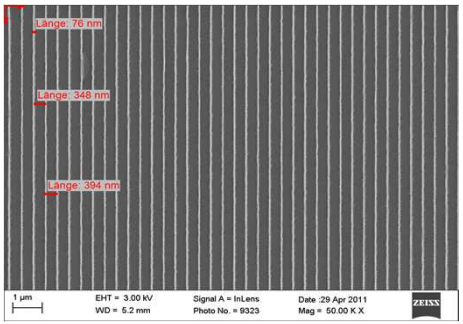
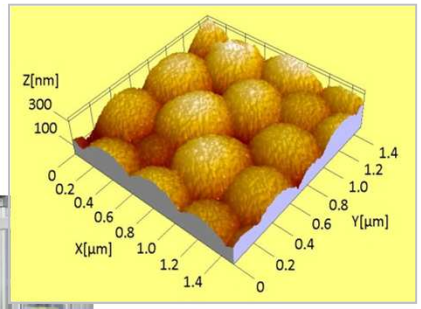
Karlsruher Institut für Technologie

# Nano- and Micro Injection Moulding of polymer, metal, and ceramic components for various applications


## Volker Piotter

*INSTITUTE FOR APPLIED MATERIALS - MATERIALS PROCESS TECHNOLOGY (IAM – WPT)*


# Content

- Machinery and process
- Submicron- and Nano Injection Moulding
- Micro Powder Injection Moulding
- 2-Component Micro Powder Injection Moulding (2C-MicroPIM)
- Summary and Outlook



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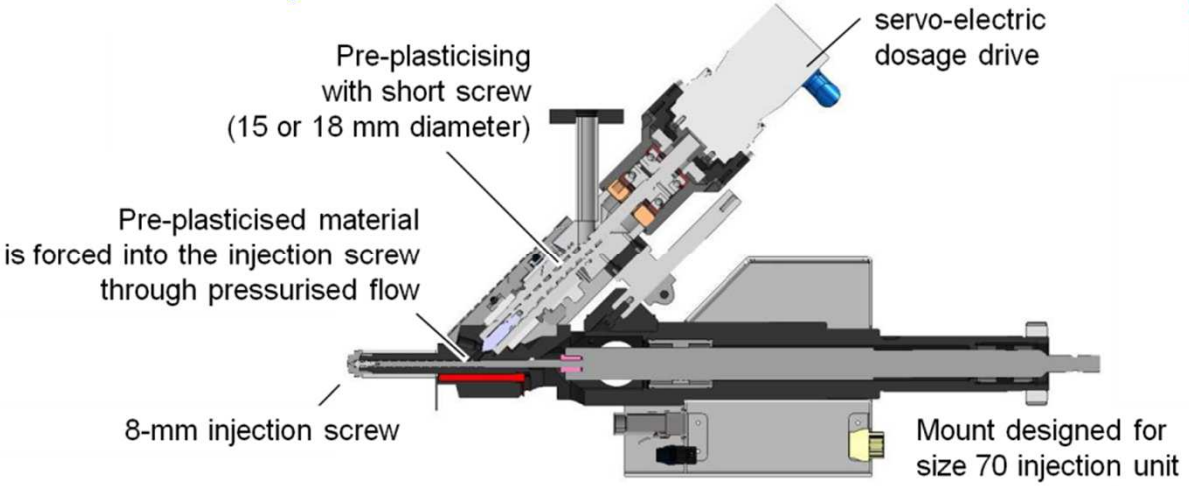
# Machinery

Arburg
micro module





Wittmann Battenfeld MicroPower


DESMA FormicaPlast 2C



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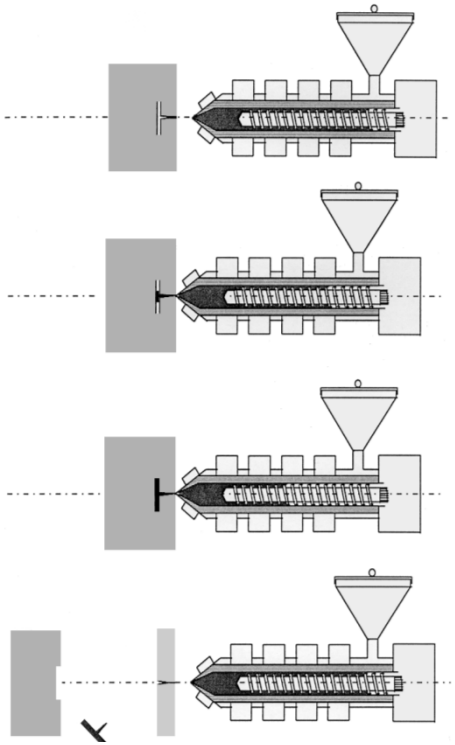
# Specialities

