

## Introduction

### Micro Injection Moulding (µIM)

- machinery, process conduct, examples

### Micro Powder Injection Moulding (MicroPIM)

- motivation, process conduct, examples

### 2-Component Micro Injection Moulding (2C-µIM)

- motivation, machinery and tooling, examples

### 2-Component Micro Powder Injection Moulding (2C-MicroPIM)

- motivation, material combinations, fixed/movable connections

## Outlook

## Contents



# Micro Injection Moulding

and

# Multi Component Micro Injection Moulding

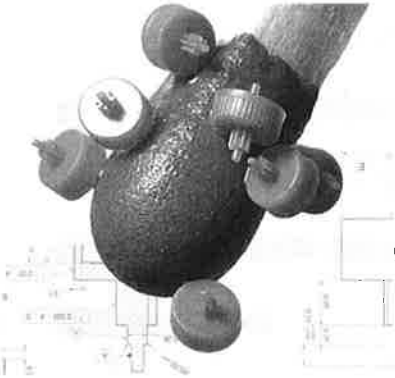
V. Plotter, E. Honza, A. Klein, T. Mueller, K. Plewa

Karlsruhe Institute of Technology (KIT)

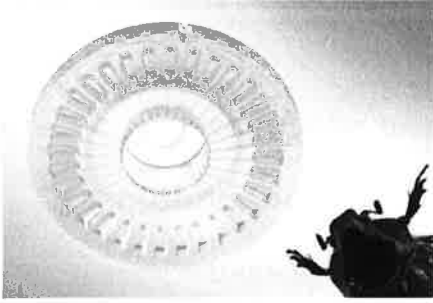
Institute for Applied Materials (IAM – WPT)



Process	Material	µ-Replication (primary shaping)	µ-Forming (re-shaping)	Subtractive µ-Processes	Additive µ-Processes (+ joining)
Polymer		Injection Moulding reaction moulding PVD, CVD rolling/calendaring extrusion, melt spinning	embossing Nanoimprint bending, drawing rolling	lithography: (UV, e-, DXL, laser) etching, plasma etching, RIE, micromachining	laser joining ultrasonic welding stereo lithography
Metal		electroplating MIM casting powder pressing	embossing bending EDM, ECM, laser, water jet, micromachining, grinding, punching/stamping (plasma) etching, RIE	laser, micromachining of green bodies lithography: (UV, DXL, laser)	laser joining laser sintering soldering welding (e-, diffusion) stereo lithography
Ceramic		CIM, casting sol-gel-processes electrophoresis extrusion	embossing of green bodies	laser, micromachining of green bodies lithography: (UV, DXL, laser)	laser sintering laser sintering stereo lithography
Silicon		epitaxial growth [CVD]		wet etching plasma etching, RIE	anodic bonding diffusion bonding

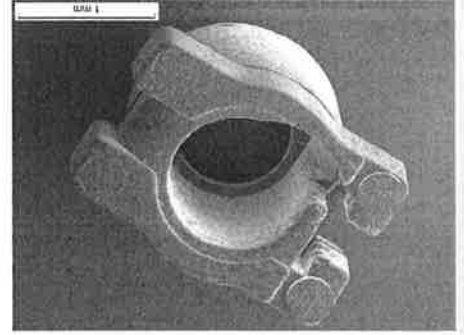


Micro gear wheels, POM  
Rolla Micro-Synthetics AG



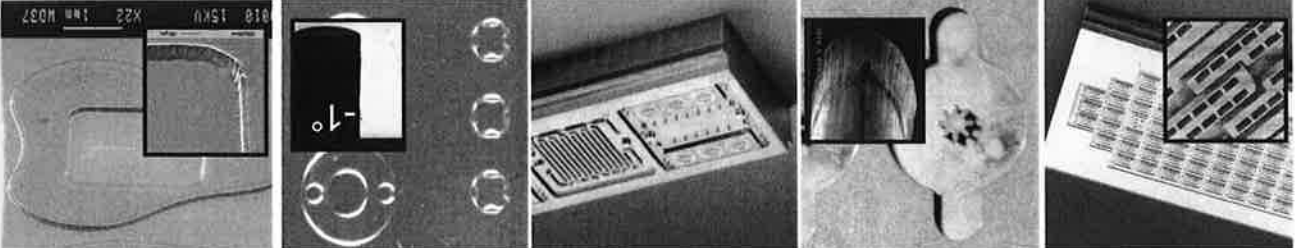
Bio-Disc, PC, PMMA  
Reiner GmbH

Switch housing, LCP  
mass: 0,0022 g  
H. Scholz GmbH



Nickel, (Ni-all.) + AR = 20-30 + $R_{max} = 0.04\mu\text{m}$ - time for delivery	Nickel, (Ni-all.) + ejection slopes AR = mind. 5 - roughness	Brass, Steel + ejection slopes AR = 5-10 $R_{max} = 0.2 - 0.5\mu\text{m}$ - critical	Silicon AR = 5 - cut-backs	Steel, HM, Ceramic wear resistant AR = 5 (10) $- R_{max} = 2\mu\text{m}$
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X-ray lithography + galvanofarming	UV-light + galvanofarming	Micro-cutting, -milling, -drilling	Si-etching	Laser-Ablation
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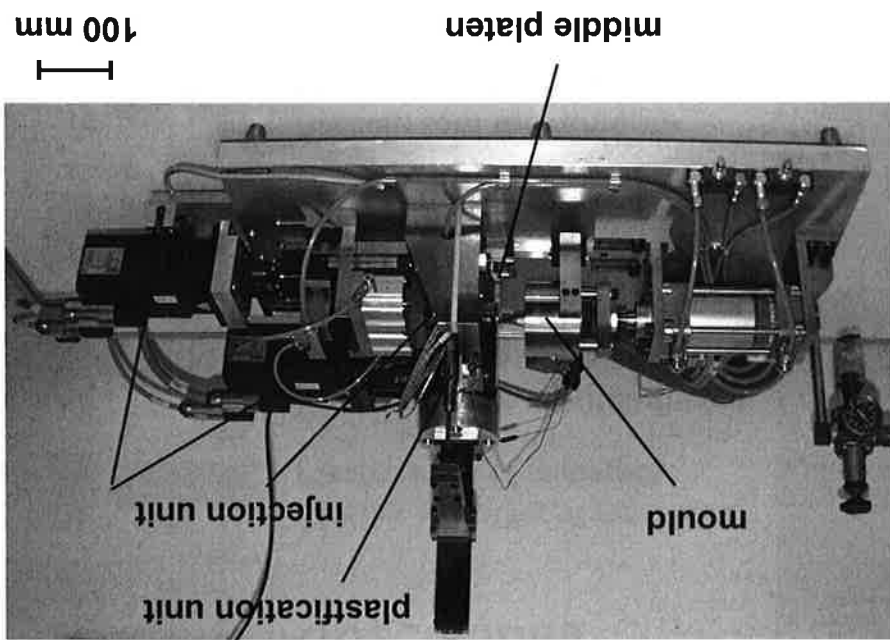
LIGA SU8 Micro-Cutting Silicon Laser

