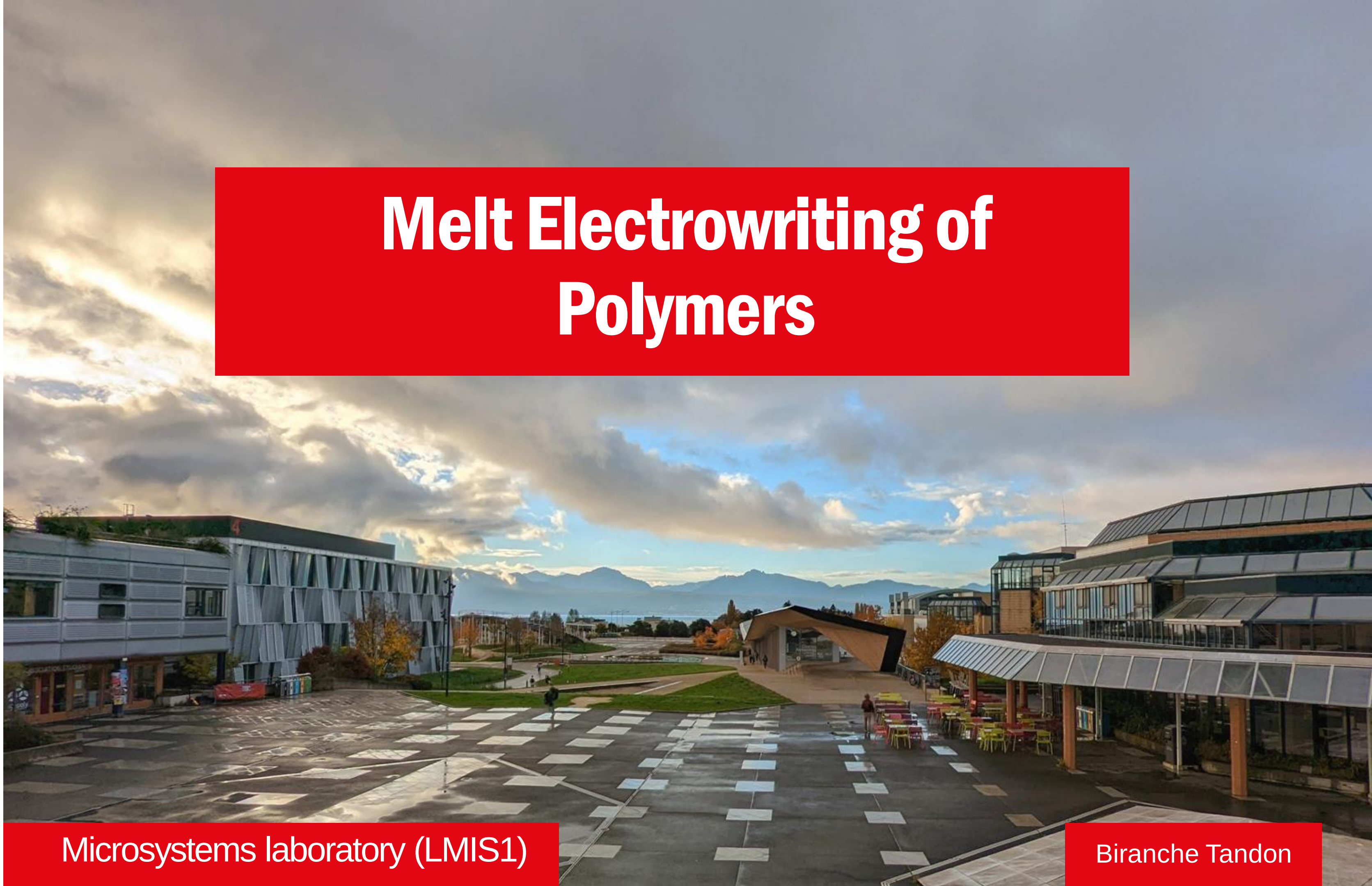
# Melt Electrowriting of Polymers



Microsystems laboratory (LMIS1)

Biranche Tandon

EPFL

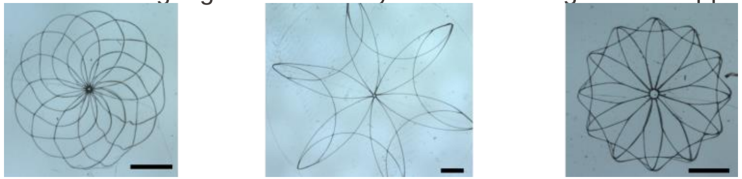
## Biranche Tandon

Additive manufacturing, functional materials, biomedical materials

**Hobbies**
Photography, cooking, Brazilian Jiu-jitsu, swimming, watching cricket and soccer

# Experience and Education

- Post Doctoral Research Scholar with Prof Paul Dalton (Germany and US)
  - Introduction to AM/3D printing
  - Melt electrowriting of a variety of polymers
  - Building high end MEW systems including custom applications



MEW structures printed to learn the technique

- PhD with Prof Sarah Cartmell and Dr Jonny J Blaker (United Kingdom)
  - Fiber fabrication using electrospinning and solution blow spinning
  - Material characterisation techniques and *in vitro* biomaterial characterisation
- Undergraduate and Postgraduate education at Indian Institute of Technology (IIT, Varanasi, India)
  - B.Tech in Bioengineering and M.Tech in Biomedical Technology

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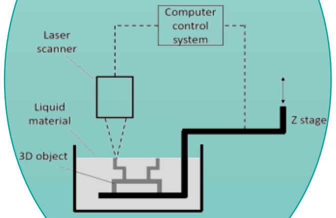
# Developmental Timeline – Additive Manufacturing

1983 – Stereo-lithography




Huang et al, *Processes* **2020**, *8*(9), 1138

1988 – Fused Deposition Modelling (FDM)

1992 – Selective Laser Sintering

1999 – Digital Light Projection (DLP)

2009 – FDM patent expires

Markforged

Carbon

MakerBot

formlabs

Today – **Melt Electro Writing (MEW)**



https://additive-manufacturing-report.com/technology/polymer/polymer-additive-manufacturing-history/

