

Polymer Microfabrication: Methods and Application

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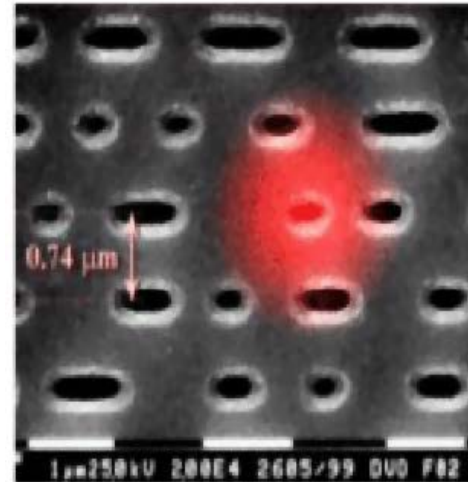
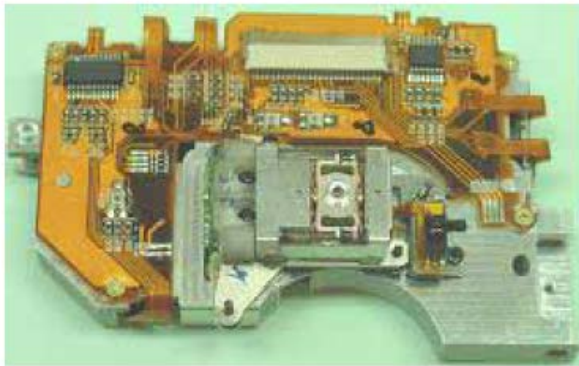


Overview

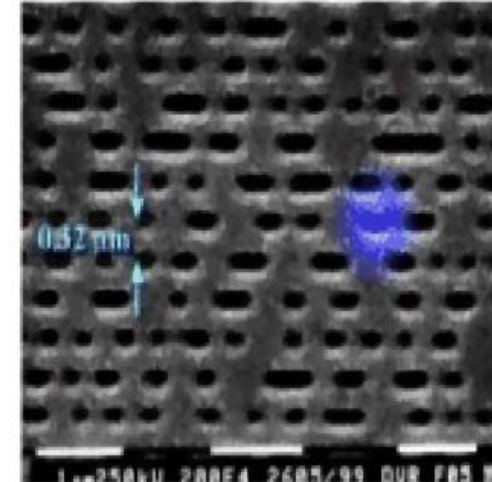
- Definitions and relevant polymer properties
 - Curing of prepolymers
 - Technical classification
 - Thermal properties
- Rapid Prototyping/Additive Manufacturing
 - Stereolithography
 - 3D-Printing
- Master fabrication
- Polymer Microreplication
 - Hot Embossing
 - Injection Moulding

Polymer Microcomponents

- Large size, high precision, high accuracy, larger shot weights (g-range) (DVD, Blu Ray)



DVD: 4.7 GB
 Track pitch: 0.74 μm
 Min. pit length: 0.4 μm

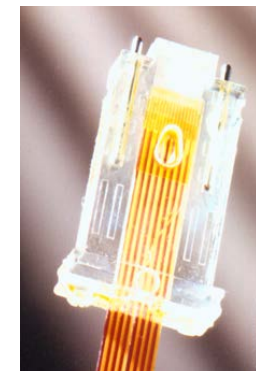
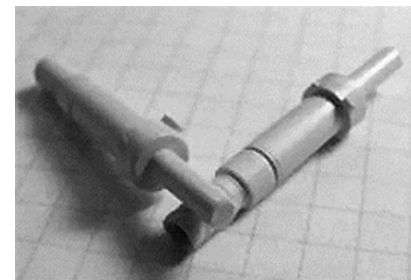


Blu ray Disc: 25 GB
 Track pitch: 0.32 μm
 Min. pit length: 0.15 μm

- Small size, high precision, high accuracy smaller shot weights (mg/g-range)



7 mg

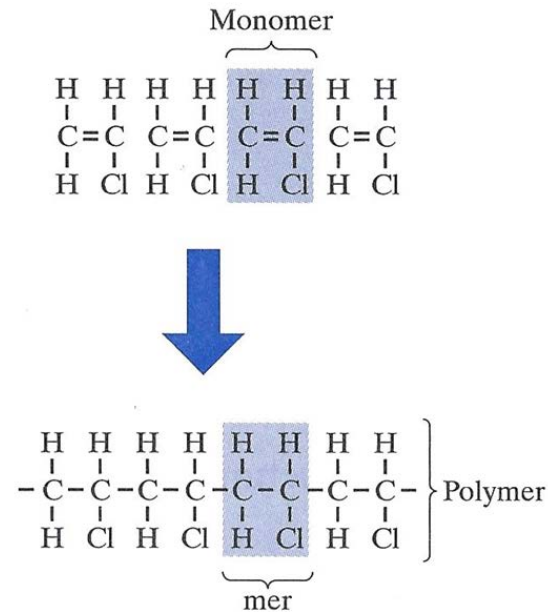


Definitions and relevant polymer properties

Microfabrication

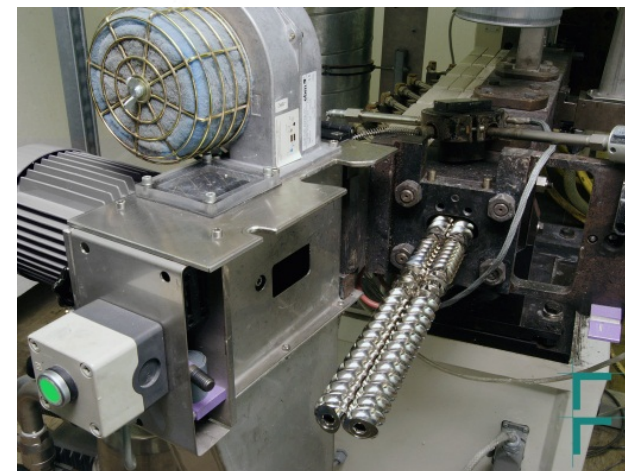
■ Reactive processing

- UV-curing (thermal-curing)
- Stereolithography
- Nanoimprint
- Reaction moulding

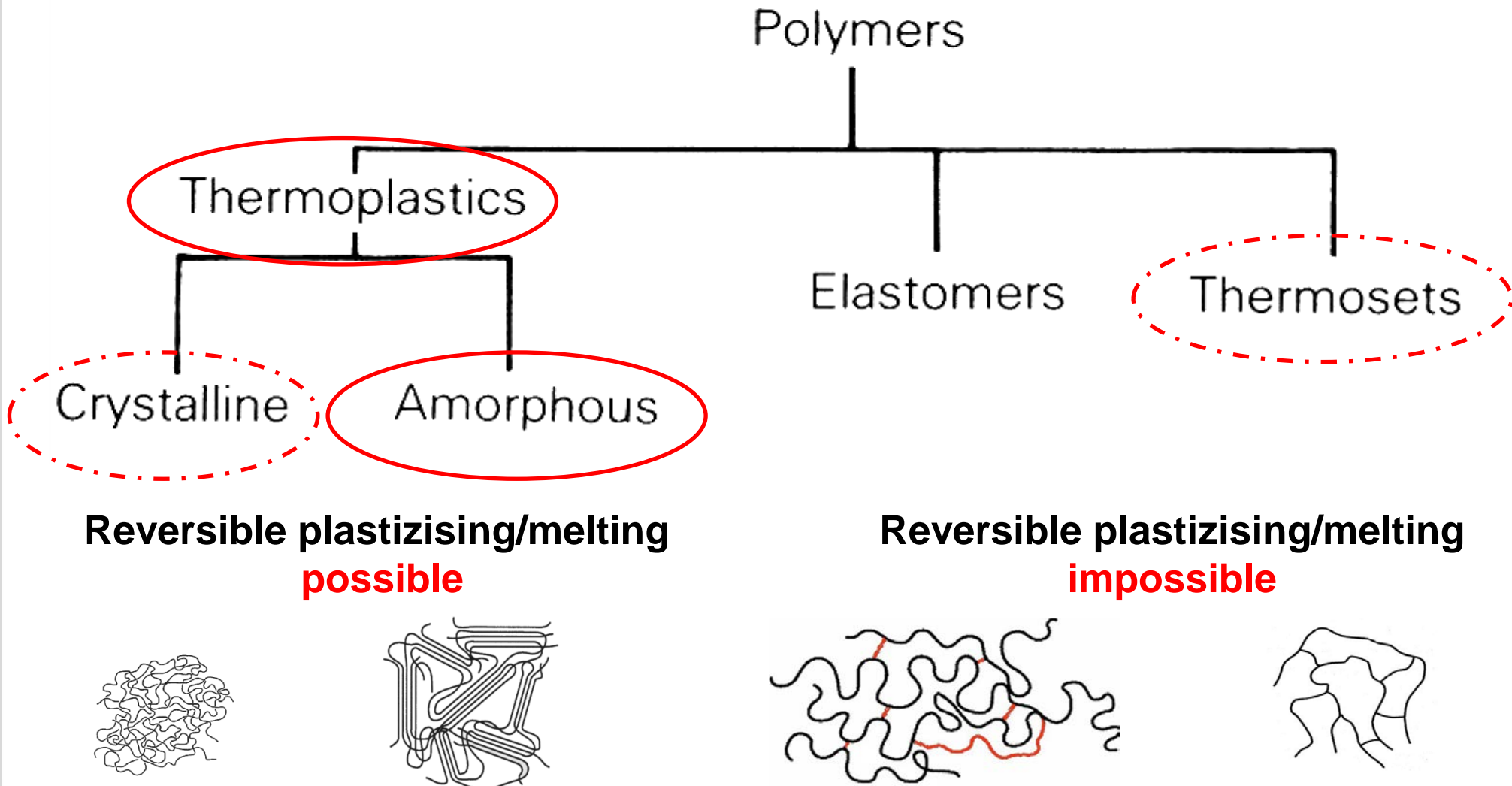


■ Melt processing

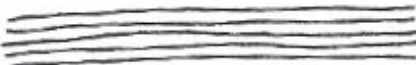
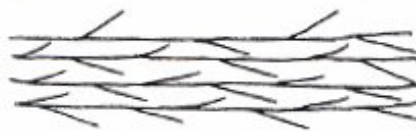
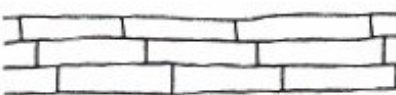