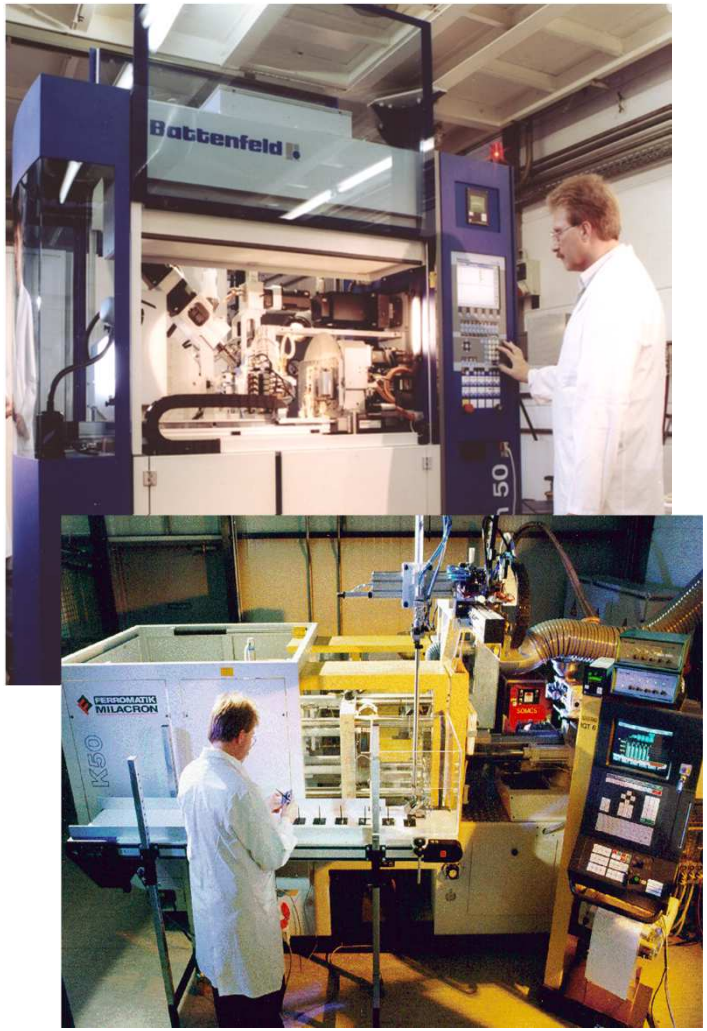


Closing + Heating of mold core
Plastification of feedstock

Evacuation of moulding tool
Injection of feedstock

Dwell pressure phase
Cooling of moulding tool

Precise tool movements
Ejection and handling




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



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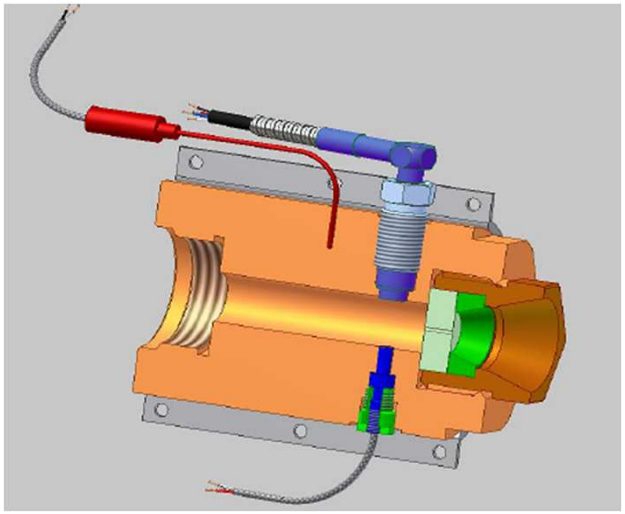
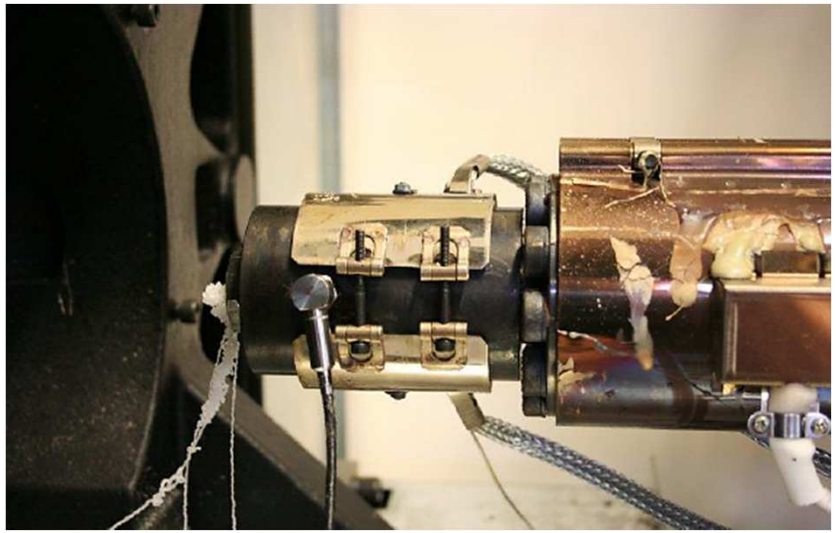
# Rheology Investigations

*Standard capillary rheometry tests are used to characterise shear flow of materials to around 100 000$s^{-1}$.*

*Bradford University converted an injection moulding machine into a rheometer which is capable of withstanding very high pressures (2800bar) and provides high injection velocities.*

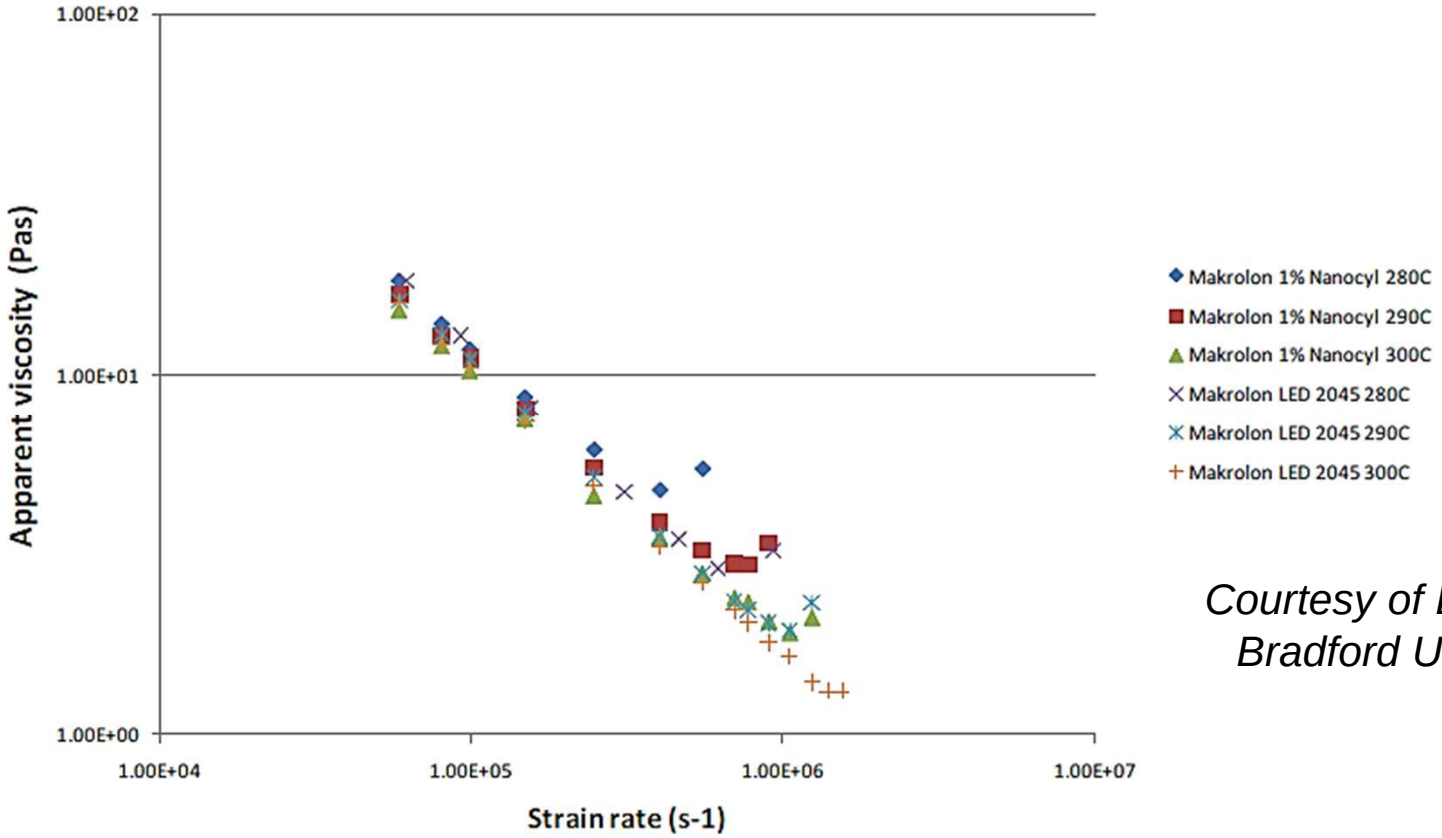
*This allows testing of materials to wall shear rates in excess of 10 000 000$s^{-1}$.*