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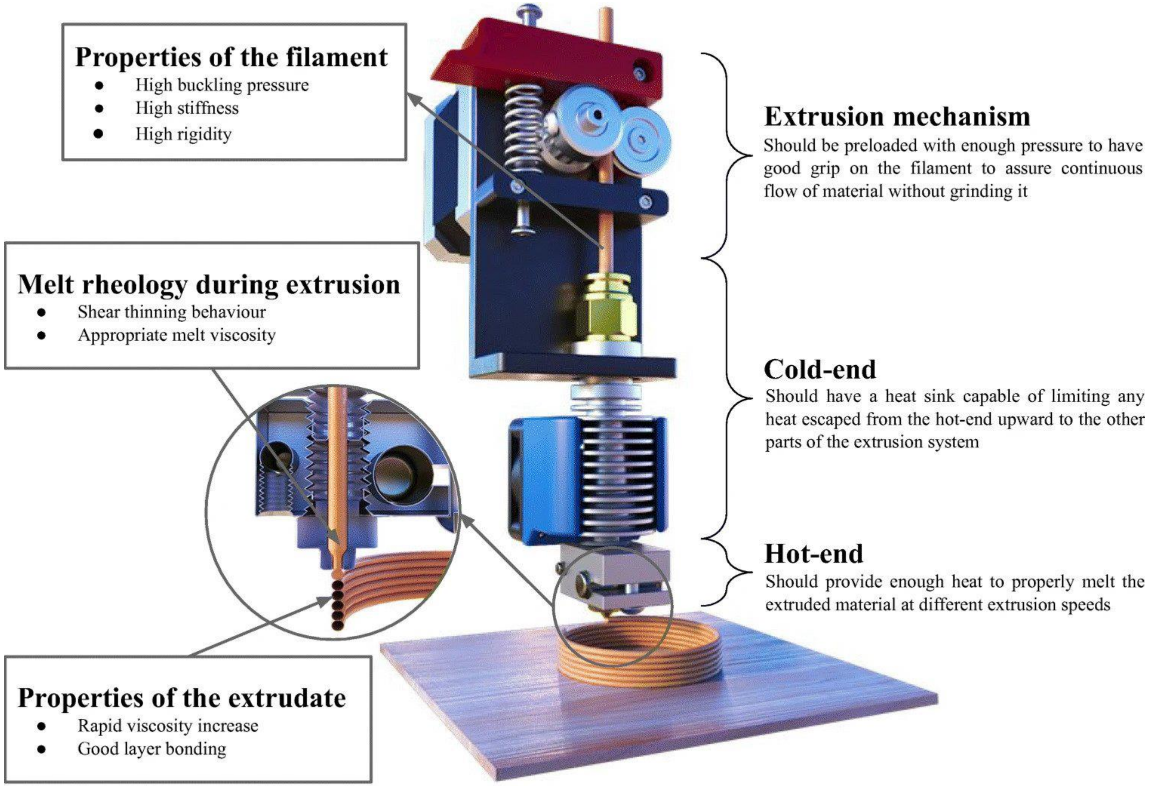
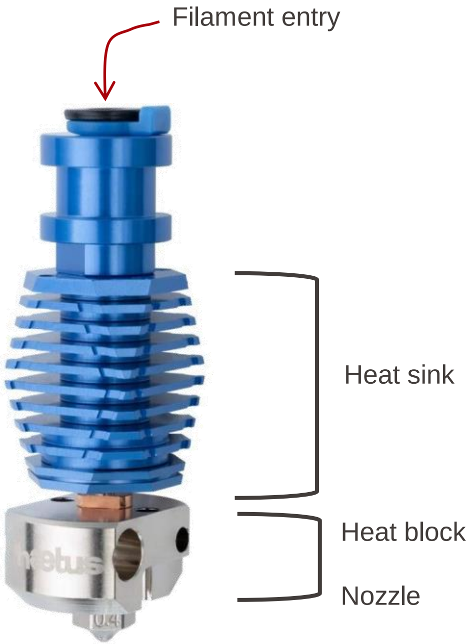
# Fused Deposition Modelling

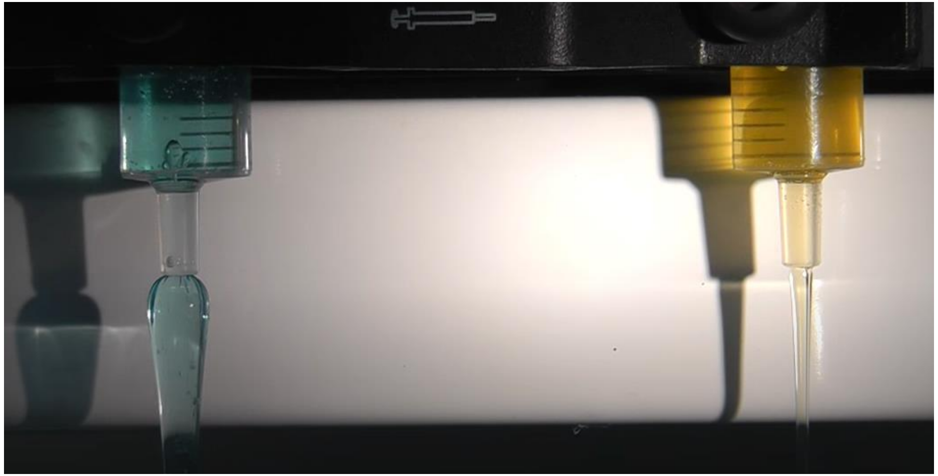


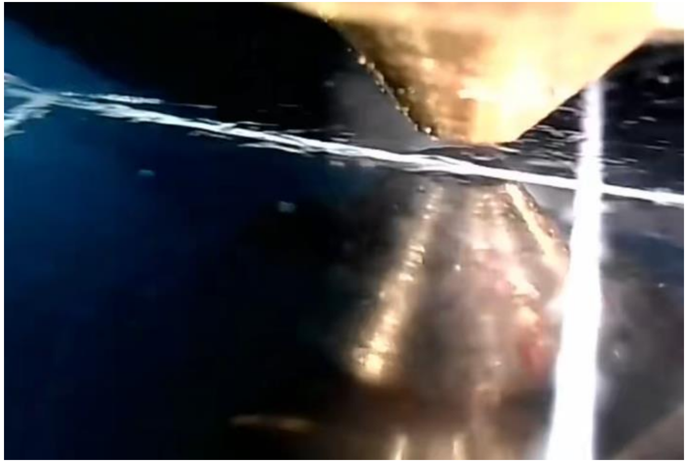

12/03/2025

Kangur et al, Developing Melt Electrowriting on an Open-Source Fused Filament Fabrication Platform, Master’s thesis, EPFL