- Hot Embossing
- Extrusion
- Injection Moulding



Technical Classification



Classification

	Molecular arrangement	Properties
thermoplastic	 <p>linear chains</p>	<ul style="list-style-type: none"> - fusible - soluble - at RT: plasticized, tough, hard
	 <p>branched chains</p>	
elastomeric	 <p>weakly crosslinked</p>	<ul style="list-style-type: none"> - infusible - insoluble - at RT: flexible and soft
thermoset	 <p>highly crosslinked</p>	<ul style="list-style-type: none"> - infusible - insoluble - at RT: tough

Phase transitions

Amorphous thermoplastics

Semicrystalline thermoplastics

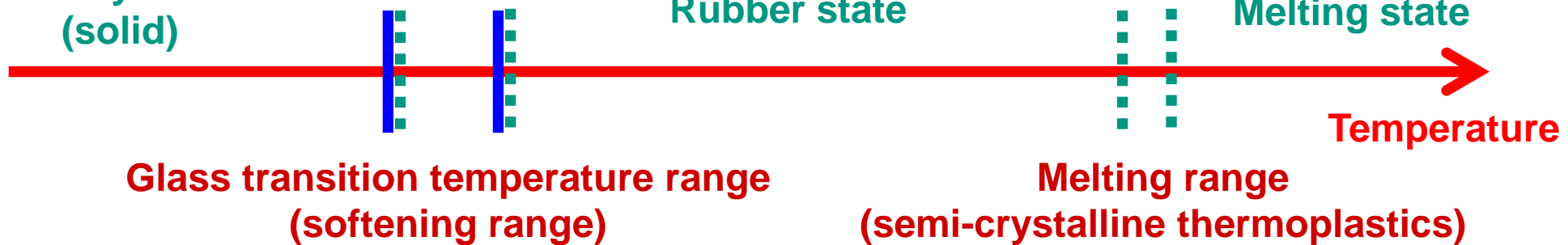
**Glassy state
(solid)**

**Glassy state
(solid)**

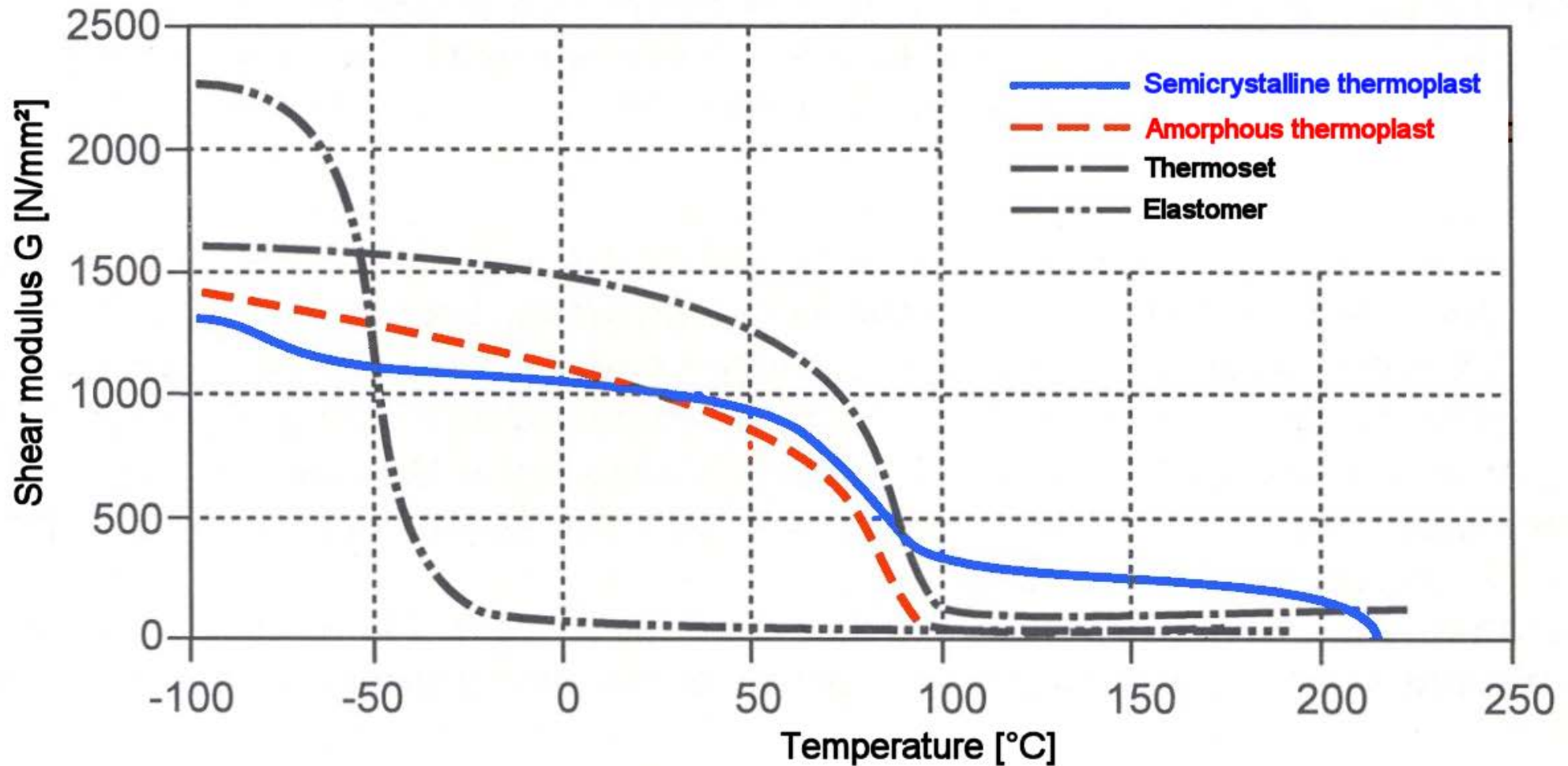
Rubber/melting state

Rubber state

Melting state



Phase transitions and mechanical properties



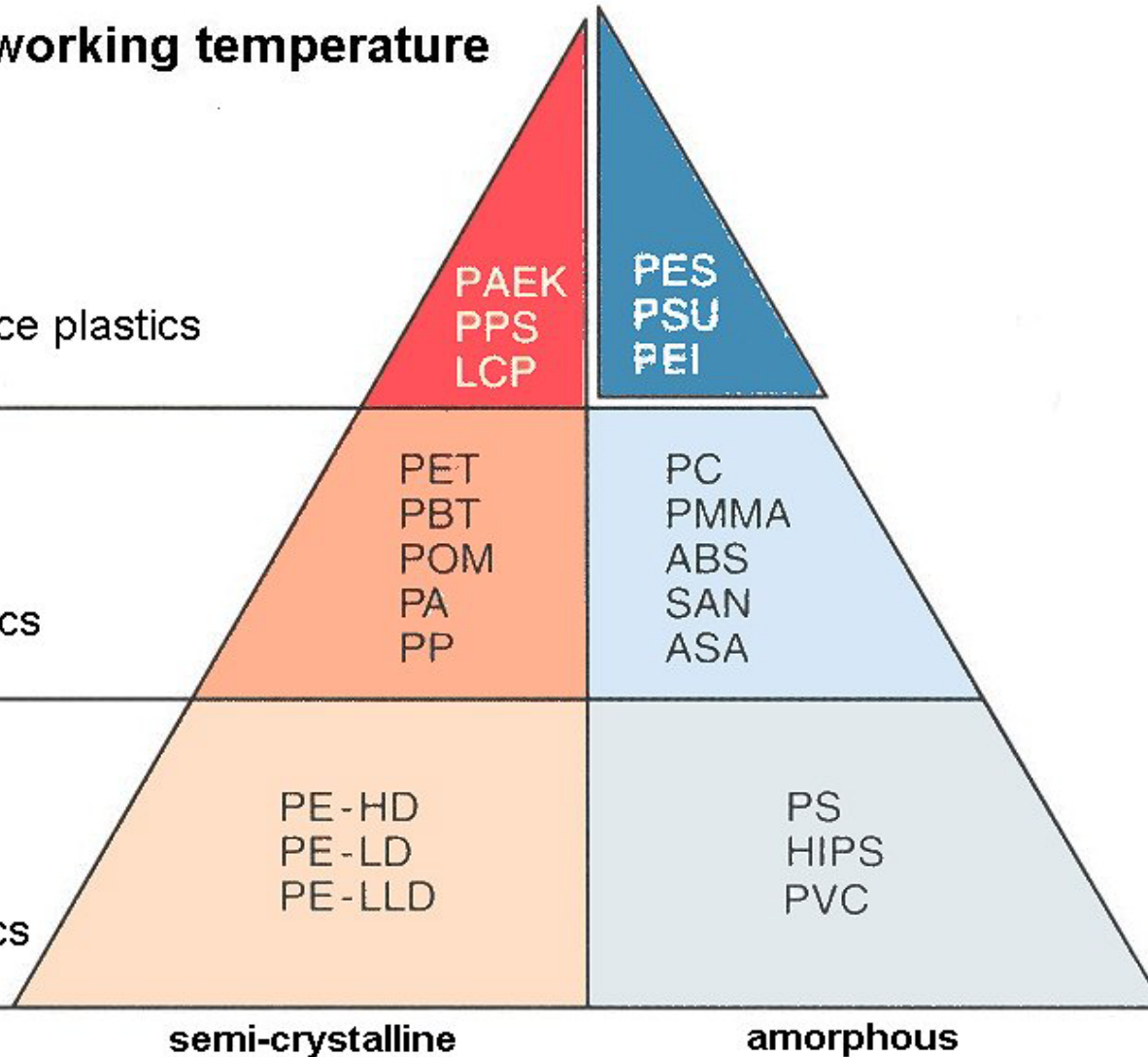
Thermal limit

Continuous working temperature

High performance plastics
140 °C <

Technical plastics
< 140 °C

Standard plastics
< 90 °C



Thermal expansion

■ Linear coefficient of thermal expansion (mm/(mm K))

