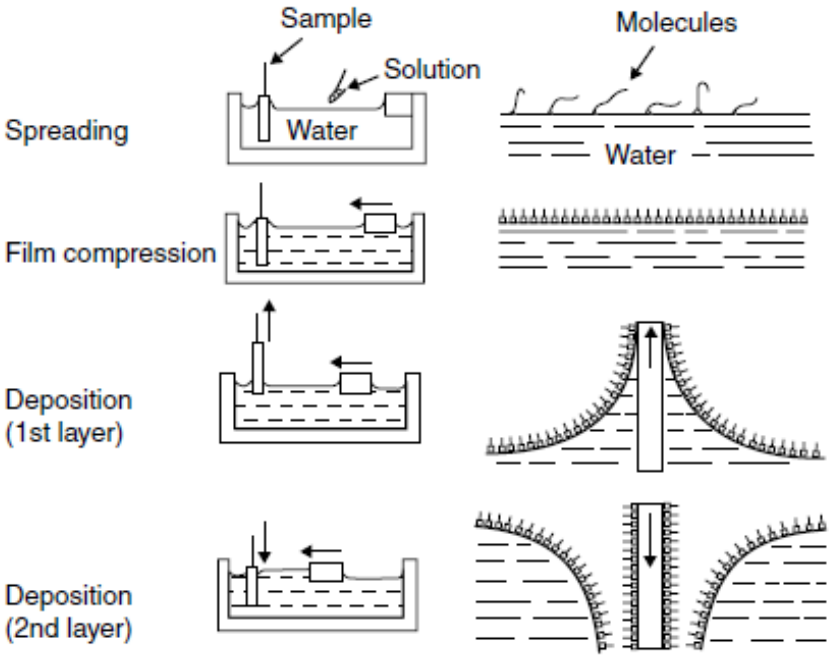


- NLO material
  - inorganic ~ $LiNbO_3$, ---
  - polymeric
    - organic-dispersed, main-chain, side-chain
    - processability, adhesion, cheap

LB films

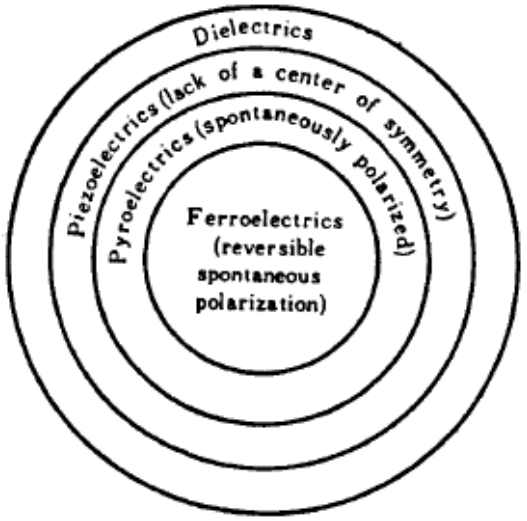
- for well-defined thin film
- monolayer at air/water interface
  - deposited and polymerized
  - polymerized and deposited
- deposition by dipping or rotating
- applications
  - NLO
  - e-beam resists
  - molecular electronics
  - sensors, ---

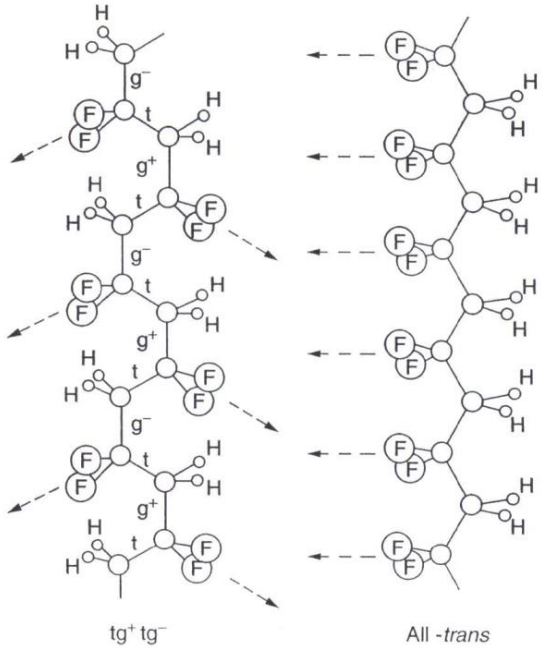




Piezo-, pyro-electric polymers

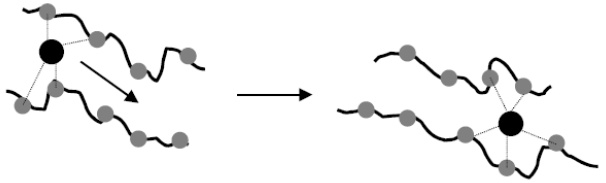
- piezo-, pyro-, ferro-electric
- PVDF and copolymers
- poling
  - poling [polarization] at high T
  - cooled with polar orientation
- compared to ceramics
  - workable, cheap, large size
  - low piezoelectric coefficient
- applications
  - heat detector
  - earphone, speaker, microphone
  - touch button





Polymer electrolytes for battery

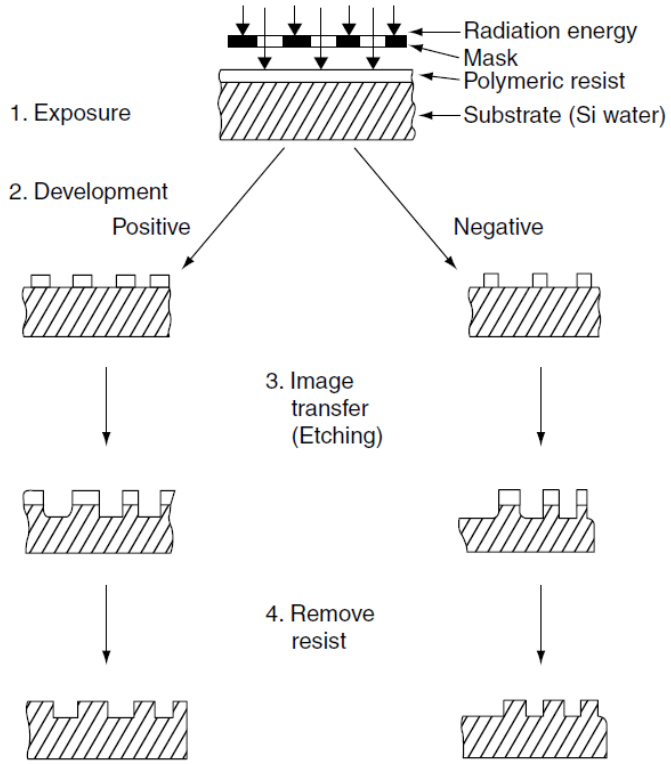
- to replace liq electrolyte in LIB
  - leakage, explosion
  - intrinsic solid polymer electrolytes
    - polymer w/ heteroatom + alkali metal salt [PEO/$LiClO_4$]
    - highly stable
    - low room temperature ion conductivity
      - Li moves through amorphous region
    - modifications
      - blend, composite, crosslinking, plasticizing
  - polymer gel electrolytes
    - crosslinked polymer + liquid electrolyte [PVDF/EC]
    - high conductivity, low stability