# Polymer Melt/Viscous Solution Extrusion



Die Swell or Barus effect

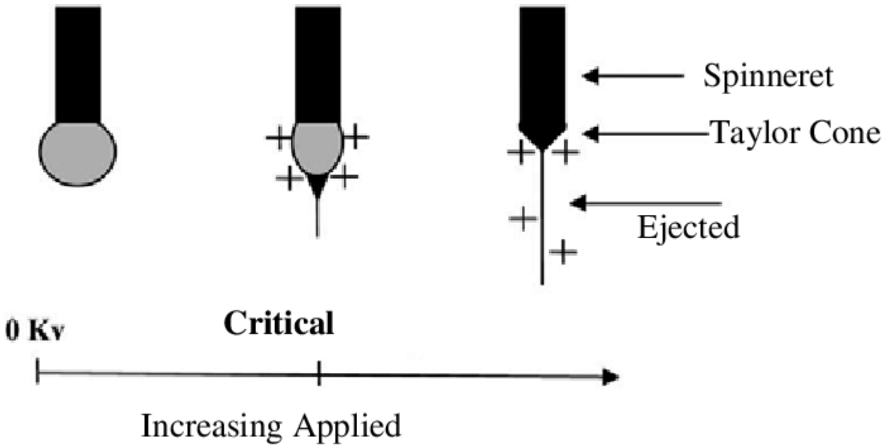


Fused Deposition Modelling

ETH soft materials (youtube) - https://www.youtube.com/watch?v=LWNhr2PM5_s
A new perspective for 3D printing - https://www.youtube.com/watch?v=J96qmJQXhAw&t=59s

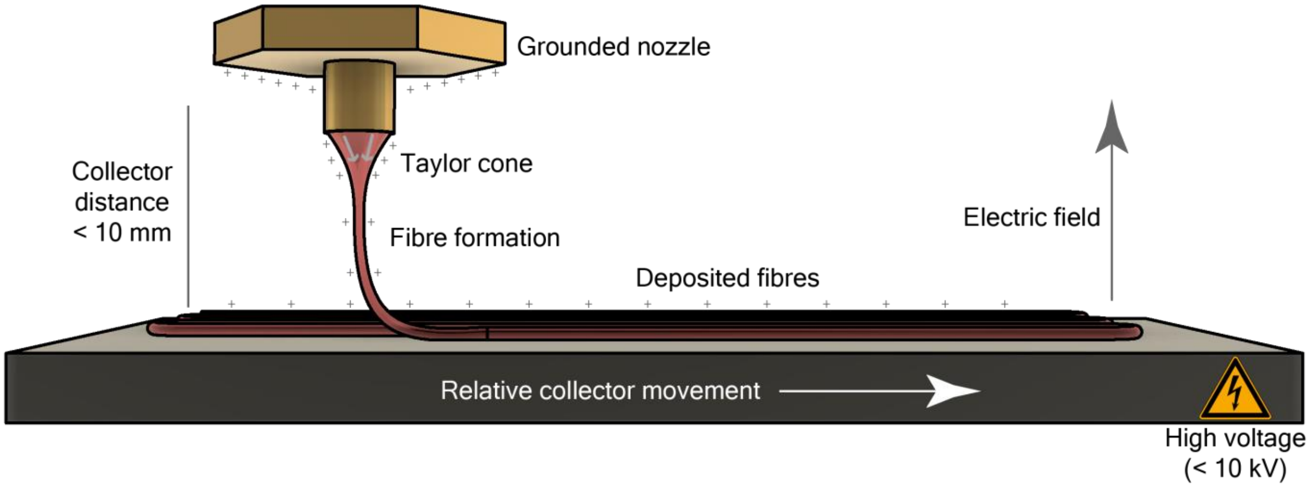
# Cone Behaviour at the Nozzle Tip

**ELECTROSPINNING**
**Electrical (High Voltage)**
**0-30 kV**




Trindade et al, Journal of polymer research, 27, 2020
Hasan et al, European Scientific journal, 2014

# Melt Electrowriting



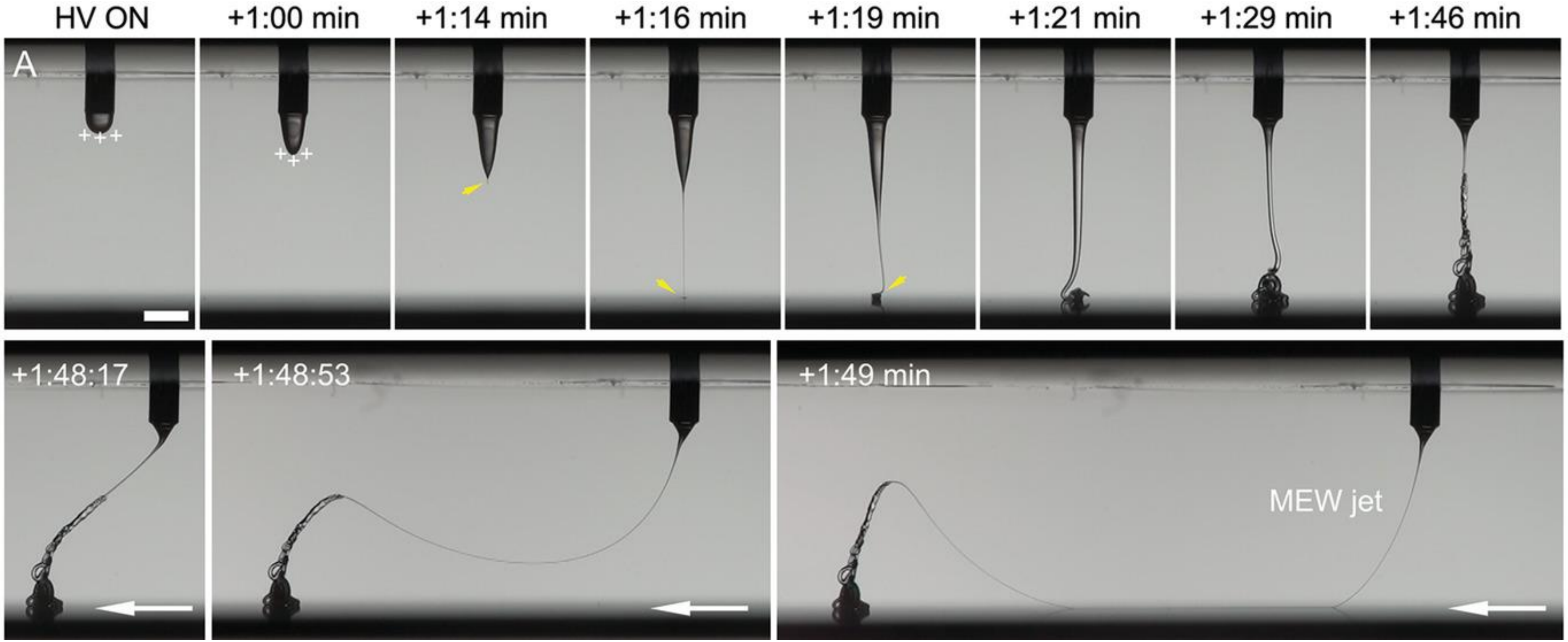

Menke et al, Melt Electrowriting of Bioderived Polyhydroxyalkanoate for Manufacturing Metal Patterned Cuff Scaffolds, Manuscript in preparation