methods to produce microstructured inserts

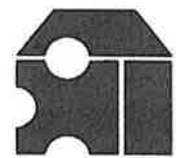
## 1-Component μIM - Tooling



Laboratory IM-machine with ultrasonic plastification for lowest shot weights



IKV, RWTH Aachen

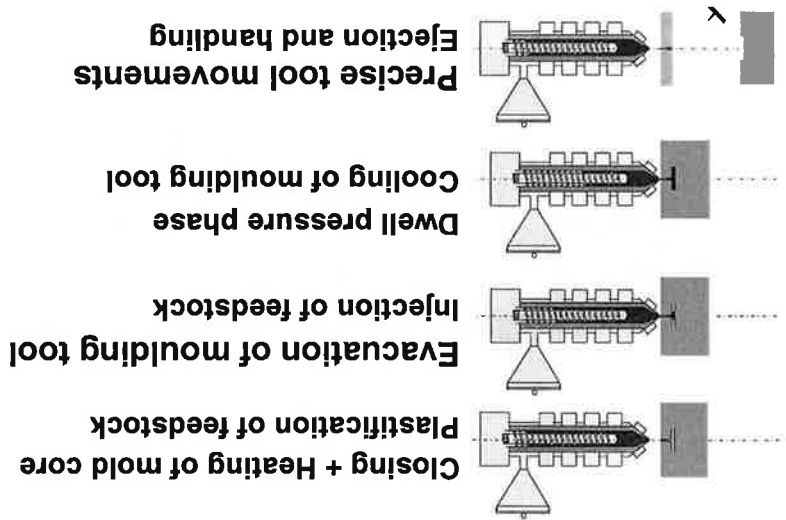


## 1-Component μIM - Machinery

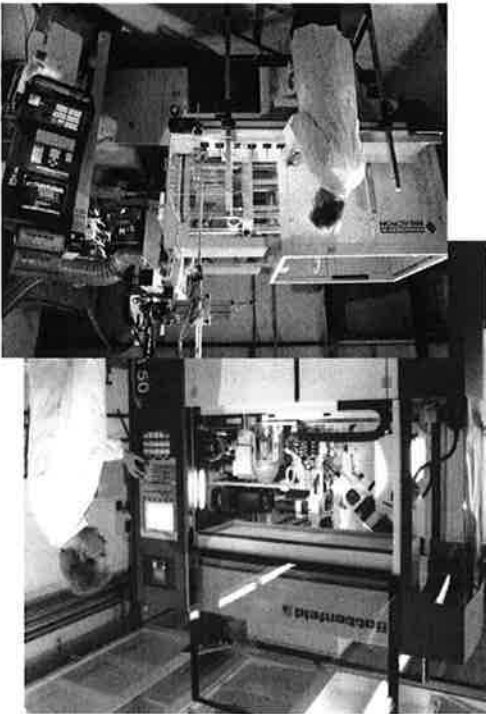


# Micro Injection Moulding

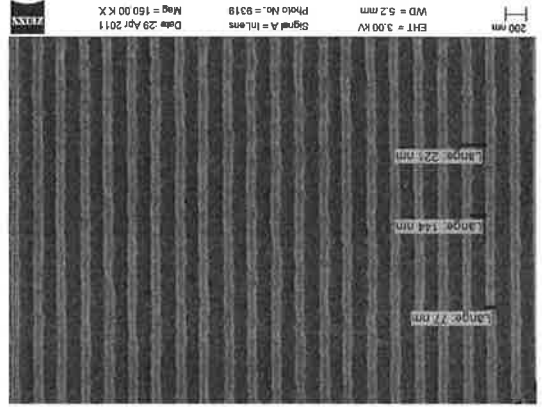
## Specialities



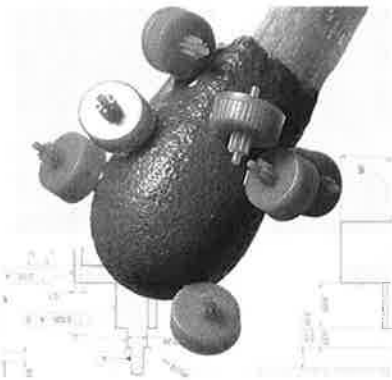
Heating / Cooling = Variotherm-process  
 necessary for replication of high aspect ratios