- for fuel cell membrane
  - PEMFC, DMFC
  - proton conductivity, separating fuel from O_2
  - fluoropolymers like Nafion
  - heat resistant polymers with polar groups
    - PI, PSF, PBI, PPO, ---
    - high thermomechanical stability

Polymers for lithography

- photoresist
  - coat – expose w/ mask – develop – etch – remove
    - positive ~ exposed area removed ← degrad'n, solubilize
    - negative ~ exposed area remains ← polym'n, Xlinking

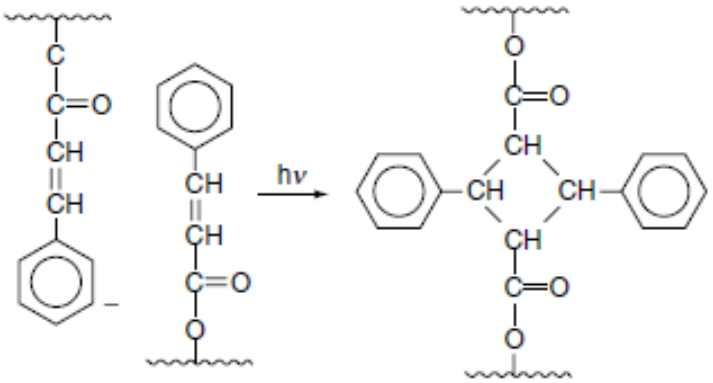


- photoresist (cont'd)
  - better resolution with lower λ light

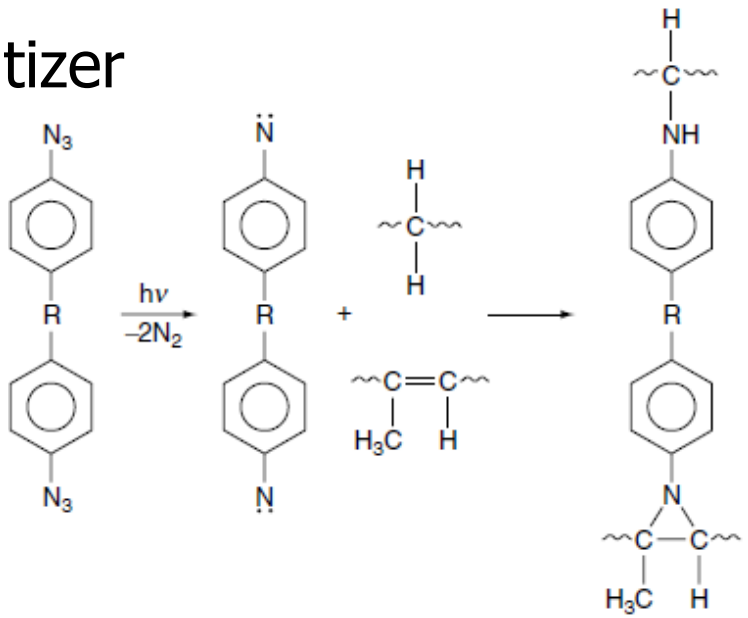
$$\text{Critical Dimension(nm)} = k_1\ (\lambda/\text{NA})$$

    - near-, mid- (350>λ>280 nm), deep-UV
    - excimer laser ~ 248 (KrF), 193 (ArF), 157 (F_2) nm
    - resolution enhancement
      - CD ~ 2 λ → CD ~ (1/3) λ → ?
    - extreme UV (13.5 nm)
      - needs reflective system (← lens)

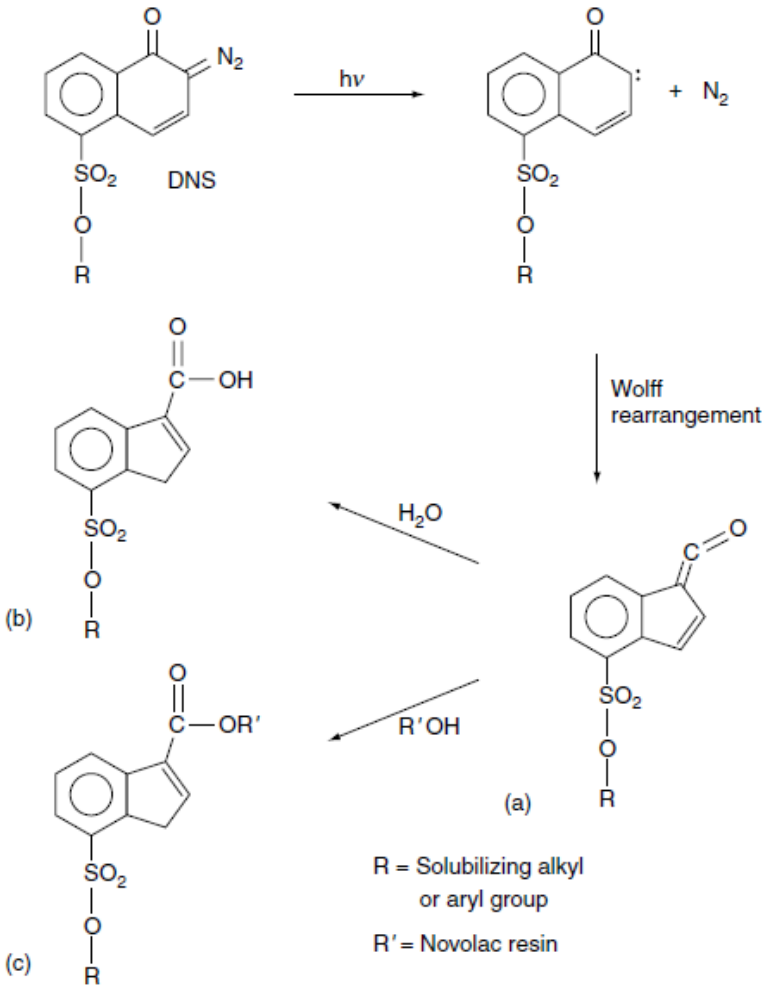
- negative PR
  - self-photocrosslinking
    - near-UV