# Rheology Investigations

*Shear thinning behaviour occurs until a critical limit above which the viscosity will rise significantly.*
*If a process is operating beyond this point, reducing the injection speed will actually help to fill the cavity.*




*Courtesy of Ben Whiteside*
*Bradford University, UK*

# Multi-scale micro/nano manufacture

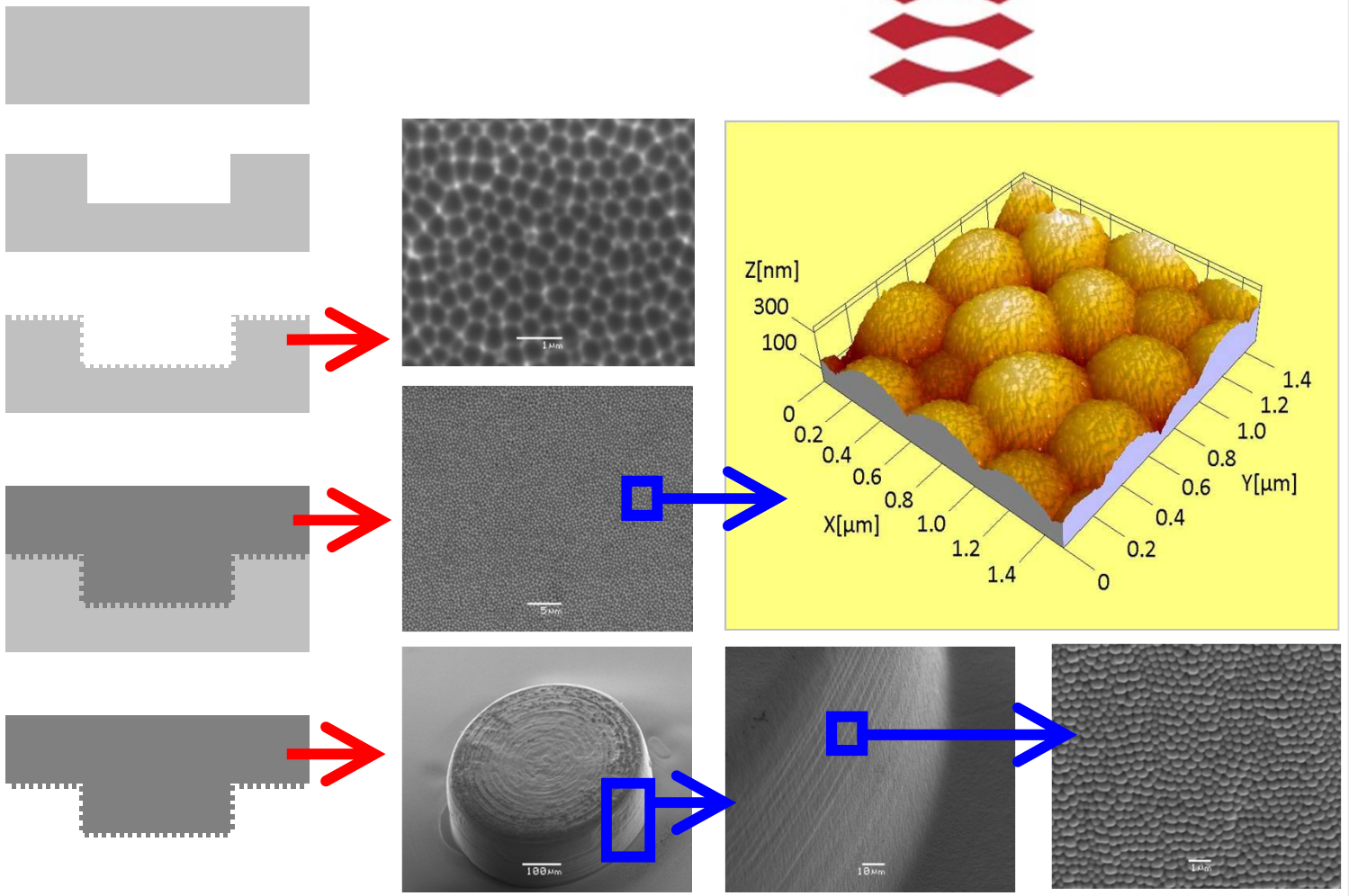
Al 99.999% Substrate

Micromachining

Anodization

Ni Electroplating

Selective etching
(Al dissolution)

