Ticona

Liquid Crystal Polymers

An Overview of Technology and Typical Applications

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NPE 2000

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Liquid Crystal Polymers

Overview of Technology and Applications

- LCPs have graduated from a niche developmental material to a plastic routinely used in high performance applications
- LCPs are one of the fastest growing high performance materials for injection molding applications
- LCP use will continue to expand by providing performance that enables the growth of new technology

Liquid Crystal Polymers

Overview of Technology and Applications

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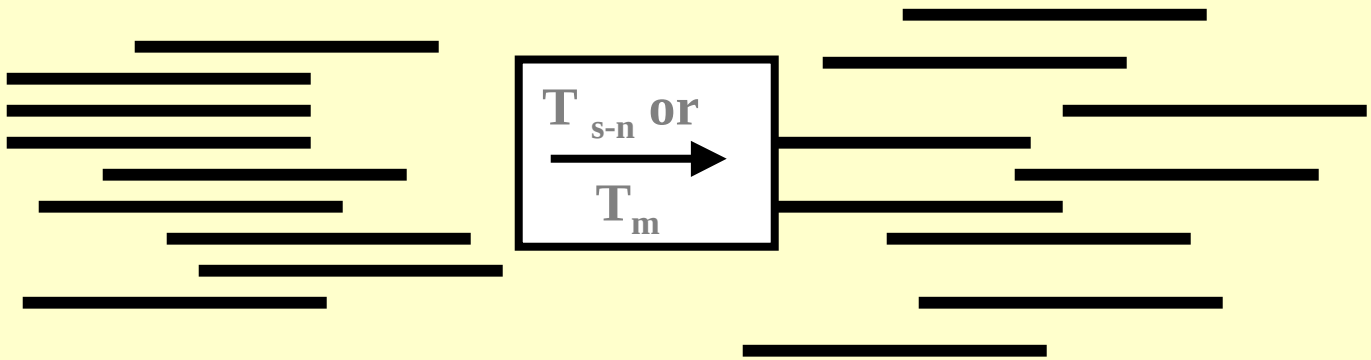
- What is a Liquid Crystal Polymer?
- How are they made?
- What are their properties?
- How are they processed?
- What are they useful for?
- What is the future for LCPs?

What is a LCP ?

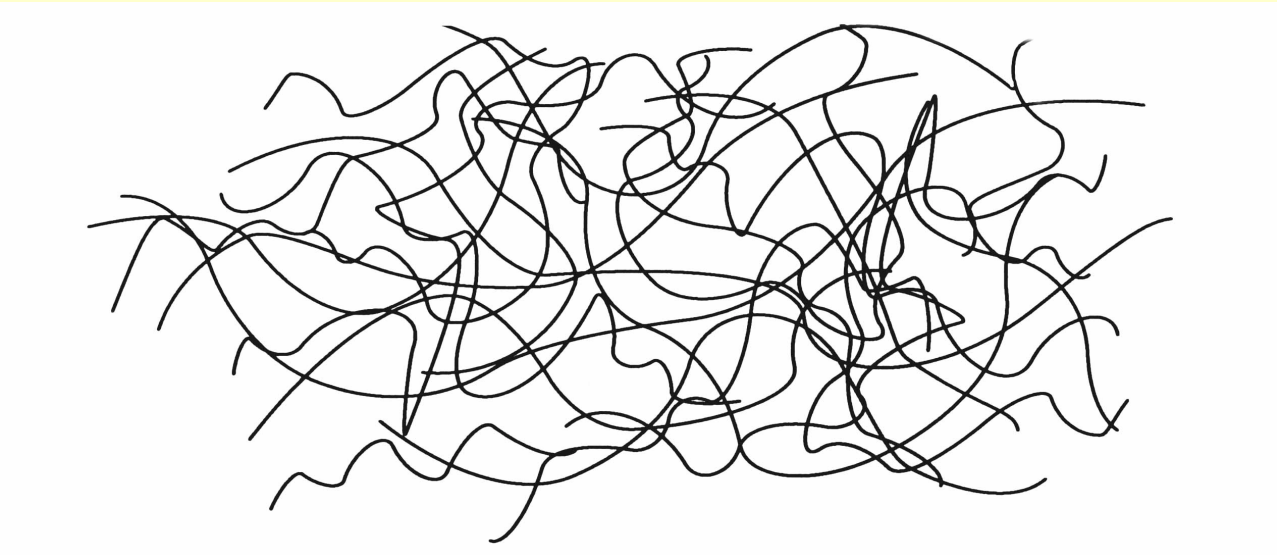
- A polymer characterized by a highly ordered fluid state between solid and isotropic (amorphous) fluid. What we call the "Tm" is the temperature at which the LCP changes from a solid to a highly organized fluid.
  - For Vectra A950 this occurs at about 280 °C. The real melting temperature (where you get an isotropic fluid) is > 500 °C !



LC Solid has some order *LC Fluid retains most of the order*

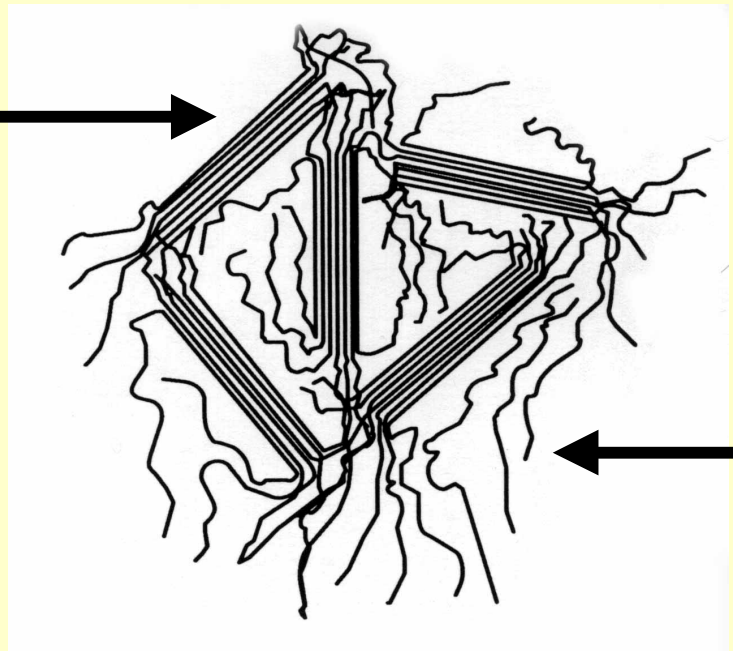
Amorphous Polymer

- Polymer chains are not organized (isotropic) and are randomly intertwined. Characterized by a glass transition temperature Tg.
  - Above Tg, amorphous polymers exhibit poor retention of strength and relatively high melt viscosity