# Comparison Table

| | FDM | MEW |
|---|---|---|
| **Flow rate [µL/h]** | 3,600 - 36,000 | 0.5-20 (>180x reduction) |
| **Temperature ranges [°C]** | 150 - 430 | 60 - 250 |
| **Material feed system** | Pushing filament | Pressurized syringe<br>Pushing filament |
| **Movement speed [mm/min]** | 1,800 - 4,800 | 300 – 500 (>3x slower) |
| **Amount of heated material at one time [µL]** | 30 - 50 | 500 – 1000 (>10 x)<br>30 - 50 |
| **Minimum fiber size [µm]** | 100 | 5 (20x smaller) |

Kangur et al, Developing Melt Electrowriting on an Open-Source Fused Filament Fabrication Platform, Master's thesis, EPFL

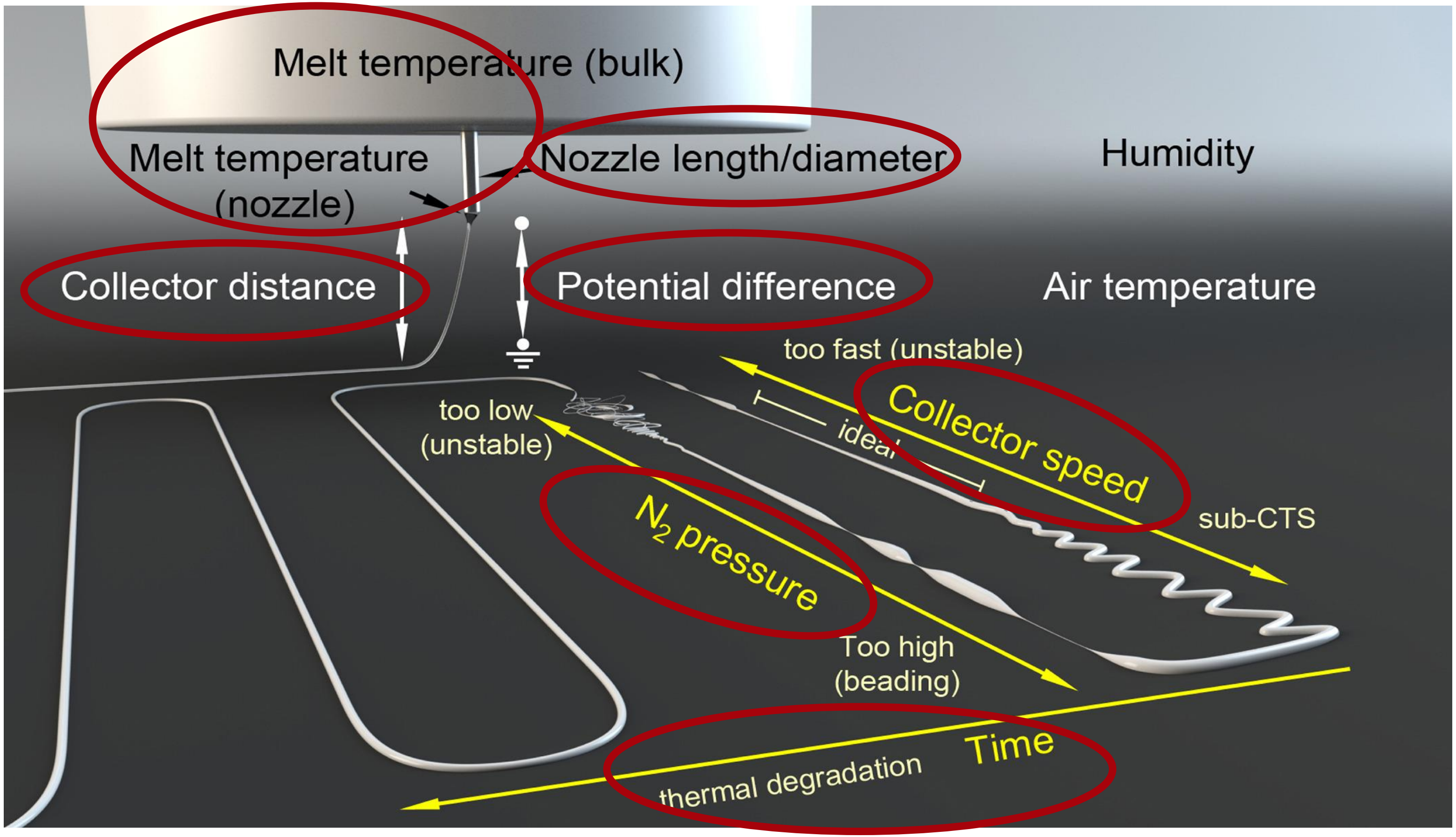
# Taylor Cone Formation – MEW




Scale bar: 1 mm

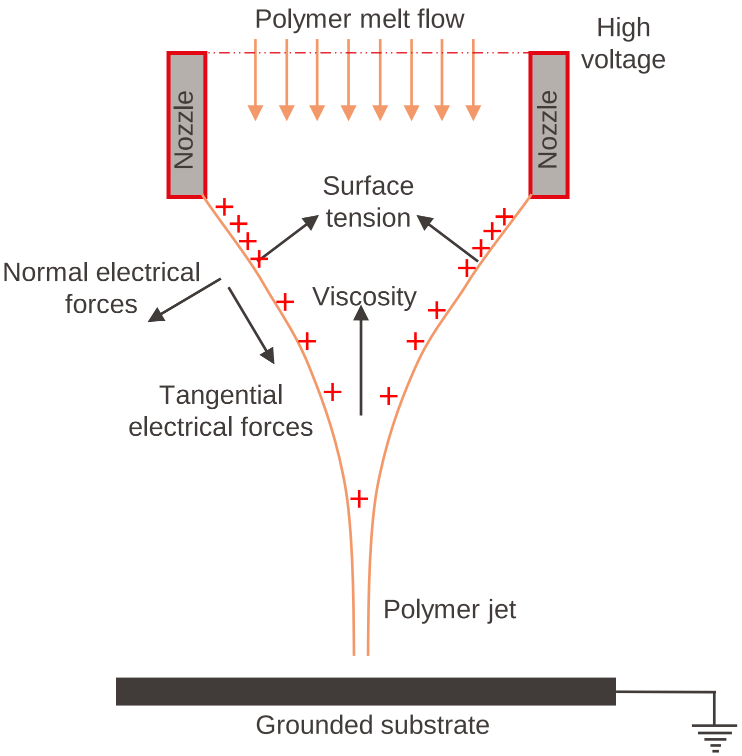
Kade et al, Polymers for Melt Electrowriting, Advanced Healthcare Materials, 2020
Taylor et al, Electrically Driven Jets, Proceddings of the Royal Society A, 1969