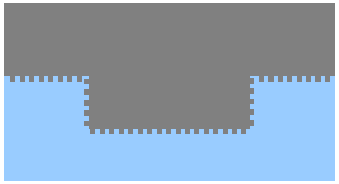


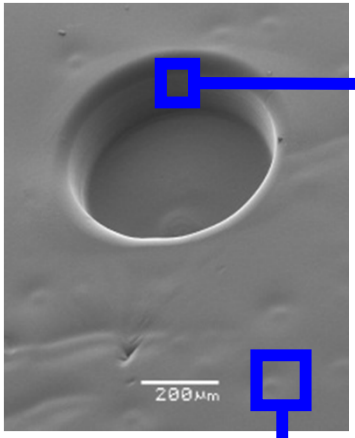

**Leap to mass fabrication => injection moulding**

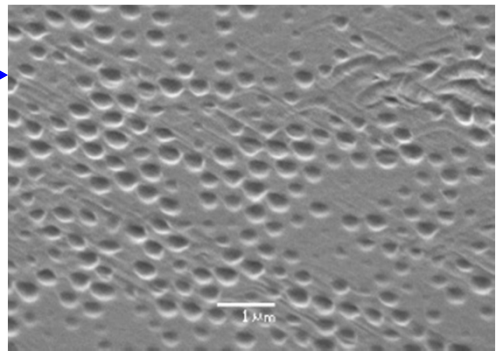
# Multi-scale micro/nano manufacture

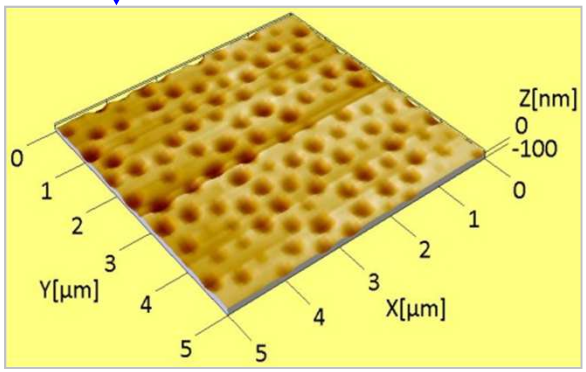
**Injection Moulding**

**Micro-Nano Structured Polymer Part**





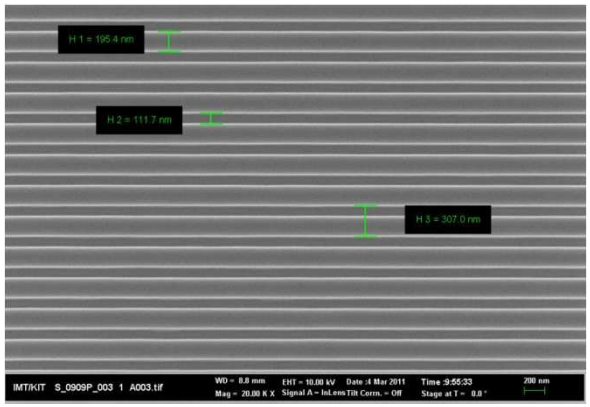




*Courtesy of Guido Tosello, Technical University of Denmark*

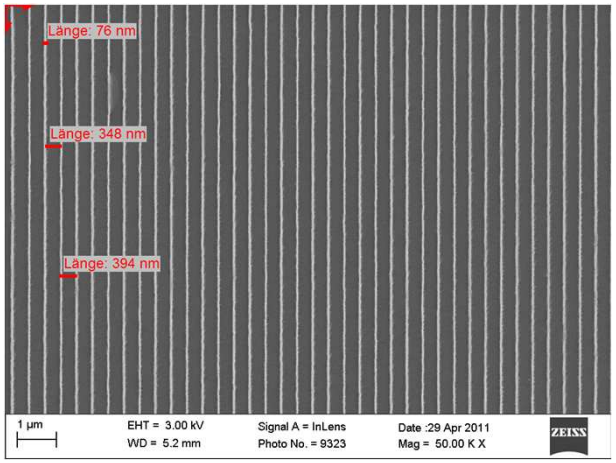
# Nano Injection Moulding

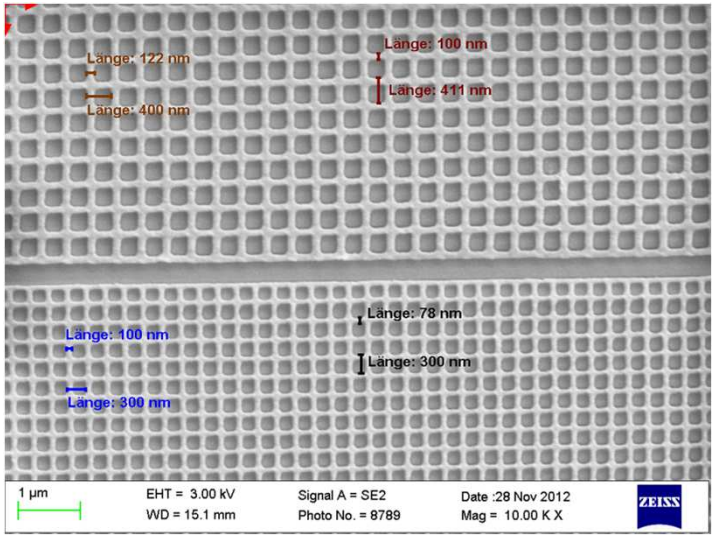
## Generation of nano-sized photonic crystal structures for surface contrast microscopy




SEM figure of mold insert made by e-beam writing and electroplating (KIT-IMT)