$$\alpha = \frac{\Delta L}{L \Delta T}$$

■ $\alpha_{\text{polymer}} > \alpha_{\text{metal}} > \alpha_{\text{ceramic}}$

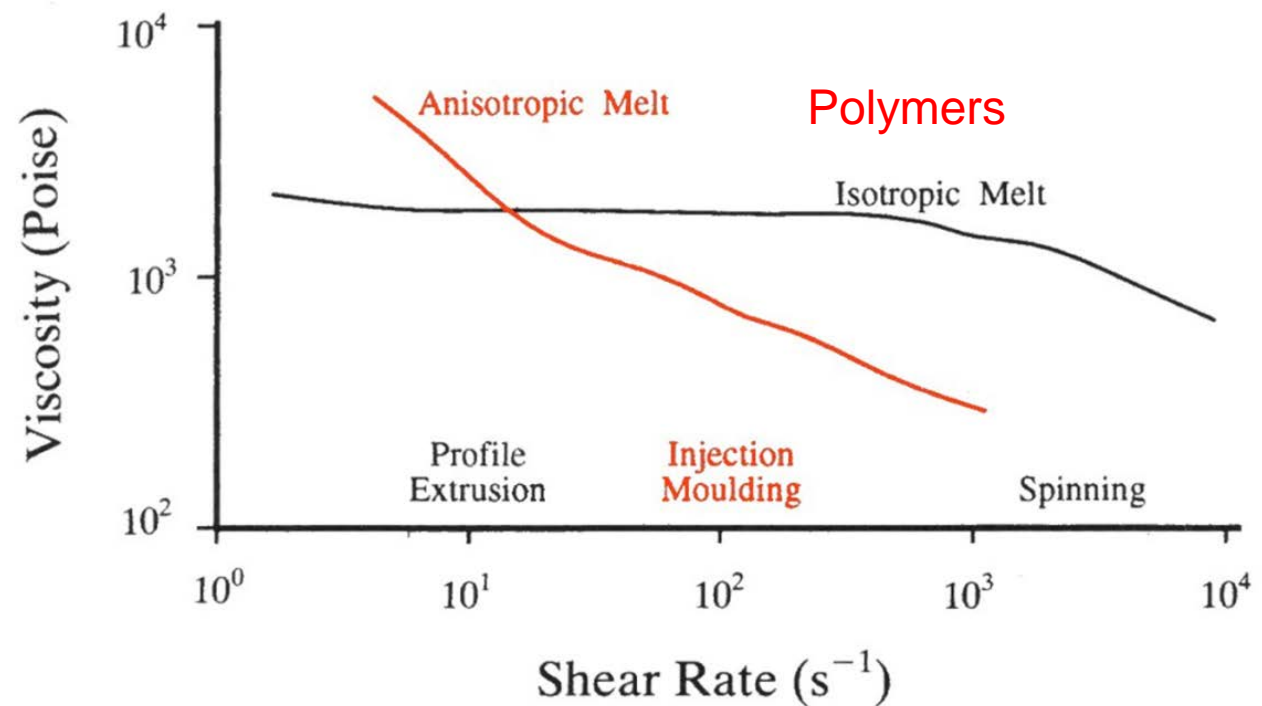
Values of Linear Coefficient of Thermal Expansion for a Variety of Materials

Material	α [mm/(mm·°C) × 10 ⁶]		
	Temperature = 27°C (300 K)	527°C (800 K)	0–1,000°C
Metals^a			
Aluminum	23.2	33.8	
Copper	16.8	20.0	
Gold	14.1	16.5	
Ceramics and glasses^{a,b}			
Mullite (3Al ₂ O ₃ ·2SiO ₂)			5.3
Porcelain			6.0
Fireclay refractory			5.5
Al ₂ O ₃			8.8
ZrO ₂ (stabilized)			10.0
SiC			4.7
Polymers^a			
Nylon 66	30–31		
Phenolic	30–45		
Polyethylene (high-density)	149–301		
Polypropylene	68–104		
Polytetrafluoroethylene (PTFE)	99		

Flow behaviour - Rheology

Polymer microfabrication: Injection Molding and Hot Embossing (Melt processing):

- Shear viscosity
 - important during injection
- Stretching viscosity
 - important during demolding



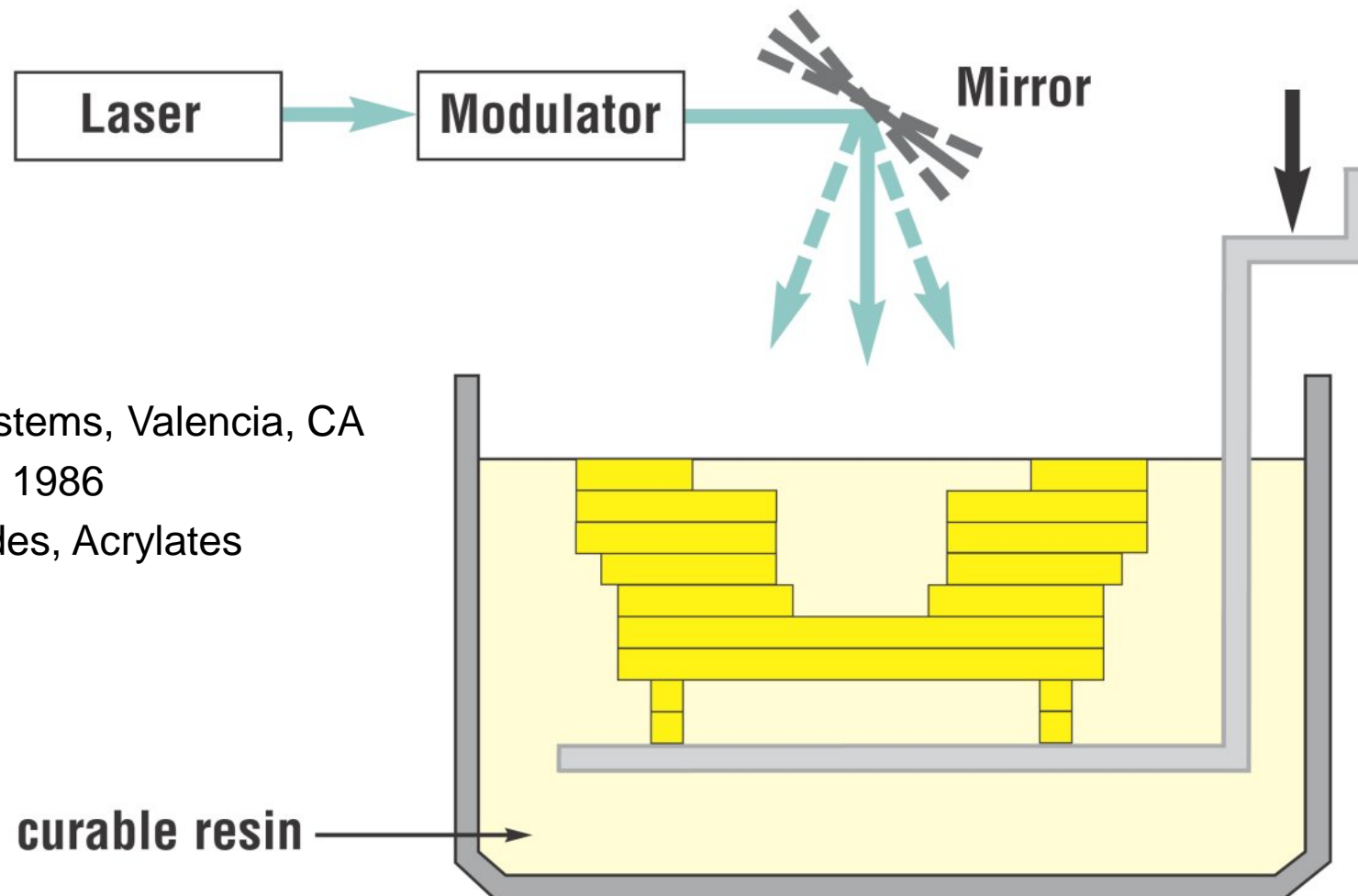
Rapid Prototyping Additive Manufacturing

Rapid Prototyping

- Rapid Prototyping:** Transformation of a conceptual design into a solid prototype
- Rapid Tooling:** Direct fabrication of molding or casting tools for small scale production
- Rapid Manufacturing:** Direct small scale fabrication without moulding
- **Optical Methods:**
 - Stereolithography (SLA)
 - **3D-Printing:**
 - Multi-Jet Modeling (MJM)
 - Fused Deposition Modeling (FDM)
 - Selective Laser Sintering (SLS)

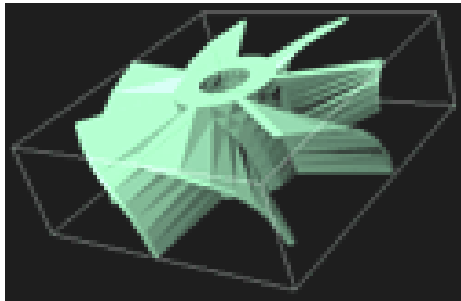


Stereolithography (SLA)