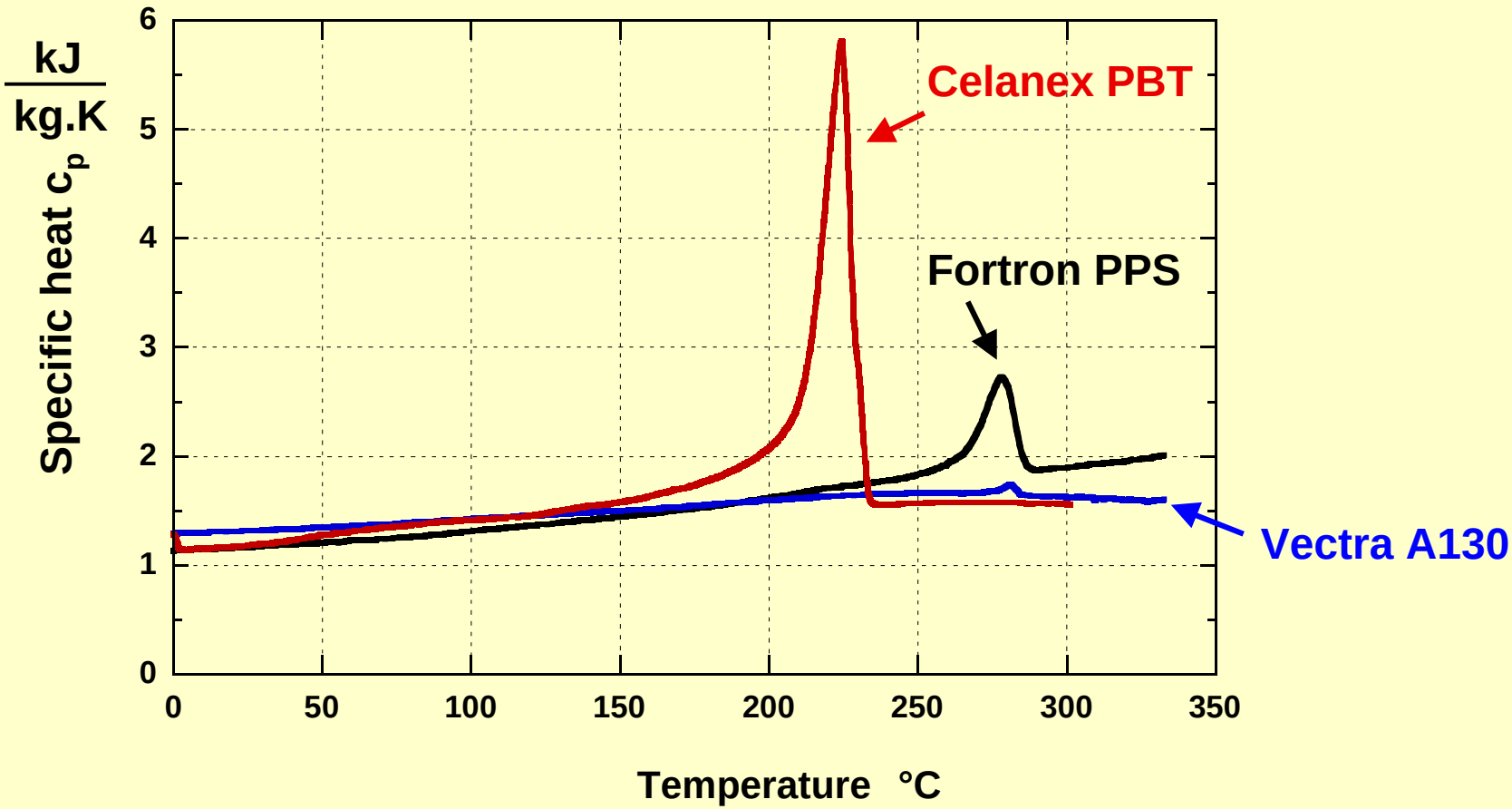


Crystalline Polymer

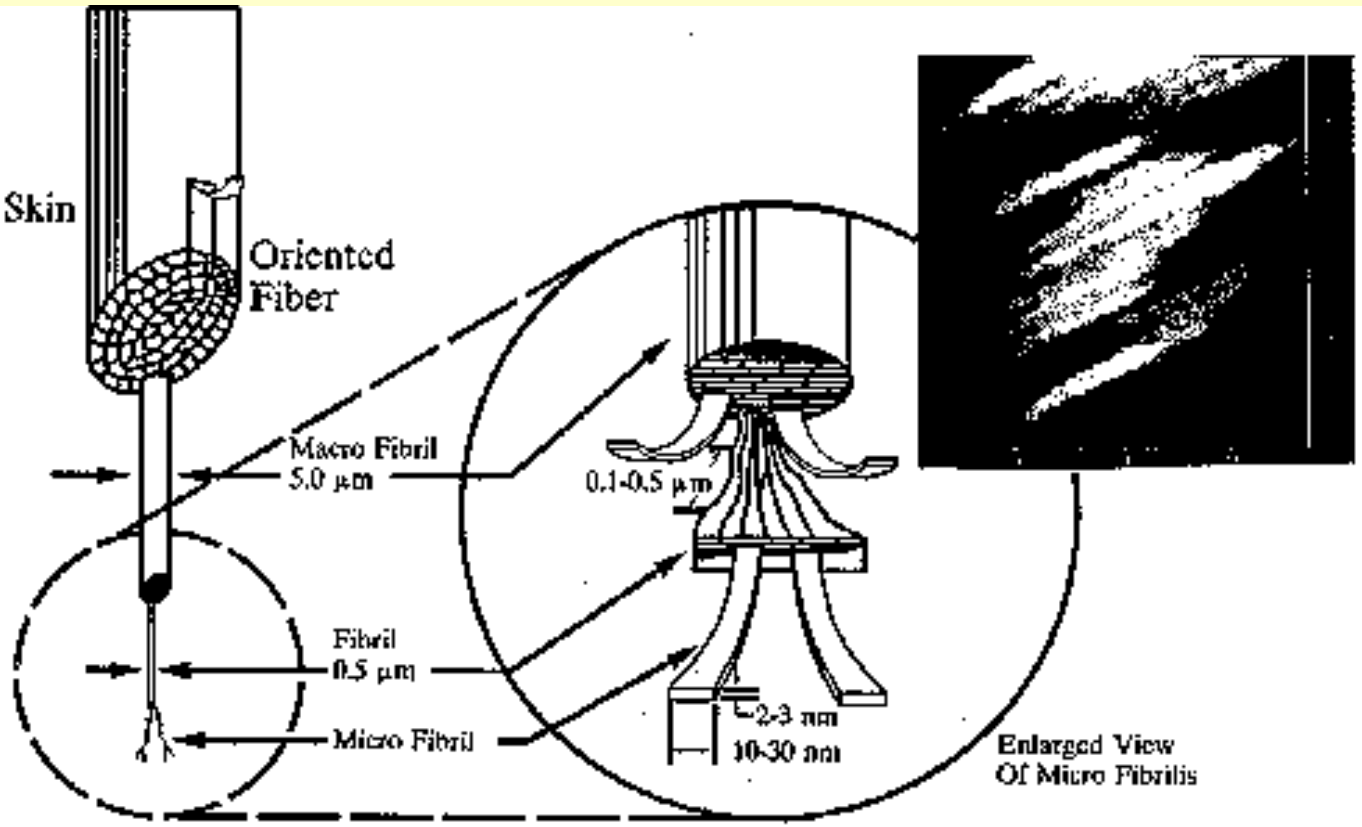
- A polymer with a well defined melting point or Tm. At temperatures below Tm, the polymer is a solid and the polymer chains line up to form crystals. Above Tm the crystals melt to form a fluid with no order.



Structure of LCP in solid and nematic fluid are similar resulting in low heat of fusion



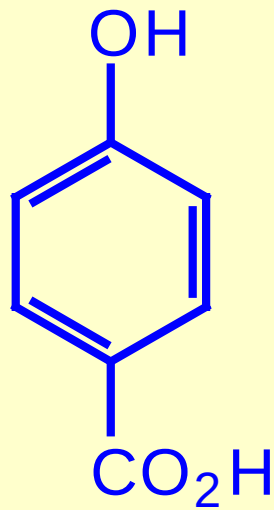
LCP Structural Model



Based on Microscopy of Vectran® LCP Fiber

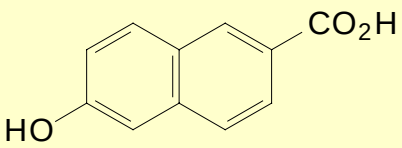
LCP Structure

- The microscopic structure observed for LCPs can be traced directly to the molecular structure of the polymer
- The principal monomer in all commercial thermotropic LCPs is 4-hydroxybenzoic acid (HBA)
- A homopolymer of HBA is liquid crystalline, but does not flow at temperatures below 500 °C

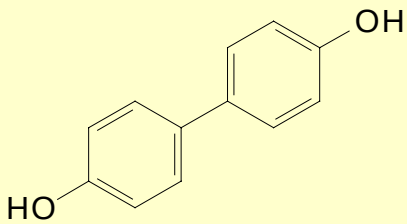


LCP Structure

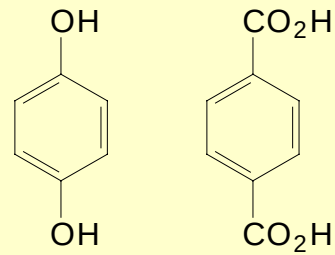
- A variety of other monomers are used by polymer chemists to reduce the processing temperature and modify performance characteristics of LCPs



HNA

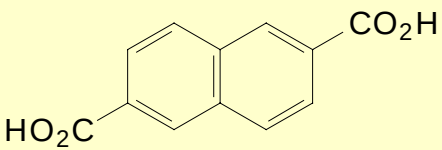


BP

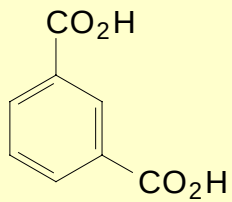


HQ

TA



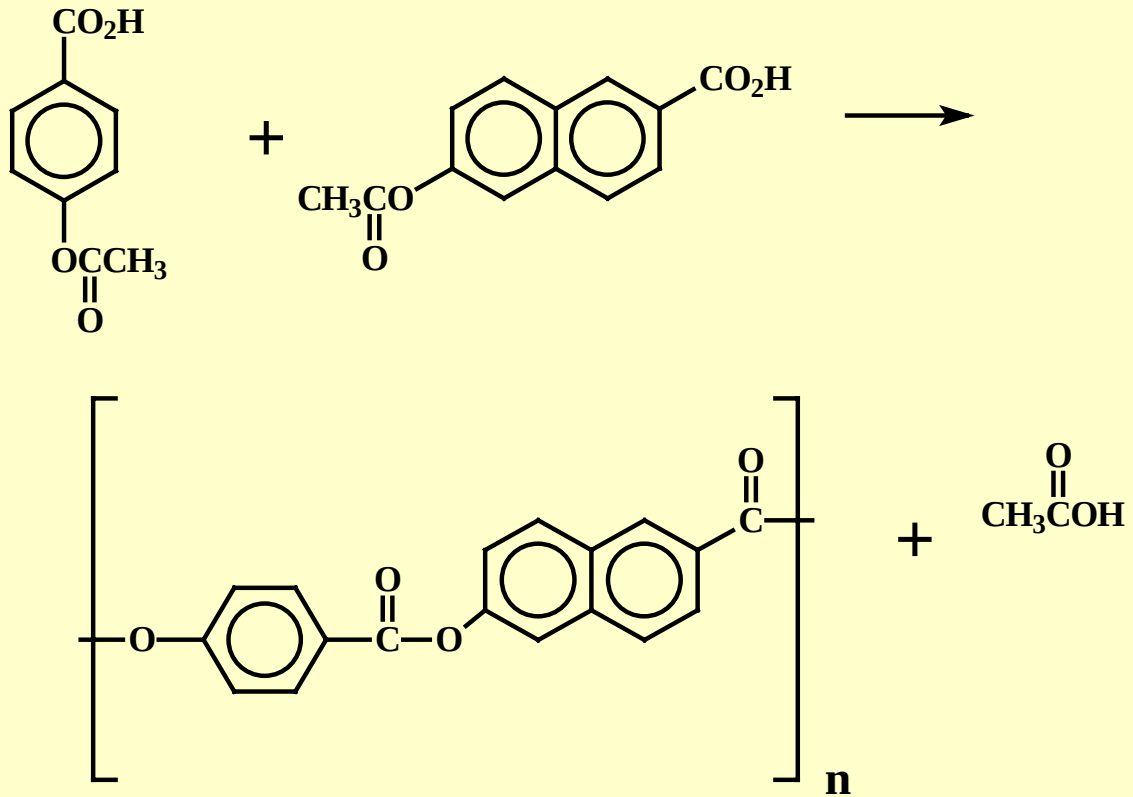
NDA



IA

LCP Manufacture

LCPs are made by condensation polymerization, similar to PET or PBT



Vectra A950

Commercial LCP Products Typically Contain Fillers

The performance of Vectra LCPs is enhanced by the use of a variety of fillers and/or reinforcements

Filler/Reinforcement	Effect(s)
Fiberglass	stiffness and sregnth
Carbon fiber	enhanced stiffness and strength
Mixed fillers/fibers	wear resistance and stiffness
Mineral fillers	toughness and surface appearance
Graphite flake	wear and chemical resistance
Carbon black	electrostatic dissipation
Proprietary fillers	improved platablity
Pigments	color concentrates

LCP Producers

US

- **Vectra® LCP - Ticona** ***Expansion Planned***
- Xydar® LCP - BP Amoco
- Zenite® LCP - DuPont
- Thermx® LCP - Eastman

Japan

- **Vectra® LCP - Polyplastics** ***Expansion 2001***
- Sumikasuper® LCP - Sumitomo
- Siveras® LCP - Toray