# Micro Injection Moulding of Polymers

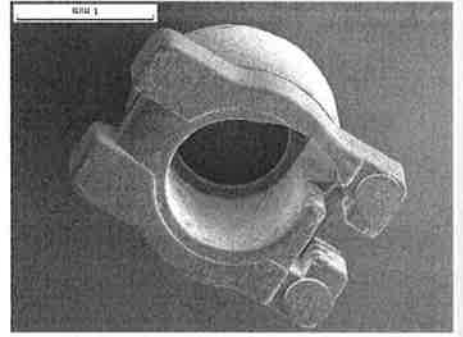


Micro grating structure  
 pitch  $\leq 80$ nm, PMMA  
 KIT

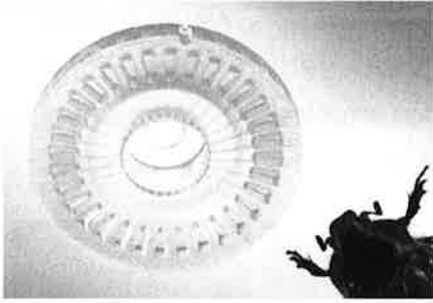


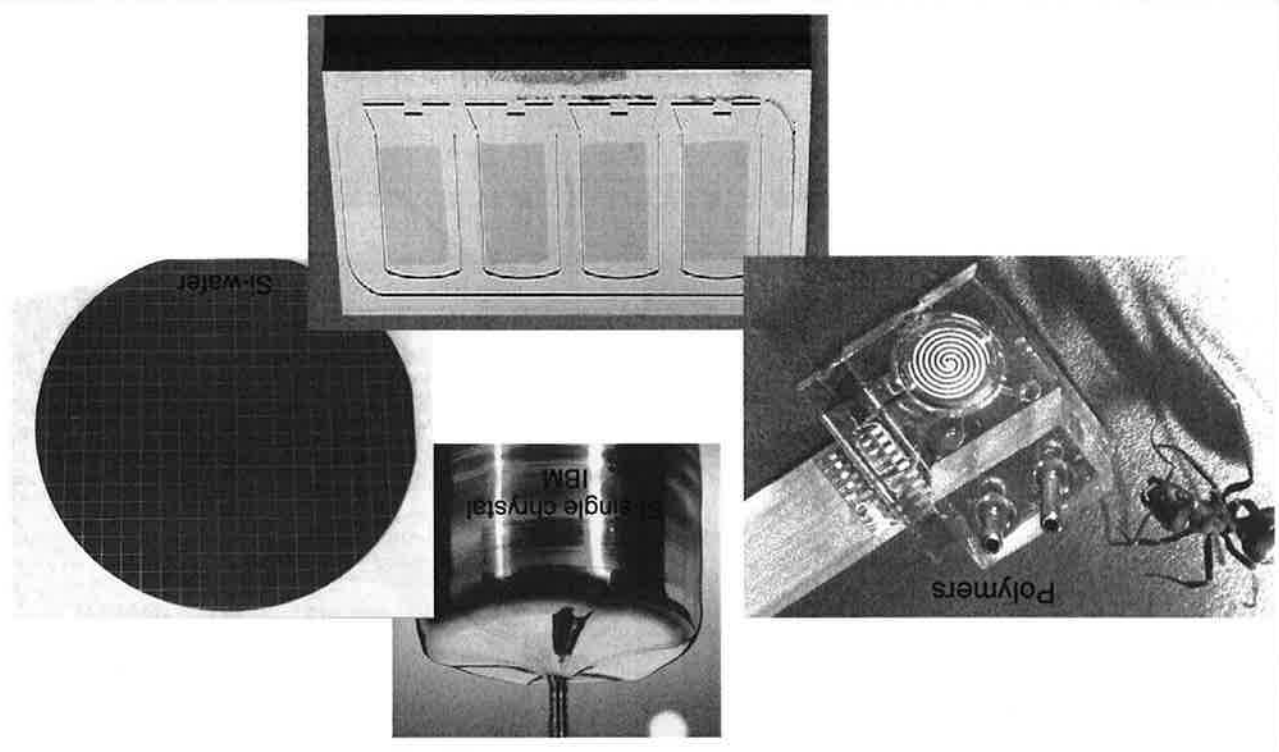
Micro gear wheels, POM  
 Rolla Micro-Synthetics AG

Switch housing, LCP  
 mass: 0,0022 g  
 H. Scholz GmbH

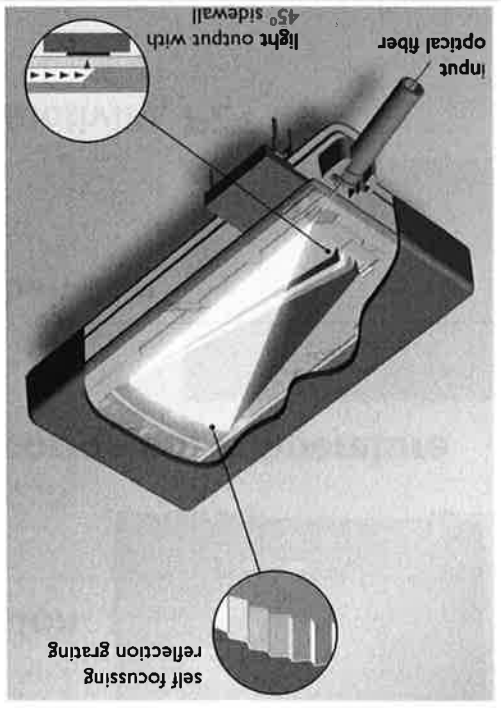


Bio-Disc, PC, PMMA  
 Reiner GmbH



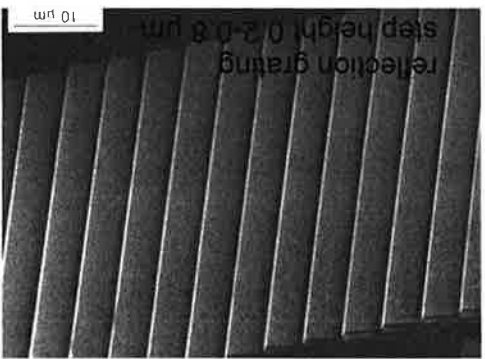


## Common materials in Micro System Technology

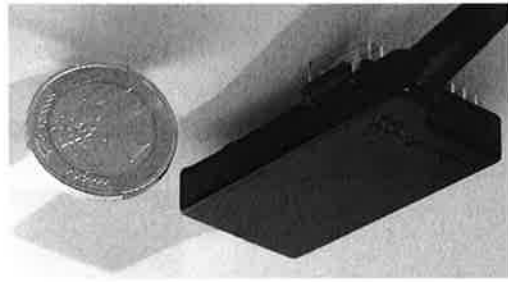


## Micro Spectrometer

## Micro Injection Moulding of Polymers



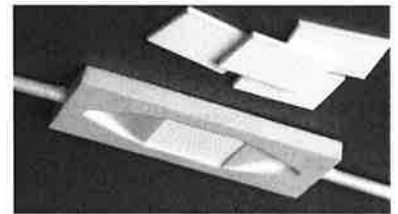
finally assembled micro spectrometer



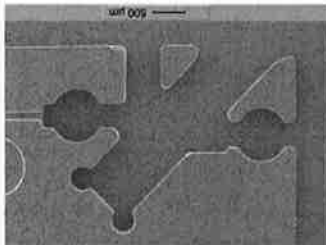
Source: Boehringer Ingelheim MicroParts

... and what about steels  
and ceramics ?

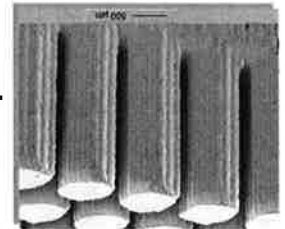
mechanics: forces, momentums, abrasion



chemistry/analytcs: corrosion, temperature



telecommunication: thermal expansion

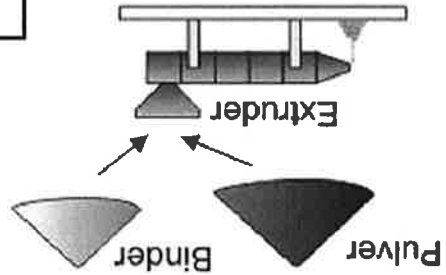


functional materials: conductivity, PZT etc.