# Parameteric Control of MEW




Florczak et al, Melt electrowriting of electroactive poly(vinylidene difluoride) fibers, Polymer International, 2018

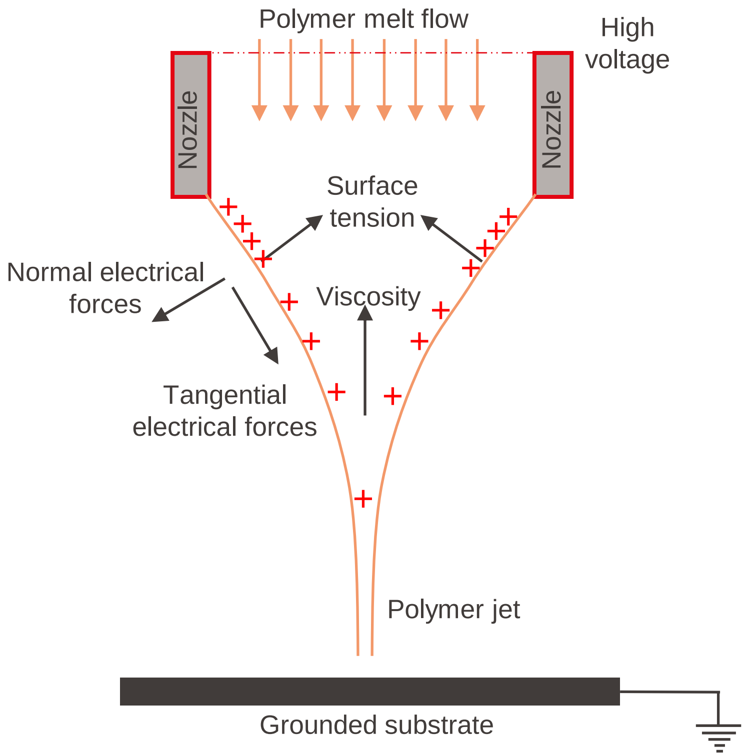
# Forces Acting on a Taylor Cone




How can we control or balance the forces????

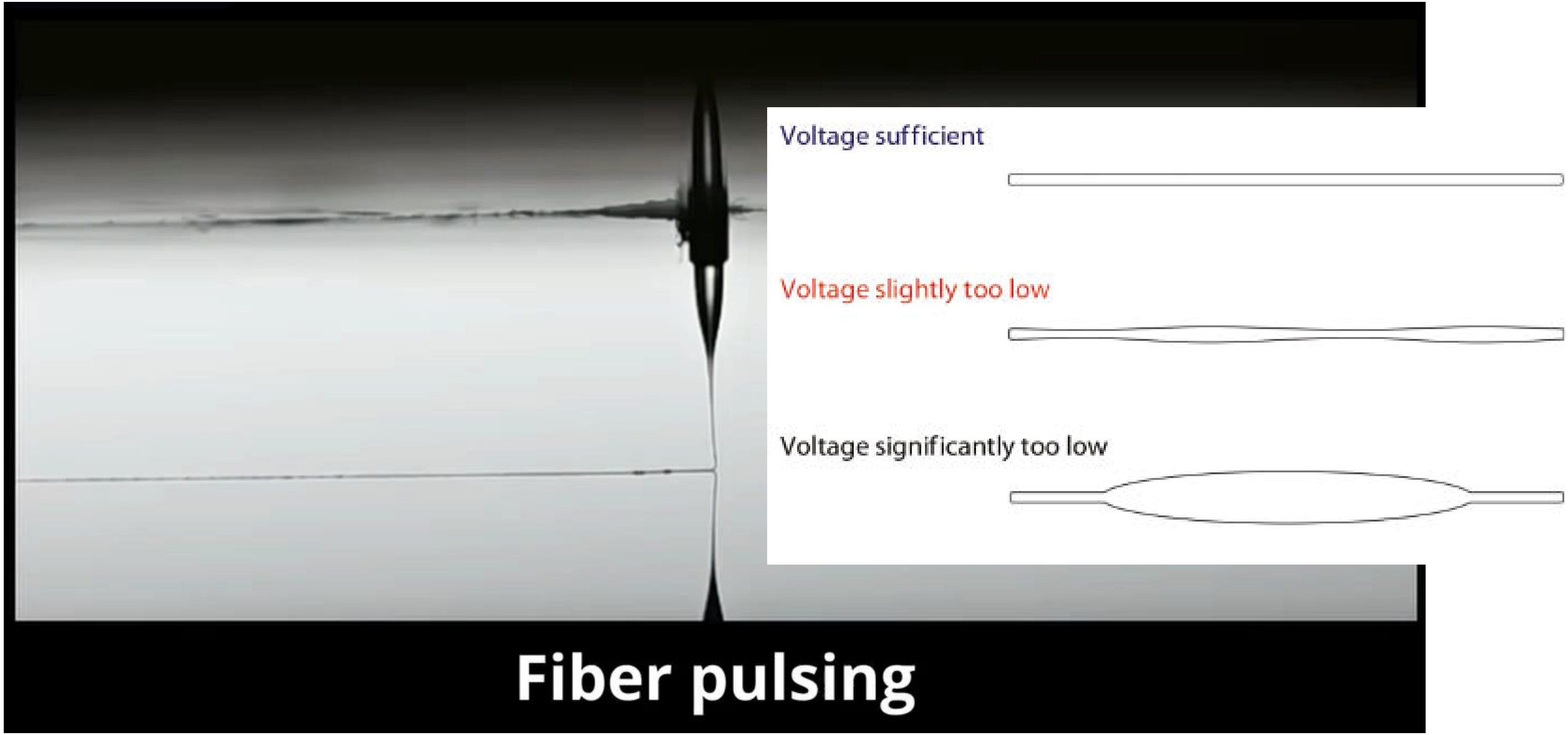
Taylor et al, Electrically Driven Jets, Proceddings of the Royal Society A, 1969

# Forces Acting on a Taylor Cone




- Type of polymer
- Temperature at the nozzle
- Amount of applied voltage (limiting factor?)
- Environmental?
- Additives?