Reliable Global Supply

Consequences of Molecular Structure

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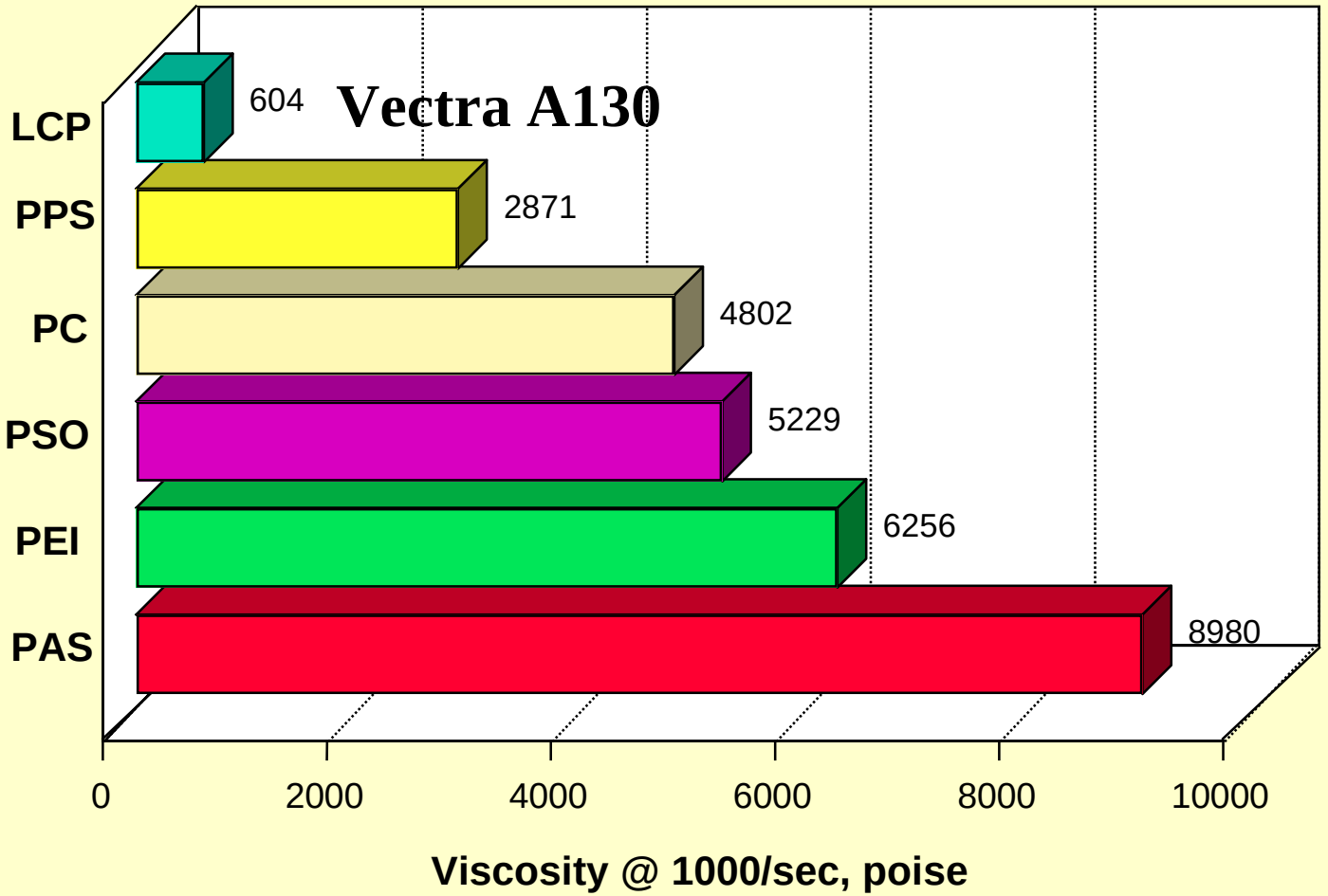
- **High Flow-Fills Thin, Complicated Parts Easily**
- Rapid Set-up - Fast Cycle Time
- Excellent Dimensional Stability
- High Strength/Stiffness
- Chemical Stability
- Excellent Barrier Properties

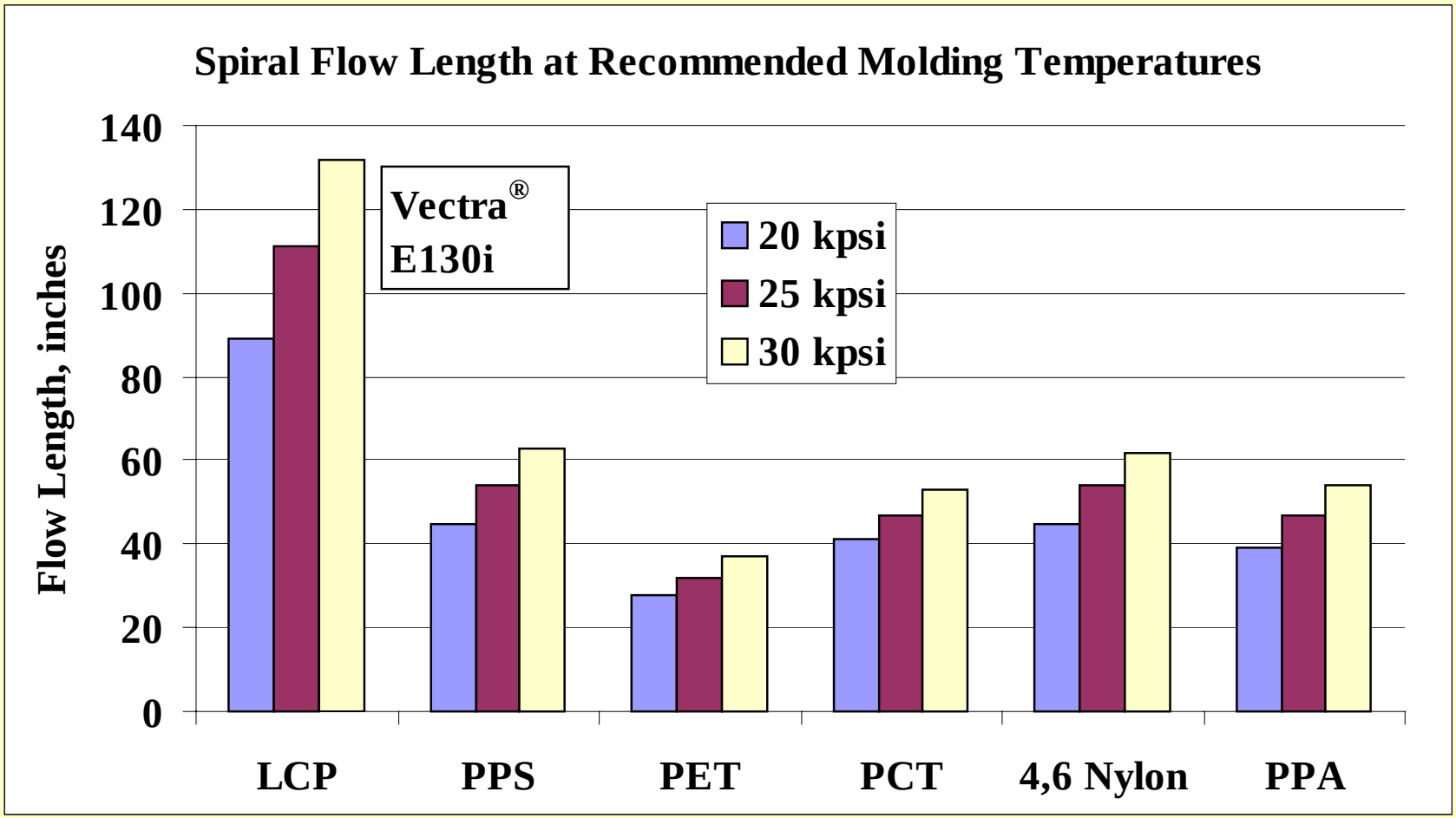
High Flow of LCPs



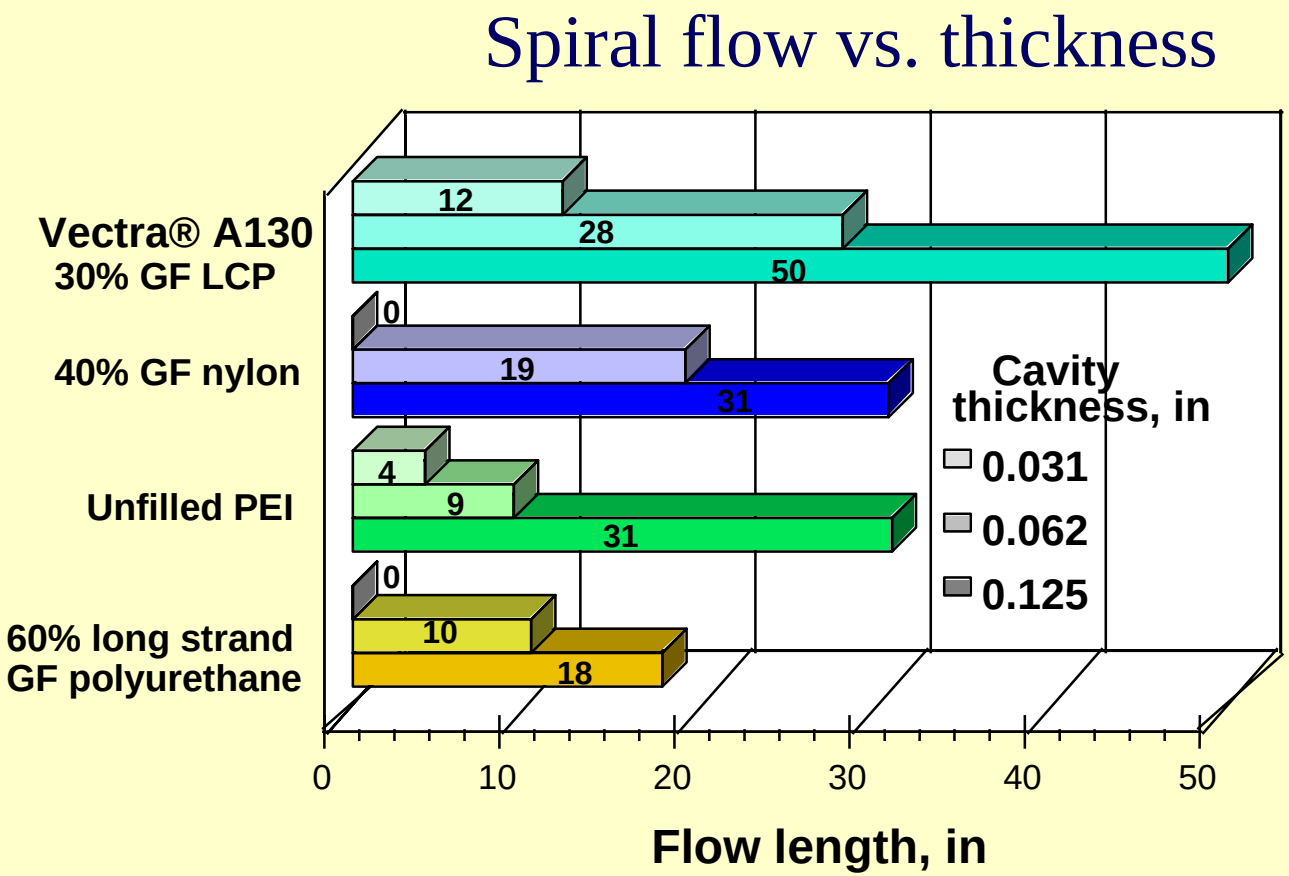
Low Melt Viscosity at Processing Temperature

