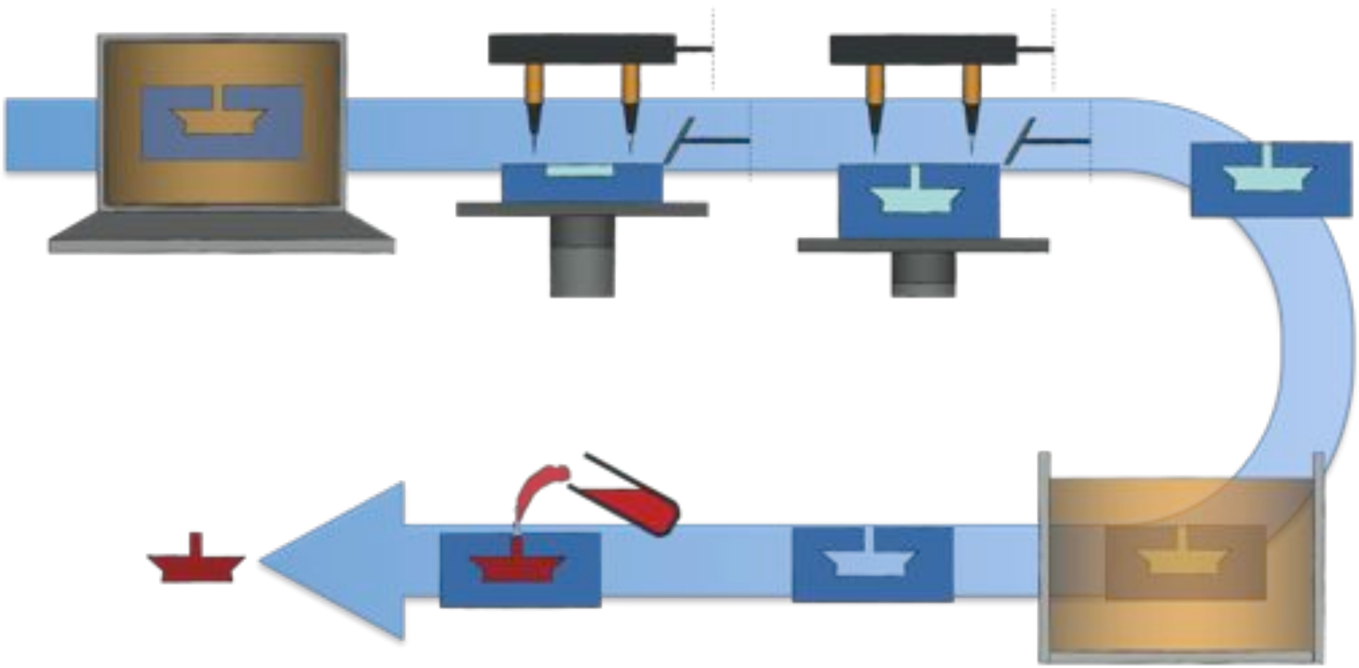
# Indirect Rapid Prototyping

Micro e Nano Sistemi

carmelo.demaria@centropiaggio.unipi.it

# Indirect Rapid Prototyping (iRP)

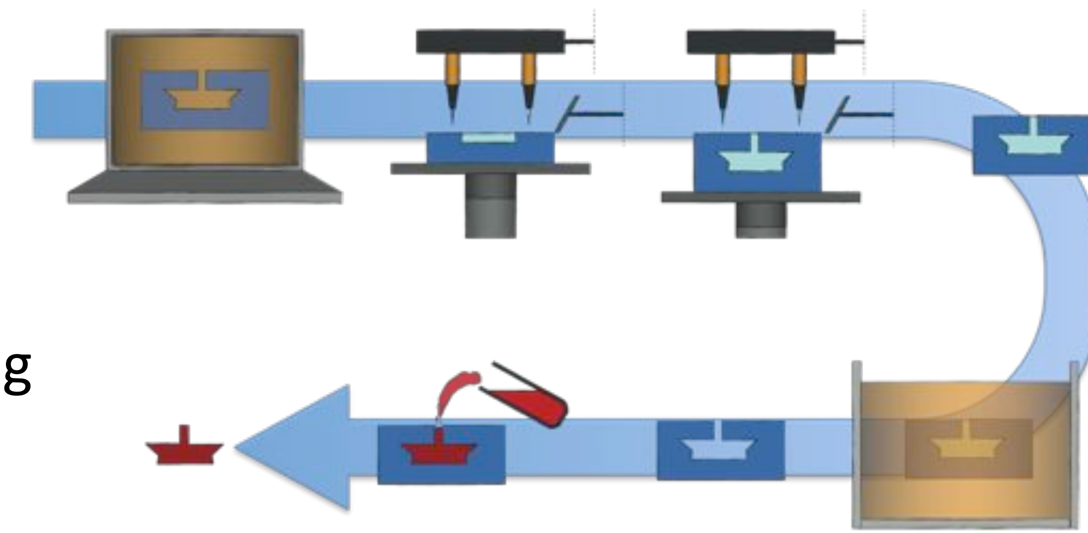
- Molds realised with RP devices (CAD/CAM)
- Casting of the desired (bio-)material
- Extraction of the final object



DW Hutmacher et al., Trends in Biotechnology, 22(7):354 – 362, 2004

# iRP – General concepts

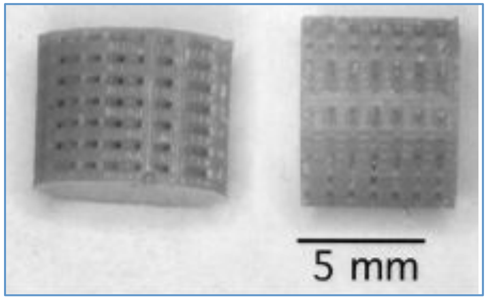
- Wide rage of (bio-)materials
- Known also as rapid tooling
- Less waste
- High fidelity
- Microporosity by:
  - critical point drying
  - free-drying
  - leaching
- Use in surgery room

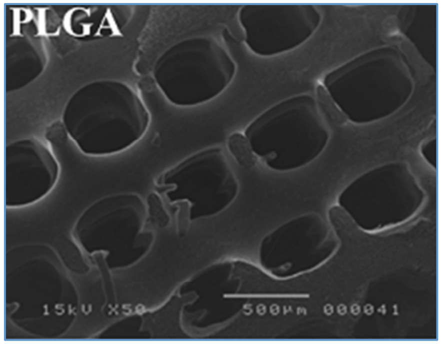


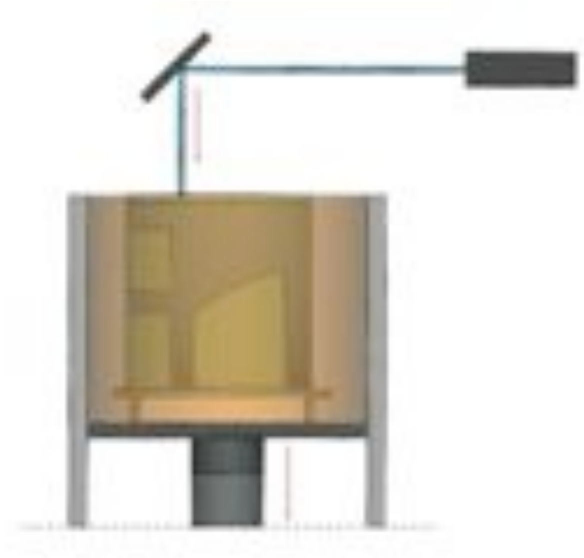
DW Hutmacher et al., Trends in Biotechnology, 22(7):354 – 362, 2004

# iRP – Stereolitography

| Casted Materials | Extraction method | Resolution (µm) |
|---|---|---|
| Thermoplastic Elastomer | Mechanical | ≈1000 |
| HA | Pyrolysis | 400 |
| PCL, PLLA, PLGA, Chitosan, alginate | Basic Solution | 200-400 |



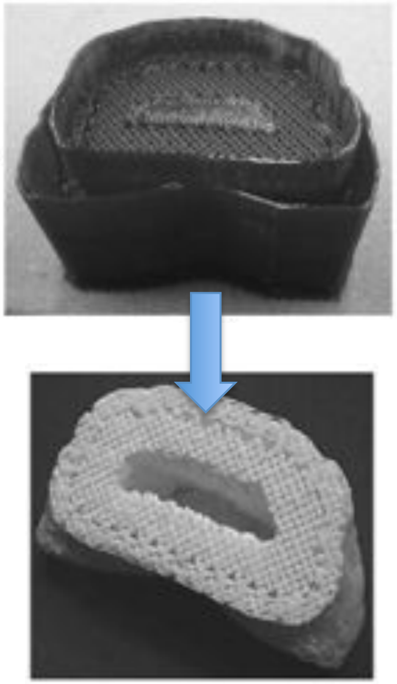


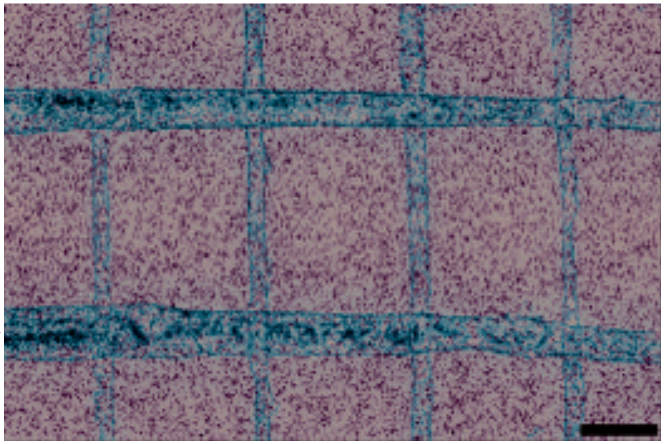



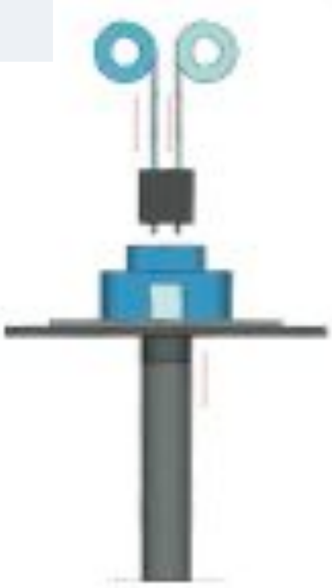
R Sodian et al,. ASAIO Journal, 48(1), 2002
T-MG Chu et al., Journal of Materials Science: Materials in Medicine, 12:471–478, 2001
YJ Seol Microelectronic Engineering, 86(4-6):1443–1446, Apr 2009
HW Kang and DW Cho. Tissue Eng Part C Methods. 2012 Sep;18(9):719-29

# iRP – Fused Deposition Modeling

| Casted Materials | Extraction method | Resolution (µm) |
|---|---|---|
| Alumina, TCP | Pyrolysis | 300-500 |
| Agarose, Alginate, PEG, Fibrin, Matrigel | Water dissolution | 500 |