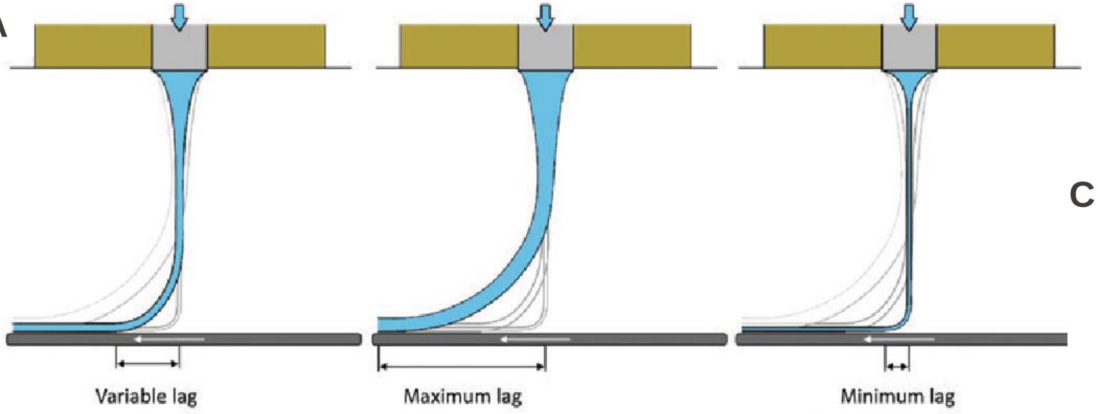
# Balancing the Force



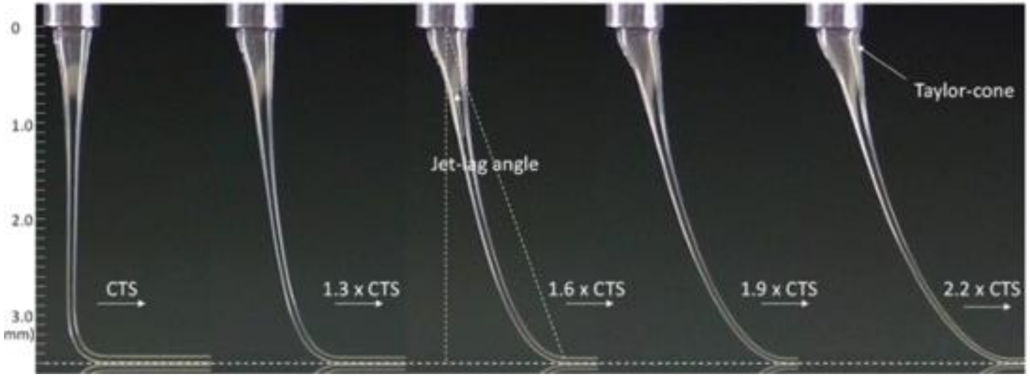

Hochleitner et al, Fibre pulsing during melt electrospinning writing, BioNanoMaterials, 2016

# Jet Lag

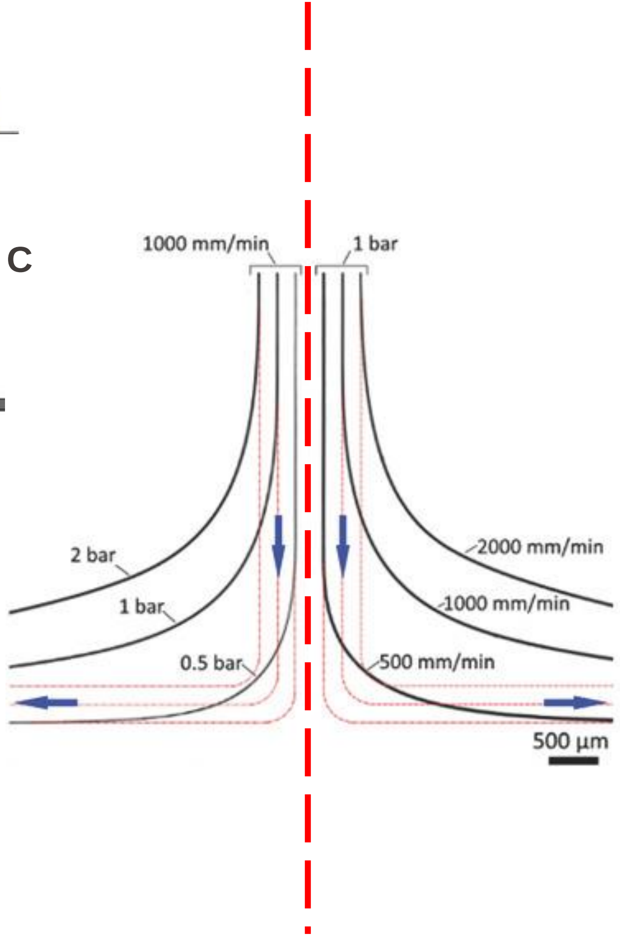
A




B



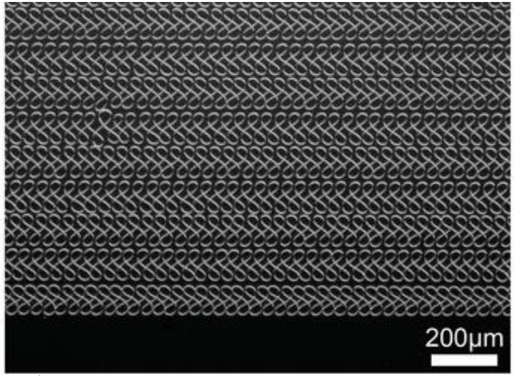

C

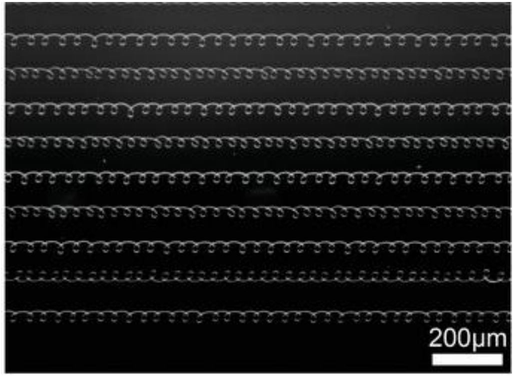




Hochleitner et al, Fibre pulsing during melt electrospinning writing, BioNanoMaterials, 2016
Hrynevich et al. *Small,* 2018, Dimension-Based Design of Melt Electrowritten Scaffolds
Xu et al, Kinematical analysis of melt electrowritten jet at various print speeds, 2022

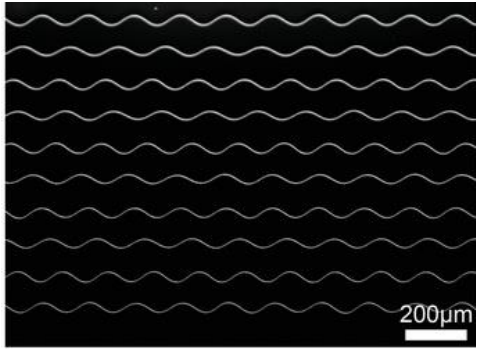
# Critical Translational Speed (CTS)