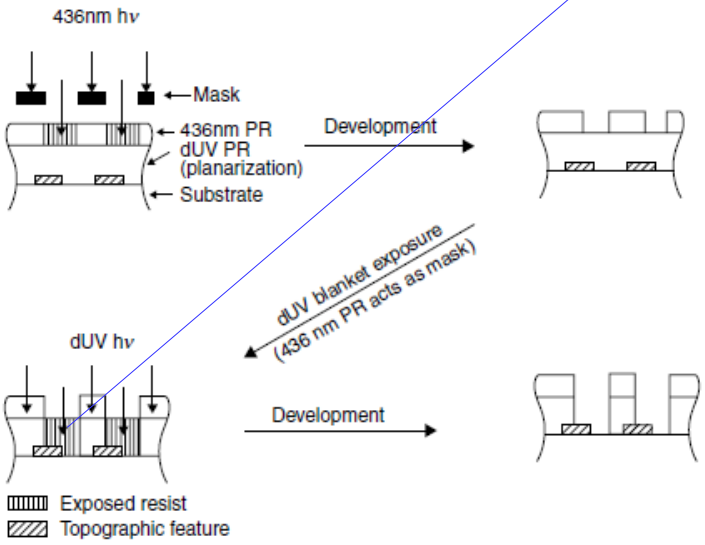
  - crosslinking by photosensitizer
    - near-UV

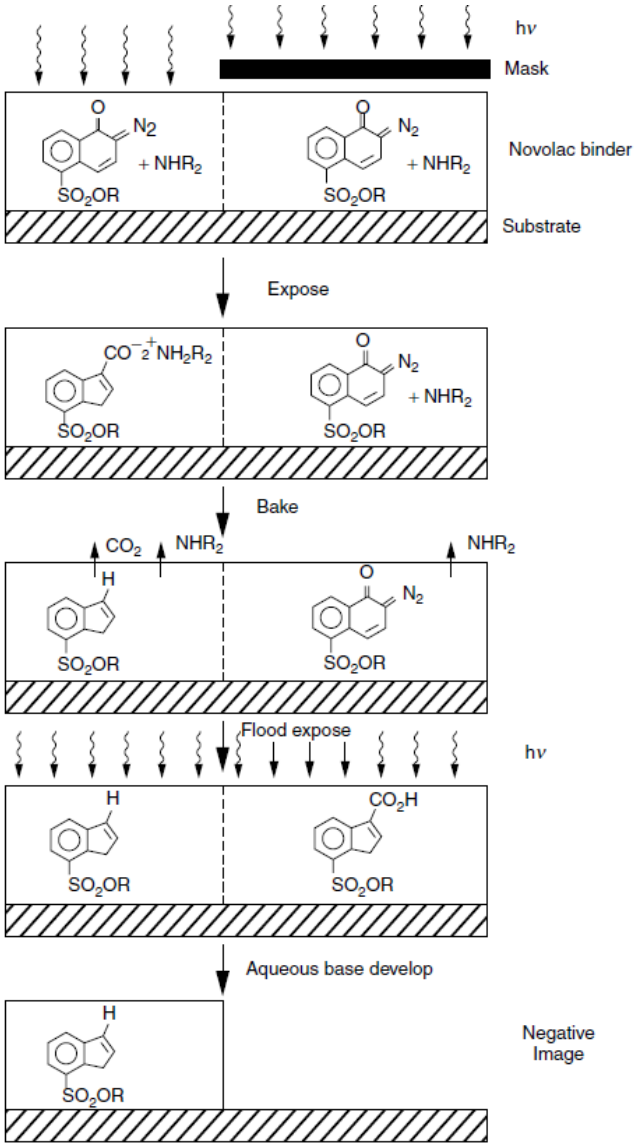


- positive PR
  - enhancing solubility
    - cresol novolac/DNS
      - DNS ~ insoluble in alkali, binding polymer photoreactive to alkali-soluble
    - near- to deep-UV

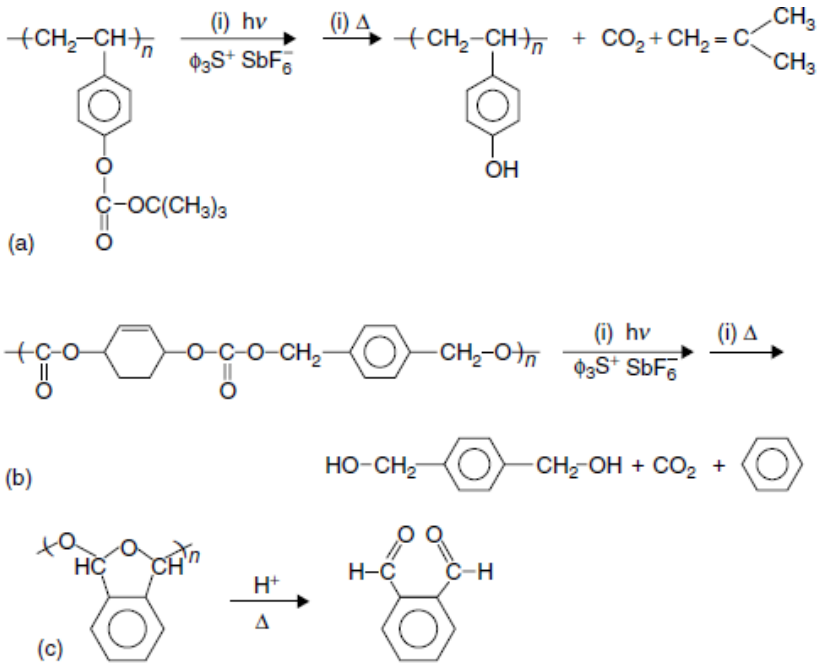


- image reversal
  - convert posi image to nega image
  - amine-treated DNS system
  - deep-UV negative
- PCM (portable conformable mask)
  - multilayer mode
  - expose to different λ