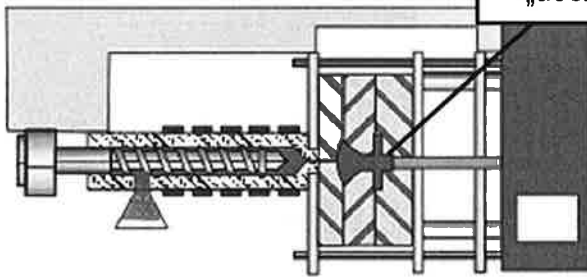
# Micro Powder Injection Moulding

© www.pulverspritzglessen.de

Feedstock preparation



Injection molding



Debinding



Sintering

„green“  
body



Ceramic	functional ceramics	PZT, TiN
	nonoxide-ceramics	Si <sub>3</sub> N <sub>4</sub> , SiC, AlN
	oxide-ceramics	Al <sub>2</sub> O <sub>3</sub> , ZrO <sub>2</sub> , ZTA, ATZ
Hard metals, Cermets	carbides, nitrides	WCxCo, TiN
	cermets	Mo-Al <sub>2</sub> O <sub>3</sub> , Fe-TiC
Metal	refractory metals	W, W-La <sub>2</sub> O <sub>3</sub> , WNiFe, WCu10, MoNb13, Mo20Cu
	nickel-base alloys	NiCr 22 Fe 18 Mo, NiCr 20 Co 18 Ti
	titanium	Ti6Al4V, TiAl7Nb
	copper	Cu, CuNi50, CuFe
	covar	Fe 29Ni 17Co
	softmagnetic materials	carbonyl-Fe, Fe50Ni, FeSi3
	low-alloyed iron	Fe2Ni, FeNi7
	precipitation hardening steel	X5 CrNiCuNb 17 4 (17-4PH, 1.4542)
	austenitic stainless steel	X2 CrNiMo 17 13 2 (316L, 1.4404)
	stainless steel	X20 Cr 13, X6 Cr 17
	tool steel	100 6W 5Mo 4 Cr 2V
	case-hardened steel	21 NiCr Mo 2, 16 MnCr 5
	tempering steel	42 CrMo 4, 40 NiCrMo 6



## PIM-Materials (macroscopic, selection)



Technological Motives	expanding the range of materials
Economical Motives	

## Driving Forces for MicroPIM



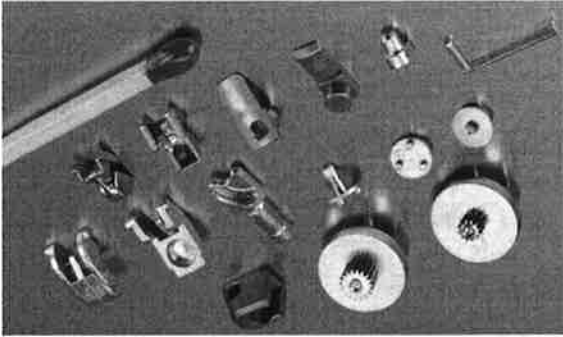
## Micro Powder Injection Moulding



## Driving Forces for MicroPIM

<b>Economical Motives</b>	low costs in medium and large series production	reduction of shaping steps	equipment based on standard machinery and tooling	attractive for SME's
<b>Technological Motives</b>	expanding the range of materials	manufacturing of complex geometries	several sub-variants of basic process	increase in micro dimensions

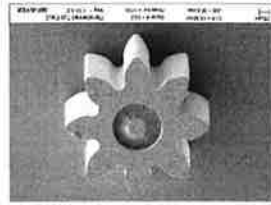
## MicroPIM - Current Status



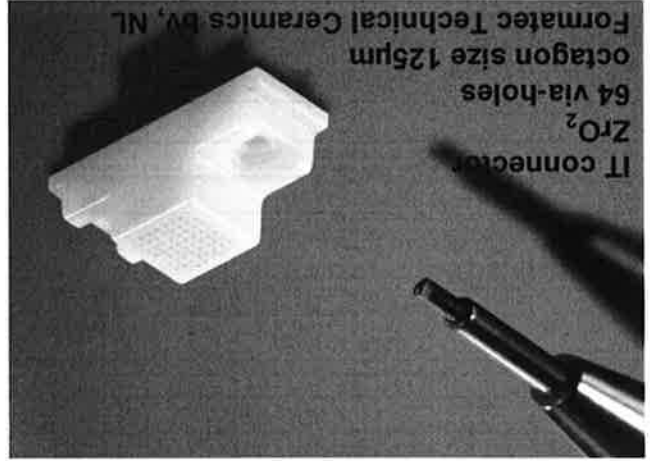
EPMA Award 2008 to  
Parmaco MIM AG, CH



Capillary for fine pitch bonding  
tip- $\varnothing$ =45 $\mu$ m, hole- $\varnothing$ =15 $\mu$ m  
SPT Roth Ltd., CH



Ceramic gear wheel  
outer- $\varnothing$  approx. 275  $\mu$ m



IT connector  
ZrO<sub>2</sub>  
64 via-holes  
octagon size 125 $\mu$ m  
Formatec Technical Ceramics BV, NL

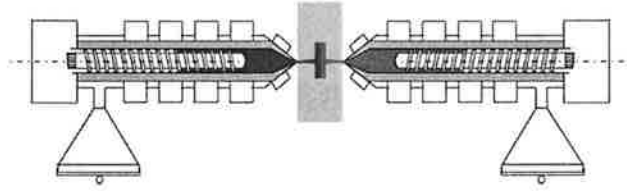


## Micro Injection Moulding – General Data

Materials	min. lat. Dimension [µm]	min. Detail [µm]	max. Height [µm]	Aspect ratio [isolated walls]	Aspect ratio [grooves]	Tolerance [%]	Roughness ** R <sub>max</sub> / R <sub>a</sub> [µm]
Plastics	10	<0.1	2500	>20 (200*)	25	± 0.05	0.05 / <0.05
Metals	50	10	1300	>10	>10	< ± 0.5	7 / 0.8
Ceramics	<10	<3	1300	<15	15	± 0.3***	2 / <0.3

\* flow length to wall thickness ratio  
 \*\* depending on mould insert  
 \*\*\* down to ± 0.1% under certain conditions