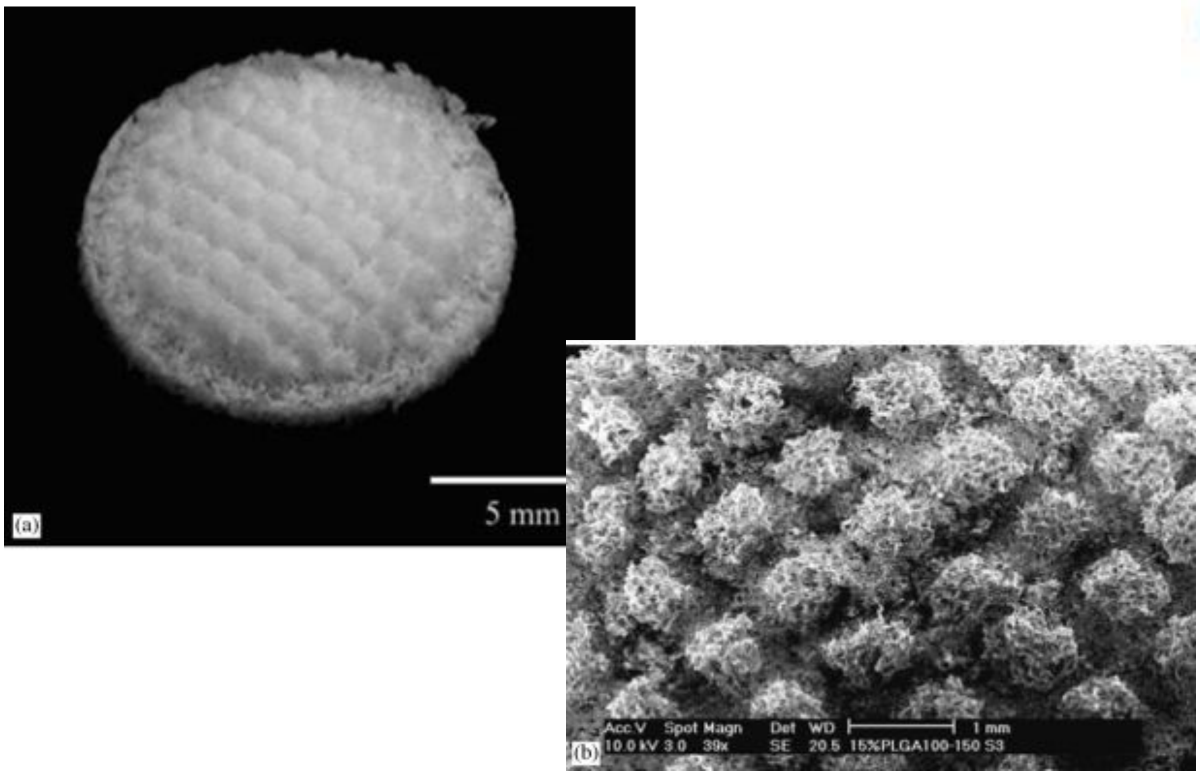


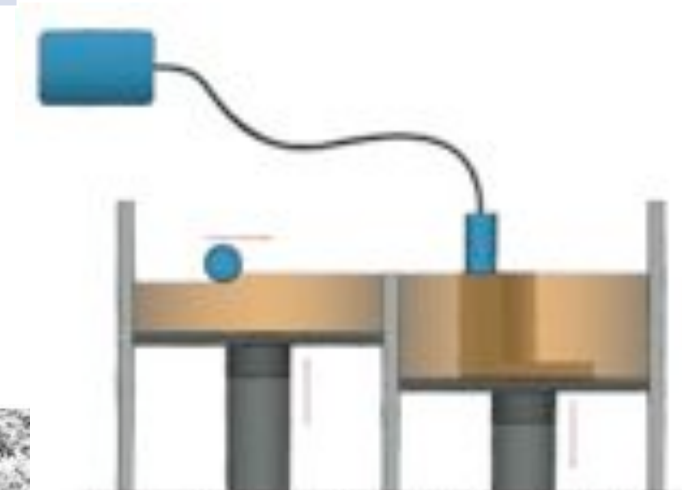


S Bose et al. Materials Science and Engineering: C, 23(4):479 – 486, 2003
JS Miller et al, Nature Materials Letters: Published online 1 July 2012

# iRP – 3D printing

| Casted Materials | Extraction method | Resolution (µm) |
| --- | --- | --- |
| PLGA | Calcium Reagent | 800 |

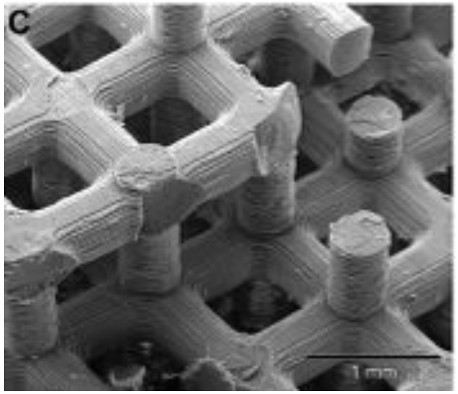


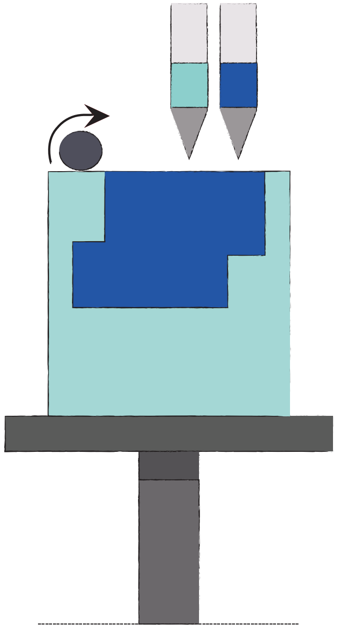
M Lee et al., Biomaterials, 26:4281–4289, Jan 2005

# iRP – Ballistic

| Casted Materials | Extraction method | Resolution (µm) |
|---|---|---|
| HA, TCP | Pyrolysis | 300-400 |
| Collagen, Silk, PLLA | Organic Solvent | 200-400 |



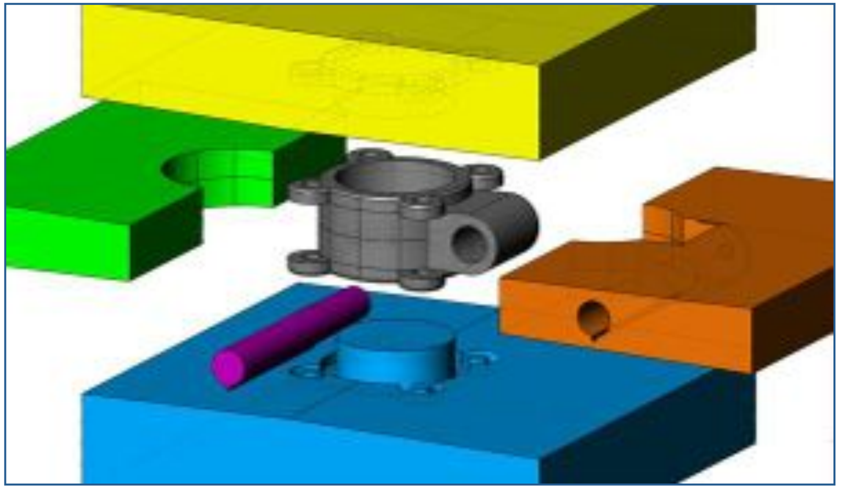





E Sachlos et al., Biomaterials, 24(8):1487– 97, Apr 2003
MJJ Liu et al.,Med Eng Phys, Nov 2011
M Schumacher et al., J Mater Sci: Mater Med, 21(12):3119–3127, Dec 2010
JM Taboas et al, Biomaterials, 24(1):181 – 194, 2003

# iRP – main problem

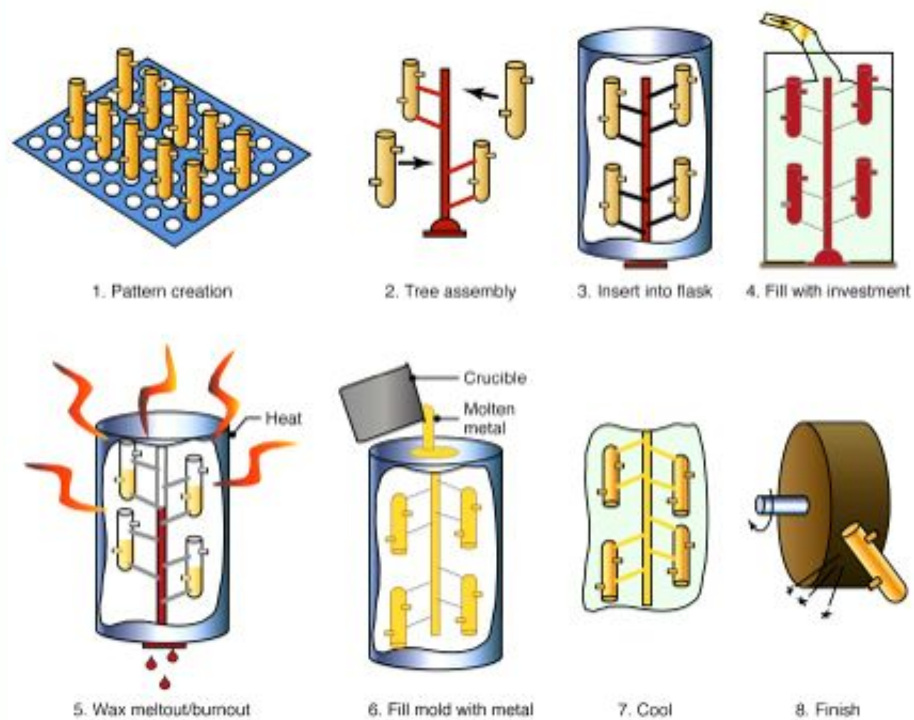
- Difficulty to extract the final object
  - Mechanical
  - Pyrolysis
  - (Organic) solvent



- IDEA:
  **CASTING INTO LOW MELTING POINT MOLDS**

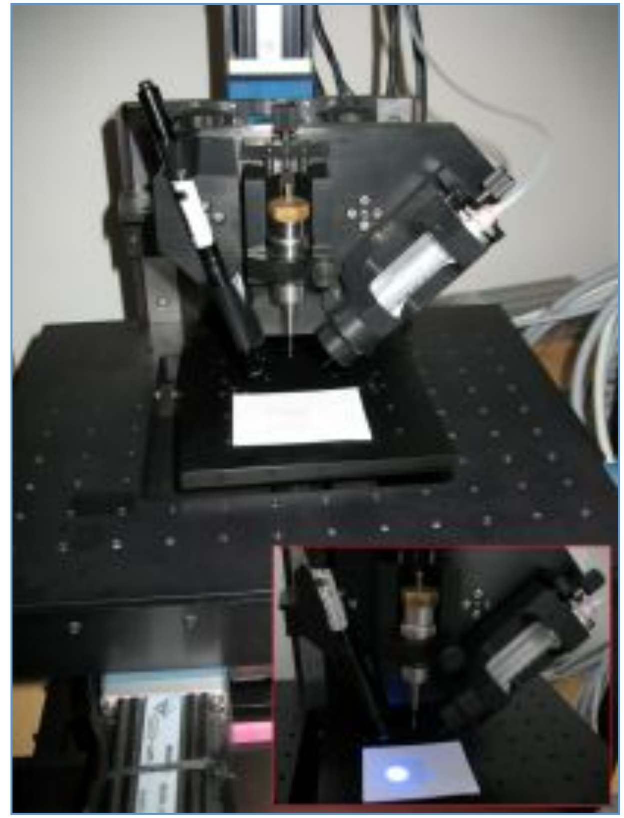
# Investment Casting Using Rapid-Prototyped Wax Parts

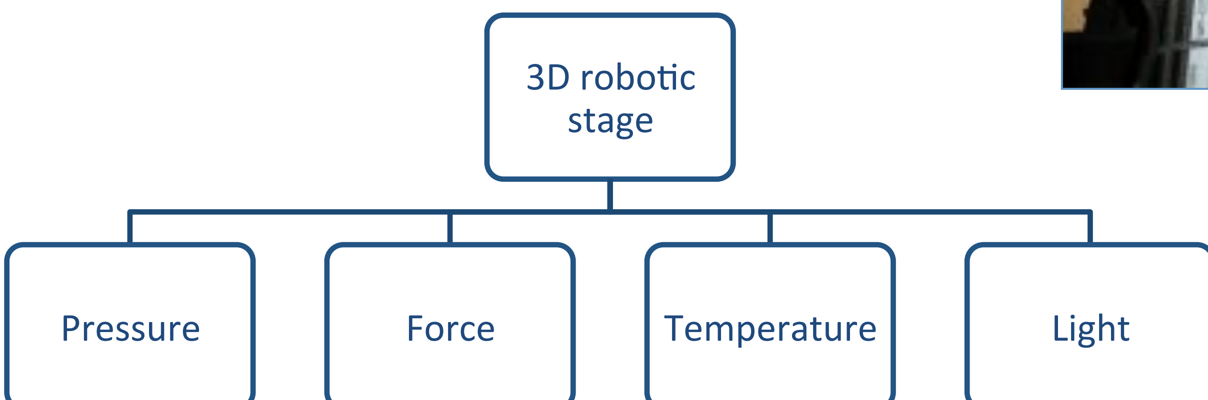
- Manufacturing steps for investment casting that uses rapid-prototyped wax parts as blanks. This method uses a flask for the investment, but a shell method also can be used. Source: Courtesy of 3D Systems, Inc.



# PAM$^2$

- Modular CAD/CAM system
- A 3-axes robotic stages:
  - position ±50 mm;
  - velocity 0-15 mm/s;
  - resolution 1 μm;
  - different extrusion modules;
  - layer-by-layer processing.