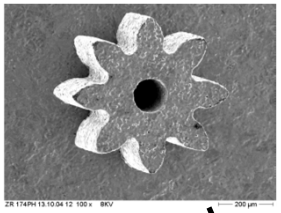
*Kiel University*
*Y. Nazirizadeh*

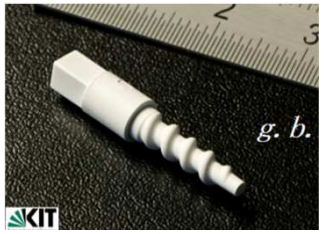


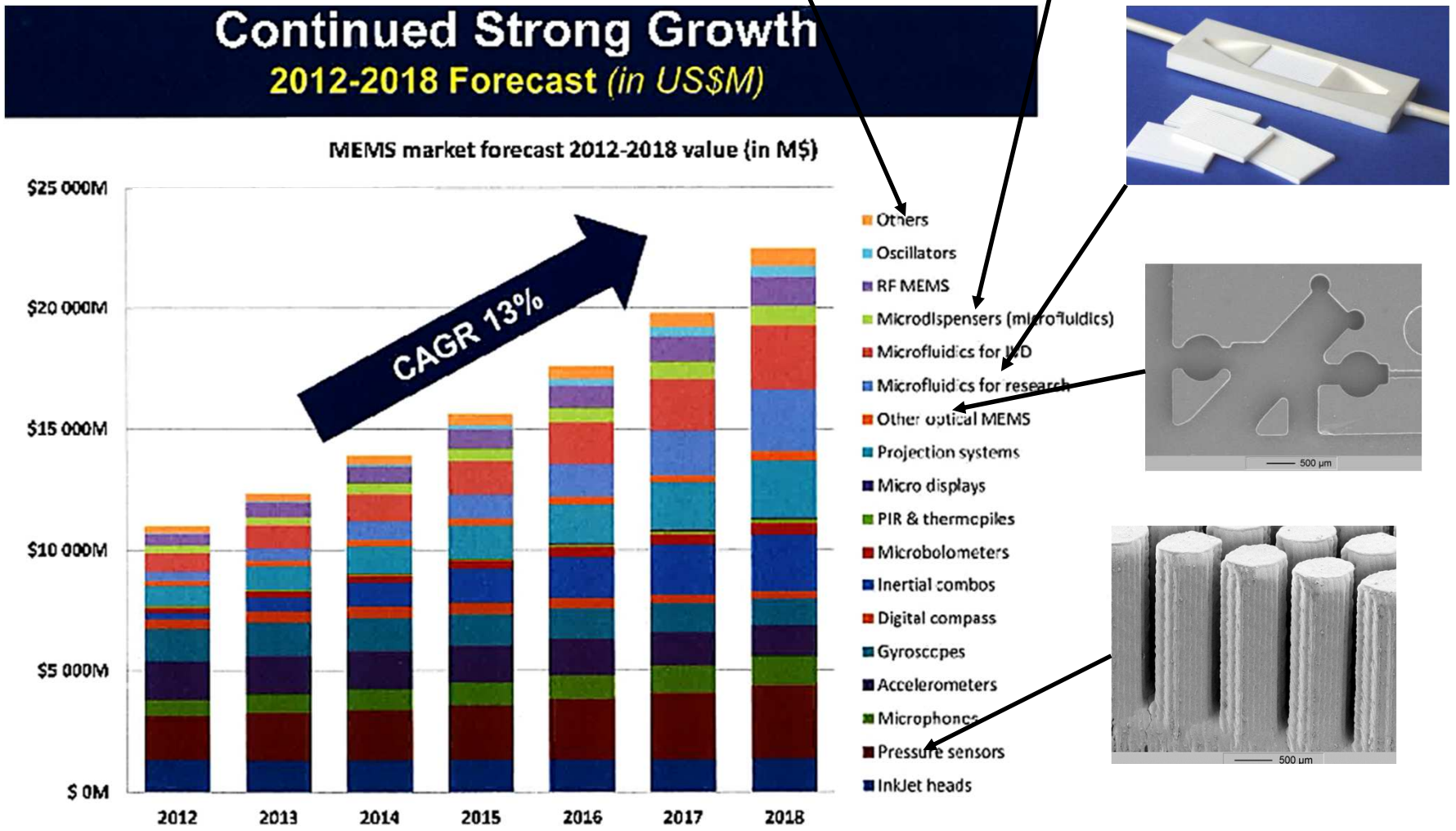

replication in the nm-range
minimum width ca. 80nm, PMMA

# Micro System Technology



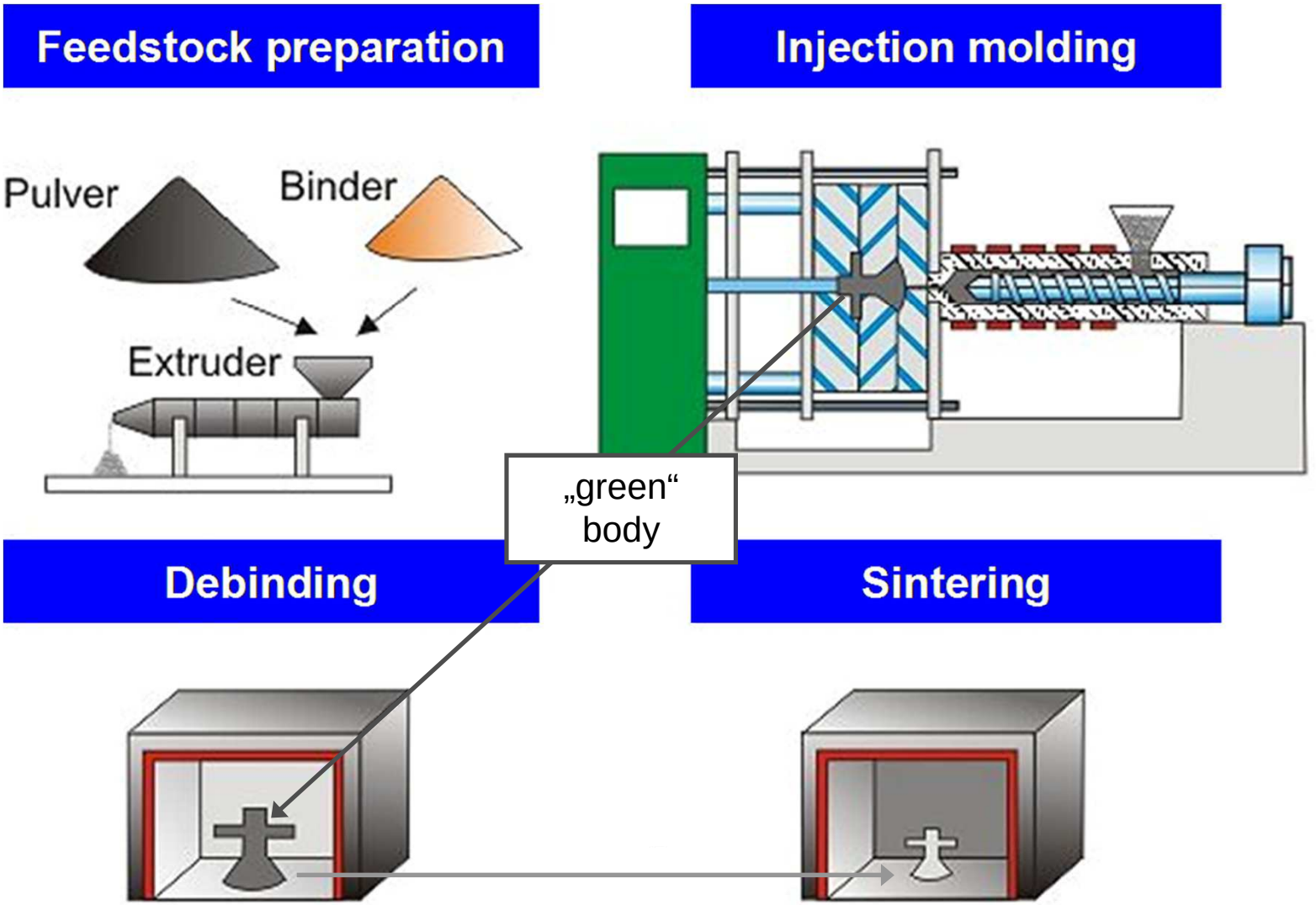



*Source: Yole Development, March 2013*



# Micro Powder Injection Moulding

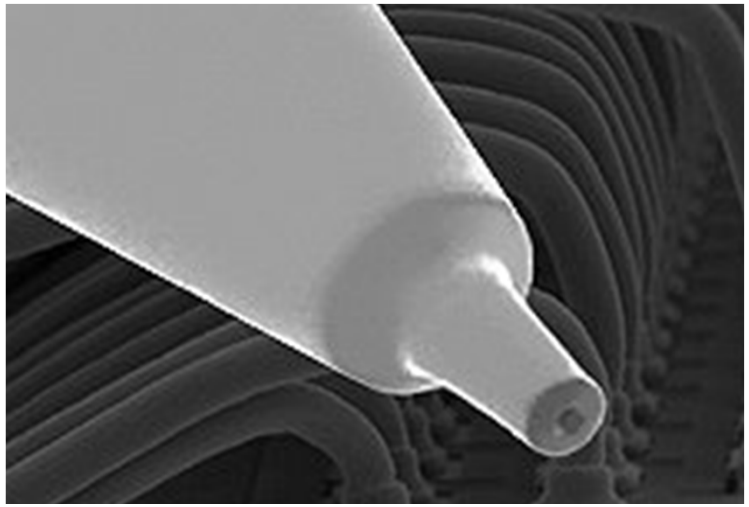
© www.pulverspritzgiessen.de



# PIM-Materials (selection)

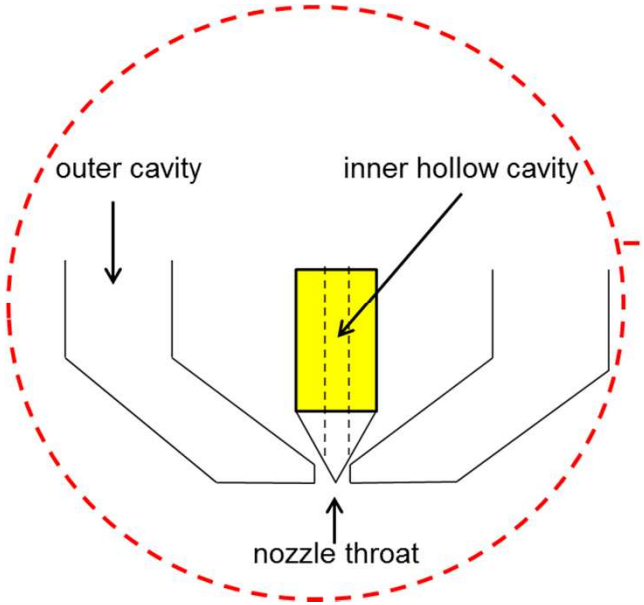
| | | |
|---|---|---|
| **Metal** | temp | |
| | case-h | |
| | t | |
| | stai | |