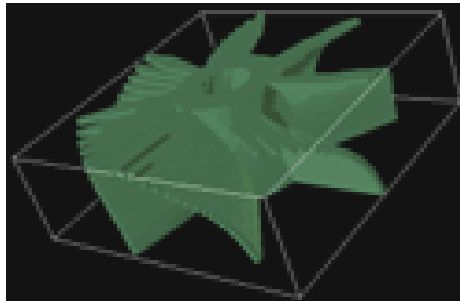


- 3D Systems, Valencia, CA
- Patent 1986
- Epoxides, Acrylates

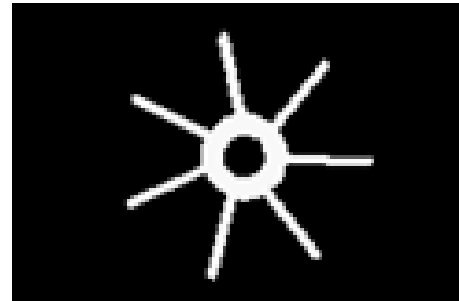
Mini-Stereolithography



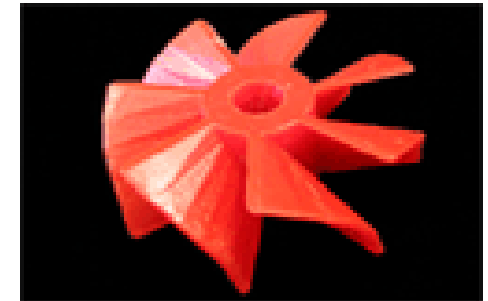
3D-data model



sliced model



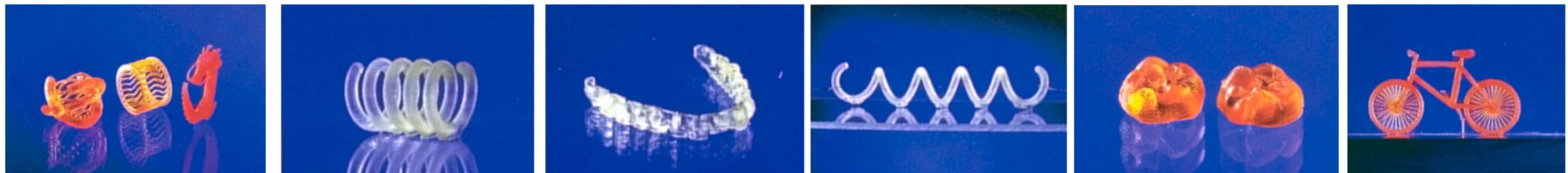
layer for mask
projection



physical model



Mask projection via DLP™-Technology from Texas Instruments.



Mini-Stereolithography

Machine Properties *	Perfactory® Micro 3D Printer
Build Envelope	1.58" x 1.18" x 3.94" (40 x 30 x 100 mm)
Resolution in X and Y	0.0012" (31 μm)
Dynamic Voxel Resolution in Z (material dependent)**	0.0010" to 0.0014" (25 μm to 35 μm)
Light Source	LED
Data Handling	STL



Hearing aids

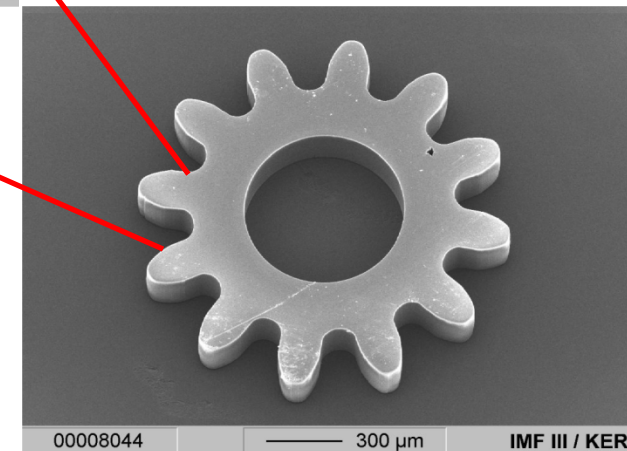
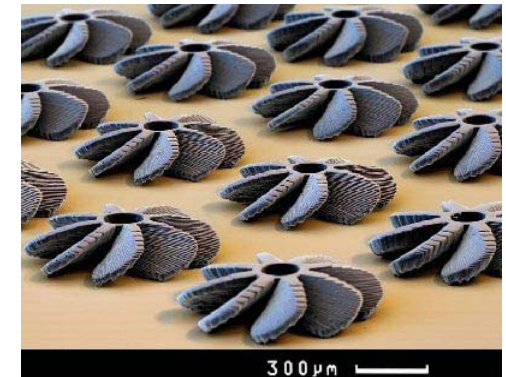
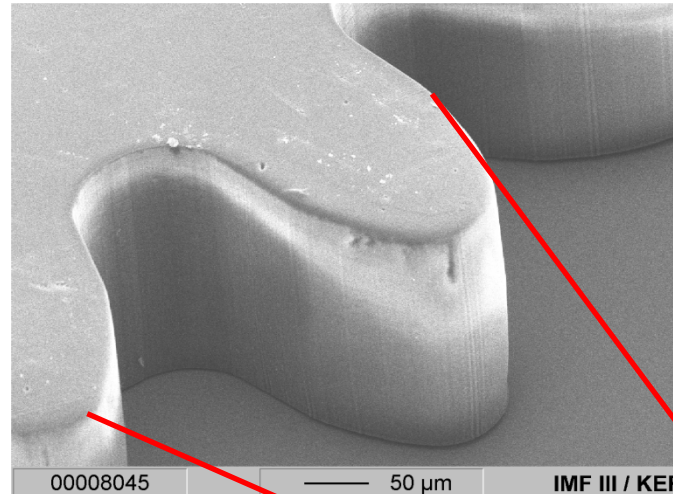


Rapid Micromanufacturing

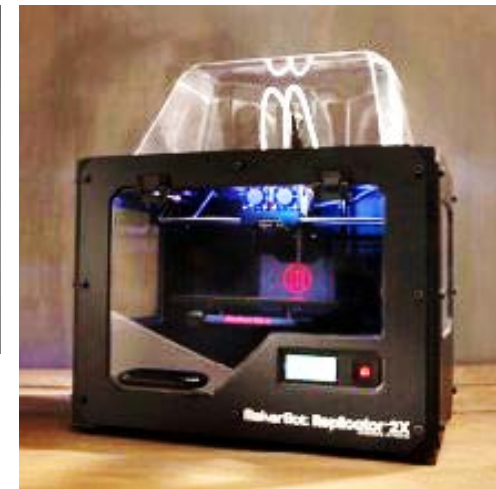
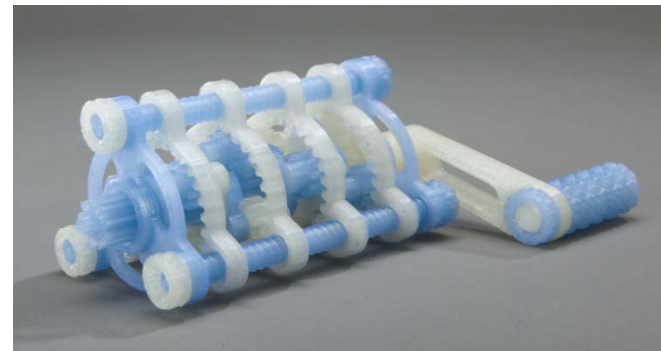
microTEC

Rapid Micro Product
Development

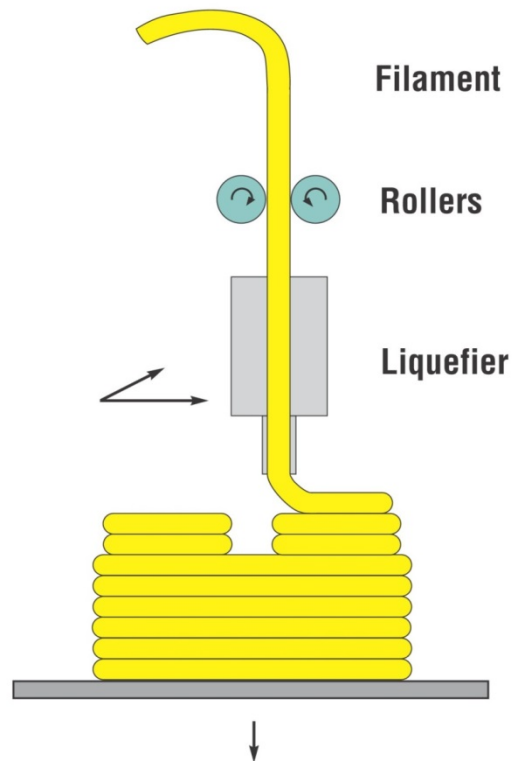
- layer thickness > 1 μm
- resolution in any direction > 10 μm
- accuracy > 1 μm layers
- materials: acrylics, epoxies
- smallest component size: 1 x 10 x 10 μm^3
- maximum component size: 50 x 50 x 50 mm³



Fused Deposition Modeling (FDM)



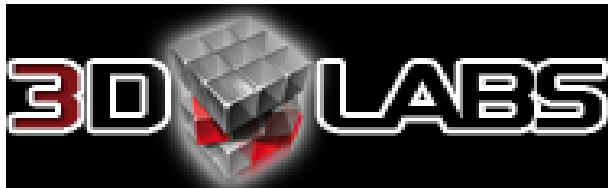
<https://store.makerbot.com>



Print Technology:
Build Volume:
Best layer resolution:
Positioning Precision:
Filament Diameter:
Nozzle Diameter:

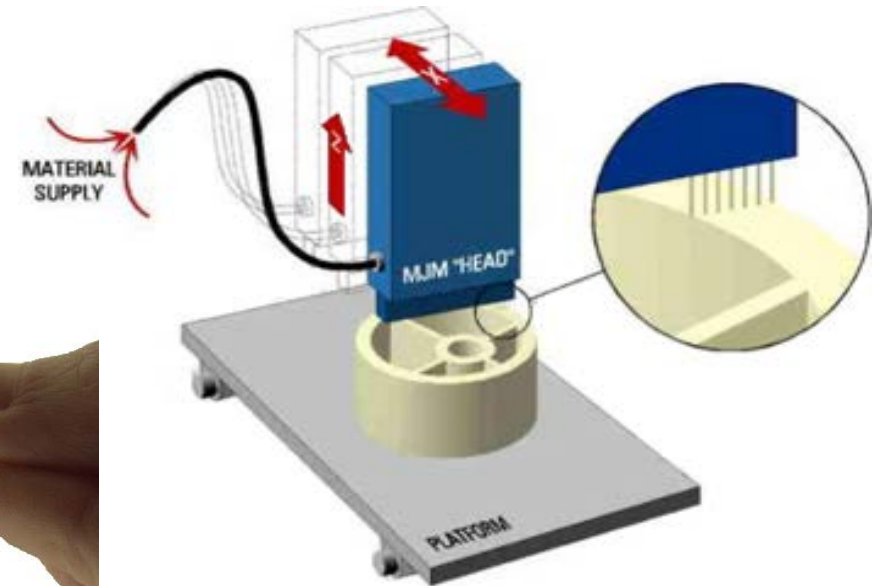
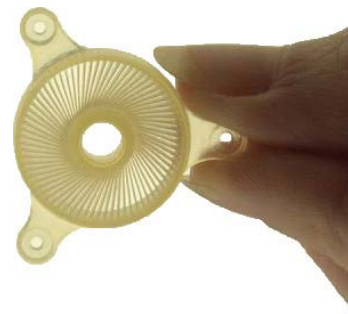
Fused Filament Fabrication
28.5 x 15.3 x 15.5 cm³
100 μm
XY: 11 μm; Z: 2.5 μm
1.75 mm
0.4 mm

Multi-Jet-Modeling



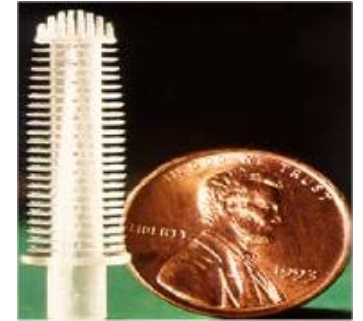
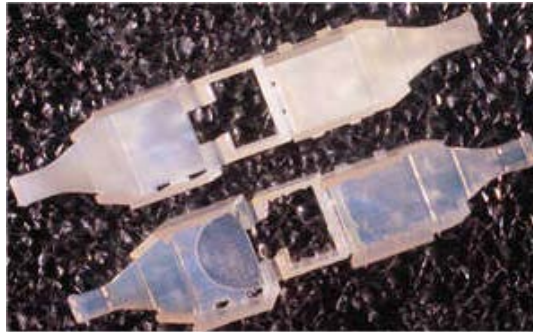
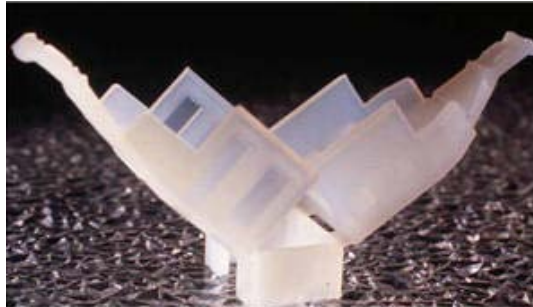
Phase-Change-Processing:

- Printing
- UV-Curing



Mode	Build Volume (XYZ)	Resolution (XYZ)	Materials
High Quality	298 x 185 x 203mm / 11.75 x 7.3 x 8"	328 x 328 x 606 DPI	Acrylate
Ultra-High Quality	127 x 178 x 152mm / 5 x 7 x 6"	656 x 656 x 800 DPI	Acrylate

Applications



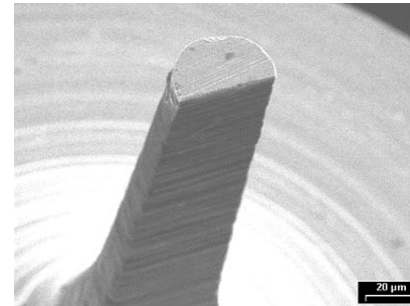
Source: DSM Somos



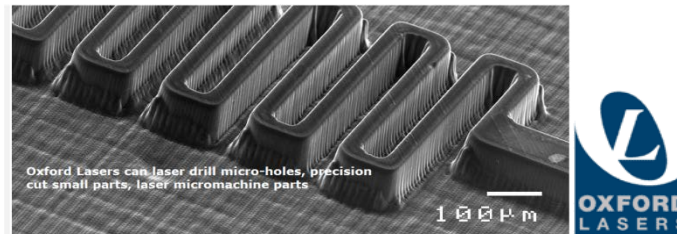
Master (mould) fabrication

Master (mould) fabrication

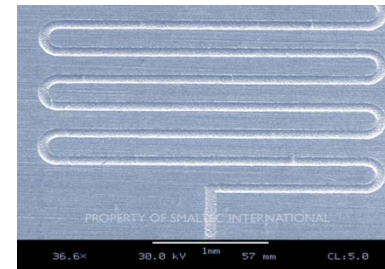
■ Micromechanical machining



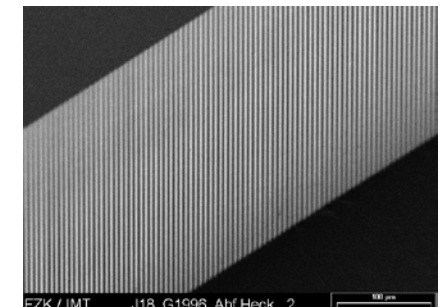
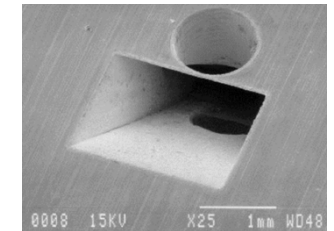
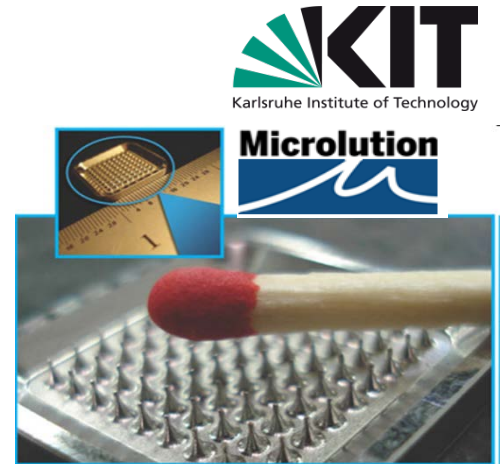
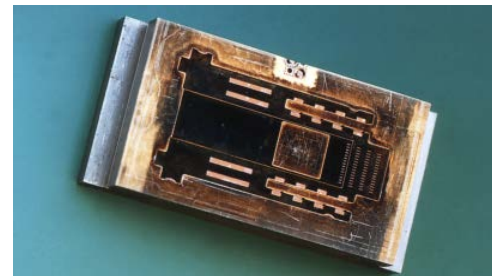
■ Laser Micromachining



■ Electrodischarge Machining (EDM)