## Multi-Component Micro Injection Moulding

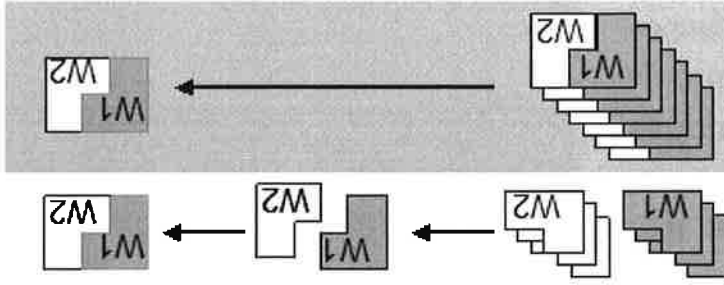


Merging of two or more  
 resins/feedstocks  
 in one tool

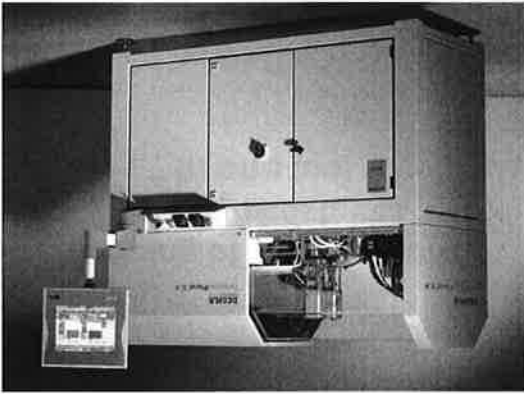
■ Feedstock 1    ■ Feedstock 2

single-piece fabrication  
 + assembly

2C-µIM  
 – assembly



- additional compression steps (µICM)
  - simultaneous or sequential injection
  - variothermal temperization
  - tool evacuation
- at KIT equipped with:



FormicaPlast® with piston injection unit  
 $(\varnothing = 2 \times 3 \text{ mm})$   
 DESMA



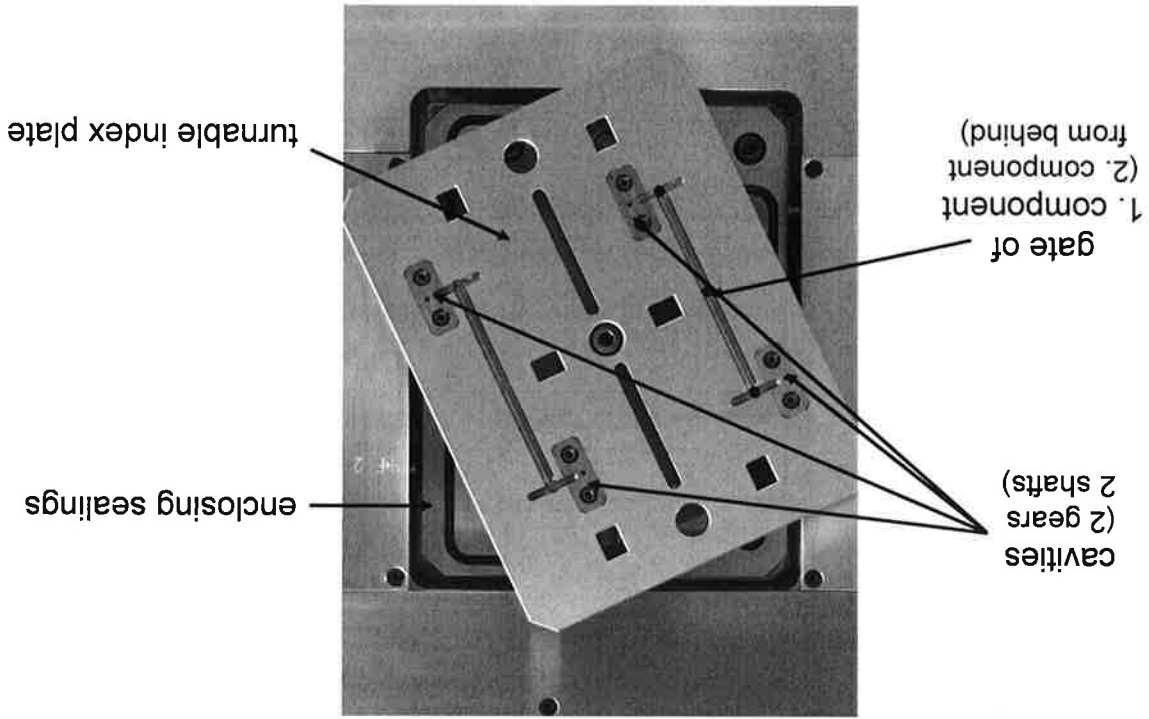
## 2C-µIM - Machinery

Technological Motives	low costs in medium and large series production	Economical Motives
production of multi-material devices	reduction of assembly costs	reduced energy, water, plant area etc. consumption
generation of fixed or movable connections		

## Driving Forces for 2C-µIM

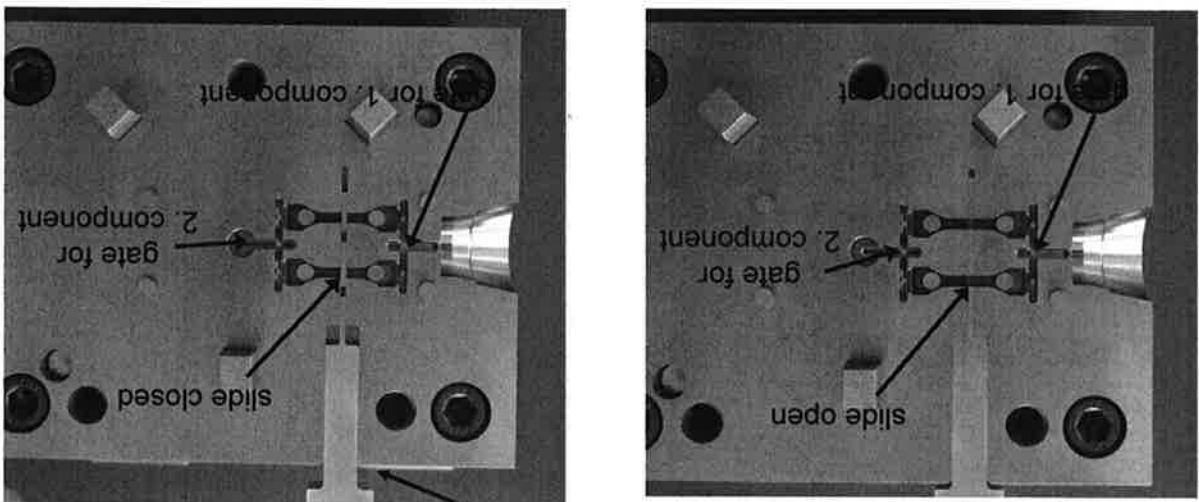


## Multi-Component Micro Injection Moulding



Three-plate tool equipped with index plate

## Multi-Component Micro Injection Moulding



Tool equipped with movable slide =>  
simultaneous or sequential injection

## Multi-Component Micro Injection Moulding



## 2C-µIM - Process Conduct

in case of high aspect ratios

The diagram illustrates the process flow for 2C-µIM in high aspect ratios. The steps are: tool closing, injection 1. component, gate valve movement, injection 2. component, cooling time, and demolding. The pressure profile shows injection pressure, environmental pressure, and vacuum. The temperature profile shows approx. 150°C and approx. 50°C. A photograph shows the mold assembly.