NPE2000

High Flow of LCPs



High Flow of LCPs

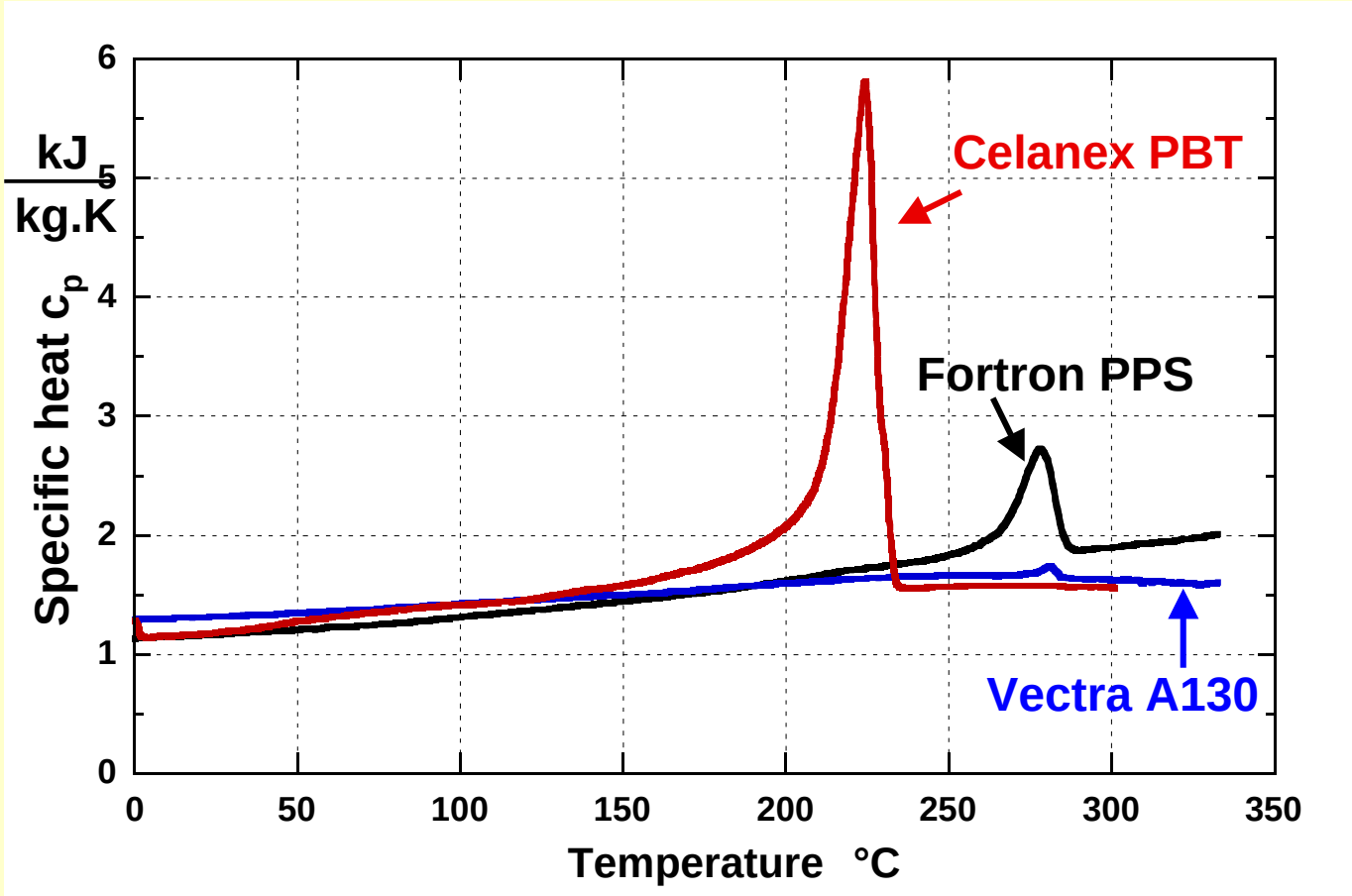


LCPs fill thin parts easily

Consequences of Molecular Structure

- High Flow - Fills Thin, Complicated Parts Easily
- **Rapid Set-up - Fast Cycle Time**
- Excellent Dimensional Stability
- High Strength and Stiffness
- Chemical Stability
- Excellent Barrier Properties

Low Heat of Fusion Contributes to Rapid Cycle Time



Cycle time savings

$ per part

Cycle time	26 sec	21 sec	16 sec
Machine cost	Others cost	Vectra® LCP saves	Vectra® LCP saves
35 $/hr	0.253	0.051	0.101
45 $/hr	0.325	0.065	0.13

At $0.01/ part/ second save $100,000 for 1 million parts ($0.10/ part)

Consequences of Molecular Structure

- High Flow - Fills Thin, Complicated Parts Easily
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- **Excellent Dimensional Stability**
- High Strength/Stiffness
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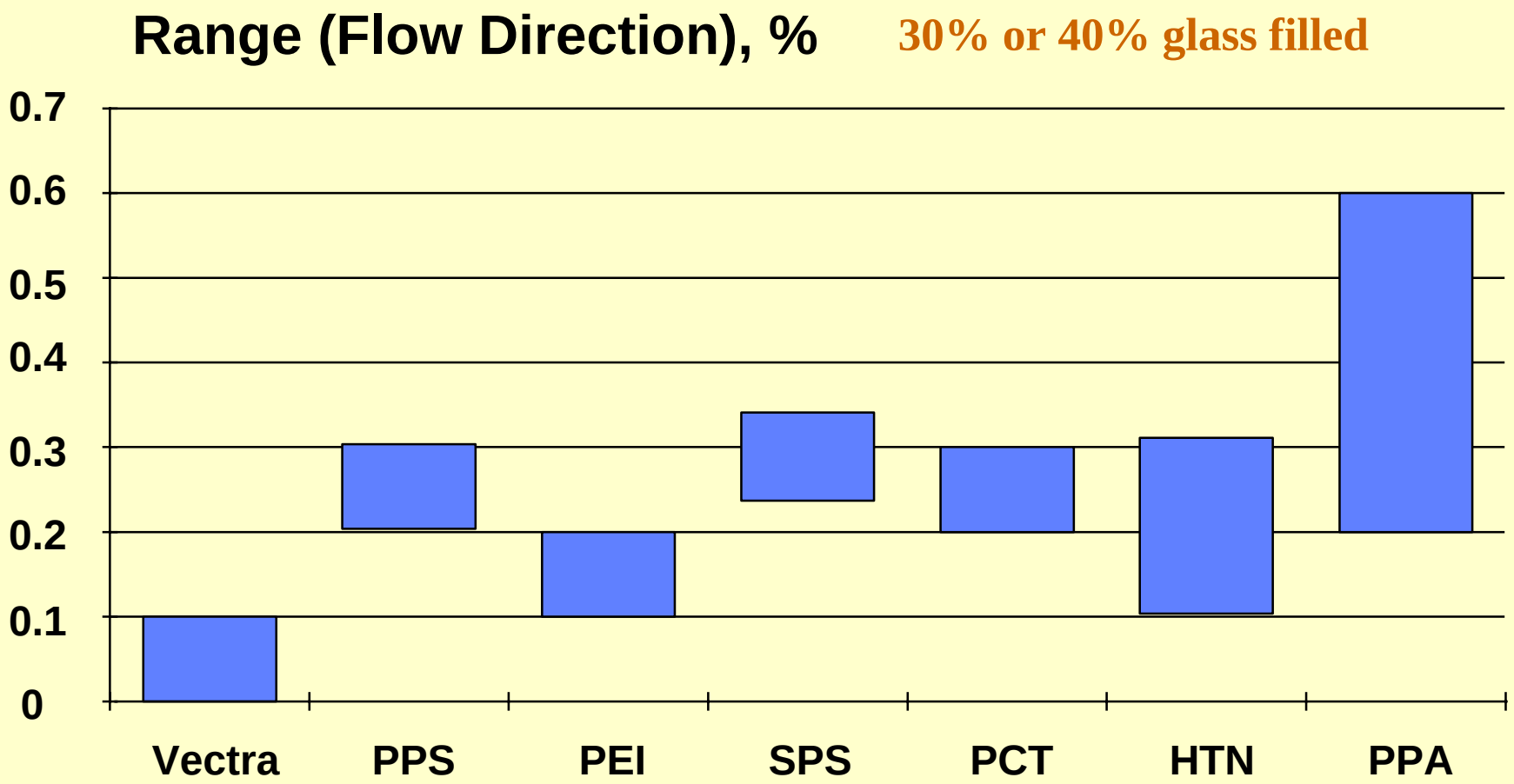
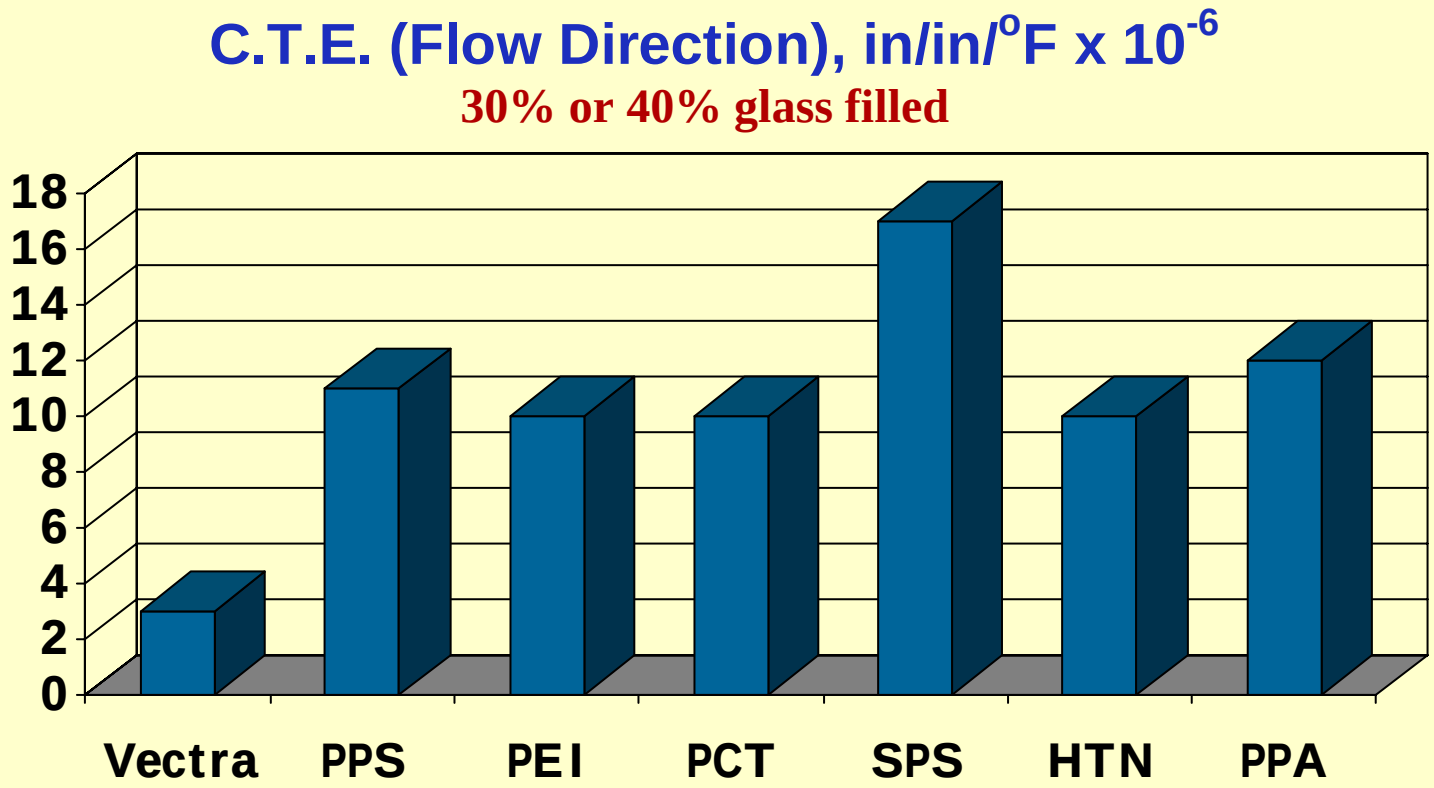
Similarity of LCP Structure in Solid and Nematic Fluid Result in Low Mold Shrinkage