| | austeniti | 404) |
| | precipitatio | 4542) |
| | | |
| | low- | |
| | softmag | 3 |
| | | |
| | | |
| | | |
| | t | |
| | ys | NiCr 22 Fe 18 Mo, NiCr 20 Co 18 Ti |
| | s | W, W-$La_2O_3$, WNiFe, WCu10, MoNb13, Mo20Cu |
| | | |
| | s | WCxCo, TiN |
| | | Mo-$Al_2O_3$, Fe-TiC |
| | | |
| | | $Al_2O_3$, $ZrO_2$, ZTA, ATZ |
| | cs | $Si_3N_4$, SiC, AlN |
| | cs | PZT, TiN |

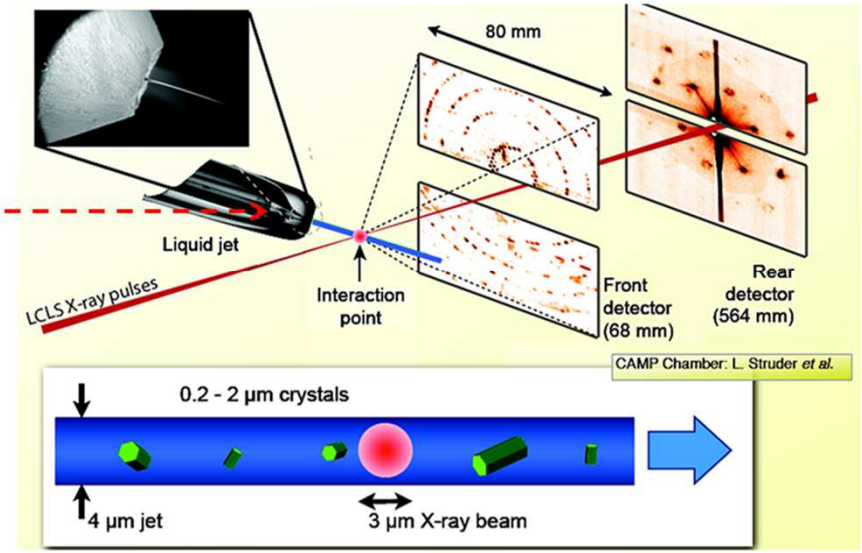

# MicroPIM



Capillary for fine pitch bonding
tip-Ø=45µm, hole-Ø=19µm
SPT Roth Ltd., CH

Scientific application: liquid jet nozzles for CFEL
collaborative project between DESY and KIT