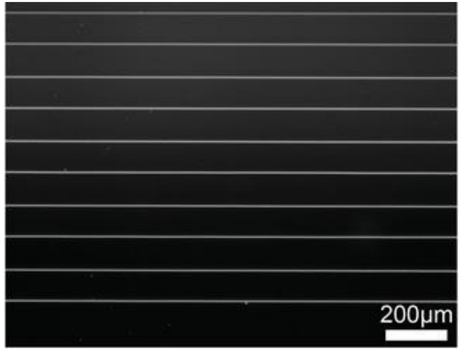



Increasing Translational Speed

Whipping

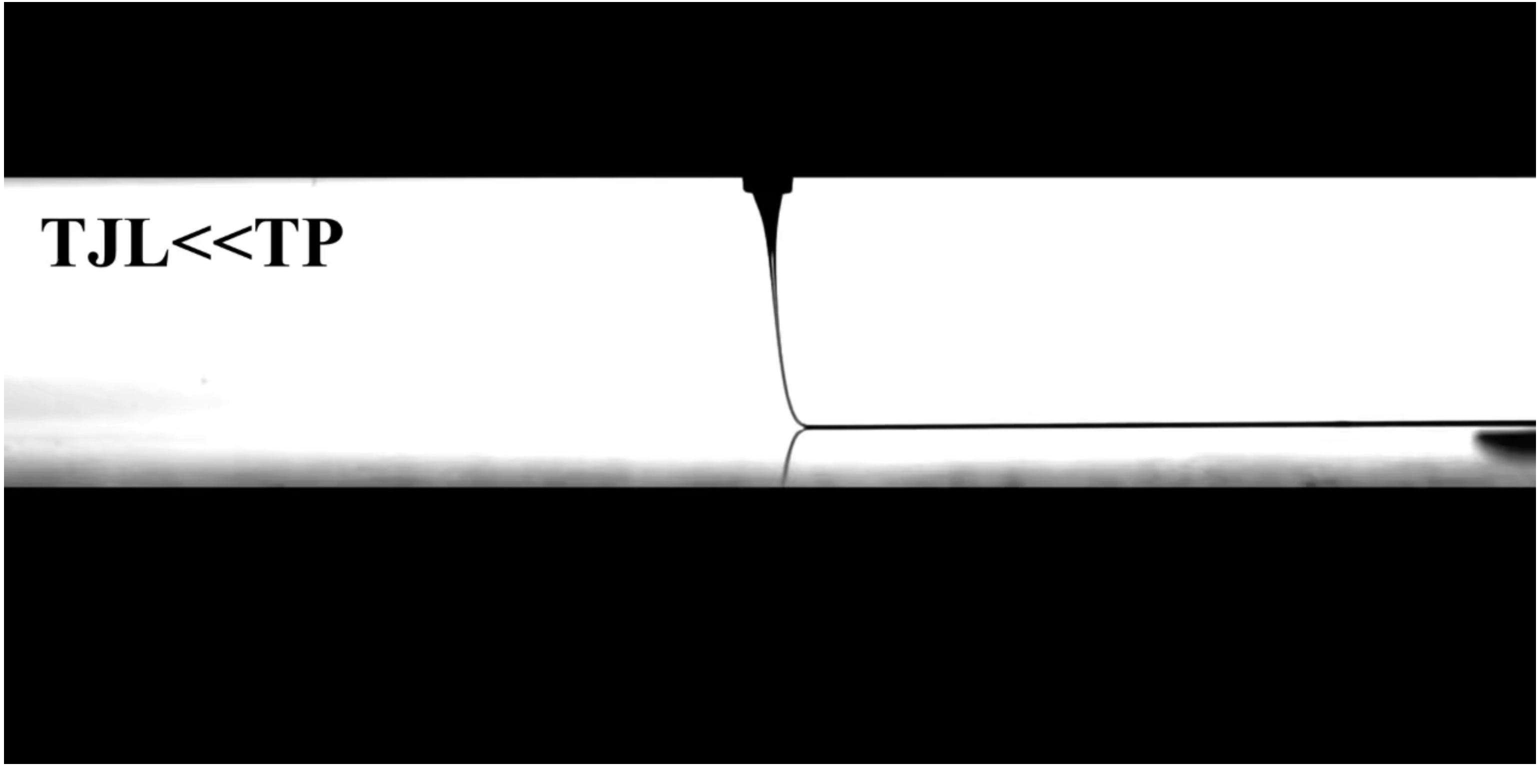




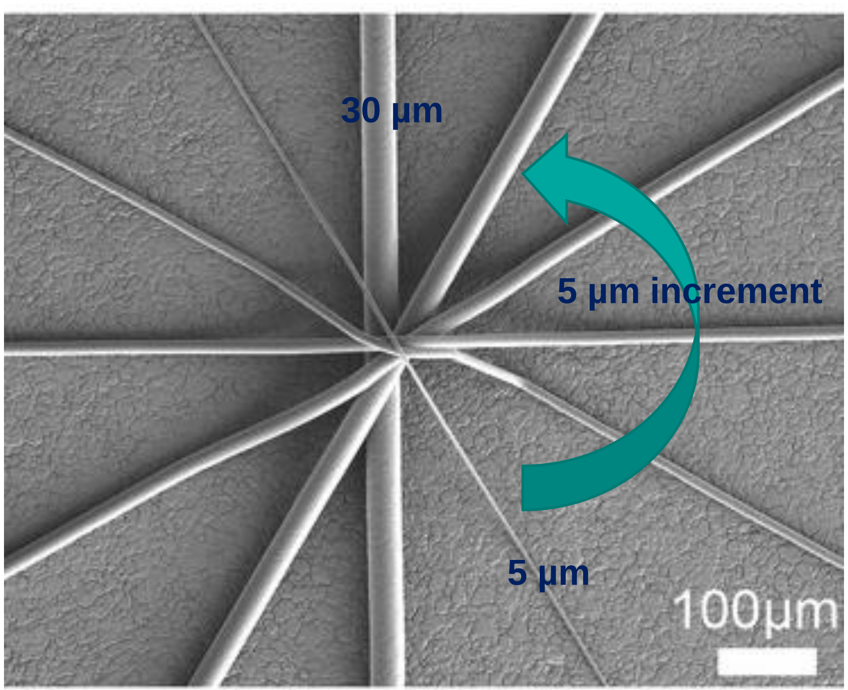

Robinson et al, The Next Frontier in Melt Electrospinning: Taming the Jet, Advanced Functional Materials, 2019