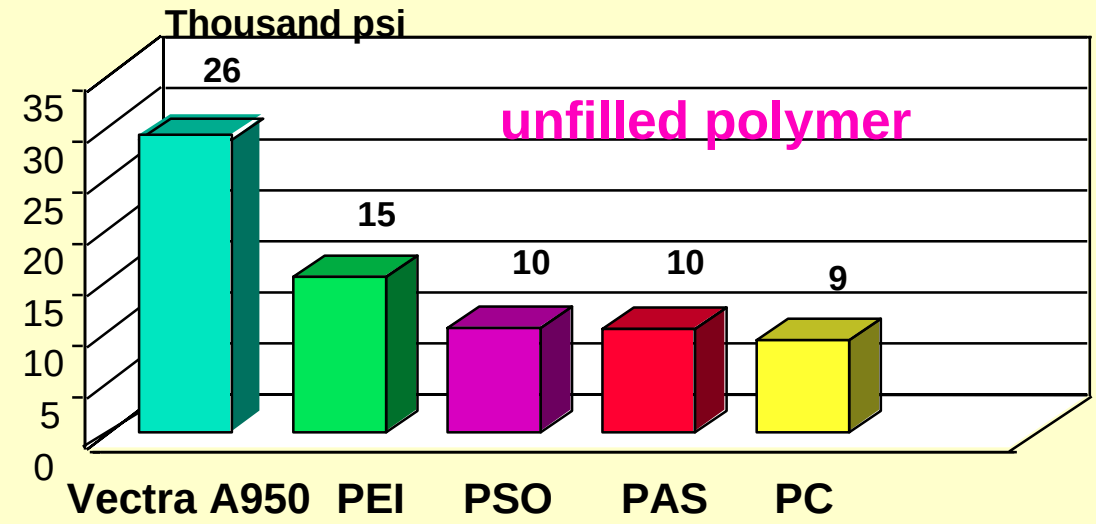
Low Coefficient of Thermal Expansion is also a Consequence of LCP Molecular Structure



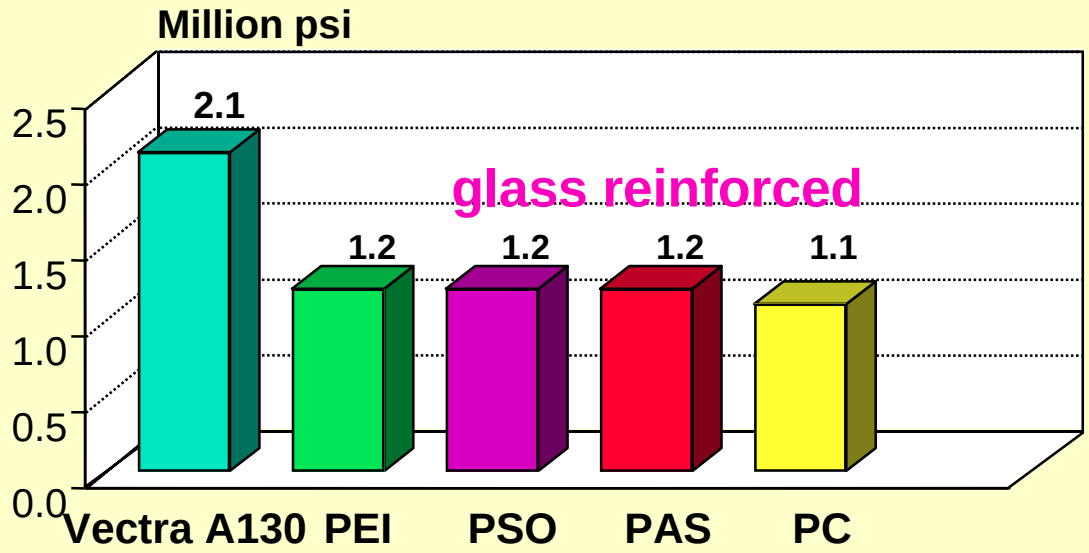
Consequences of Molecular Structure

- High Flow - Fills Thin, Complicated Parts Easily
- Rapid Set-up - Fast cycle Time
- Excellent Dimensional Stability
- **High Strength and Stiffness**
  - **Retained at High and Low Temperatures**
- Chemical Stability
- Excellent Barrier Properties