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# Micro Injection Moulding – General Data

| Materials | min. lat. Dimension [µm] | min. Detail [µm] | Aspect Ratio [isolated walls] | Tolerance [± %] | Roughness ** $R_{max}$ / $R_a$ [µm] | Materials tested |
|---|---|---|---|---|---|---|
| **Plastics** | **10** | **<0.1** | **>20 (200*)** | **0.05** | **0.05 / <0.05** | **Thermoplastics, TPE** |
| **Metals** | **50** | **10** | **>10** | **< 0.5** | **7 / 0.8** | **17-4PH, 316L, Cu, W, W-alloys** |
| **Ceramics** | **<10** | **<3** | **<15** | **(0.1***) / 0.3** | **<3 / <0.3** | **$ZrO_2$, $Al_20_3$, ZTA, $Al_2O_3$/TiN, $Si_3N_4$** |

* flow length to wall thickness ratio

** depending on mould insert

*** after thorough process optimization

# Multi-Component Micro Powder Injection Moulding

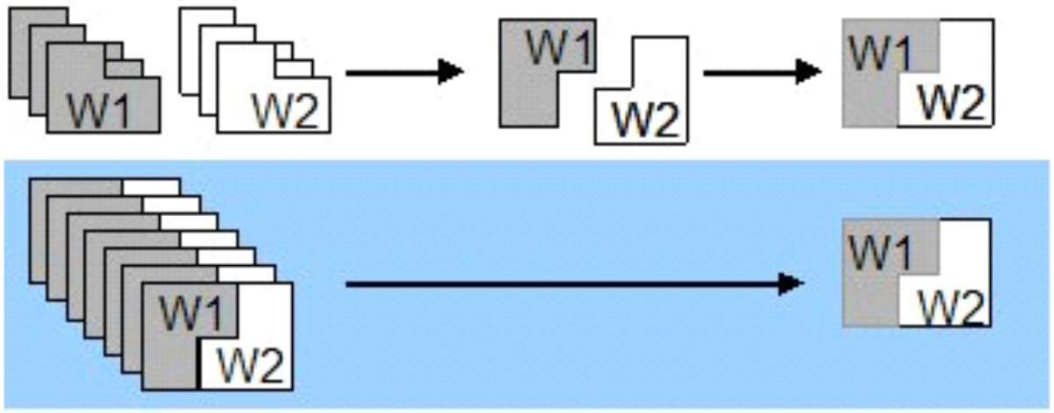
**Functions integration by combining different materials**

**Realization of (im-)mobile connections**

**Reduction of handling and assembly expenditure**

single-piece fabrication
+ assembly

2C-MicroPIM
– assembly



# Multifunctional- / Multimaterial Products

**with complimentary or contradictionary properties, e.g.**

| | | |
|---|---|---|
| **conductive** | ↔ | **insulating** |
| **hard** | ↔ | **tough** |
| **magnetic** | ↔ | **non-magnetic** |
| **hydrophilic** | ↔ | **hydrophobic** |
| **tight** | ↔ | **porous** |

→ **2-Component MicroPIM (2C-MicroPIM)**

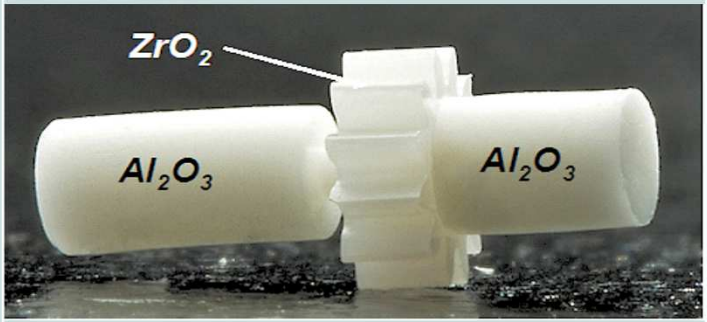
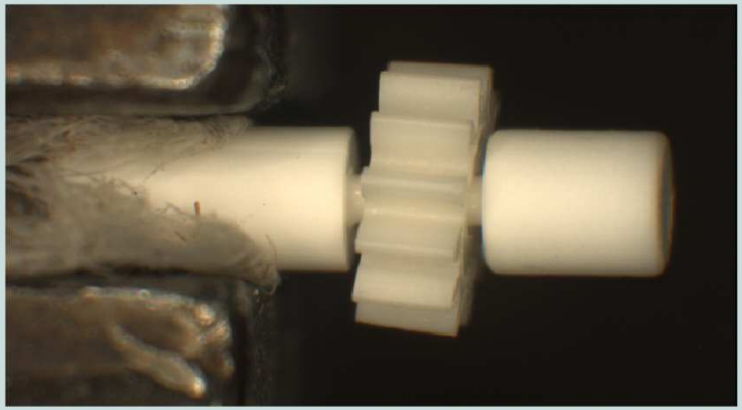
# 2-Component PIM


Combination of a magnetic steel (17-4PH)
with a non-magnetic steel (316L)