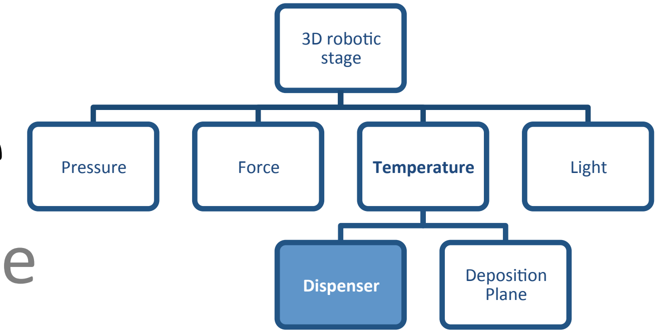


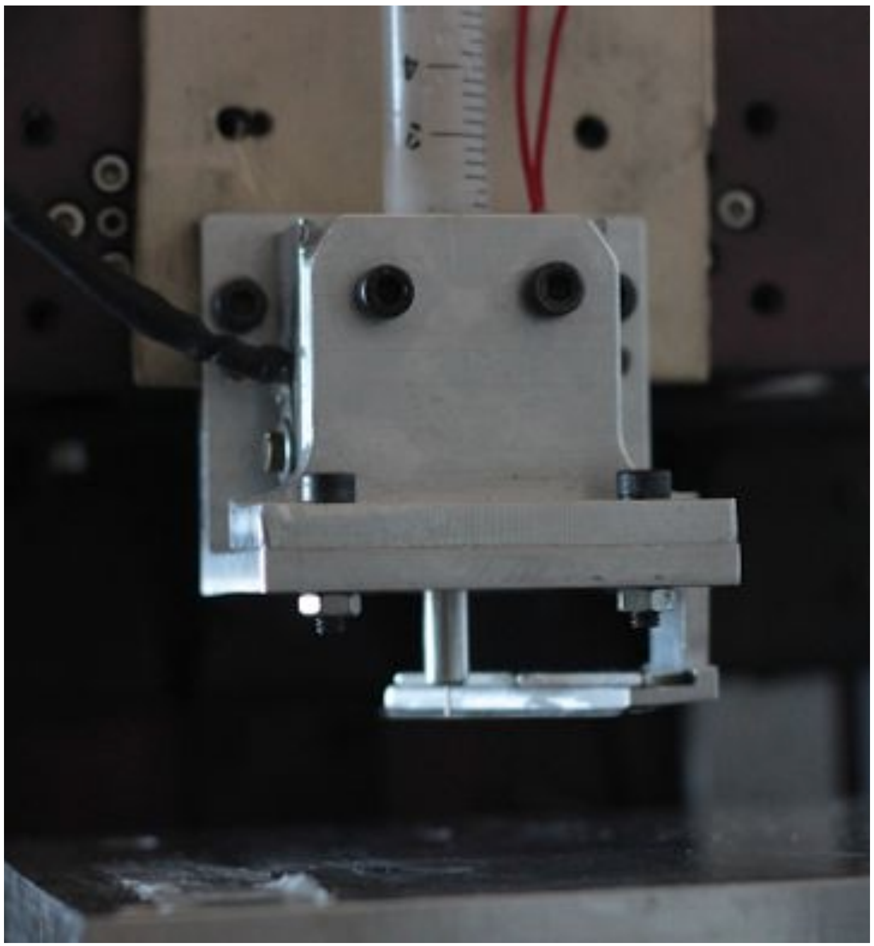


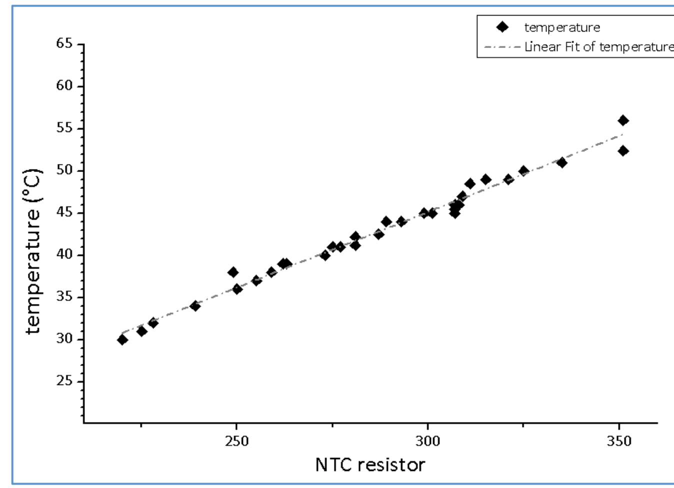

Tirella A, De Maria C, Criscenti G, Vozzi G, Ahluwalia A. The PAM$^2$ system: a multilevel approach for fabrication of complex three-dimensional microstructures. Rapid Prototyping J 2012;18(4):5-5

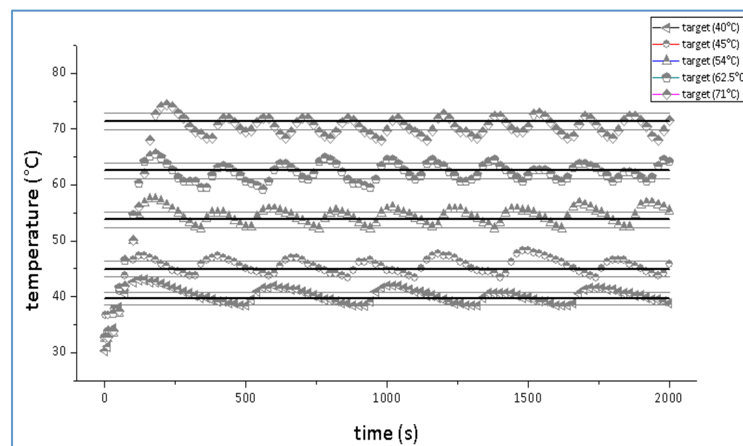
# TCS extrusion module

## Temperature Controlled Syringe



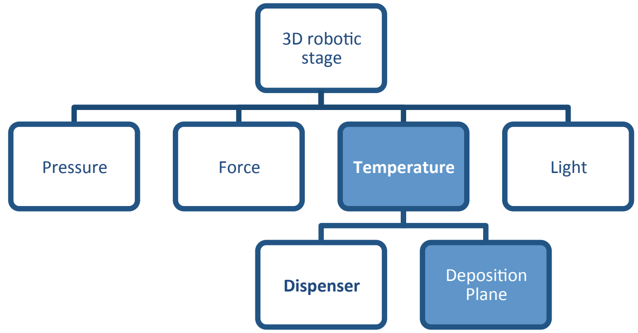





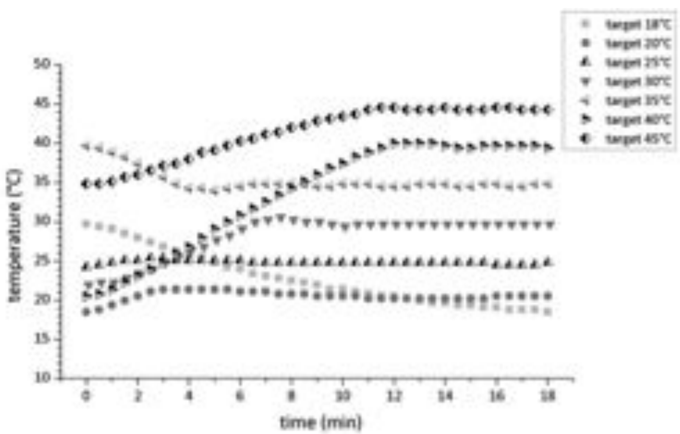



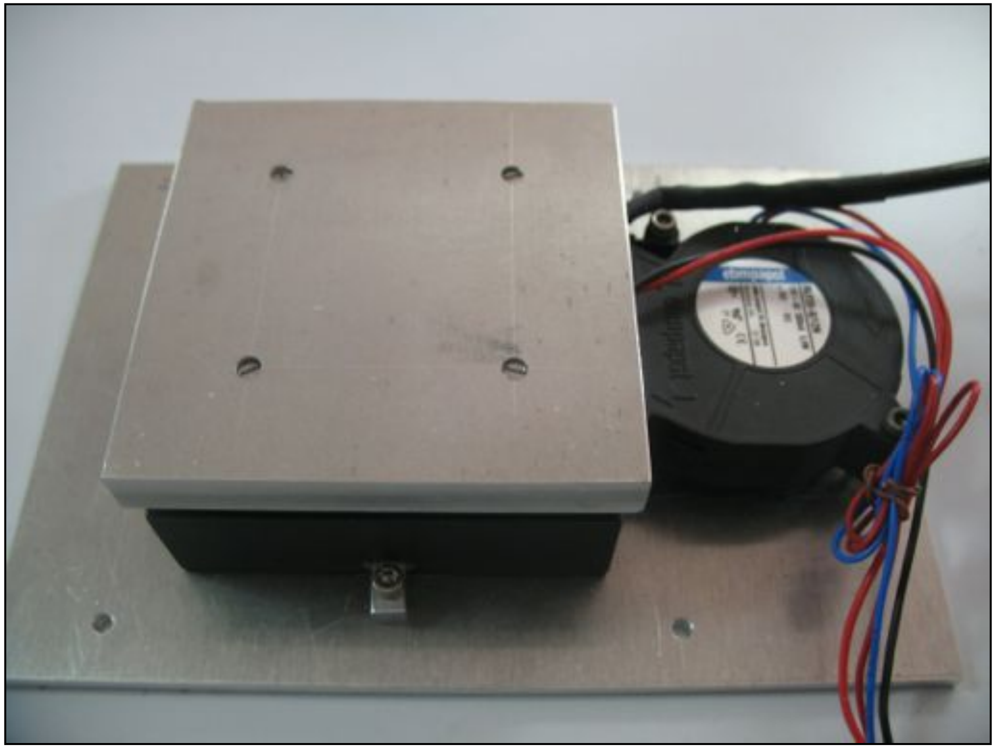
# TCD module

## Temperature Controlled Deposition plane



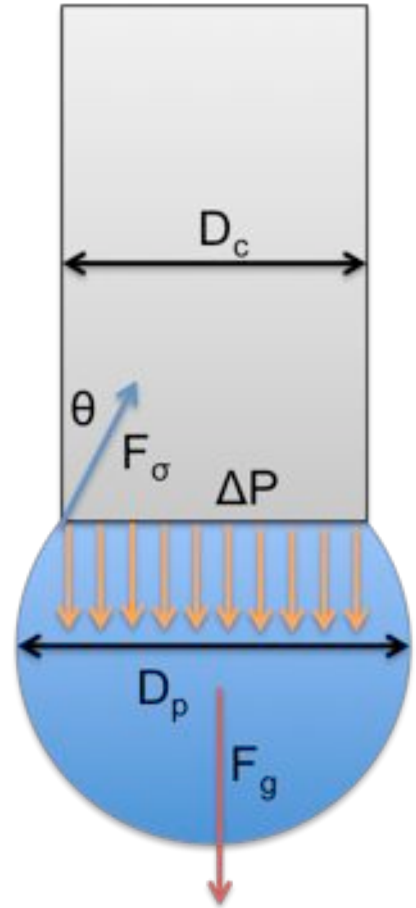

- Peltier Cell
- H-Bridge drivers
- Control algorithm based on step strategy
- ± 40°C respect to room temperature



# Plotting
# low melting point waxes

# Drop formation



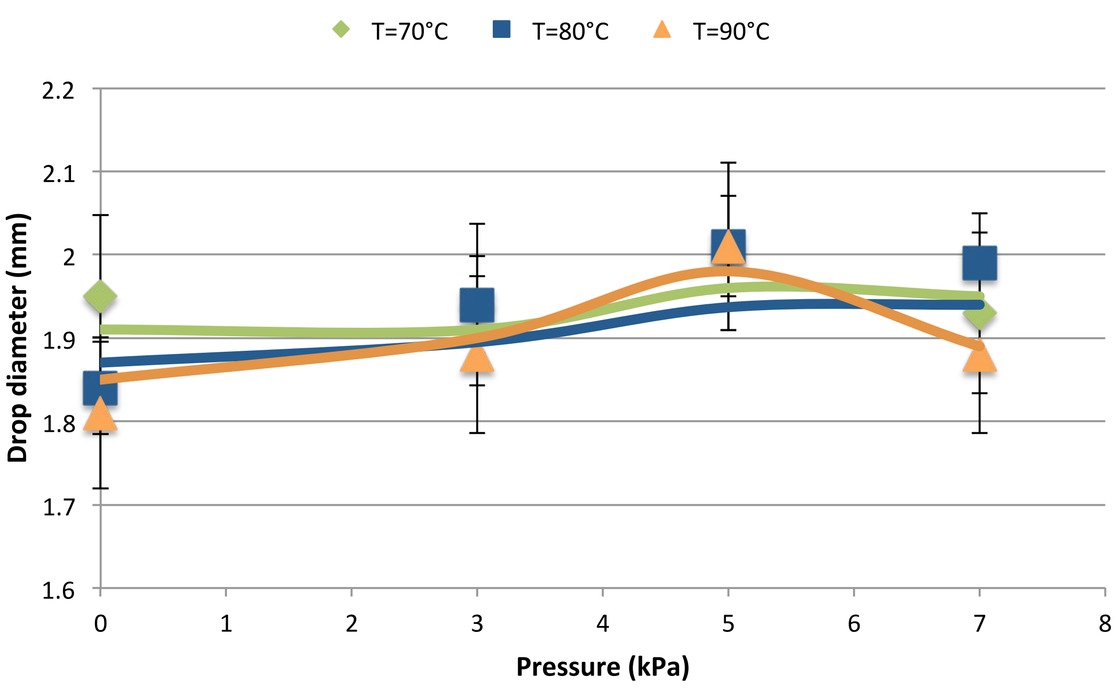

$$\frac{d(MV)}{dT} = \gamma(\pi D_0)\cos(\theta_c) \pm 2\pi\mu L \frac{V}{\ln\left(\frac{D}{D_0}\right)} - Mg$$