Rigid LCP Structure Yields High Strength and Stiffness

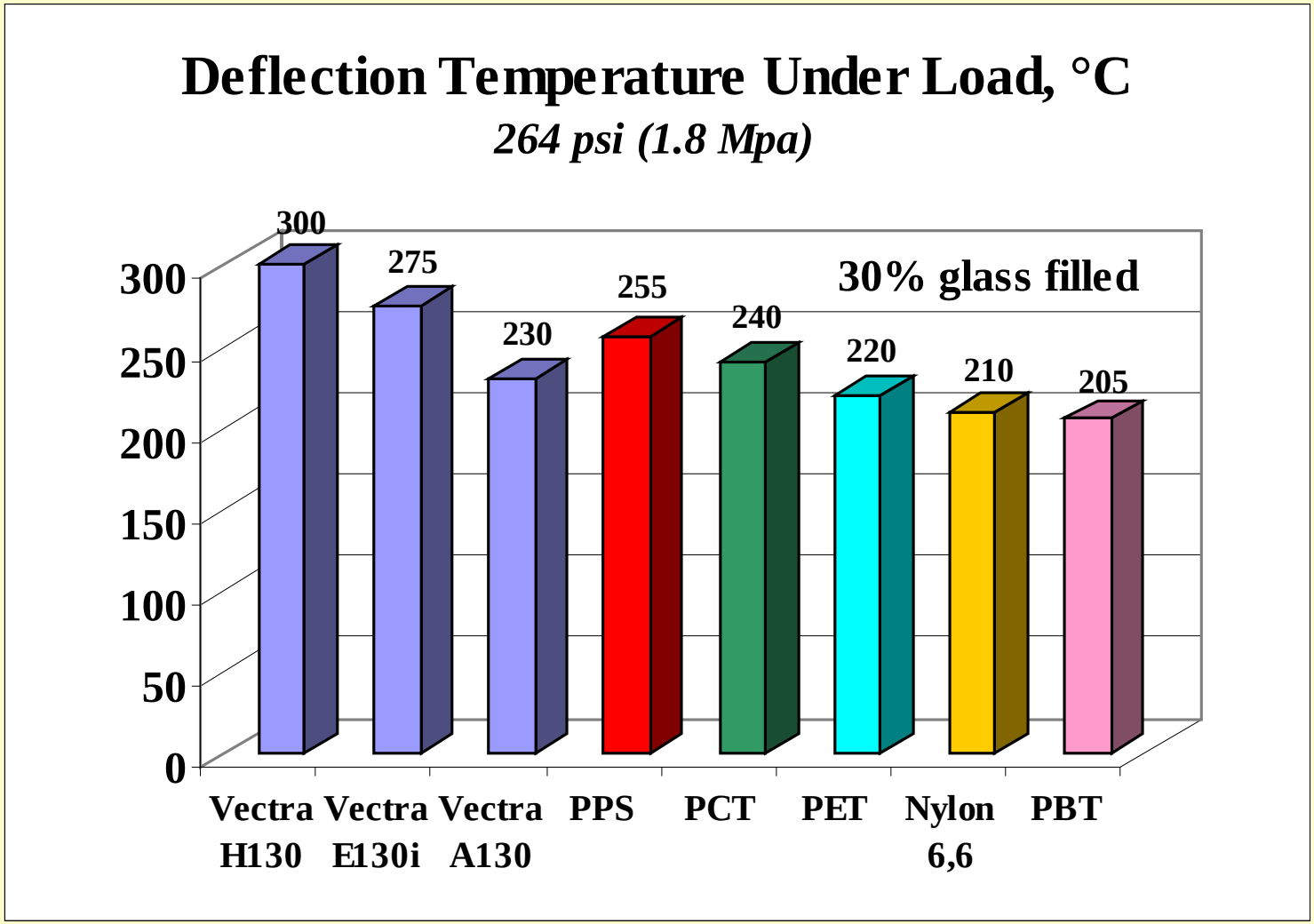


Tensile Strength

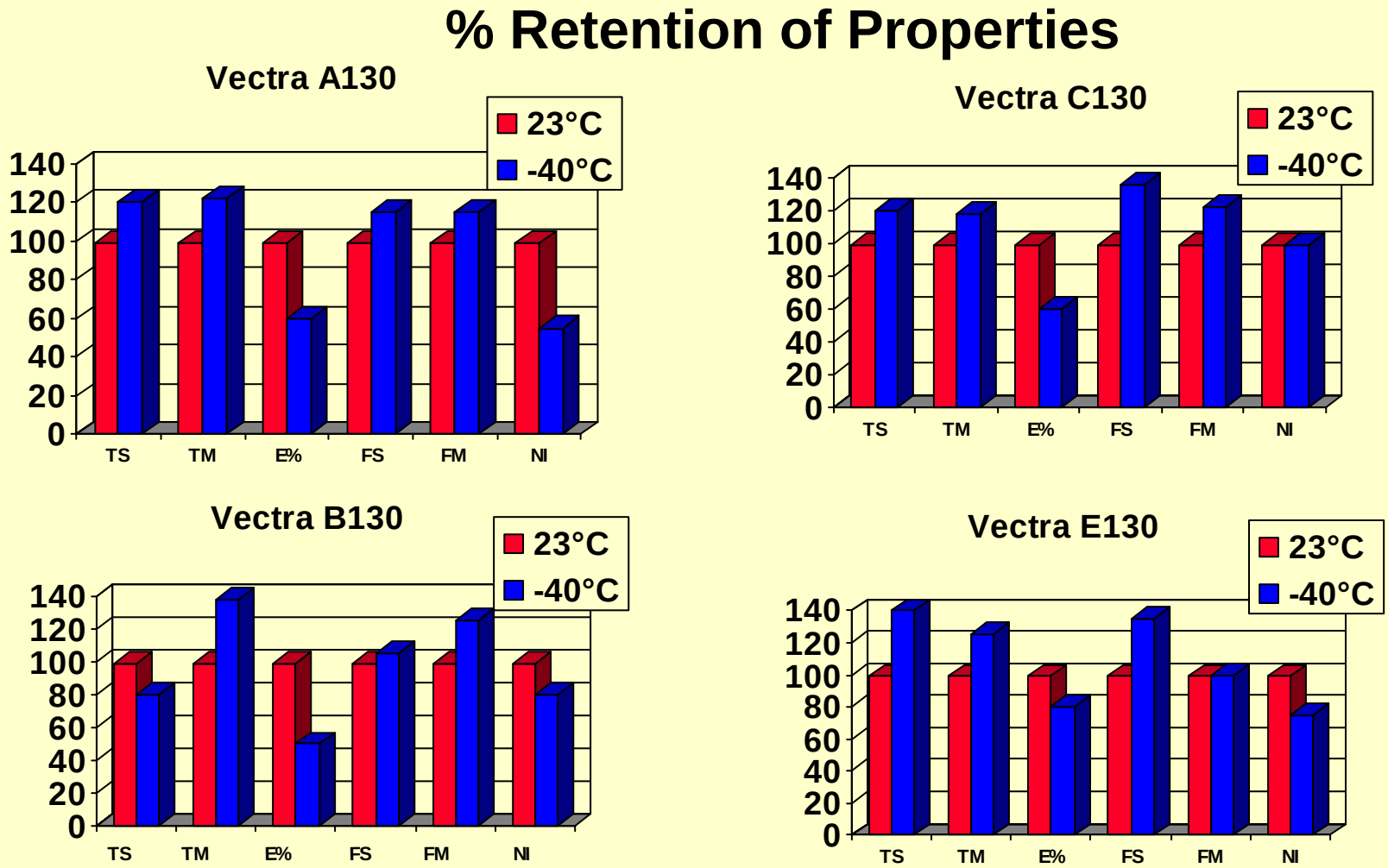


Flexural Modulus

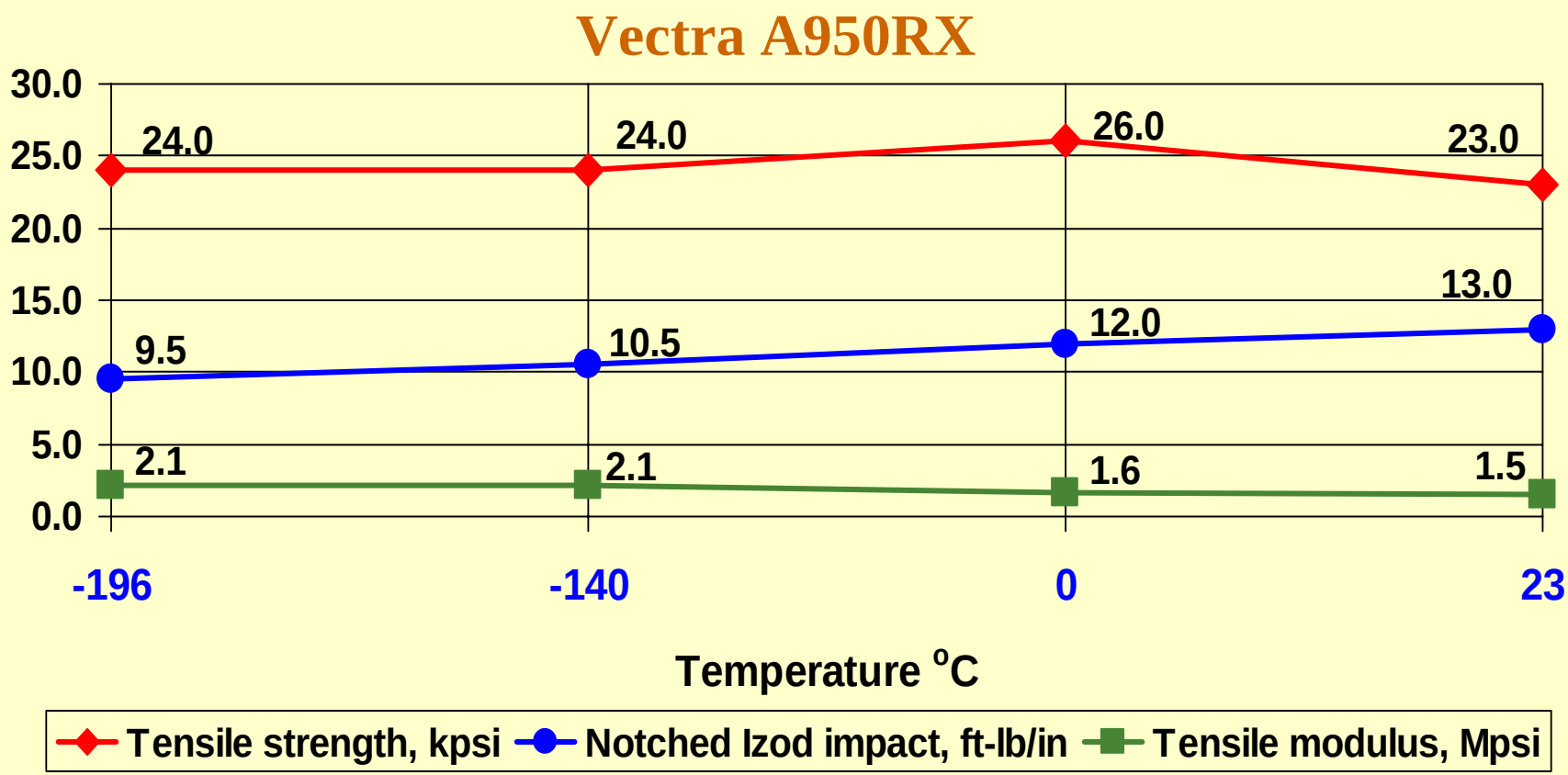
LCPs Retain Strength and Stiffness at High Temperatures…….



….And at Low Temperatures



Some LCPs Retain Their Strength Even at Liquid Nitrogen Temperatures



Consequences of Molecular Structure

- High Flow - Fills Thin, Complicated Parts Easily
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- High Strength and Stiffness
- **Chemical and Environmental Stability**
- Excellent Barrier Properties

Solvent Resistance

Organic Solvent	Temperature (°C)	Time (days)
acetone	56	180
methanol	64	30
ethanol	52	30
methylene chloride	40	180
trichloroethylene	66	90
nitrobenzene	66	30
ethyl acetate	77	180
gasoline	121	30
sour gas	121	30

Exposure to typical Organic Solvents has essentially No Effect on Vectra LCP physical properties

Chemical Resistance

LCPs are also stable to acidic environments

Acid	Temperature (°C)	Time (days)
formic acid, 80%	104	30
glacial acetic acid	118	30
sulfuric acid, 50%	88	60
nitric acid, 50%	70	60
chromic acid, 70%	88	30
hydrochloric acid, 37%	88	30

Not recommended for use in:

- strong oxidizing agents
- strong alkalis
- alcohols at elevated temperatures for prolonged time

Continuous Use Temperature

UL746B Relative Thermal Index

	Electrical	Mechanical w/ Impact	Mechanical w/o Impact
A130	240°C	220°C	220°C
C130	240°C	220°C	240°C
E130i	240°C	220°C	240°C
L130	240°C	200°C	220°C

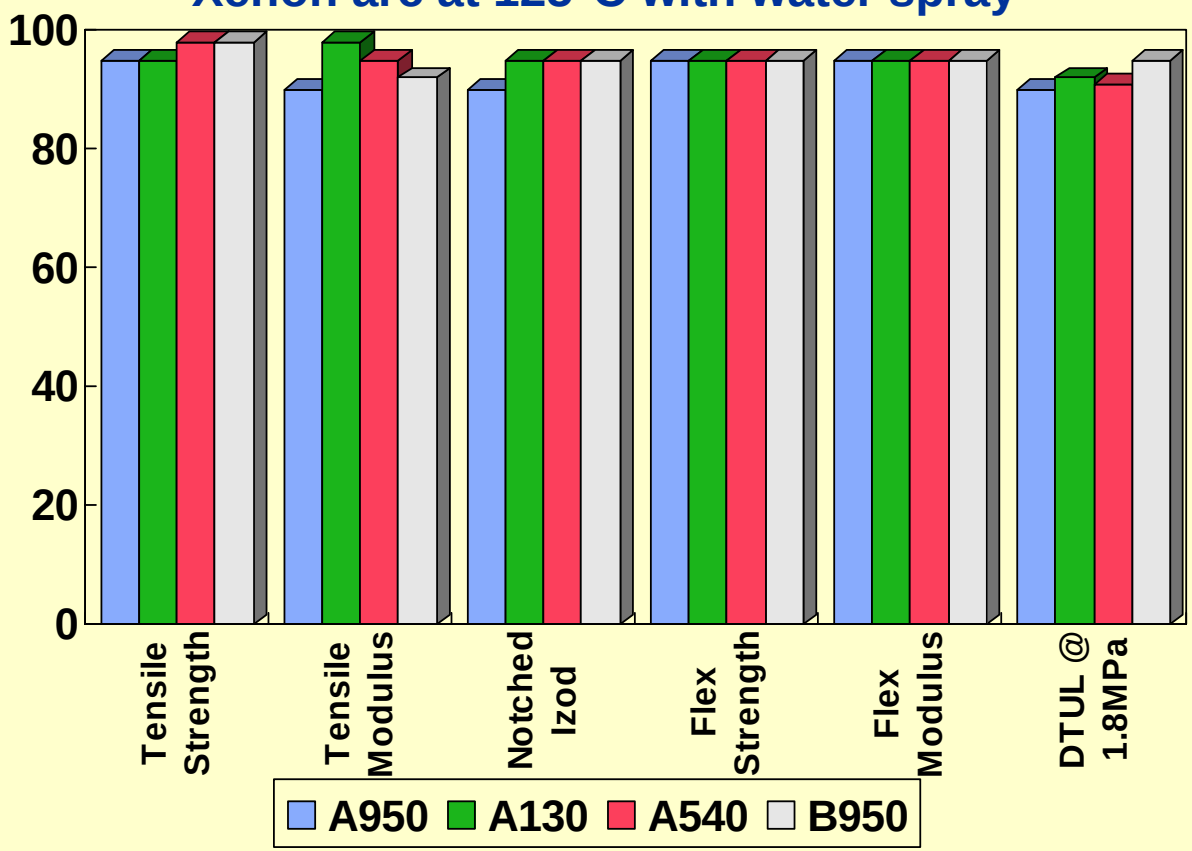
Data for 1.5 mm thickness

All-aromatic structure of LCPs resists thermo-oxidative degradation

Weatherometer Test Results

Thermal, UV and hydrolytic stability make LCPs well suited for outdoor environments