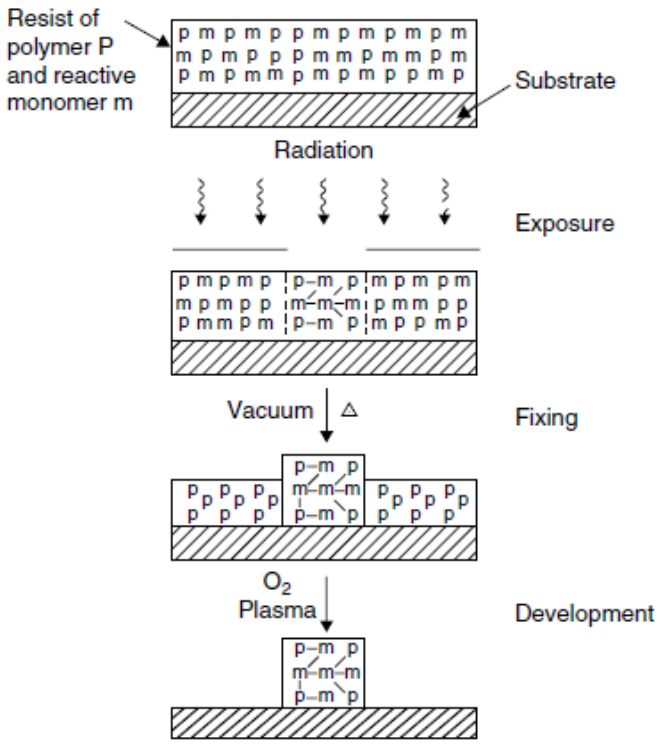


- CAR (chemically amplified resist)
  - photolabile acid generator/acid-labile polymer
    - I or S salt
    - t-butyl carbonate or esters
    - copolycarbonates
- self-developing
  - depolymerization
  - low T_c
- PR for higher resolution
  - Si, F, --- polymers



- e-beam resist
  - shorter λ
  - positive ~ PMMA, polyolefin sulfone
  - negative ~ polymers with glycidyl, allyl
  - X-ray or ion-beam promising
- plasma developable PR
  - no-solvent, dry ~ no undercut
  - plasma-resistant polymers
    - aromatic or heteroatom
  - photolocking
- nanoimprinting, dip-pen [DPN]
- block copolymers

Fig 5.50

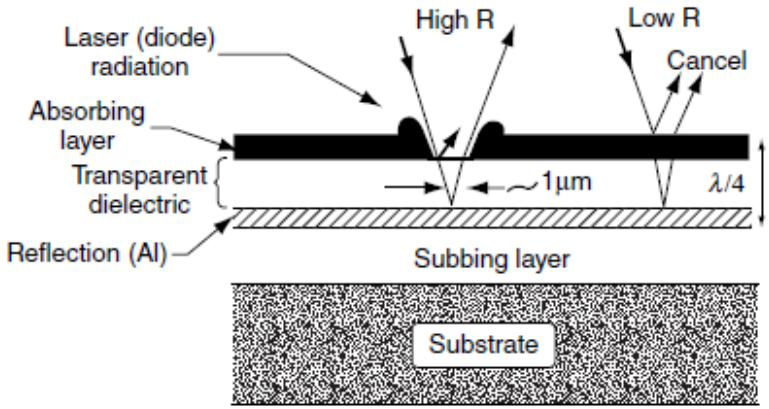


Photoresist for printing

- printing plates
  - replacing metal plates for newspaper etc
  - solid plates ~ photo-crosslinkable polymers
  - allyl-PU, acrylates, ---
- photoengraving
  - for illustrations, photographs
  - photosensitive coating on metal crosslinked and etched
- printed circuits
  - circuit/negative PR/Cu exposed and etched

Polymers for optical disc

- ROM ~ injection molding of PC on metal stamper
  - PC ~ transparent, low birefringence (low MW), low hygroscopic
- WORM
  - absorbing layer ~ metal/polymer or dye
- rewritable
  - inorganic ~ magnetic
  - organic
    - bump ~ rubber/thermoset
    - LCP
    - pyroelectric polymer
- DVD ~ high density, low λ laser



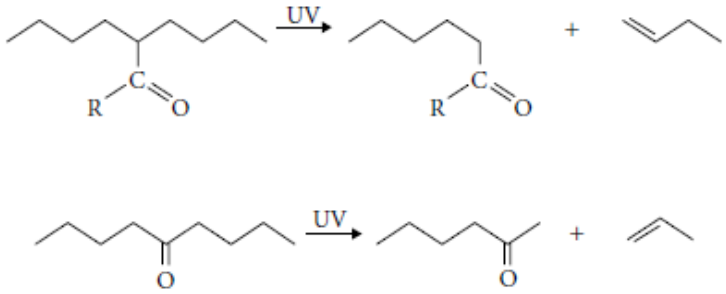
Adhesives

- liquid (to wet) to solid (for strength)
  - monomer or prepolymer polymerize
    - epoxy, cyanoacrylate, PF, ---
  - polymer at $T > T_m$ (T_g) or in solution
- solvent-based
  - PU ~ one- (high MW, shoe) or two-part (low MW, engineering)
  - substituted nylon, rubbers
- water-based
  - no VOC
  - water-soluble ~ PVA, --
  - emulsion or dispersion ~ PVAc, EVA, ---

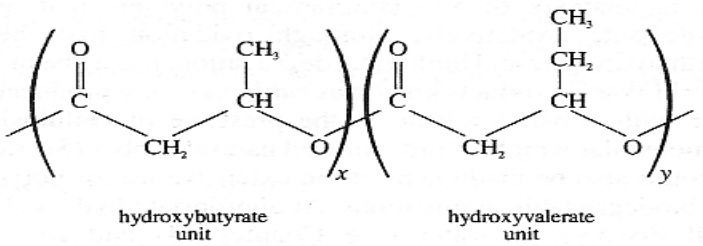
- hot-melt
  - fast, no VOC
  - EVA, polyesters, polyamides, ---
  - low service T and strength
- radiation-curable
  - UV-curing of acrylate- or epoxy-terminated resin
    - epoxy, PU, polyester, ---
    - fast, no VOC
    - need transparency, shallow cure depth
  - e-beam curing ~ expensive
- pressure-sensitive adhesives ~ post-it

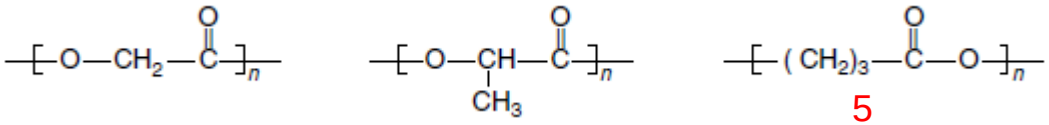
Degradable polymers

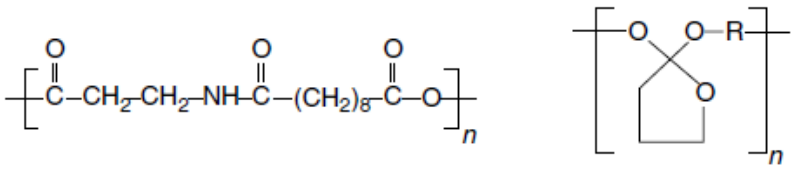
- photodegradable
  - environmental issue ~ time of degradation
    - UV-absorbing group like C=O
    - photosensitizer
  - photoresist