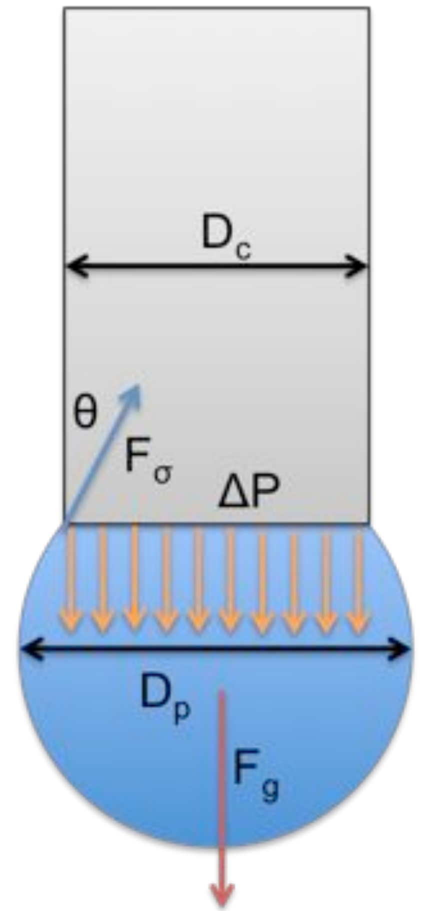
Chang B et al., Commun Nonlinear Sci Numer Simulat 17 (2012) 2045–2051

# Drop formation

- Just before drop detachment:

$$\gamma \pi D_0 \cos(\theta) = \rho g \left( \frac{\pi D^3}{6} \right)$$

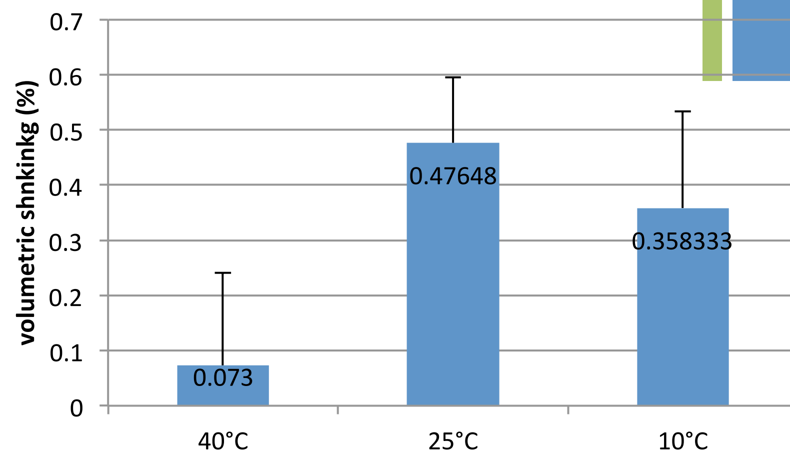


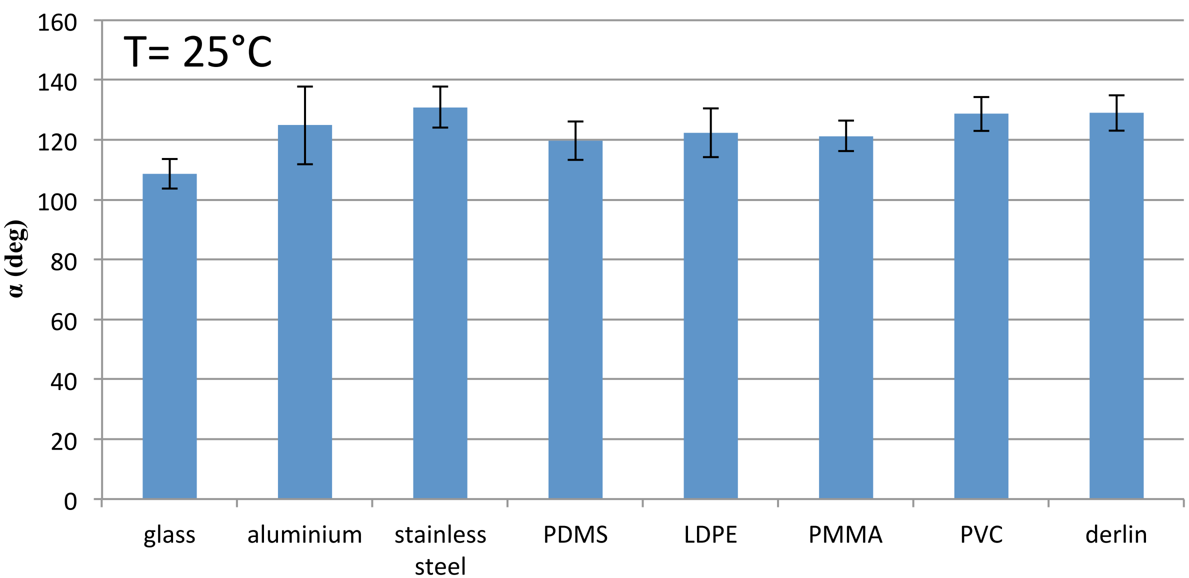



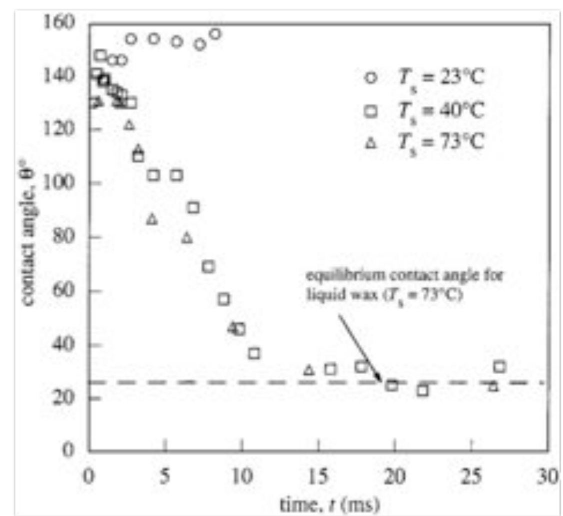
# System calibration

## preliminary tests

- Volumetric shrinking
  - Casting into an aluminium mold
- Contact angle
  - Several material tested