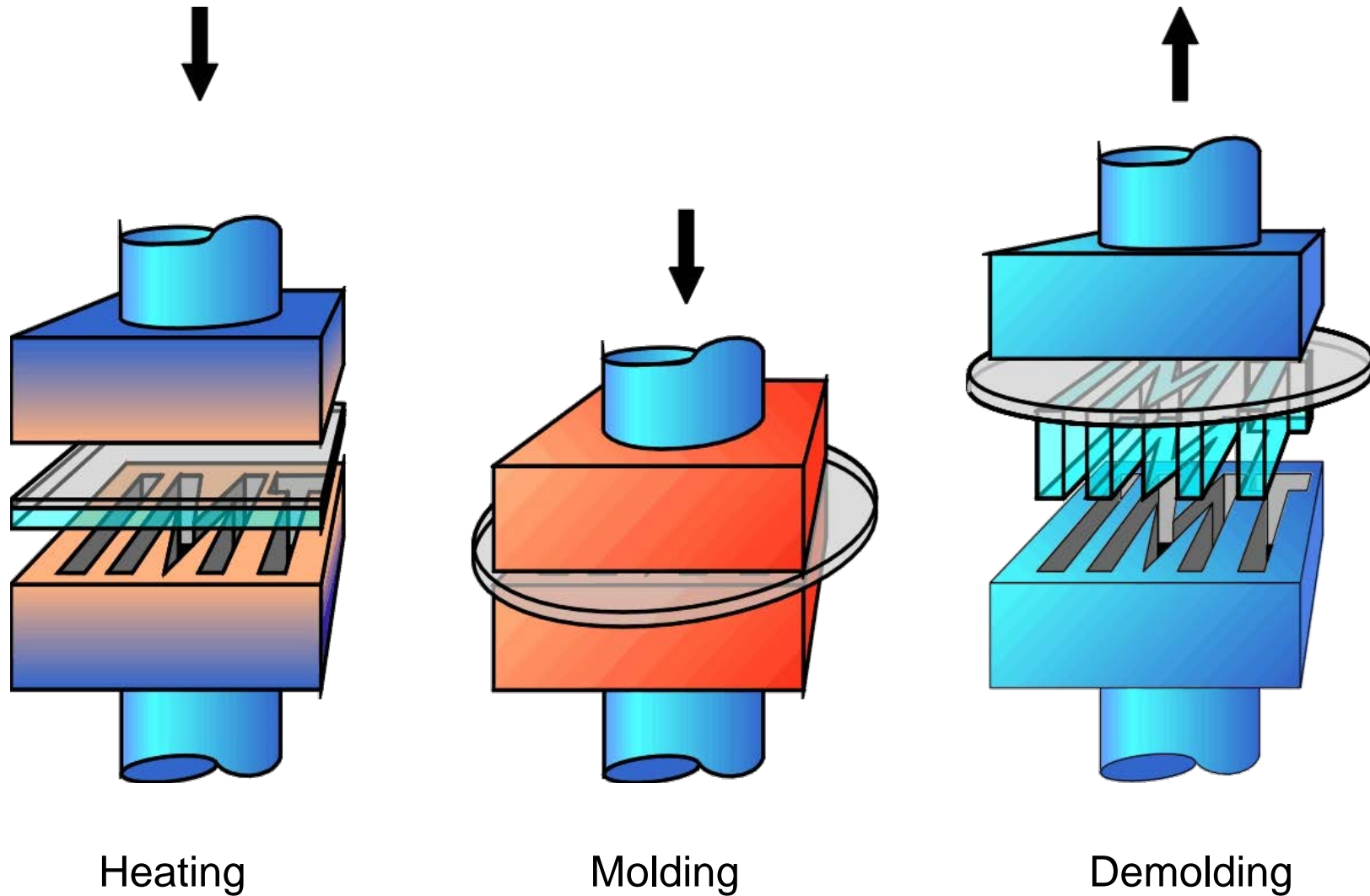


■ Lithography - Electroplating



Polymer Microreplication

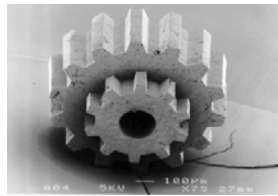
Hot Embossing Process



Polymers for Hot Embossing

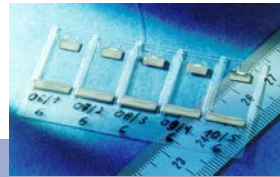
POM

$T_{\text{mold}} \sim 130^{\circ}\text{C}$



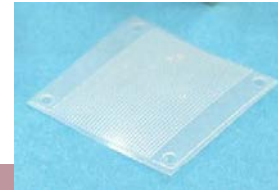
PMMA

$T_{\text{mold}} \sim 170^{\circ}\text{C}$



PVDF

$T_{\text{mold}} \sim 175^{\circ}\text{C}$



PSU

$T_{\text{mold}} \sim 230^{\circ}\text{C}$



PEEK

$T_{\text{mold}} \sim 350^{\circ}\text{C}$



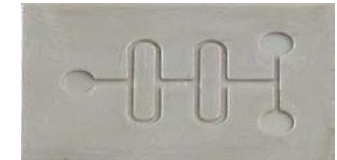
PP

$T_{\text{mold}} \sim 150^{\circ}\text{C}$



PC

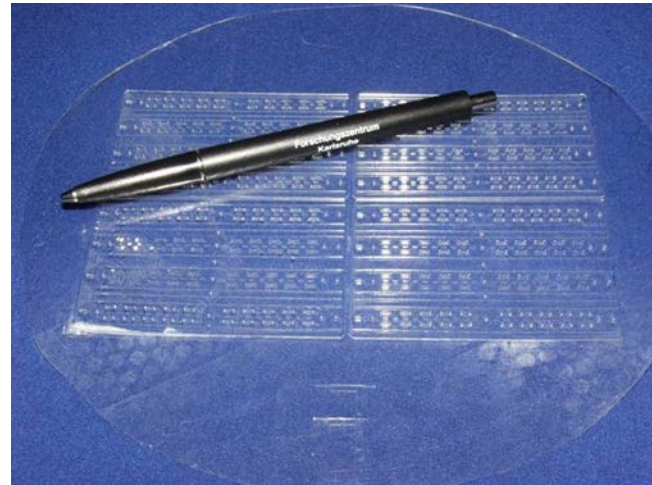
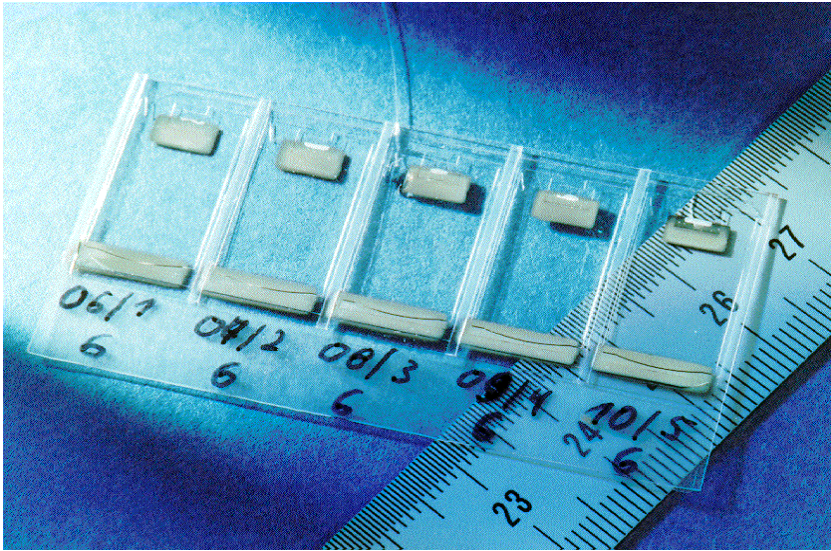
$T_{\text{mold}} \sim 180^{\circ}\text{C}$



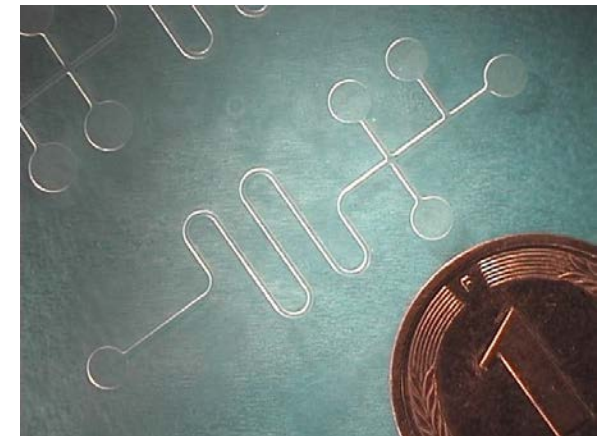
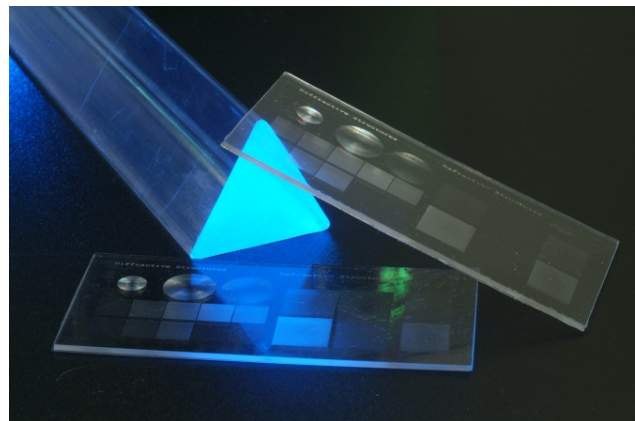
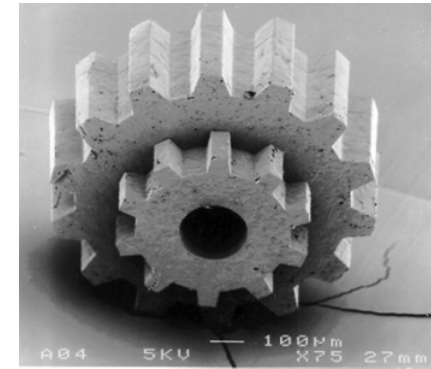
LCP

$T_{\text{mold}} \sim 310^{\circ}\text{C}$

Gallery



200 mm



Commercial Equipment



Obducat



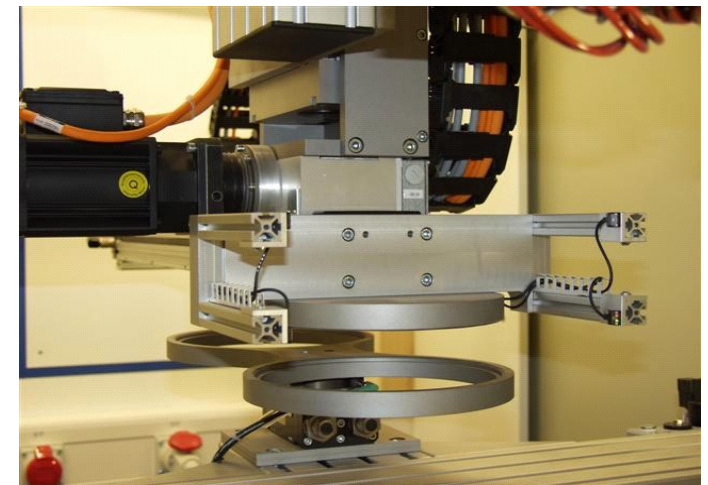
Suss NPS 200



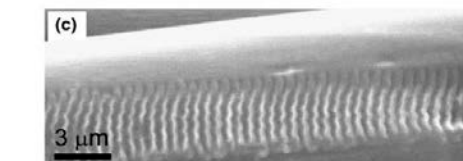
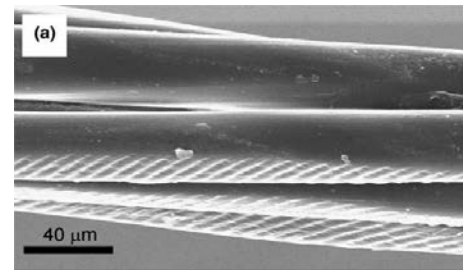
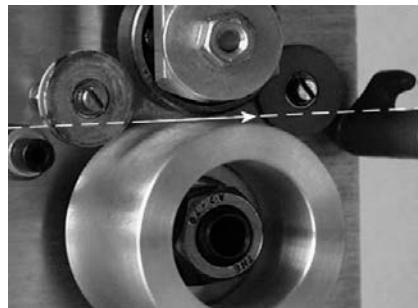
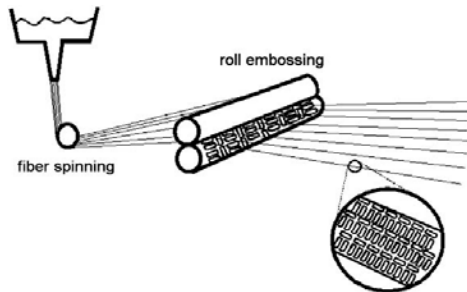
Wickert WMP 1000