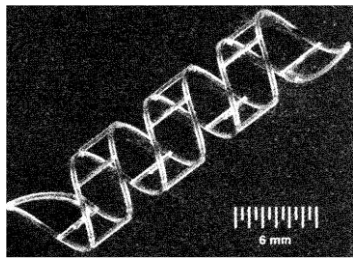
- biodegradable
  - biodegradable polymers
    - aliphatic polyesters
      - PHB, PHV
      - PLA, PGA
      - PCL
    - aminoacid derivatives
    - polyorthoesters

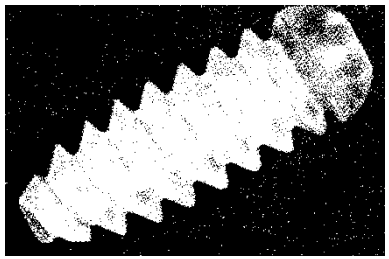




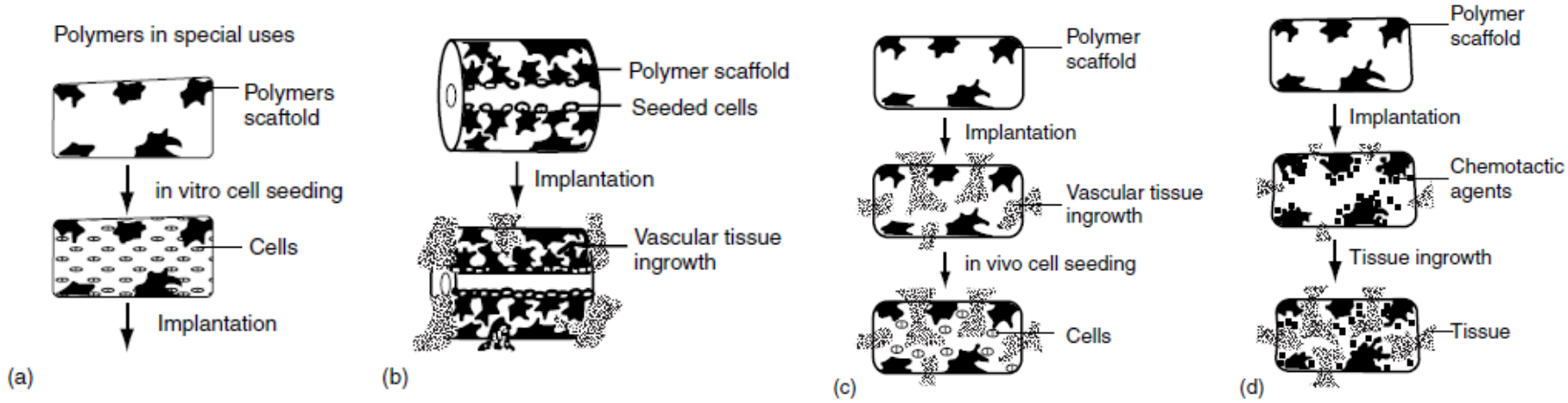


- environmental issue ~ packaging
  - blending starch ~ 'biocollapsible'
  - PHB, PHV, P(HB-co-HV) ~ Biopol®
    - bio-produced and biodegradable ~ expensive
  - PLA
- for pesticides ~ controlled release
  - chelating or ester pendant group
  - encapsulation in starch, lignin, PHB, PLA
- DDS
  - encapsulation in PLGA (biodegradable), PEO, PHEMA (not)
  - oral, injection, or transdermal
- surgical instruments
  - suture, stent, screw, --





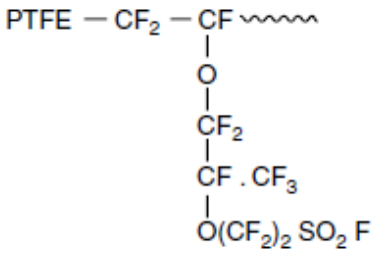
- tissue engineering
  - organ regeneration or cell therapy
  - biodegradable polymer as scaffold
    - PLA (2 yrs), PGA (8 wks), PLGA
    - skin and cartilage commercialized
  - hydrogel
    - injectable
    - PEO, PVA, PHEMA copolymers



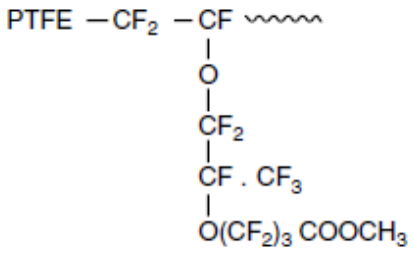
Ionic polymers

- ion-containing polymers
  - low ion conc'n ~ ionomer
  - high ion conc'n
    - linear ~ water-soluble ~ polyelectrolyte ~ thickener, sizing
    - crosslinked ~ insoluble ~ ion-exchange resin
- ionomers
  - P(E-co-MAA) ~ random copolymer then ionized
    - ionic crosslinking ~ physical ~ processable
    - small crystallites ~ transparent, tough ~ packaging
  - elastomeric ionomers
    - AA, MAA copolymerize with BD, EPDM, ---, then ionized
    - ionic vulcanization ~ higher strength, processable
    - not used as TPE ~ low service T, high stress relaxation
    - adhesives, coatings, ---

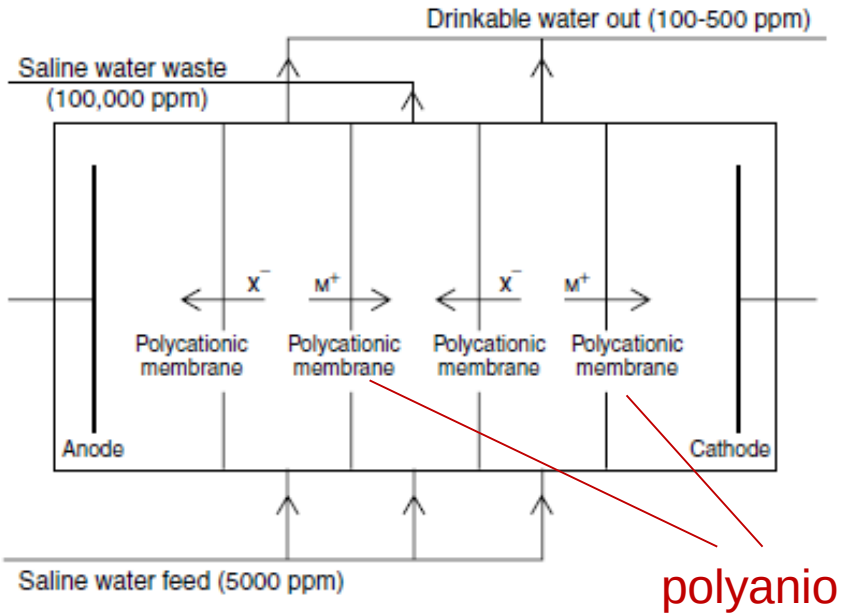
- Nafion ~ ion-exchange membrane
  - cation exchange
  - fuel cell, alkaline cell
  - electrodialysis
    - desalination