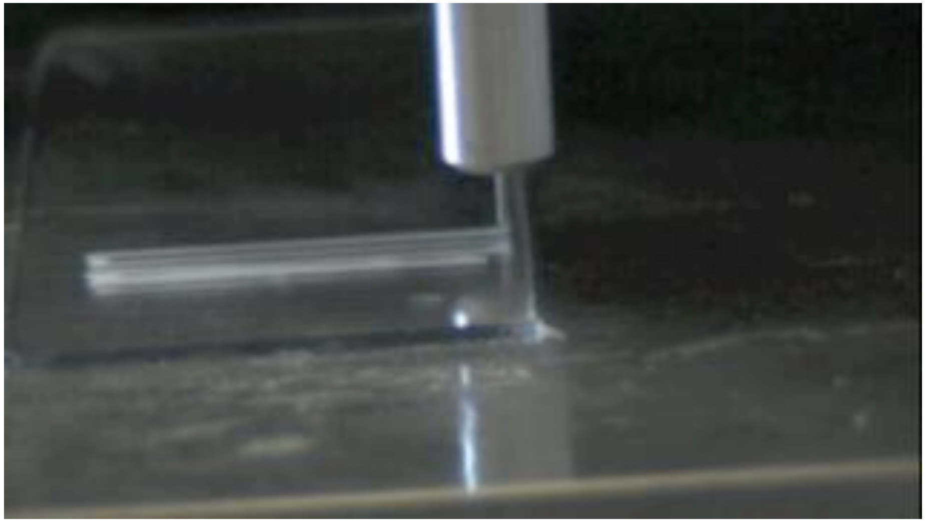


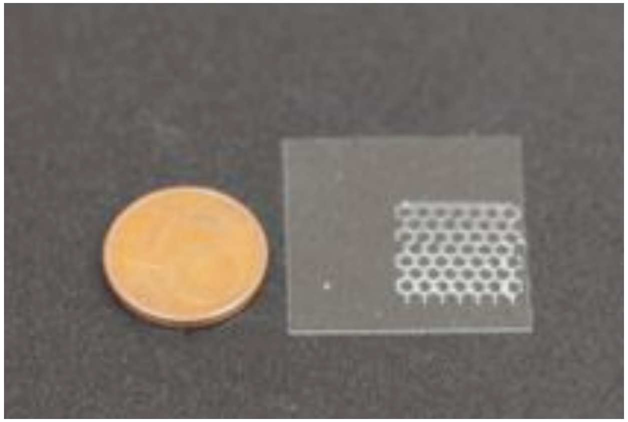



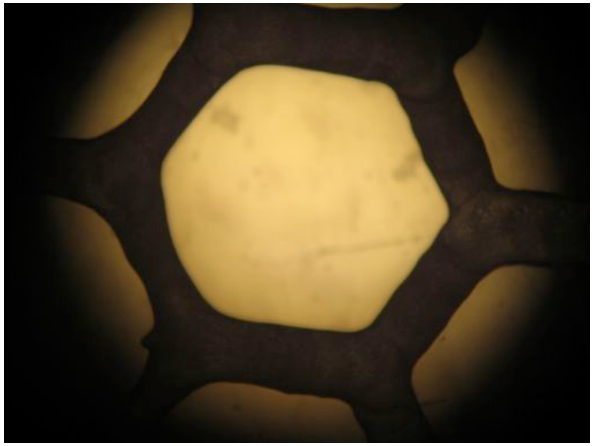



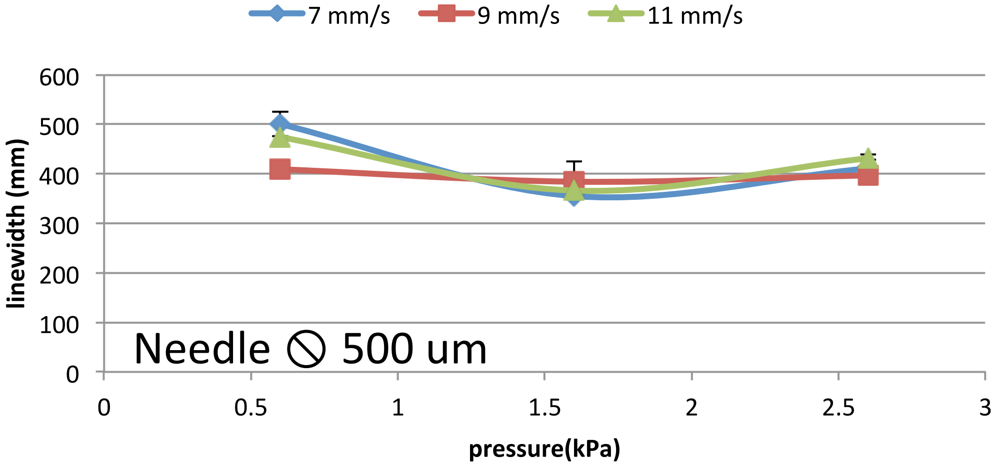

Bhola R, Chandra S, J. MATER SCI 34 (1999) 4883– 4894

# Processing parameter in PAM$^2$



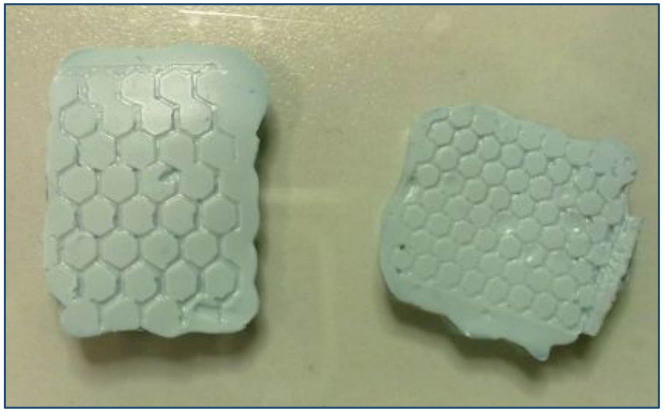


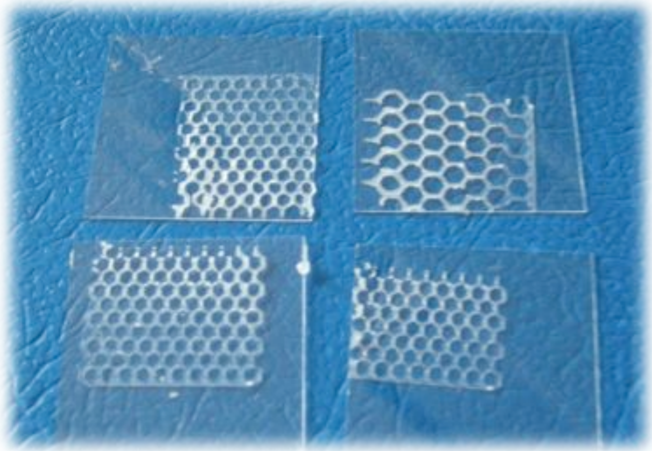


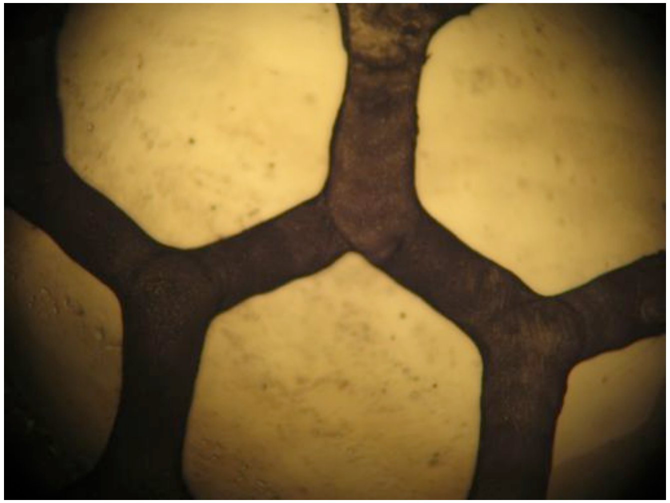


# Low melting point mold – 2D

- Hexagonal path:
  - Side 2 mm, linewidth 400 µm
  - Side 1 mm, linewidth 300 µm
- 60% W/V HA in gelatin gel (5% W/V), crosslinked with genipin 0.5 W/V
- Volumetric change < 1%

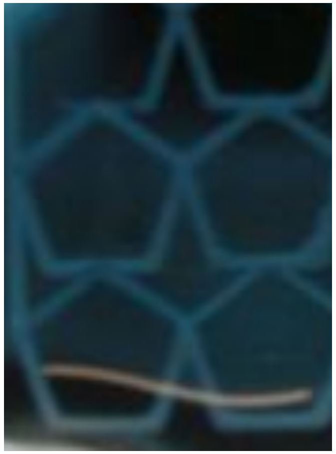




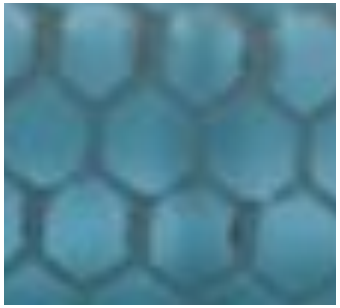


# Low melting point mold – 2D

- Hexagonal path:
  - Side 2 mm, linewidth 400 µm
  - Side 1 mm, linewidth 300 µm
- Pentagonal path:
  - Side 2 mm, linewidth 300 µm
- 5% gel-collagen 1:1 + 0.2% GP
- Volumetric change < 6 %

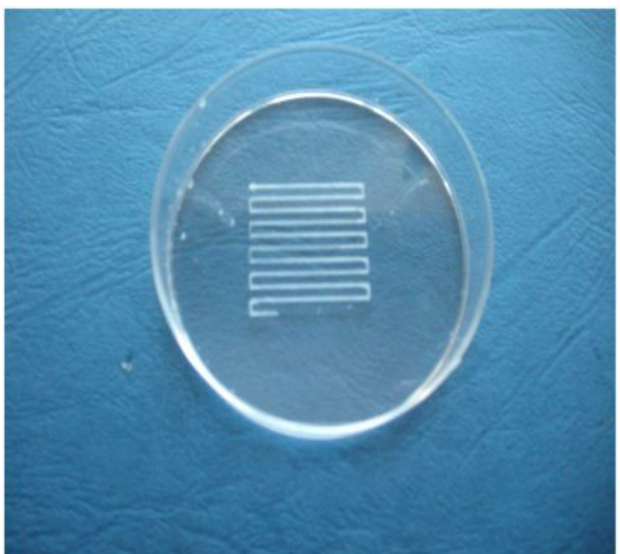





# + Low melting point mold for microfluidic devices

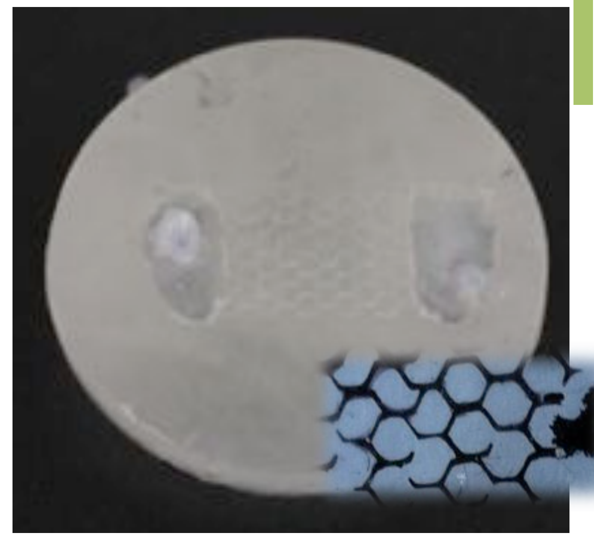
- Serpentine path
  - Length 20 mm, height 2
- Casting with 5% w/v gelatin gel crosslinked with genipin

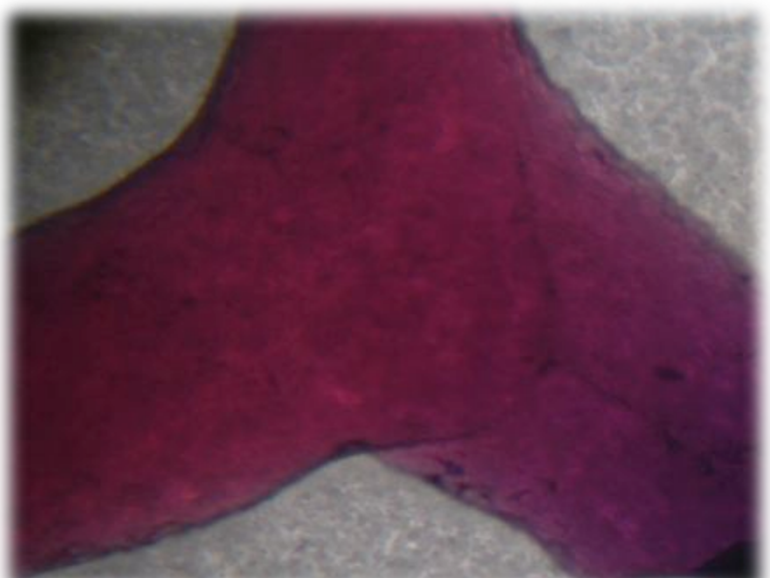


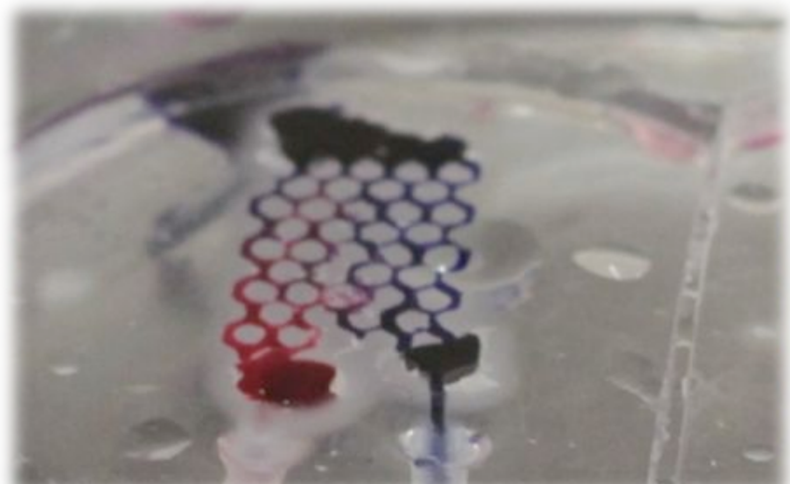
Huang et al., Biofabrication, 2011 vol. 3 (1) pp. 012001

# + Low melting point mold for microfluidic devices

- Hexagonal path
  - Side 2 mm, linewidth 400 um
- Casting with PDMS







# SHAPE DEPOSITION MANUFACTURING (SDM)

# Shape Deposition Manufacturing

- Rapid production method with repetitive addition and selective removal of materials.
- It uses conventional machining facilities, hence also achieves the same order of machining tolerances.
- Multi-material parts can be created to compose functional mechanisms, also with embedded functional parts such as sensors and actuators.
- Cross-boundary embedding is the key for realizing highly integrated structures.