% retention of properties after 2000hr exposure



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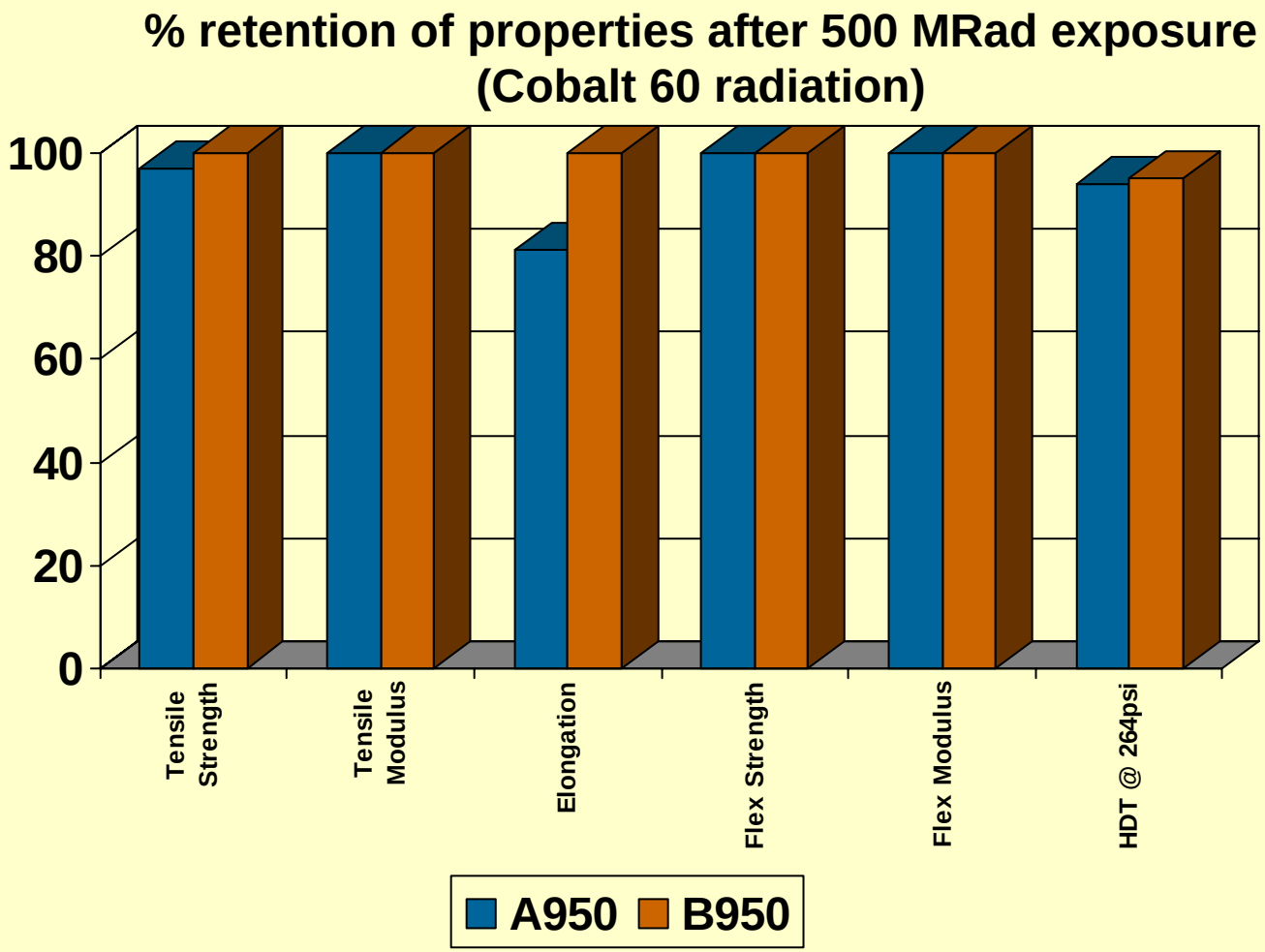
LCPs are Resistant to Radiation

Useful for Medical Applications where γ Radiation is used for sterilization



Consequences of Molecular Structure

- High Flow - Fills Thin, Complicated Parts Easily
- Rapid Set-up - Fast Cycle Time
- Excellent Dimensional Stability
- High Strength and Stiffness
- Chemical and Environmental Stability
- **Excellent Barrier Properties**

Oxygen Permeability

Highly ordered structure of LCPs leads to excellent O_2 barrier properties

Permeability, cm^3-mil/100in^2-day-atm

	Temperature (^oC)	0% relative humidity	100% relative humidity
A950	23	0.08	0.045
A950	38	0.35	0.145
PET	23	5.9	5.9
HDPE	23	150	150
Saran wrap	23	0.8	0.8
PVA copolymer - eval-F	40	0.01	0.15
PVA copolymer - eval-E	40	0.09	0.65

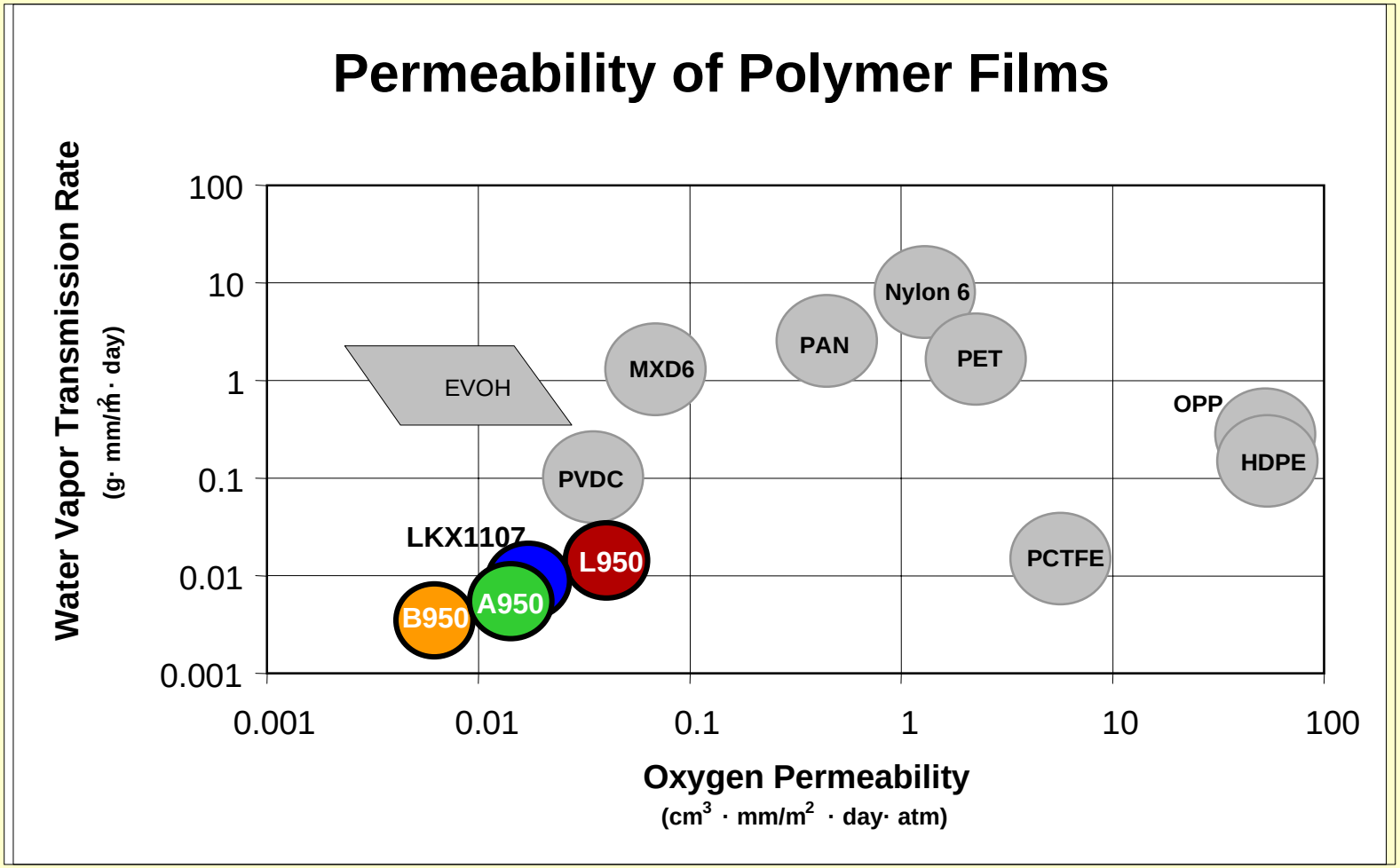
Moisture Vapor Transmission

Highly ordered structure and low polarity combine to make LCPs an excellent moisture barrier

Moisture vapor transmission, gm-mil/100in^2-day

	Temperature (^{o}C)	100% relative humidity
A950	23	0.07
A950	38	0.13
PET	23	0.65
PET	38	2.0-3.0
HDPE	23	0.3-0.4
Saran wrap	23	0.2
PVA copolymer - eval-F	40	3.8
PVA copolymer - eval-E	40	1.4

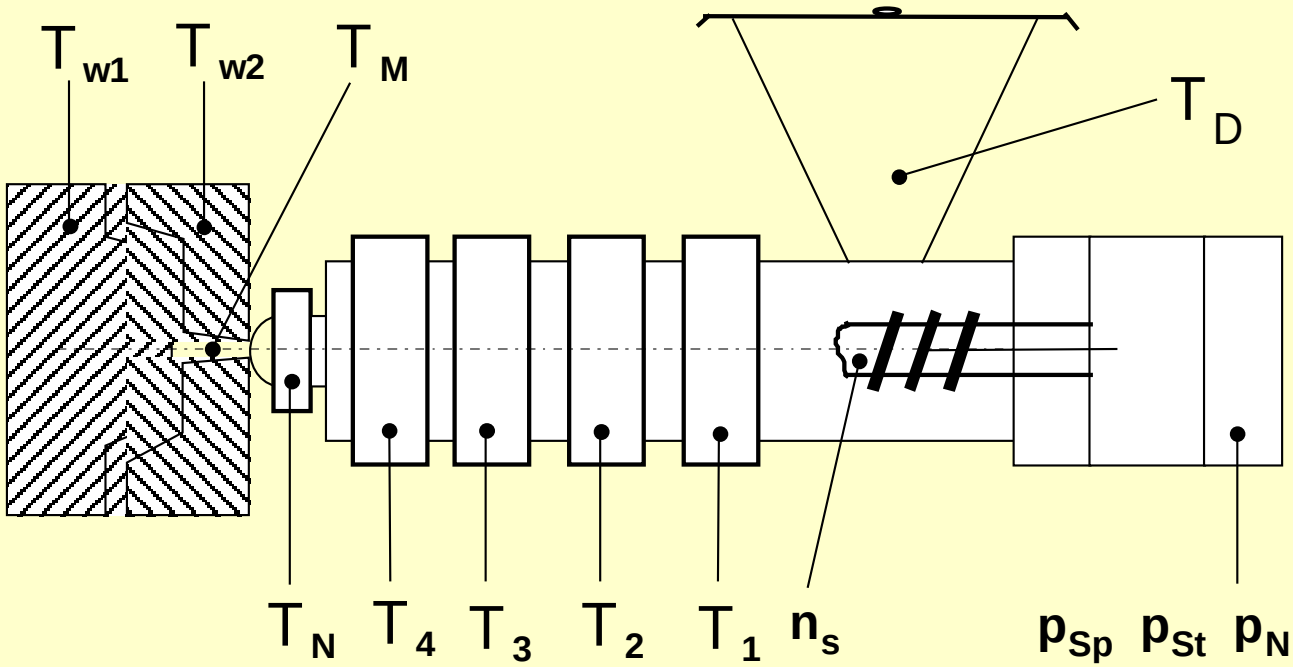
Combined Barrier Properties Make Some LCPs Excellent Candidates for Packaging Applications