## Multi-Component Micro Injection Moulding

Tensile test specimen to investigate interface strength, COTECH

The images show multi-component micro injection molded parts. The top image shows hearing aid housings with labels for PA 6, TPE, and ABS. The bottom image shows tensile test specimens for interface strength investigation, with labels for TPE and ABS. Source: Nanologic Ltd., Portugal.



and others more ...

porous	↔	tight
mechanically strong	↔	bio-compatible
non-magnetic	↔	magnetic
tough	↔	hard
insulating	↔	conductive

with complementary or even contradictory properties

## Multifunctional Products

### 2C-MicroPIM – Opportunities



Thermal expansion	nearly equal	nearly equal
Sintering temperature	inner section < outer section	nearly equal
Powder loading	inner section < outer section	nearly equal
Binder system	n. r.	compatible
	Mobile	Immobile

=> debinding and sintering steps have to be considered

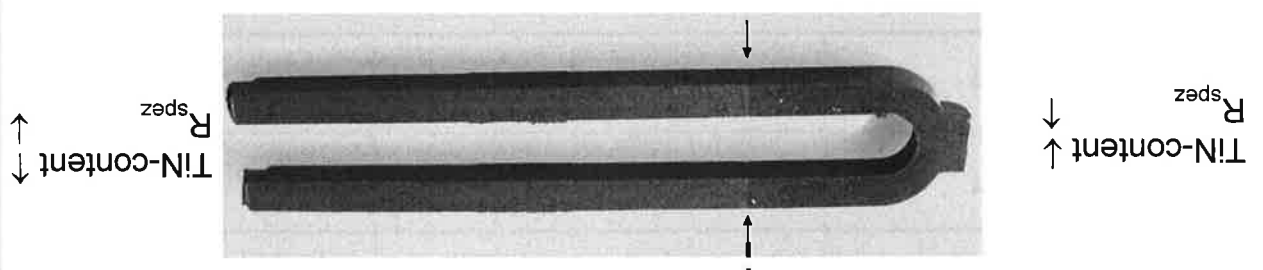
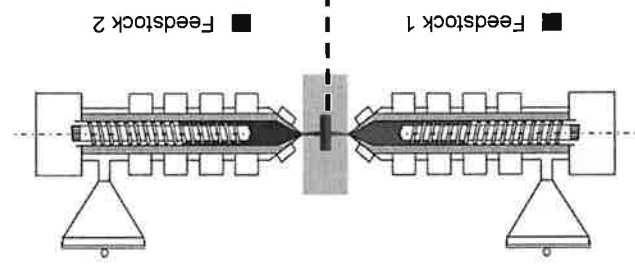
## 2C-Micro Powder Injection Moulding