EV 520HE, EVG



Roll-to-Roll Technologies



+ very fast

+ continuous

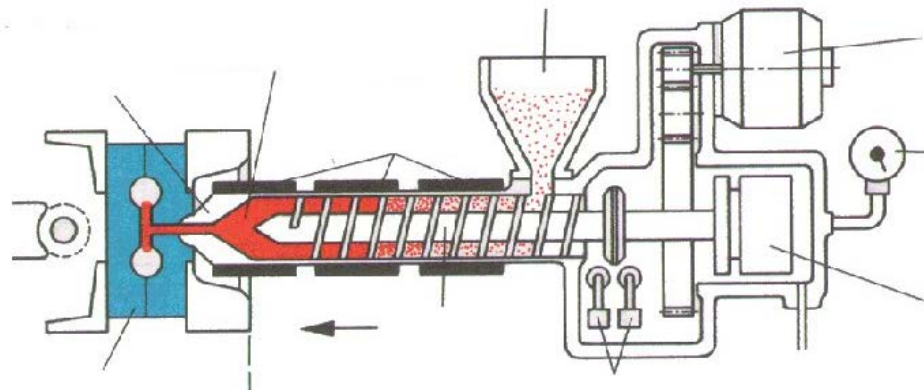
+ in-line process

- complex machinery

- restricted to low aspect ratios

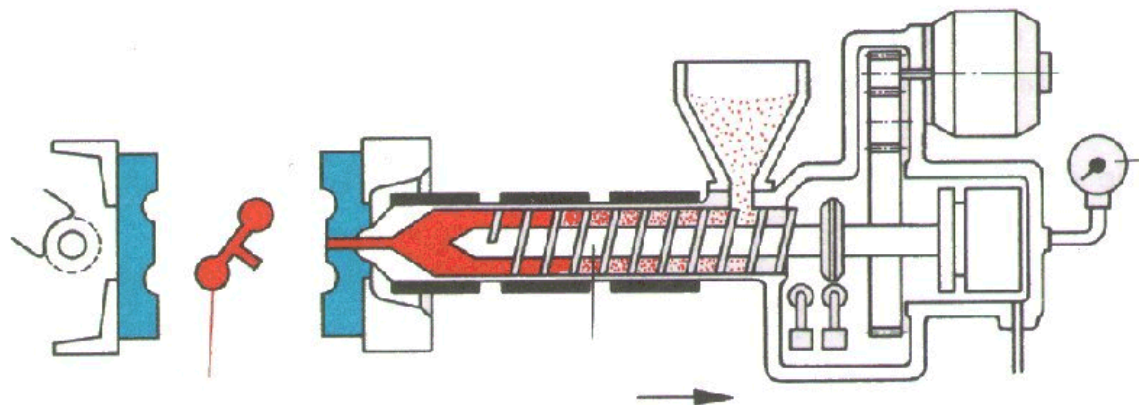
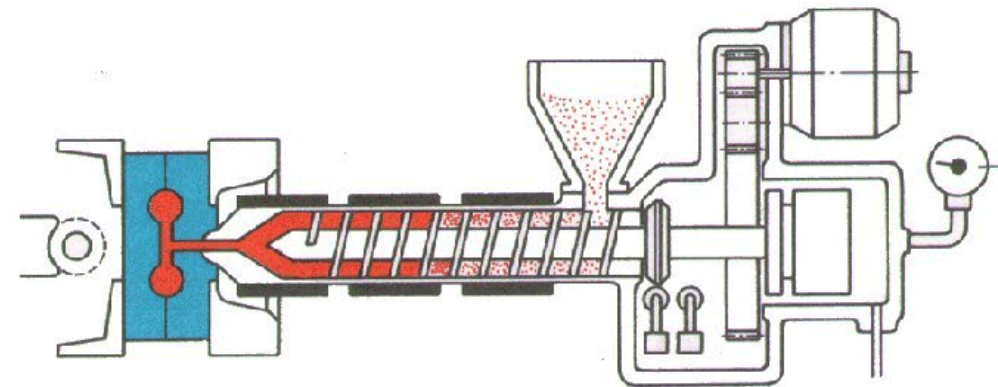
- small parameter window

Injection molding - macro



1. Injection

2. Holding

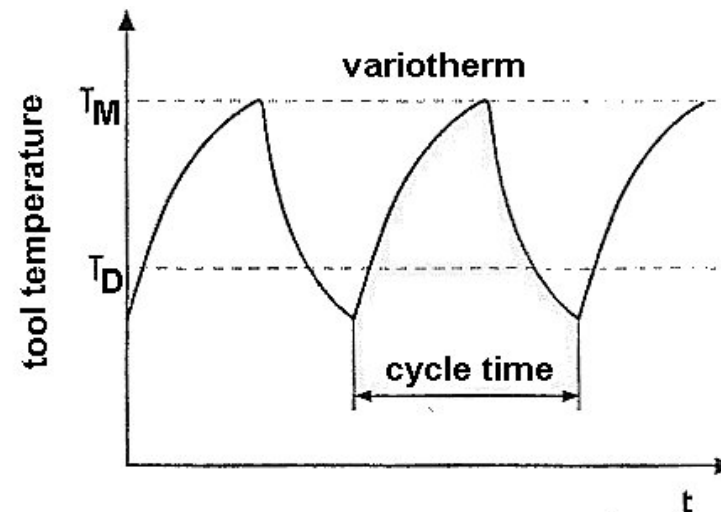
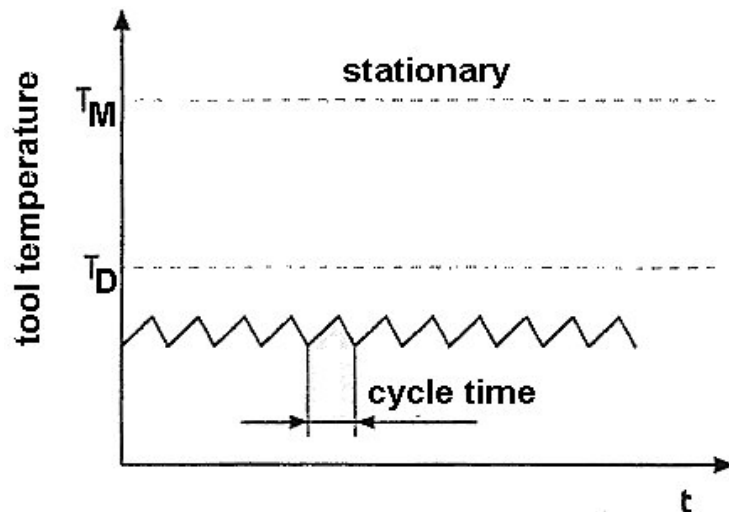


3. Demolding, Plastication

Micro-Injection Molding

Aspects of the miniaturisation of the injection molding process:

- smallest shot weights down to 1 mg
- large flow length to width ratio
- size of the microstructures in the same range like vents & venting channels
- cold molding tools result in solidifying of the polymer resin prior to a complete mold filling

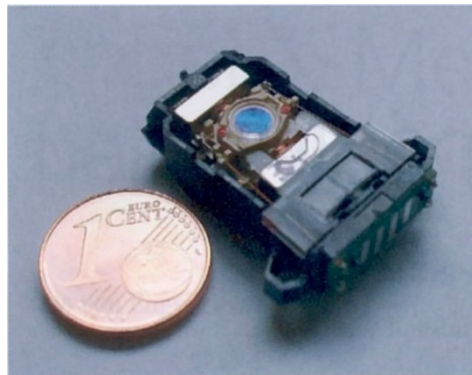


T_M : Molding temperature
 T_D : Demolding temperature

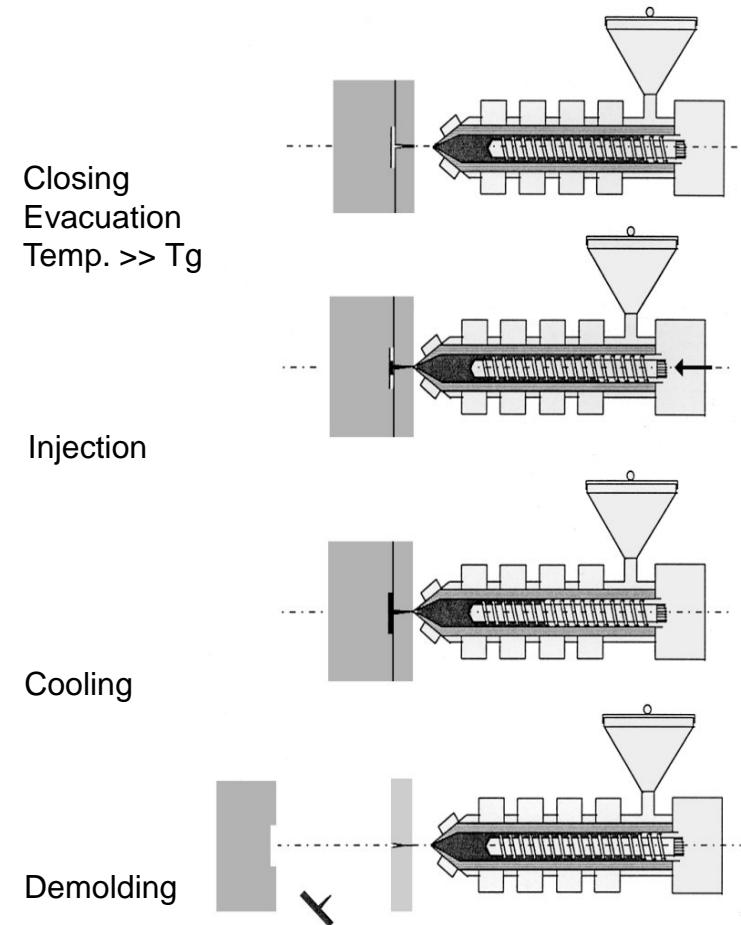
Micro-Injection Molding

Machinery Concepts - the Improved Conventional Approach

- conventional injection molding machinery with full electric drive
- suitable for clean room production
- enhanced shot weight control
- enhanced position control ± 0.01 mm