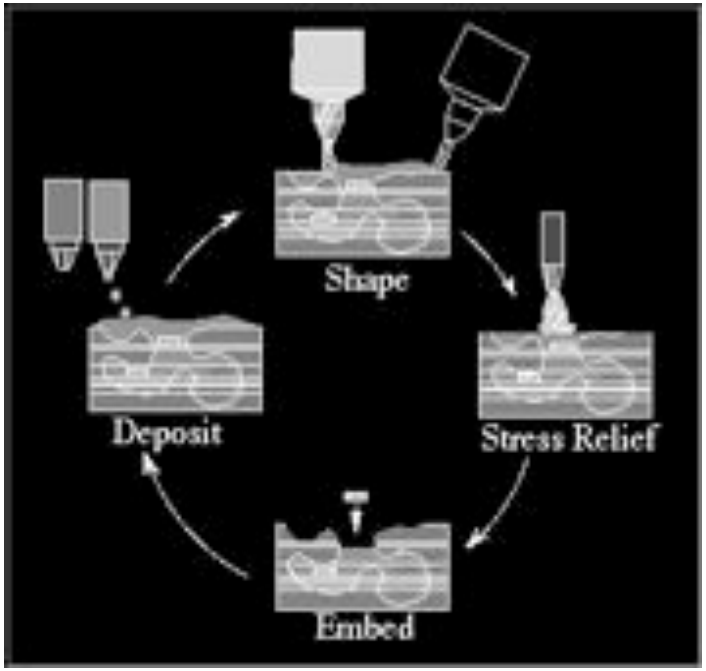
http://www-cdr.stanford.edu/biomimetics

Motohide Hatanaka: motohat@cdr.stanford.edu

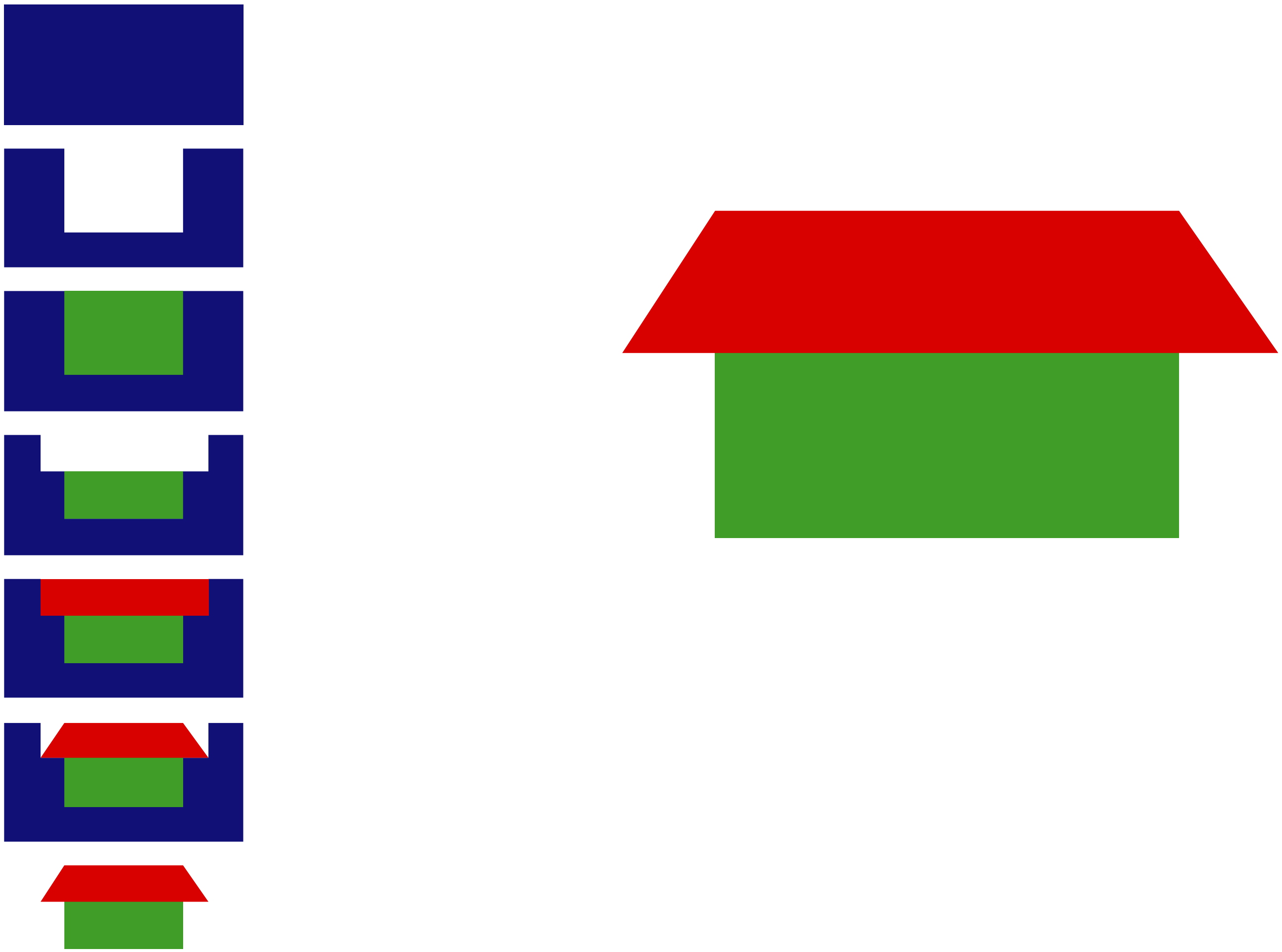
# Shape Deposition Manufacturing

- Developed at Stanford & Carnegie Mellon
- Is it a pure SFM process?

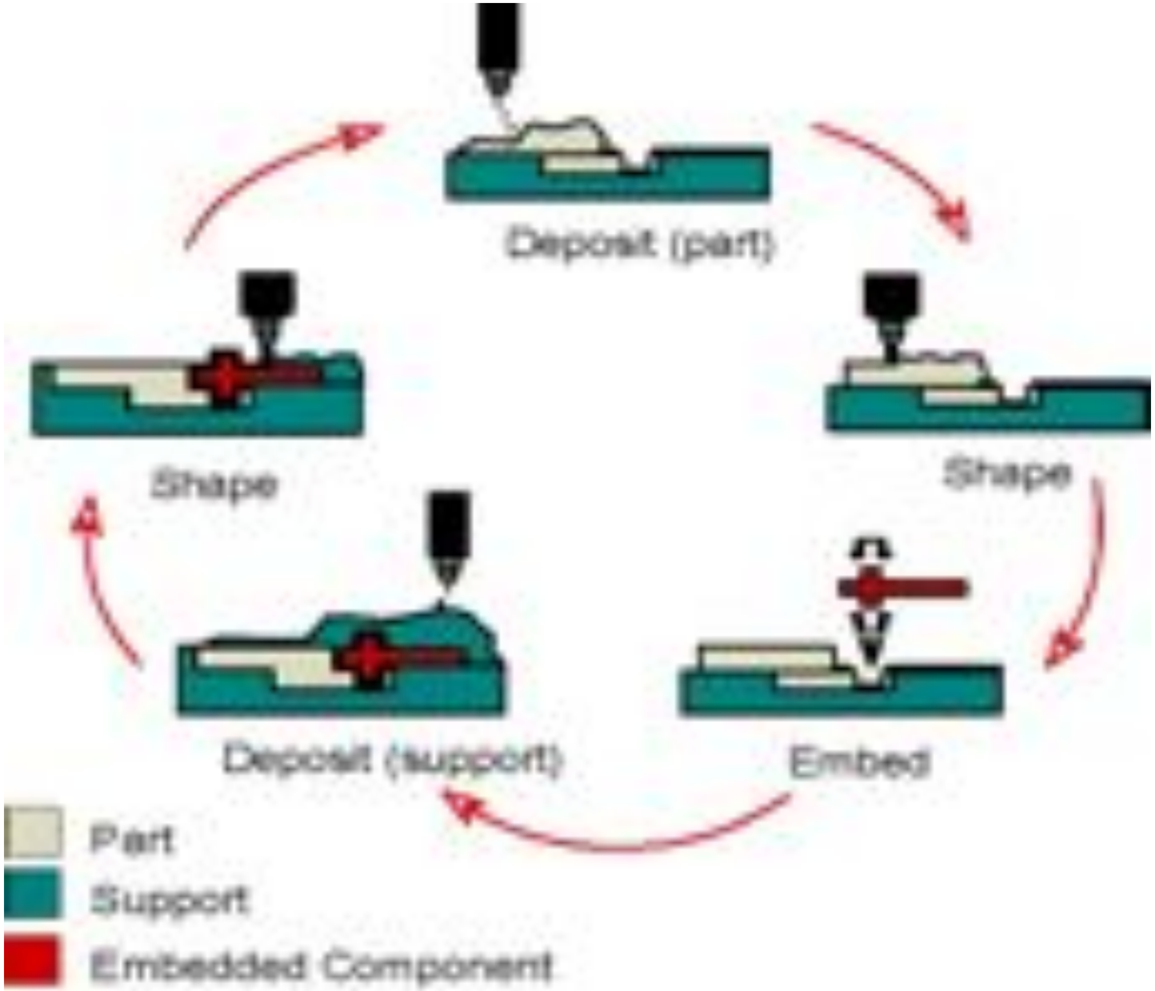
1. Deposition - material is added by plasma or laser based welding techniques
2. Filler material is deposited around part and Material is shaped using conventional CNC
3. Solid is stress relieved
4. Components can be embedded
5. Filler is removed to leave only finished part



# Why not add material in bulk and then selectively remove?



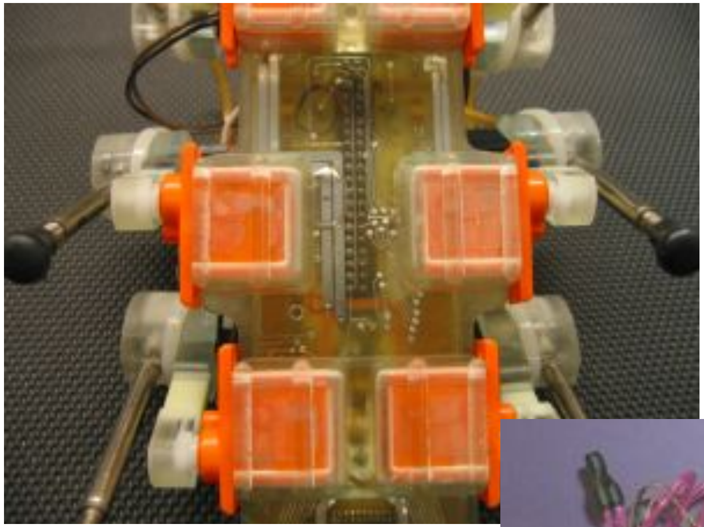
# Why not add material in bulk and then selectively remove?



# + Comparison between common RP methods and SDM

| RP | SDM |
| --- | --- |
| – Limited material variation<br>– Limited fabrication tolerance<br>– Requires special equipment | – Wide variety of materials<br>– Fabrication tolerance comparable to conventional machining<br>– Conventional machining tools used.<br>– Can embed parts (sensors, actuators, reinforcement) |