### 2C-MicroPIM - Basic Rules

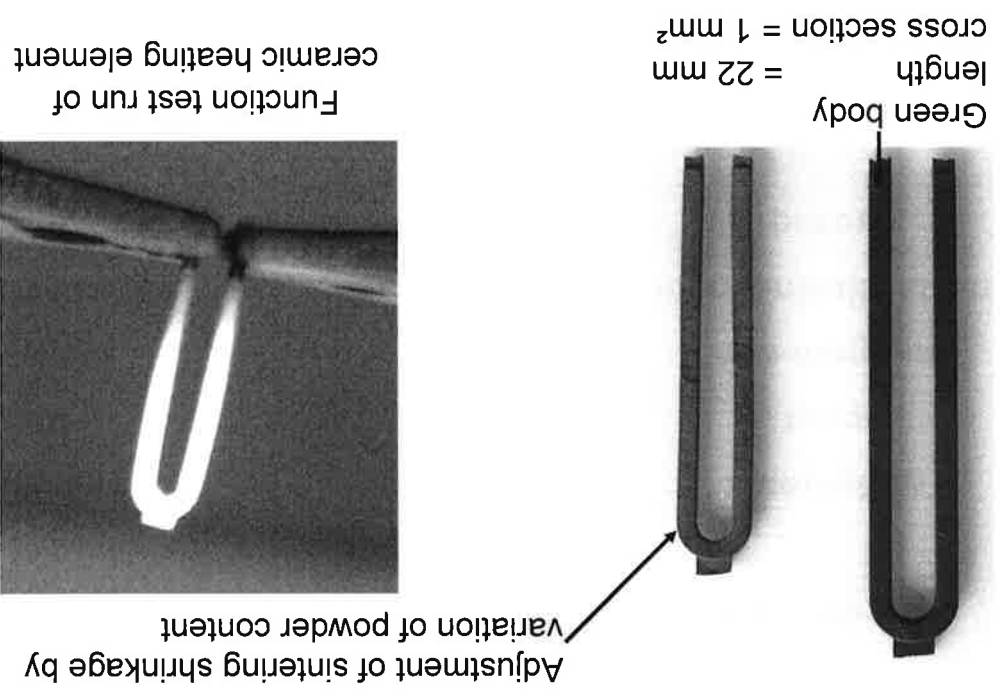


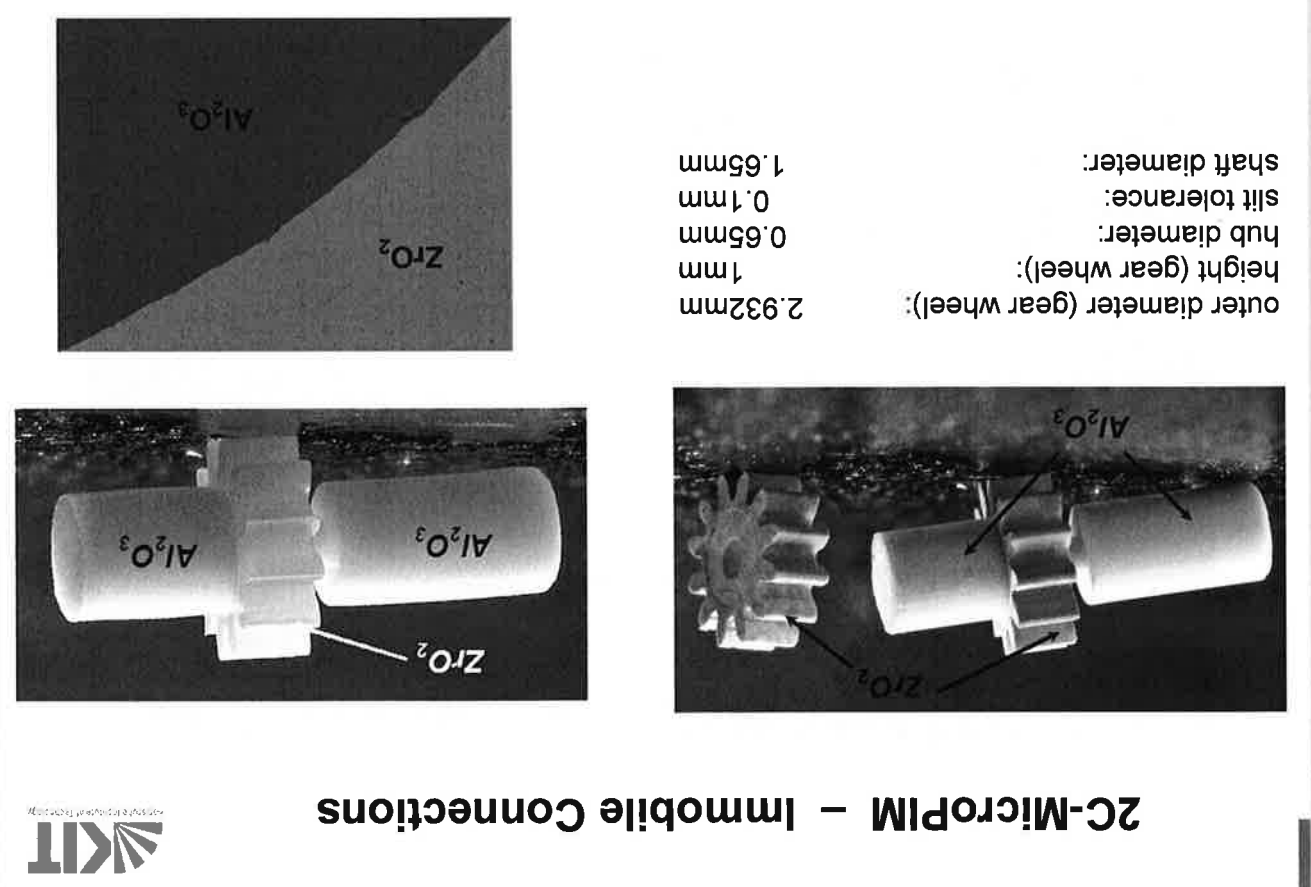
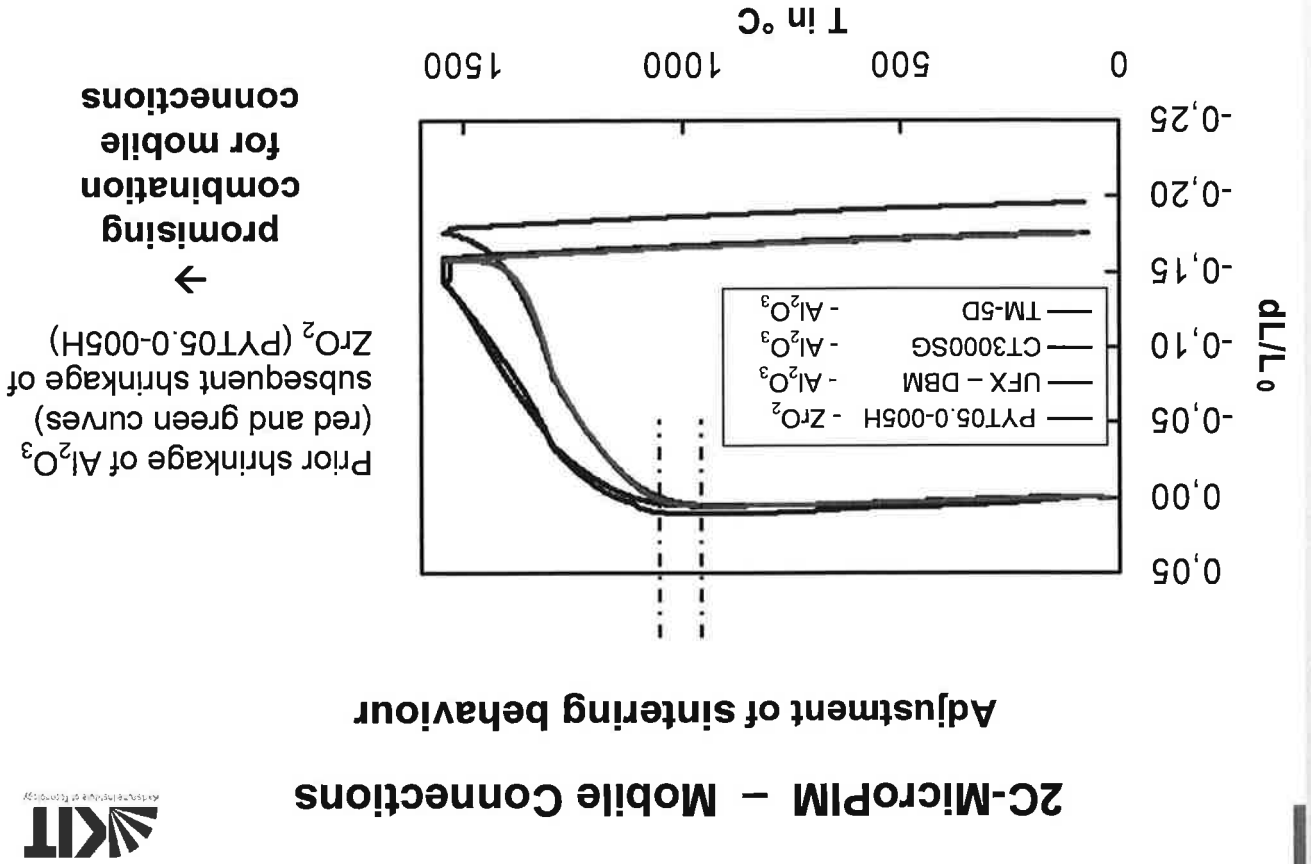
## 2C-MicroPIM – Immobile Connections

Material:  $\text{Al}_2\text{O}_3/\text{TiN}$ -mixture, electrical conductivity according to TiN-content  
 Demonstrator: ceramic heating needle