Hard metal WCxCo with different
Co-contents (16% and 6%)
ARBURG

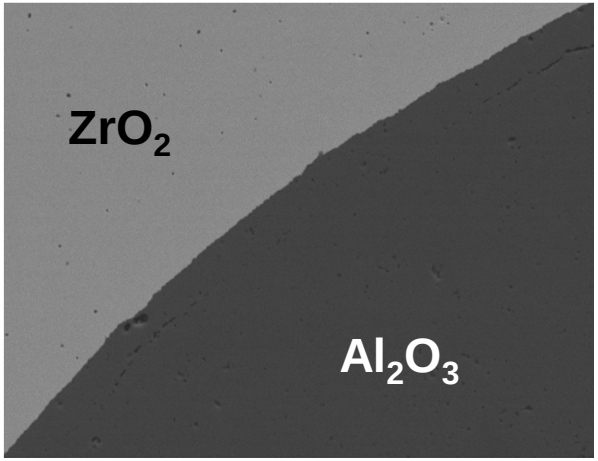

2-Component MIM, steel
AMT, Singapore

# 2-Component PIM

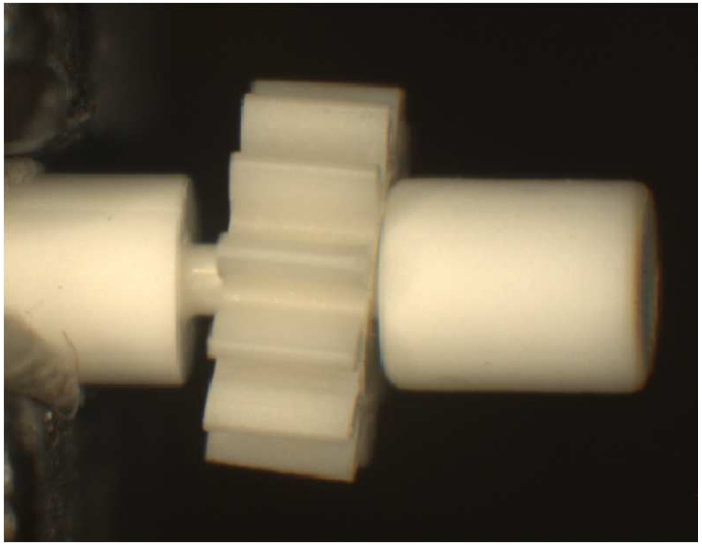
| connection | fixed | movable |
|---|---|---|
| binders | compatible | not relevant |
| powder loading | nearly equal | $\varphi_{outside} > \varphi_{inside}$ |
| sintering-T | nearly equal | $T_{outside} > T_{inside}$ |
| CTE | nearly equal | nearly equal |
| |  |  |

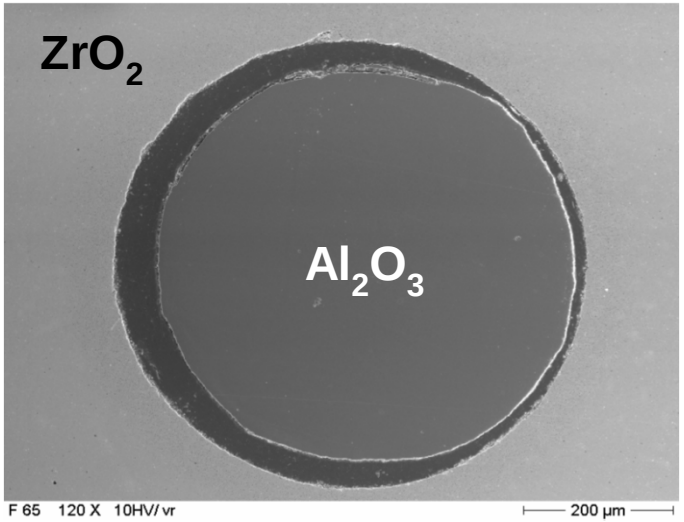
# 2C-MicroPIM

**Fixed connections of different ceramics**




**Realisation of movable connections**





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# Summary and Outlook

- **Enhancing technical performance**

  **larger variety of materials, e.g. nanopowders**

  **improve simulation/predictability**

  ***=> talk of Mr. Marhoefer***

  **thermal contact resistance**

  *resistance to heat flow across the melt/mould interface*

- **Improving economic efficiency**

  **flexible machinery**

  **saving of material and energy**

# Summary and Outlook

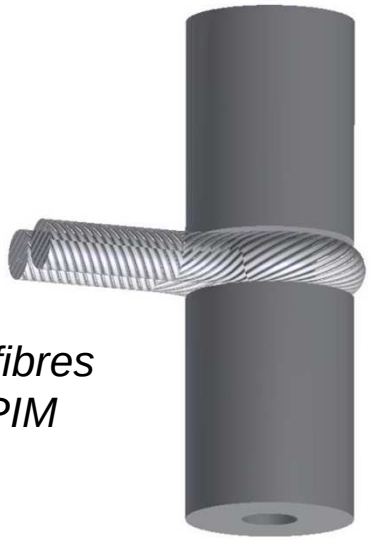
- **Enhanced multi-component process variants**

  **two-component micro injection moulding**

  **sinter-joining of PIM green bodies**

  ***=> talk of Mrs. Klimscha***

  **insert powder injection moulding**



*Lightweight applications:*
*material compounds of C-fibres*
*and metal insert parts by PIM*

# Summary and Outlook

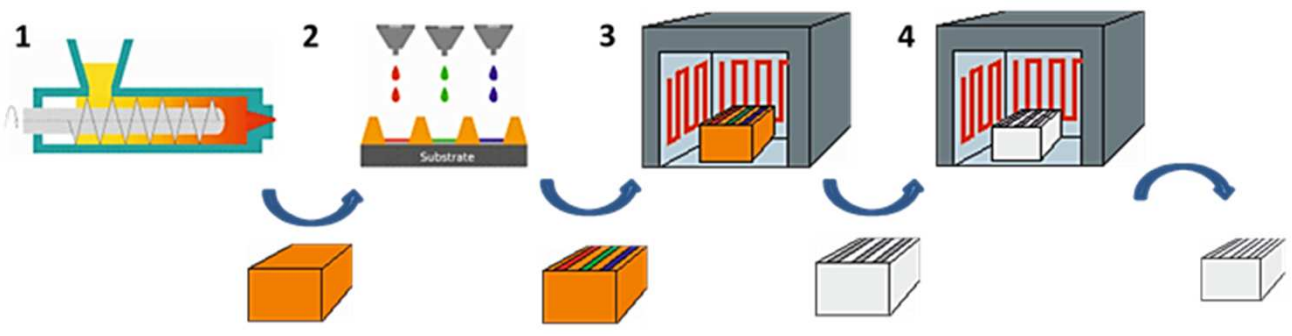
- **Hybridization of micro processing technologies**

  **3D-MID and variants**

  ***=> talk of Prof. Hansen***

**PIM + Additive Manufacturing**

1. Micro PIM
2. 3D inkjet printing
3. Debinding
4. Sintering



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# Acknowledgment


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- **BMBF and State of Baden-Wuerttemberg**
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***Thank you !***