Nafion precursor

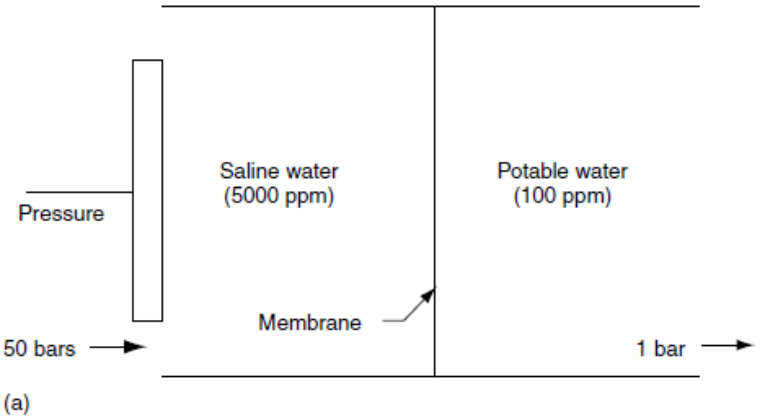


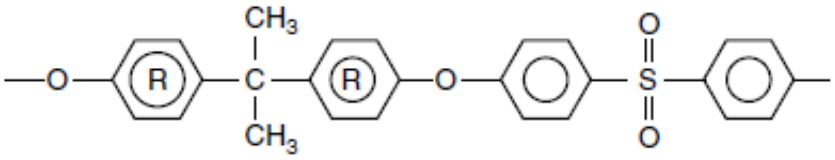
Flemion precursor

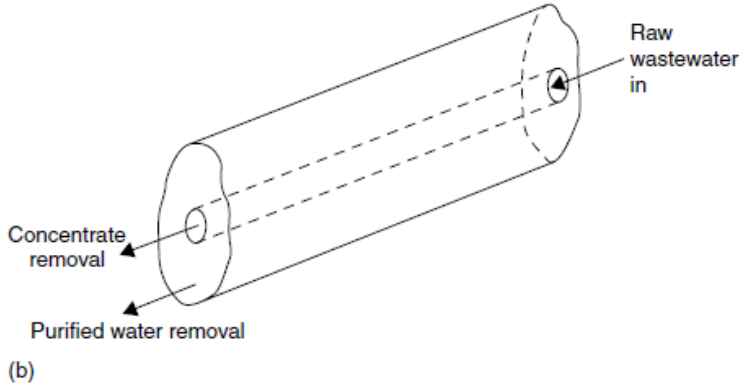


polyanionic membrane

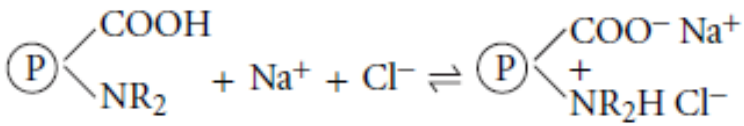
- PSF, PES ionomers
  - sulfonation of PSF, PES
  - reverse osmosis membrane
    - need not be ionic
    - should be hydrophilic
    - desalination, purification



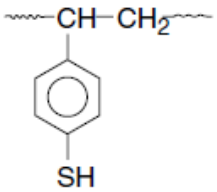




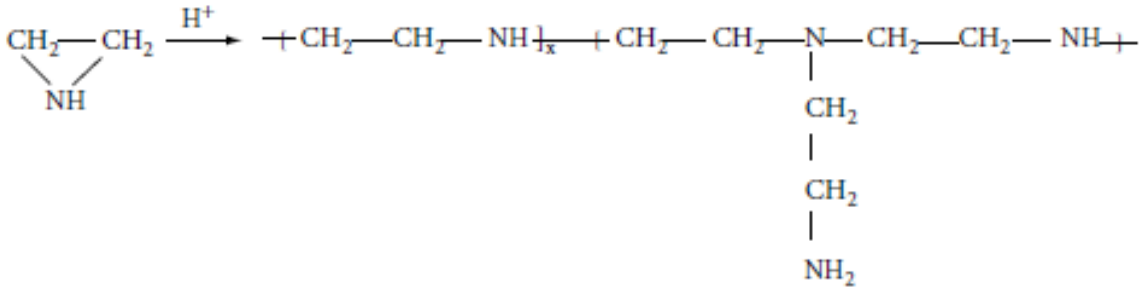
- ion-exchange resins Table 5.18
  - cation exchange $\text{(P)}SO_3^-H^+ + M^+X^- \rightleftharpoons \text{(P)}SO_3^-M^+ + H^+X^-$
    - P(S-co-DVB) sulfonated ~ regenerated by acid
  - anion exchange $\text{(P)}NR_3^+OH^- + H^+X^- \rightleftharpoons \text{(P)}NR_3^-X^+ + H_2O$
    - P(S-co-DVB) chloromethylated/aminated ~ regenerate by alkali
  - ampholytic
    - cation and anion exchanger in one bead
    - regenerated by hot water



  - specific ~ modified to be selective to specific ion
    - for Hg^{2+}



- applications
  - deionizing water ~ cation/anion
  - softening water ~ cation
  - metal recovery
- ionene ~ ion in backbone



- scavenger resin ~ polymer with reagent
  - for purification in organic synthesis