## 2C-MicroPIM – Immobile Connections



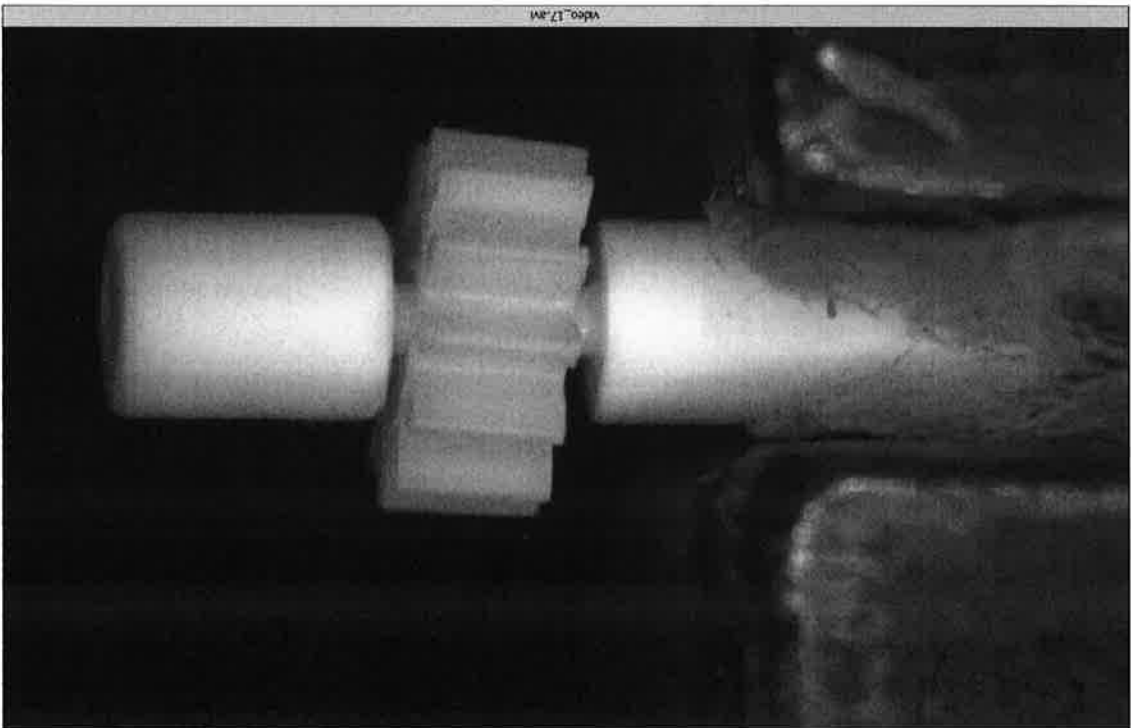






- Improvement of dimensional accuracy and surface quality  
e.g. EU-Project „COTECH“, combine µIM + hot embossing
- Enhanced multi-component process variants  
e.g. EU-Projects „COTECH/Multilayer“

## Outlook



## 2C-MicroPIM – Mobile Connections

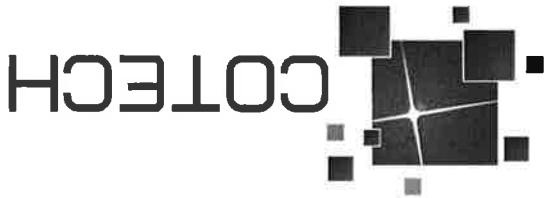


### Idea:

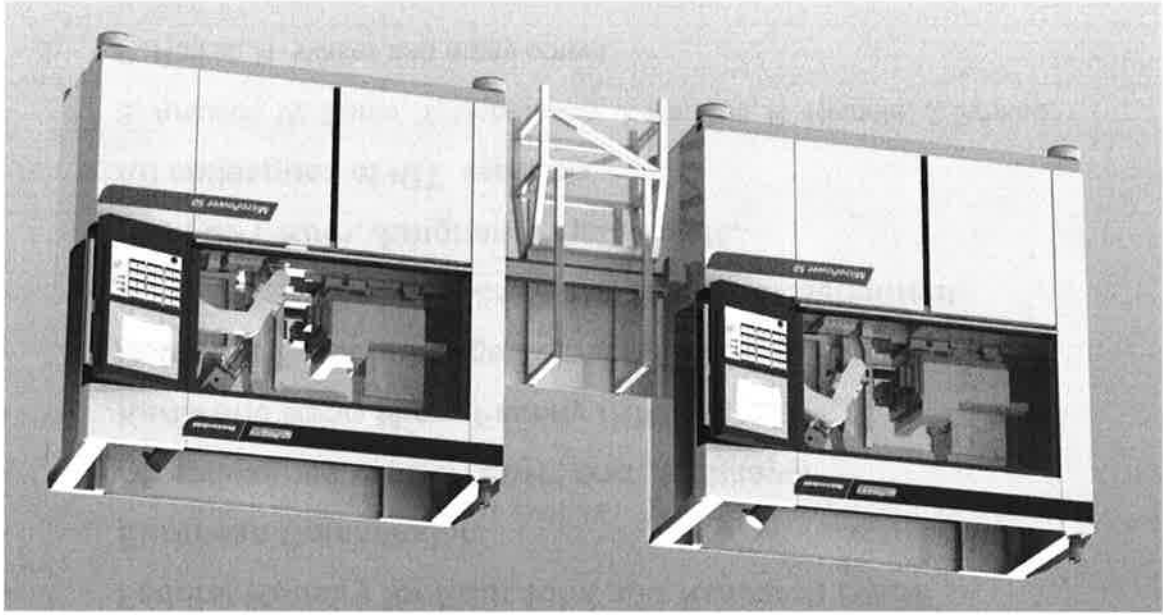
- series connection of two 1C-µIM machines (Micropower®) in row
- rapid transfer of 1. shot to 2nd machine by robot
- machines can be easily connected and disconnected

### Advantage:

Both machines can be fully used as 1C-units if no order for 2C-parts has to be executed



Source: Wittmann Battenfeld, Austria



Source: Wittmann Battenfeld, Austria

# Thank you !

- Federal Ministry for Education and Research BMBF
- European Commission
- All colleagues in „COTECH“ and „Multilayer“
- Karlsruhe Nano Micro Facility (KNMF)
- Deutsche Forschungsgemeinschaft DFG (SFB 499)
- Companies Arburg, microParts, Wittmann Battenfeld,
- RKT, SPT Roth, Junghans, Imatec etc.
- All colleagues at KIT especially
- S. Antusch, W. Bauer, T. Hanemann, J. Hauselt, R. Heldele, J. Prokop,
- P. Holzer, H. Walter and many others

## Acknowledgment



- Improvement of dimensional accuracy and surface quality
- e.g. EU-Project „COTECH“, combine µIM + hot embossing
- Enhanced multi-component process variants
- e.g. EU-Projects „COTECH/Multilayer“
- Expanding the range of materials
- functional materials
- fine and nano powders etc.
- Special Software for Simulation

## Outlook