# SDM capabilities

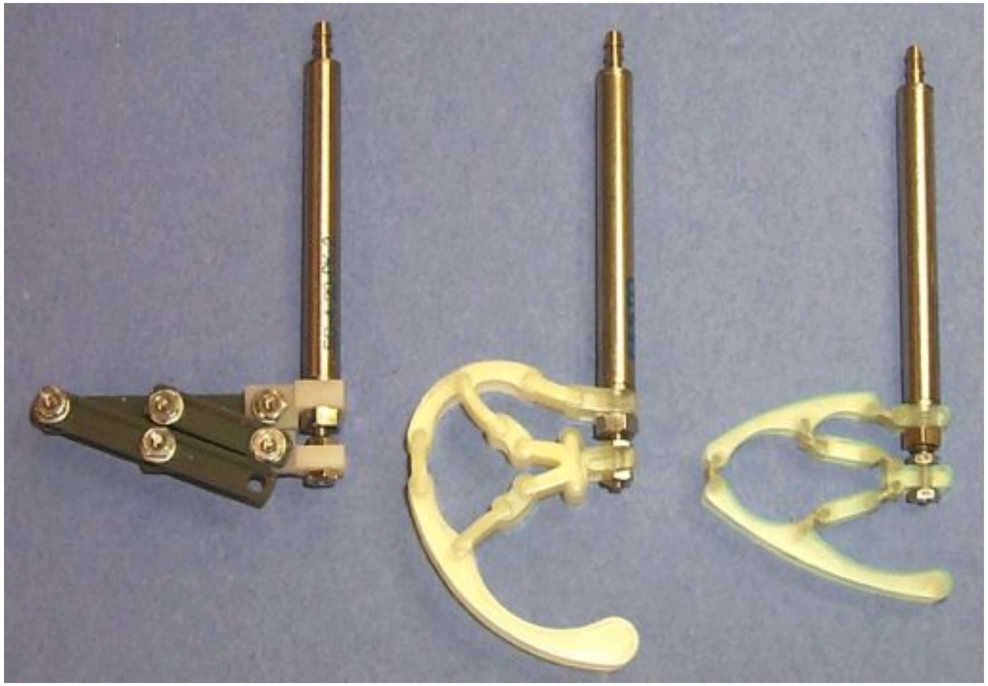


Multi-material molding

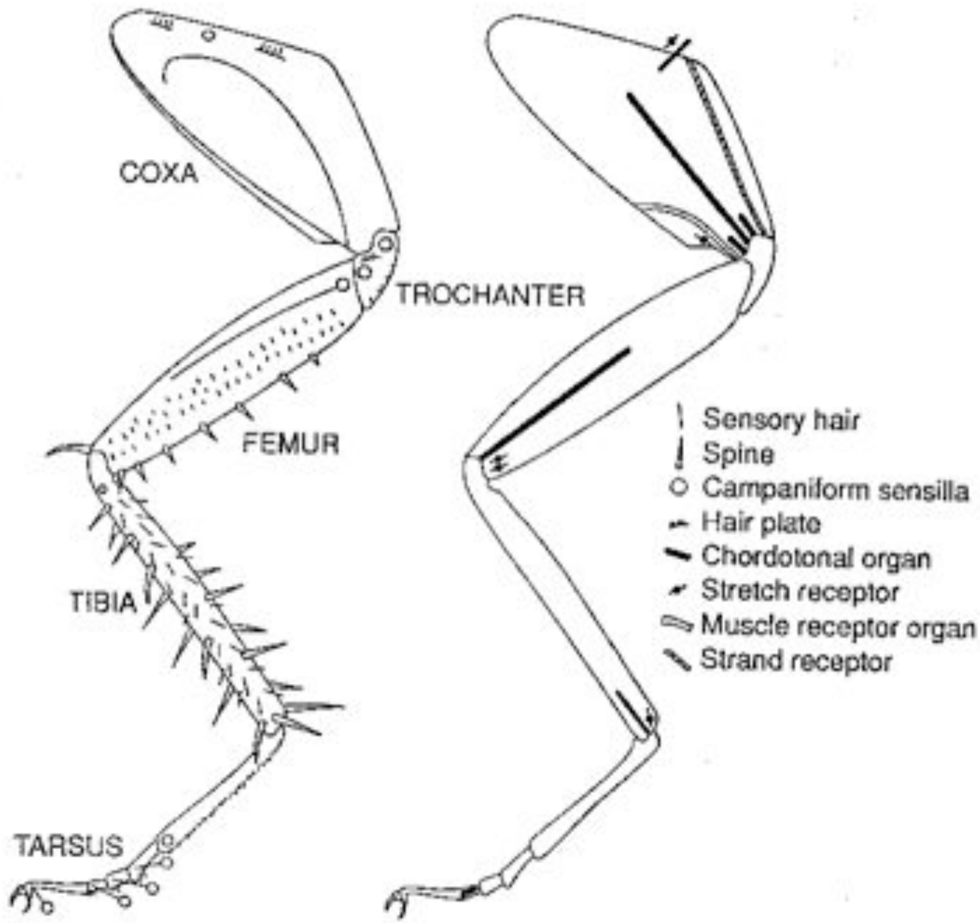
Component embedding

# Fabric-reinforced flexural hinges

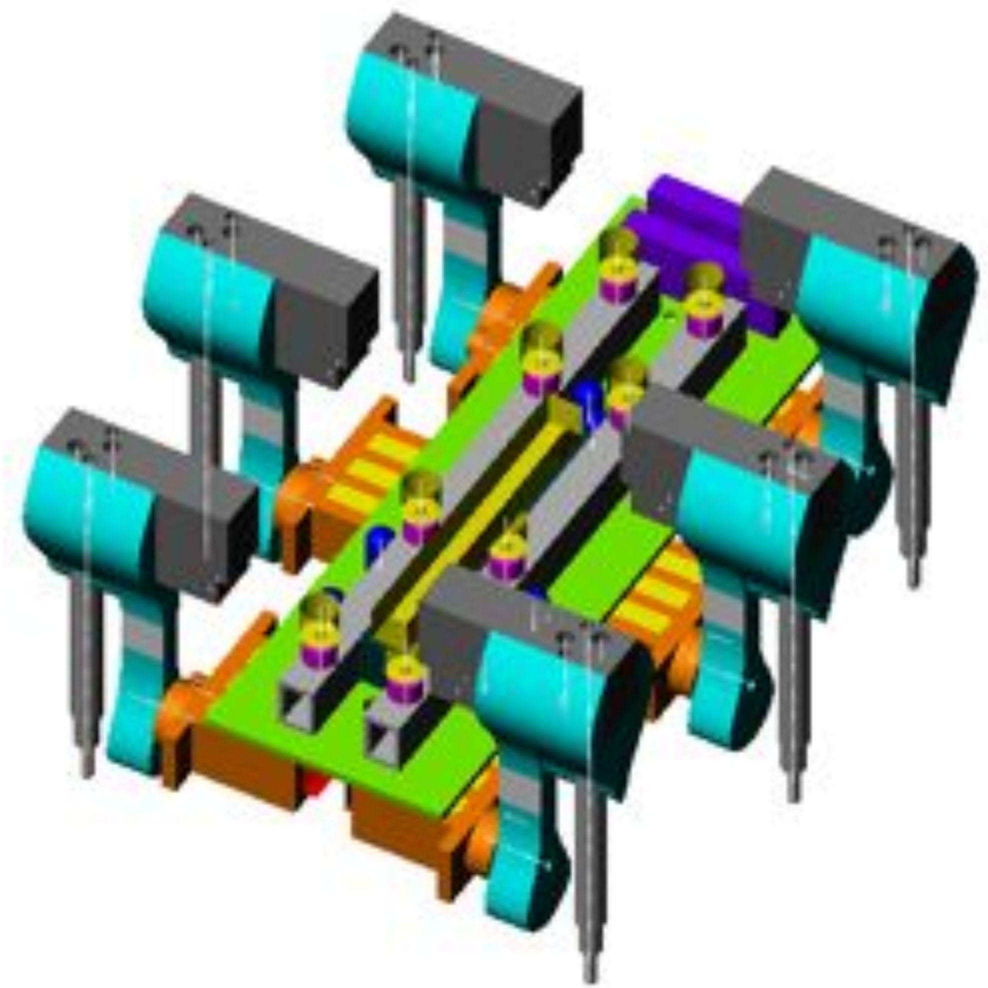
- Left: Kinematic prototype of stroke extension linkage with 31 parts
- Center: Single component SDM linkage with thick flexures
- Right: SDM linkage with thin fabric-reinforced flexures (2001)



# Biology is a target for complex integrated structures manufacturing



# SDM is suited for complex integration



- Material properties can be locally altered by multi-material fabrication.
- Components can be assembled without fasteners, hence easier and more room for complex integration.
- Semi-automated process allows detailed fabrication.

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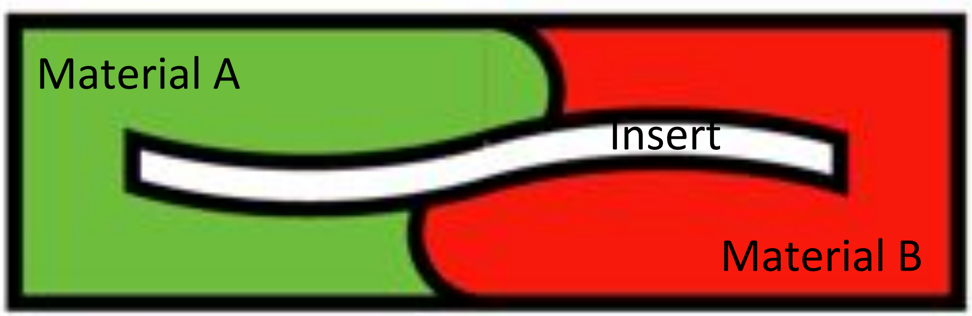
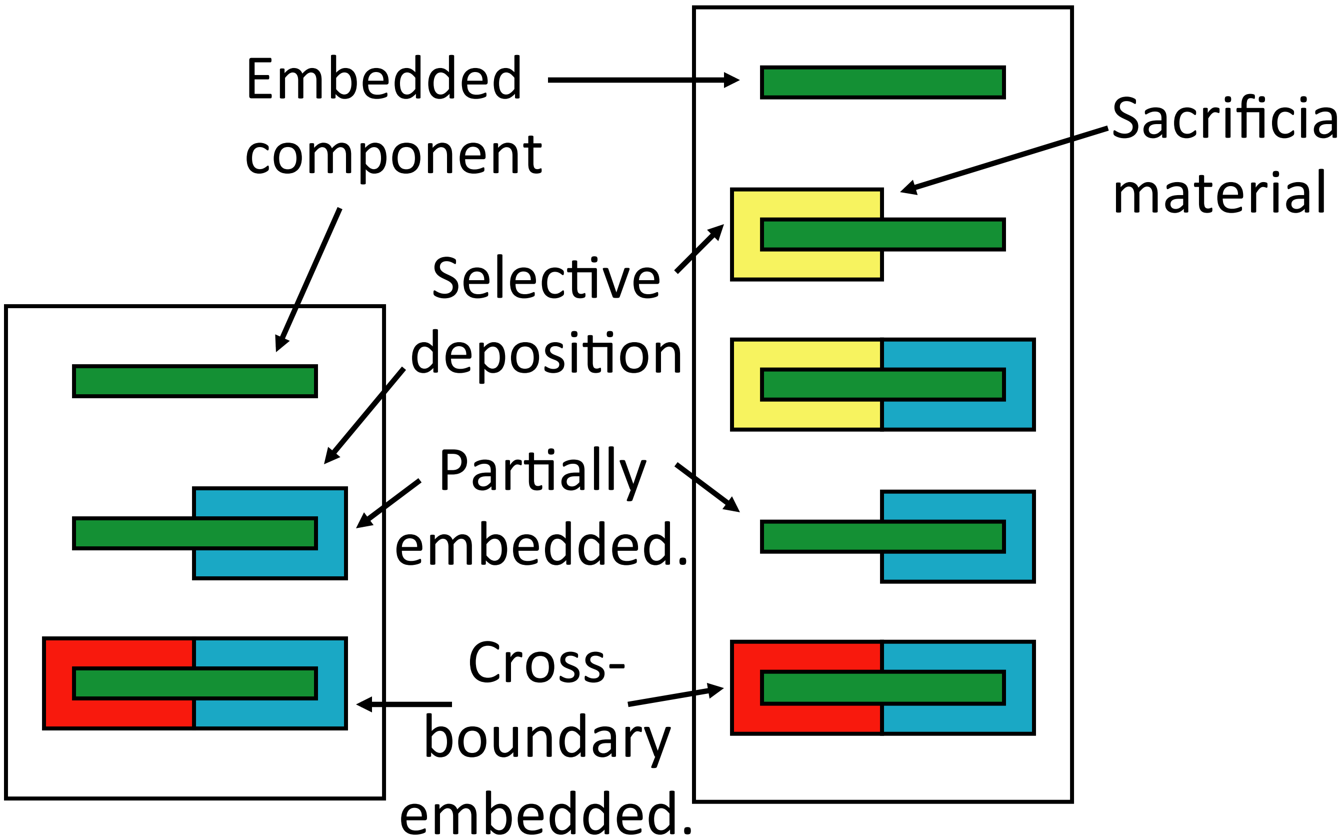
# Cross-boundary embedding

- Selectively adding, removing or otherwise processing material around the flexible strands without damaging them or being hindered by them.



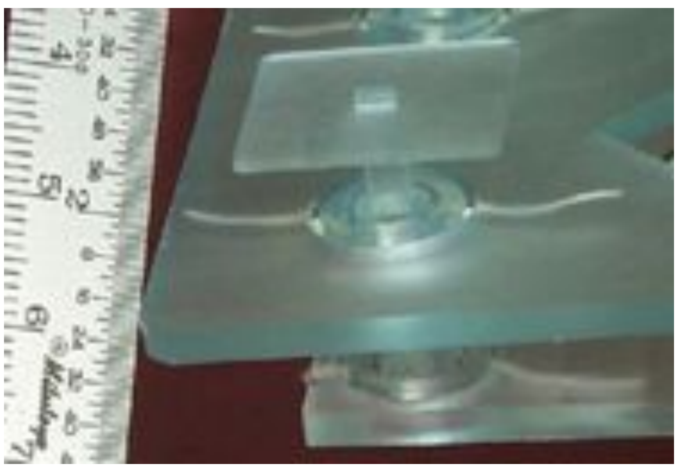
# Selective deposition




Selective deposition of part material

Selective deposition of sacrificial material

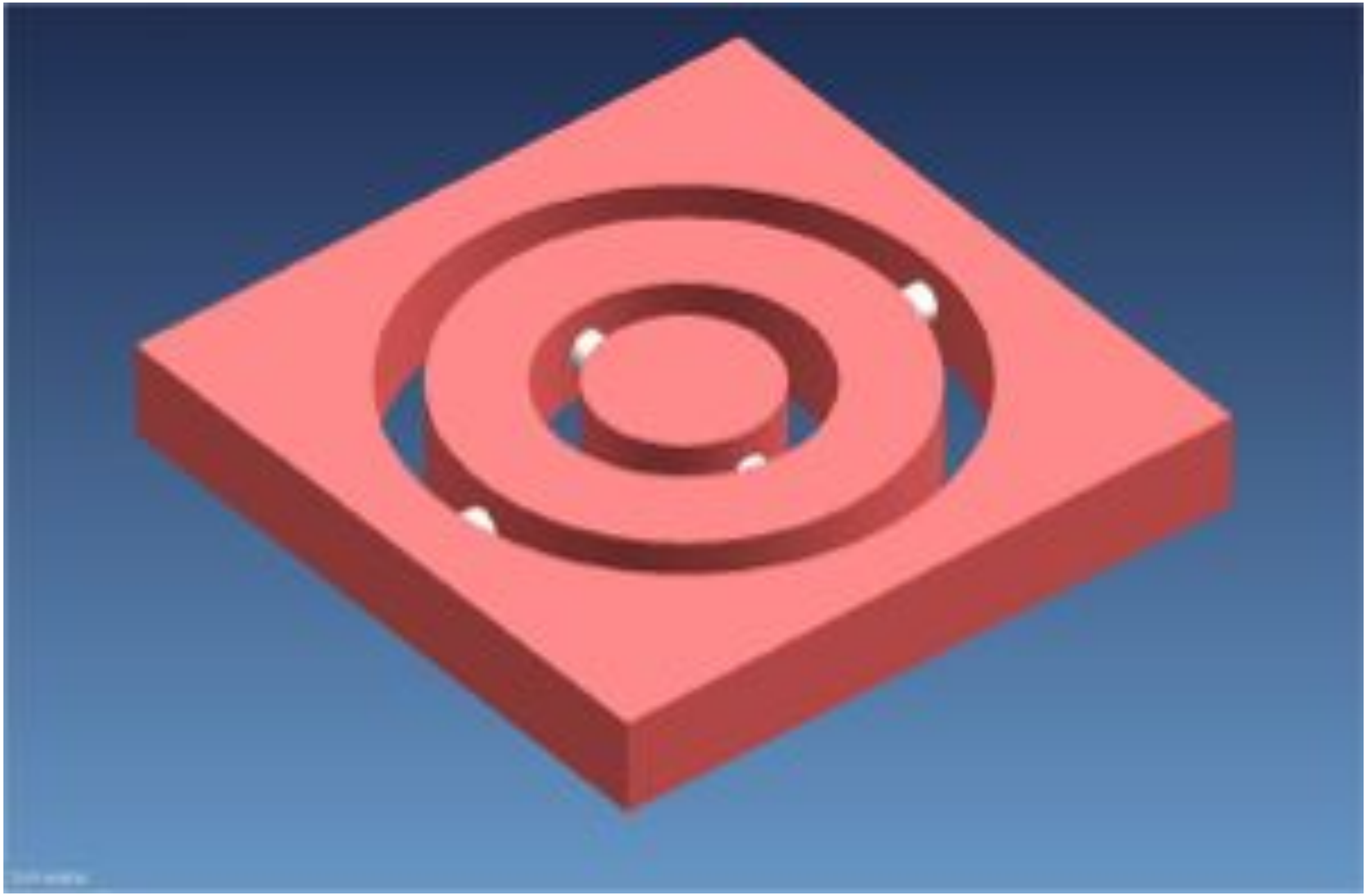
# Capillary effect for selective deposition