Polymer membranes

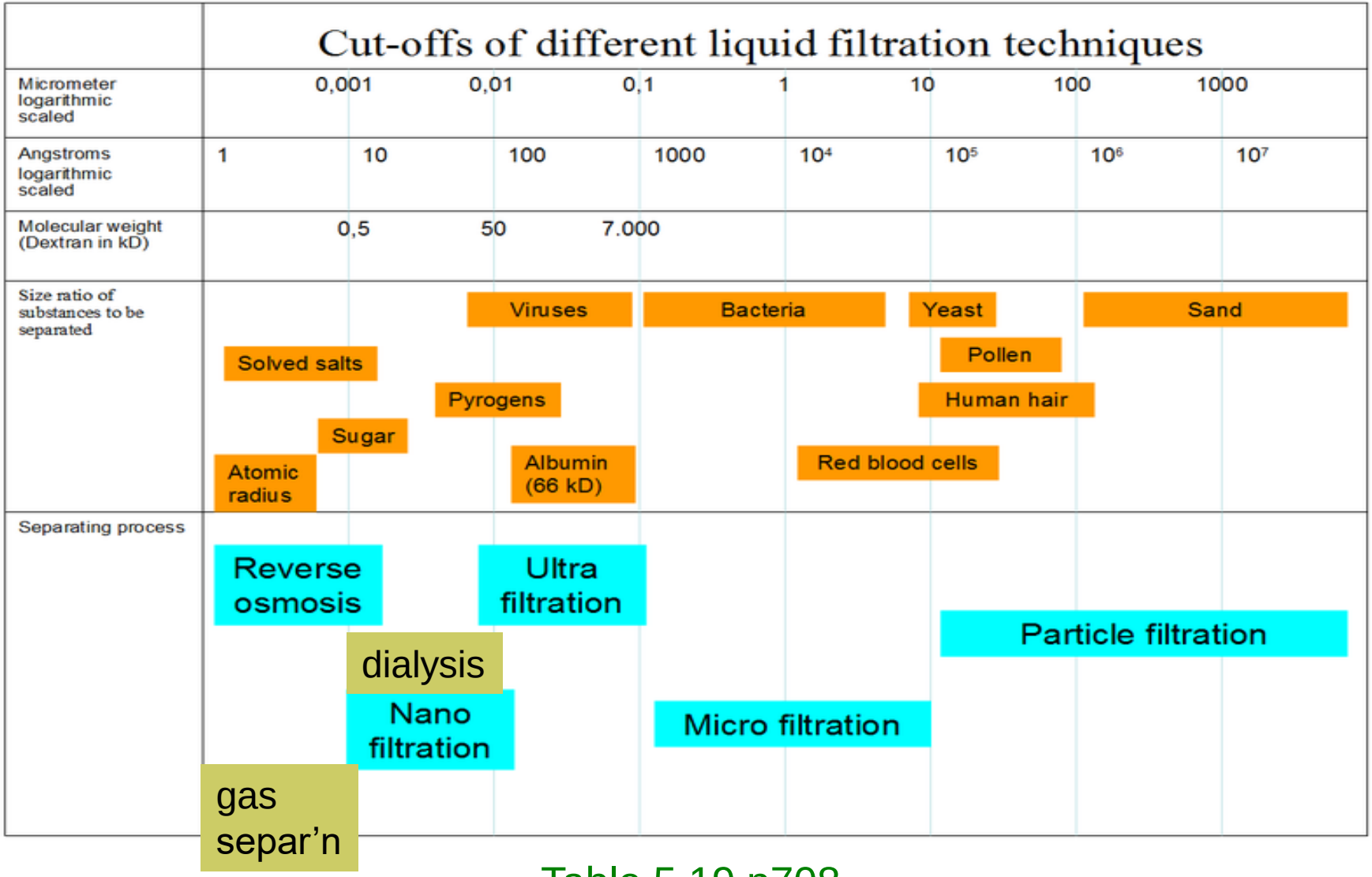
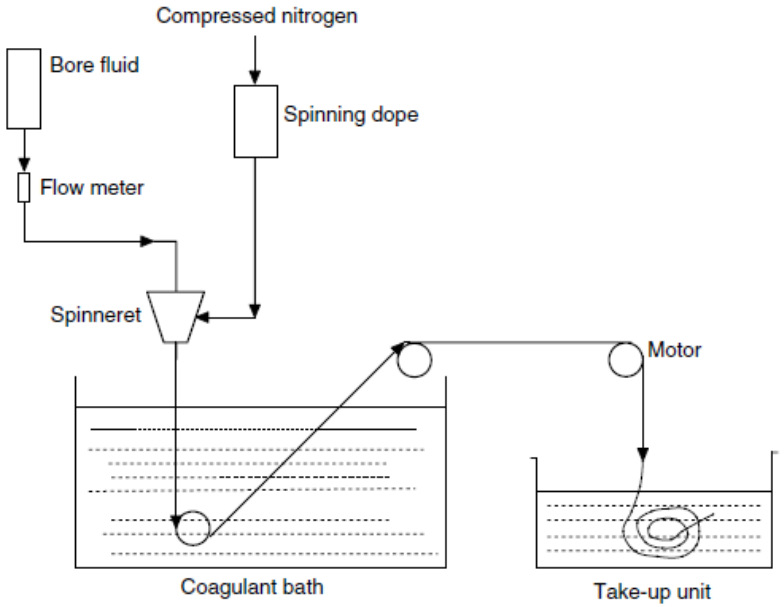
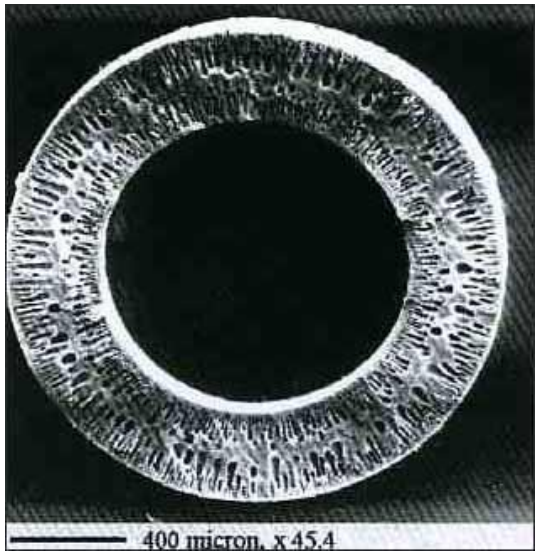


Table 5.19 p708

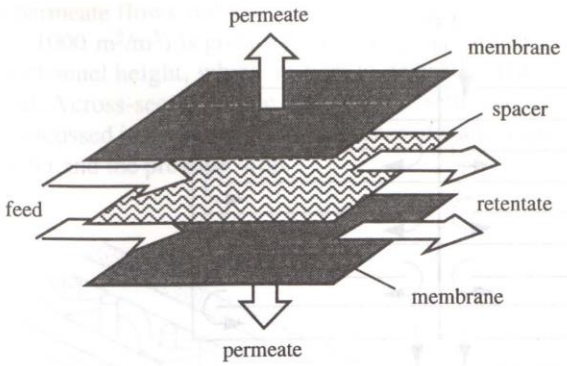
- morphology
  - isotropic (homogeneous; dense or porous)
  - anisotropic (asymmetric; dense to porous)
  - composite (dense/porous)
- preparation
  - melt extrusion
    - polymer only ~ dense, isotropic
    - polymer/diluent ~ temp-induced phase separation ~ porous
  - wet extrusion
    - polymer solution extruded and coagulated
    - to air, vapor, or liquid ~ isotropic or anisotropic