DVD optical pick up system: lens holder

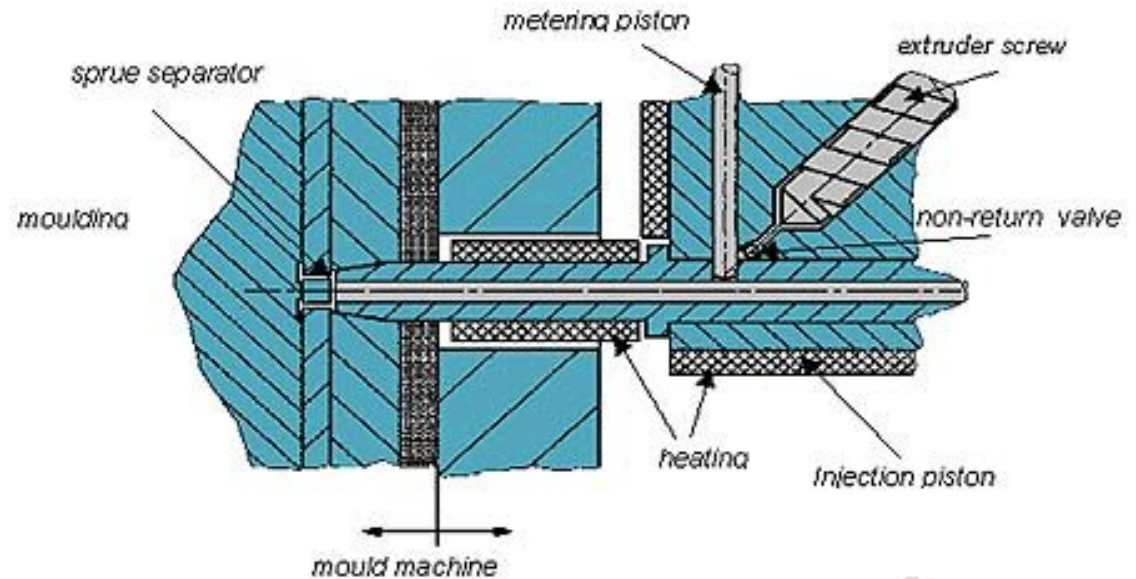


Micro Molding Cycle

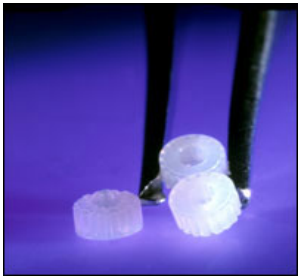
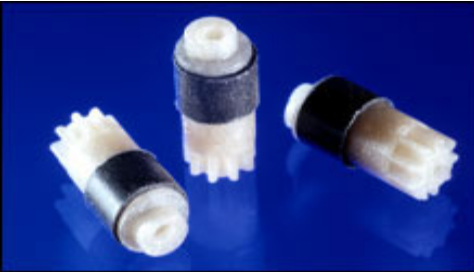
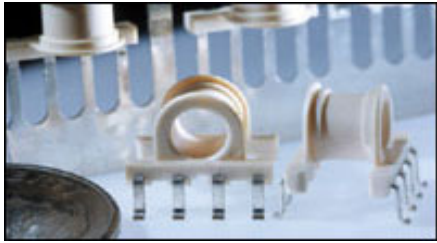
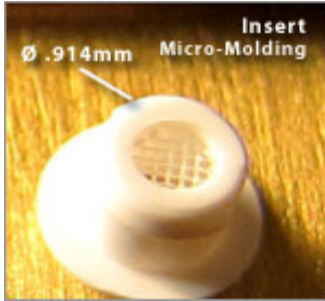
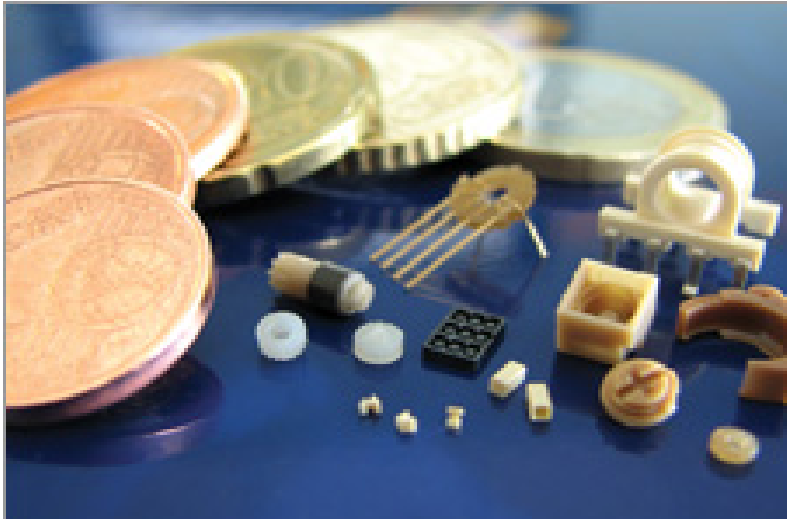
Micro-Injection Molding

Machinery Concepts - the real “Micro“ Approach

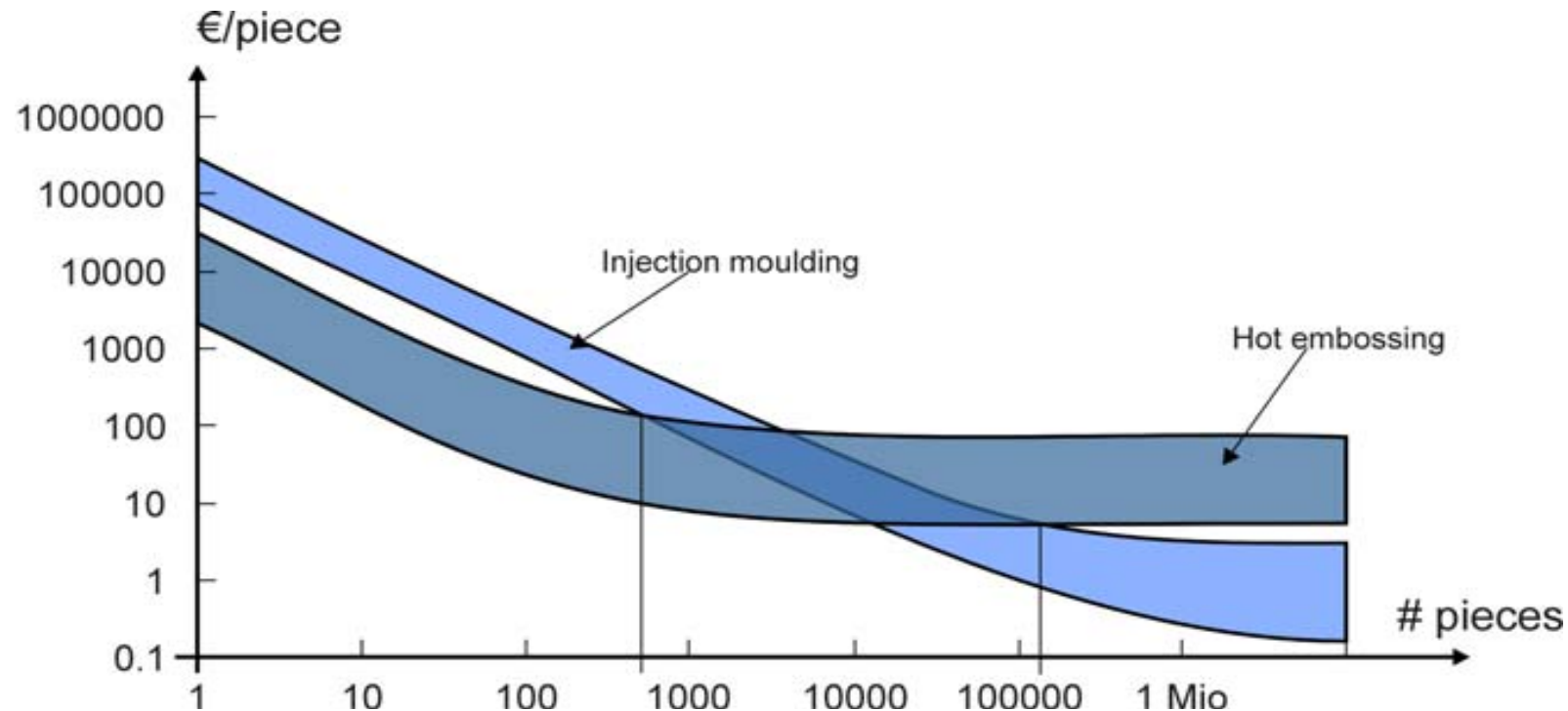
Concept: - integrated construction of a small injection unit with an all electric machinery and peripheral equipment



Gallery



Comparison



- High fix costs for injection moulding requires large numbers to get reasonable prices
- Low automation, long cycle times are responsible for lower limit in hot embossing

Resumé

- Polymers offer a huge variety of different properties
- Established construction rules
- Established master structure fabrication methods
- Rapid Prototyping possible
- Mass fabrication methods established