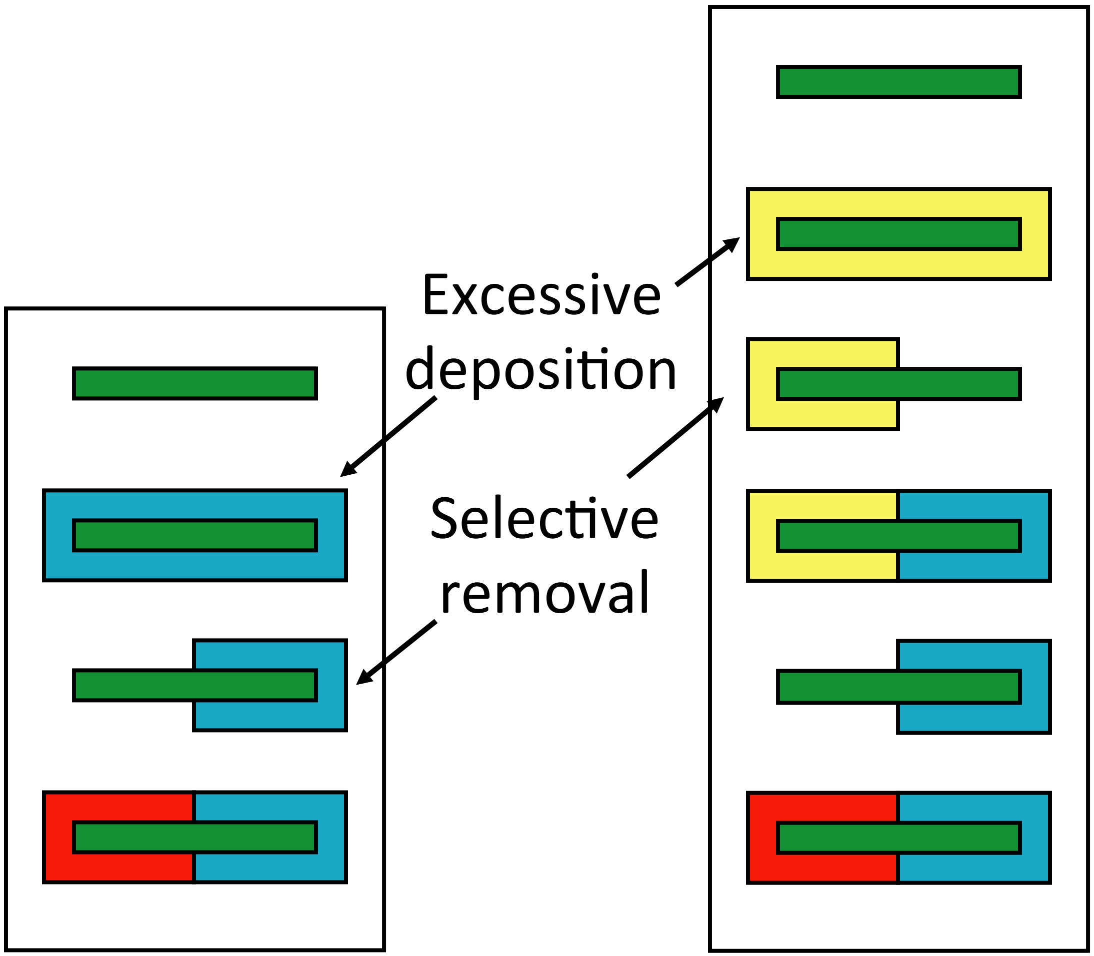
Example:

Small string-suspended gimbals with two rotational degrees of freedom. Developed for attitude control of solar panels on a small satellite (100mm-side cube).

# Selective deposition



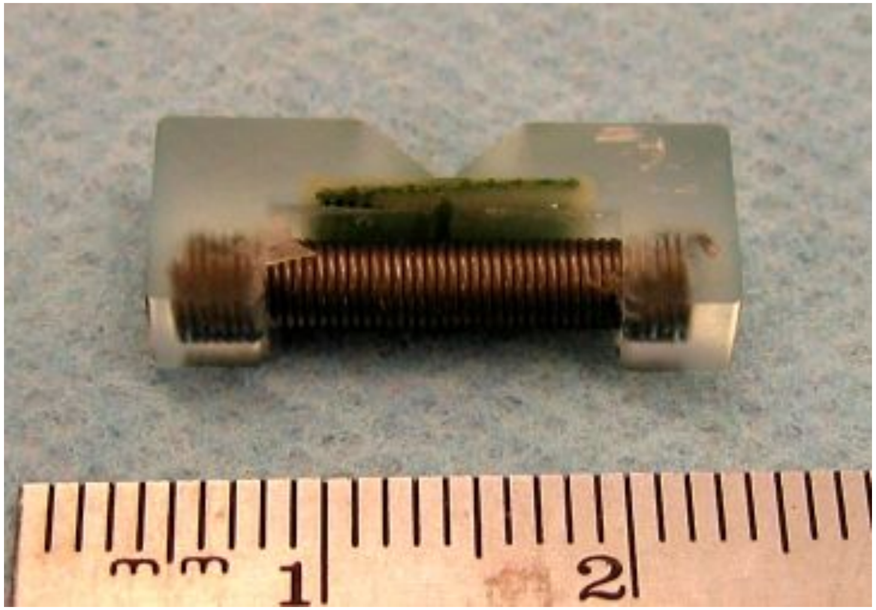
# Selective removal




Selective removal of part material

Selective removal of sacrificial material

# Manual Selective Removal

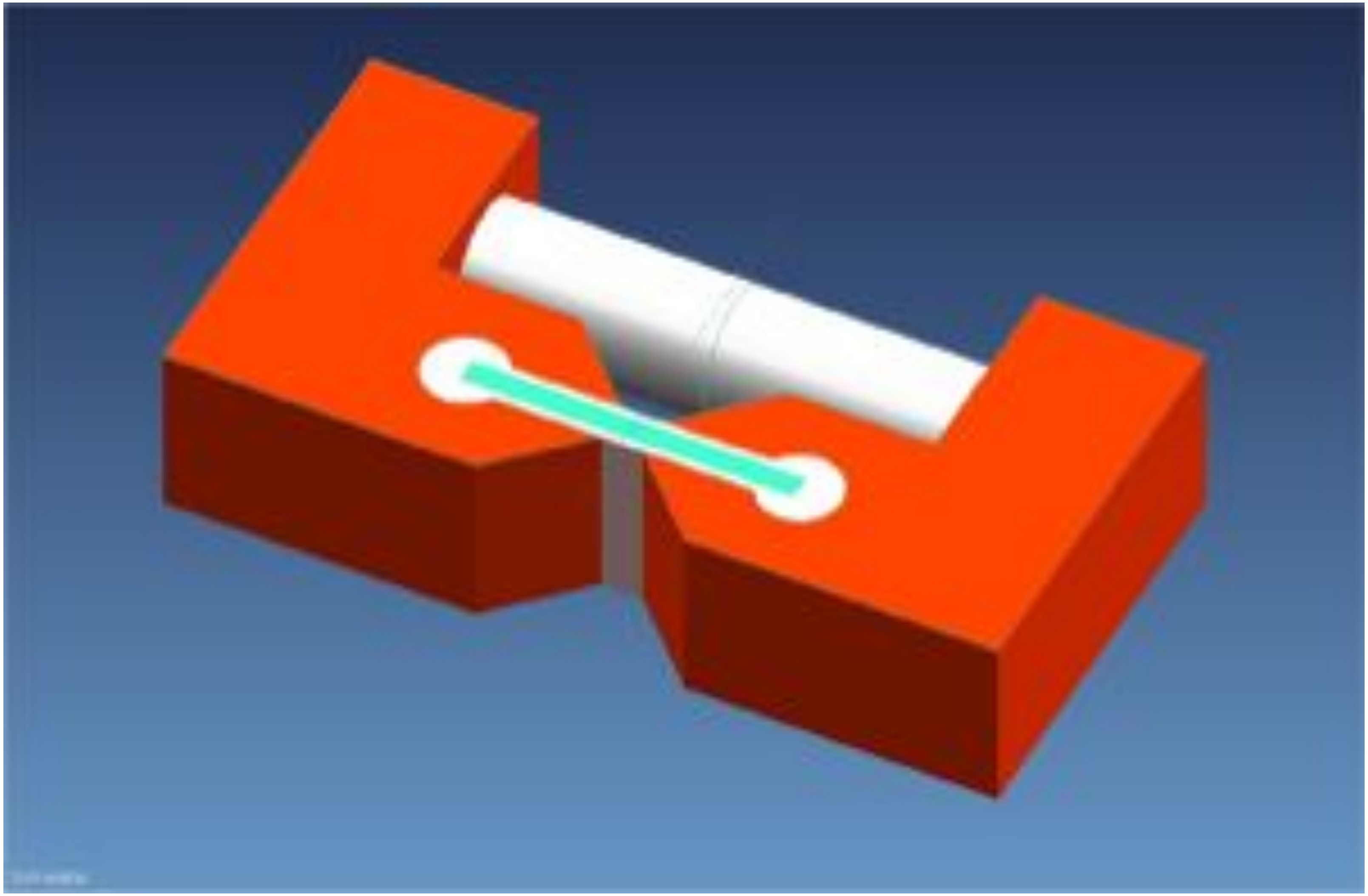


Example:

Spring-loaded hinge with partially embedded coil-spring and fiber-reinforced flexure. Developed for deploying solar-panels for a small satellite.

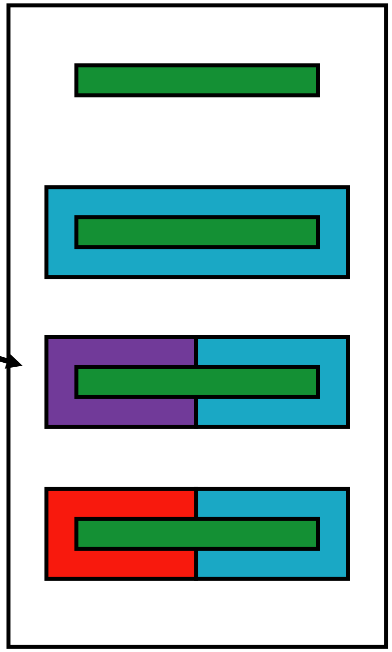
+

# Selective removal

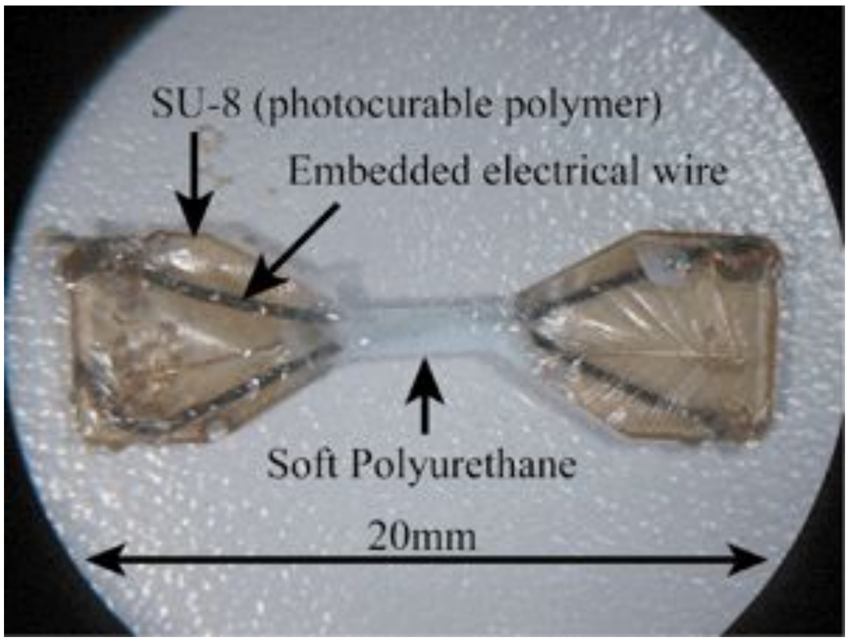


# + Material property alteration by post-processing

Material property alteration.
E.g. by heat treatment, light exposure, or material addition.



# Selective removal by photo-lithography




Example:

A small flexural hinge with embedded electrical wires.

# Selective removal by photo-lithography