Data source: Permeability and Other Film Properties

Plastics Design Library, 1995

LCPs Offer Significant Molding Process Advantages



Processing Temperature Ranges

T_M	**=**	**545 °F - 645 °F**
T_2	=	515 °F - 610 °F
T_3	=	525 °F - 620 °F
T_4	=	530 °F - 625 °F
T_N	=	545 °F - 640 °F
T_{W1} & T_{W2}	=	50 - 200 °F

Molding Process Advantages

- Rapid cycle times
  - 30% to 50% less than PPS, PPA, PCT
  - 50% to 75% less than PES, PEI, PSO
- Thin walled parts easily filled at very low pressures
  - 50% less than PPA
  - 10% to 20% less than PEI, PES, PSO, PCT
- Alternate processing techniques
  - Two-shot or overmolding
- Oil heated molds not necessary

Molding Process Advantages

- No additives
  - No vent plugging or mold deposit
  - UL V0 without FR additives
  - Some variants contain low levels of lubricant
- Mold wear
  - Equal or less than PCT, PPA, PEI, PES, PSO
  - No corrosion from FR additives
- No de-flashing necessary
- Use of up to 50% regrind is possible

Issues

- Cost ($/lb.)
  - Need to look at total manufacturing cost per part
    - Rapid cycle times
    - No de-flashing necessary
    - Use of up to 50% regrind is possible
      - Minimize waste with hot runner tooling
    - Less resin per part
      - Higher strength and stiffness
    - Dimensional stability makes designs easier to implement - Value of speed to market

Issues

- **Weld Line Strength**
  - Avoid multiple gates
  - Optimize part design
  - Adjust process conditions
  - Use seam weld vs. butt weld
- **Cohesive strength can limit strength of bonding with adhesives**
- **Anisotropy - Highly Ordered Molecular Structure**
  - Properties can be different in flow and transverse directions
  - Minimize effect by proper part design and process conditions

LCP performance profile fits...

EE - Interconnects good flow in thin walls dimensional precision heat resistance stiffness, strength	**Business Machines** good flow in thin walls dimensional precision chemical resistance
Healthcare good flow in thin walls chemical resistance sterilization	**Packaging** excellent barrier properties stiffness, strength
Telecom good flow in thin walls dimensional precision stiffness, strength	**Cryogenics** excellent barrier properties good low temp. properties stiffness, strength

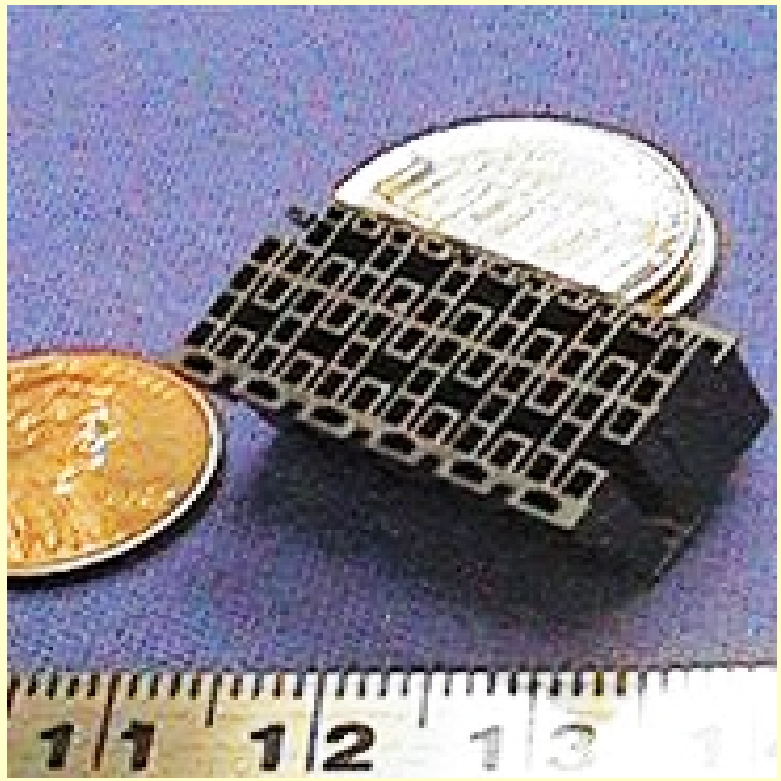
...applications in a broad range of markets

Electronic Connectors are the Best known Use of LCPs...

High Density Connector

Why Vectra LCP

- **Fills 0.010” (0.25mm) wall w/o flash**
- **Warp/bow < 0.001”/”**
- **Withstands IR/vapor phase reflow soldering (215-250ºC) w/o significant bow, warp or shrinkage**

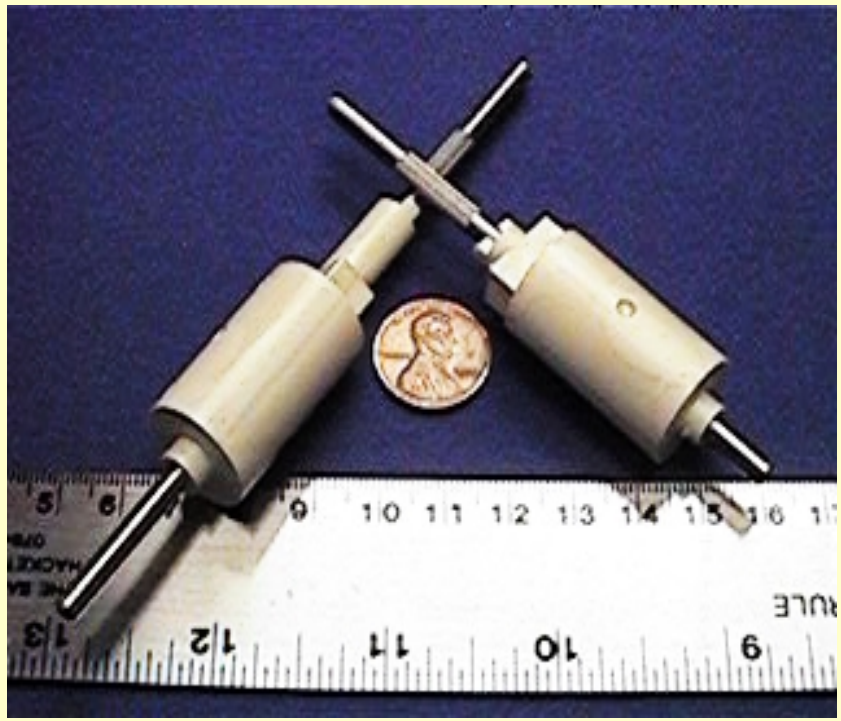


…But Applications in Other Markets...

Cruise control actuator motor

Why Vectra LCP

- Fills very wide wall thickness range
- Minimum 0.010” (0.25mm) wall w/o flash
- Maximum 0.125” (3.5mm) wall



…will continue to grow LCP market

Biaxially oriented extruded tubing for Minimally Invasive Surgical Instrument

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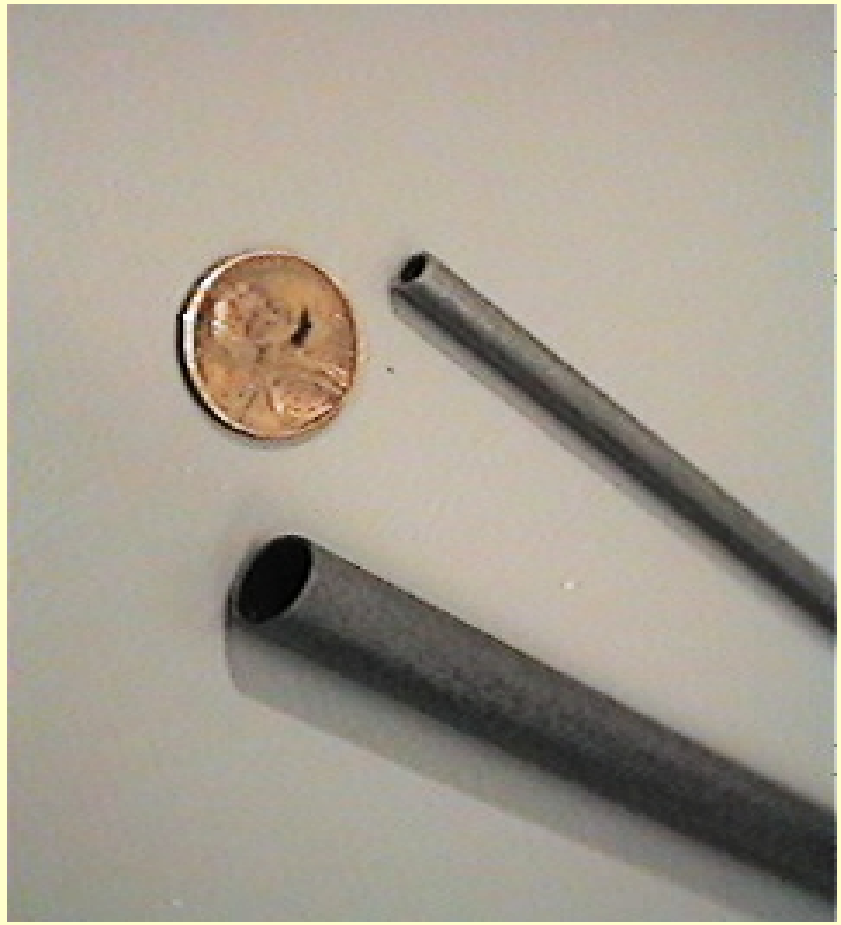
- Why Vectra LCP
  - ➢ Precision dimensions, high modulus, Resists all sterilization methods
  - ➢ Enables new types of MIS instruments
  - ➢ Meets USP Class VI
- ◆ Competition: Stainless steel



LCPs Enable Implementation and Growth of New Technology

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Cell phone battery housing

- Why Vectra LCP
  - Faster cycle
  - Fills 0.020” (0. 5mm) wall w/o flash
  - Molds w/o distortion
  - Stiffness
- Competition: High flow PC, PC/ABS, PPO

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Products Offered by Ticona

Celcon® and **Hostaform**® acetal copolymer (POM)
GUR® ultra-high molecular weight polyethylene (UHMW-PE)
Celanex® thermoplastic polyester
Impet® thermoplastic polyester
Vandar® thermoplastic polyester alloy
Riteflex® thermoplastic polyester elastomer
Vectra® liquid crystal polymer (LCP)
Celstran®, **Compel**® and **Fiberod**® long fiber reinforced thermoplastics
Fortron® polyphenylene sulfide (PPS)
Celanese® nylon 6/6 (PA 6/6)
Topas® cyclic olefin copolymer (COC)
Encore® Recycled Thermoplastic Molding Resins
Duracon™ acetal copolymer (POM) and **Duranex**™ thermoplastic polyester are offered by Polyplastics Co., Ltd.

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