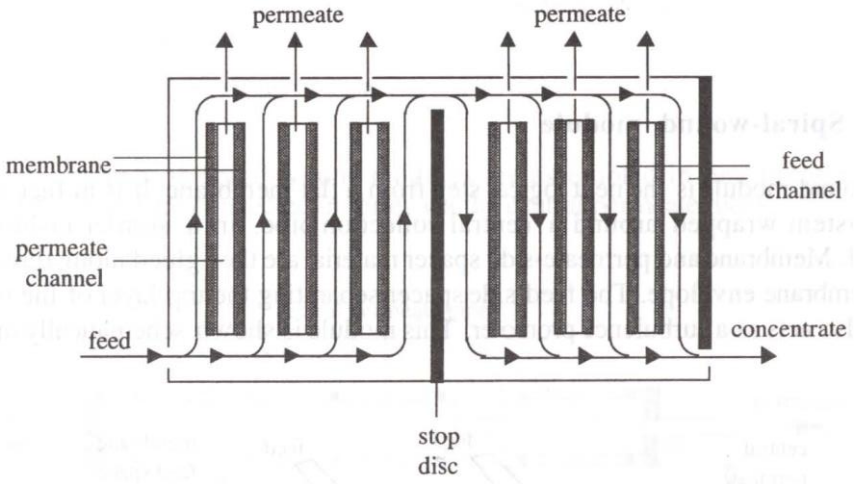
- polymerization/crosslinking/formation
  - prepolymer crosslinked between plates
  - for rubbery gas separation membranes ~ PEO, PDMS
- spinning
  - with bore fluid to coagulation bath
  - for hollow-fiber membranes



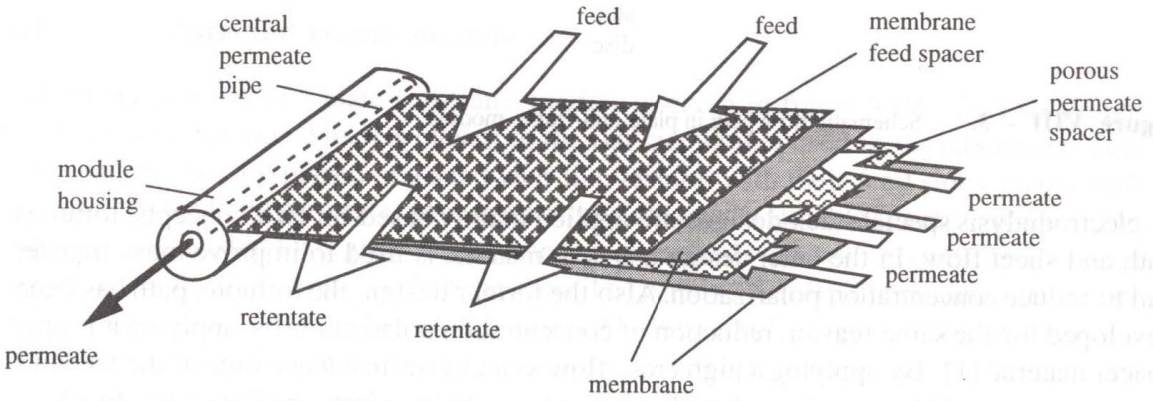


- membrane modules
  - plate-and-frame

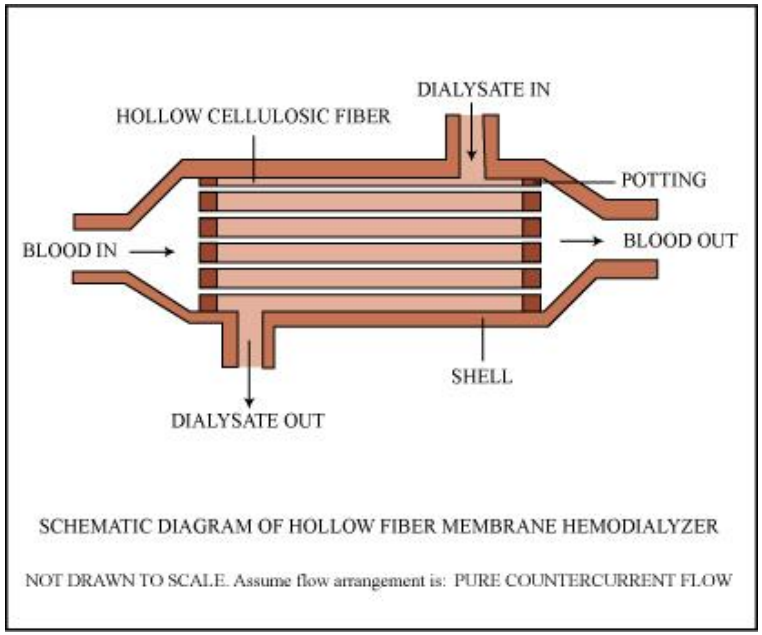




  - spiral wound

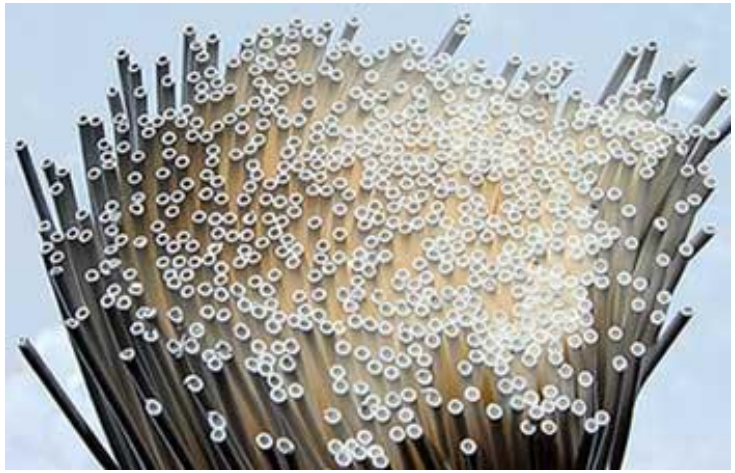


- tube-in-shell
  - high flux, high solid content
- hollow fiber
  - large surface to volume
  - need clean feed (plugging)



SCHEMATIC DIAGRAM OF HOLLOW FIBER MEMBRANE HEMODIALYZER

NOT DRAWN TO SCALE. Assume flow arrangement is: PURE COUNTERCURRENT FLOW



- applicatoins
  - hemodialysis, hemofiltration
    - cellulosics, PSF, PC-PE block
  - plasmapheresis
    - cellulose acetate, PE, PP
  - oil/water emulsion separation
    - hydrophilic preferred (PEO) ~ less adsorption
  - gas separation
    - O_2 ~ medical, environmental, industrial (combustion)
    - N_2 ~ explosion, food
    - H_2 ~ energy
    - CO_2 ~ energy, environment
    - PP (porous)/PDMS (dense), PSF, PC