# Jet Lag and Pausing : Direction Change




TJL – time taken by jet lag to recover
TP – pausing time before direction change

# Controlling Structure and Properties




| | 15 to 10 µm | 5 to 25 µm |
|---|---|---|
| Voltage | ↑ | ↓ |
| Pressure/ Extrusion | ↓ | ↑ |
| Translational Speed | ↑ | ↓ |
| Temperature | ? | ? |

$$D_2 = D_1 \cdot \sqrt{\frac{P_2}{P_1}}$$

$$D_2 = D_1 \cdot \sqrt{\frac{V_1}{V_2}}$$



Hrynevich et al. *Small*, 2018, Dimension-Based Design of Melt Electrowritten Scaffolds

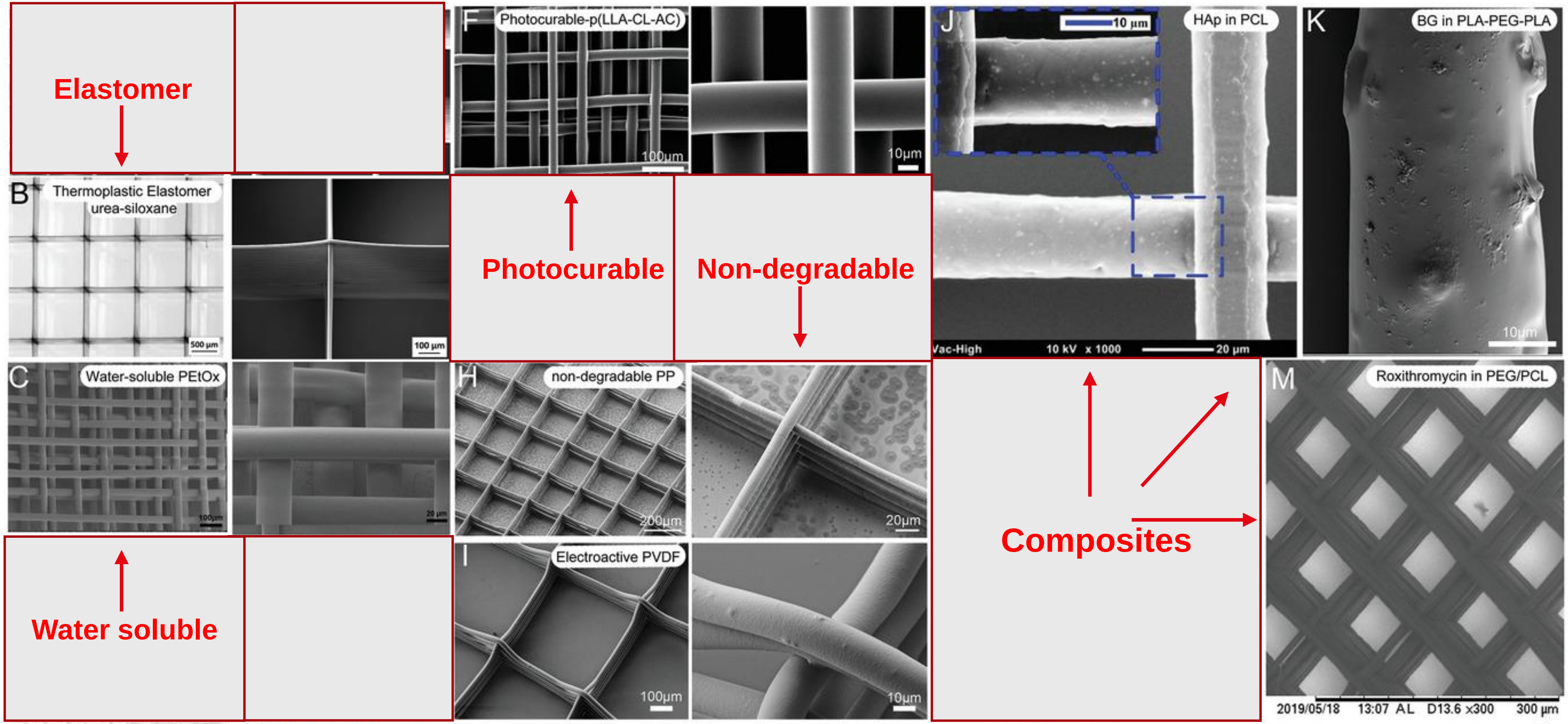
# Mass Conservation on Extruding Polymer

$$d(F,E)\,[\mathrm{mm}] = 2\sqrt{\frac{0.179 \cdot 10^{-3}}{F} \cdot E}$$

Feed rate F
Extrusion rate E

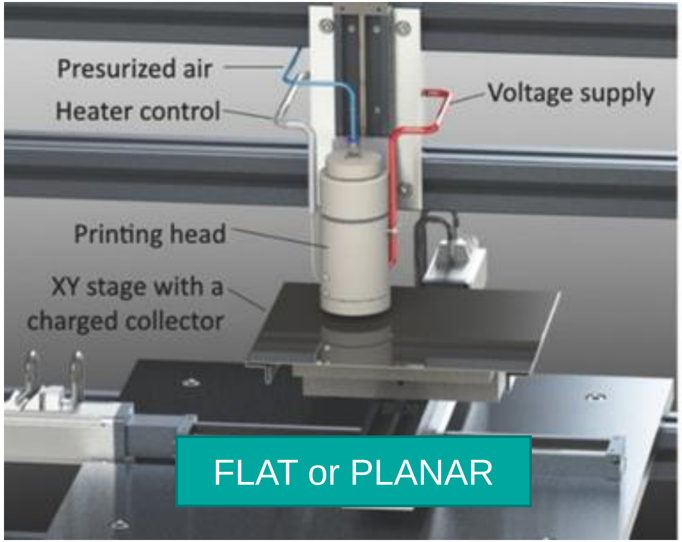
Equation of the theoretical diameter  Menke et al, Report on MEW, internship, University of Oregon

# Variety of Polymers

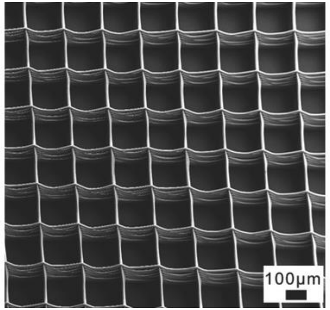


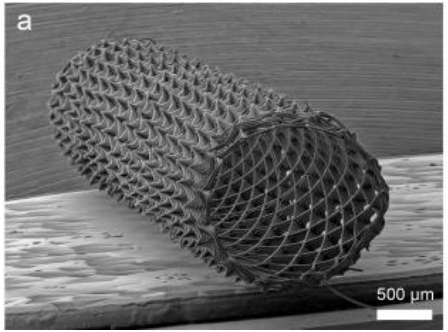

Kade et al, Polymers for Melt Electrowriting, Advanced Healthcare Materials, 2020

# Collectors

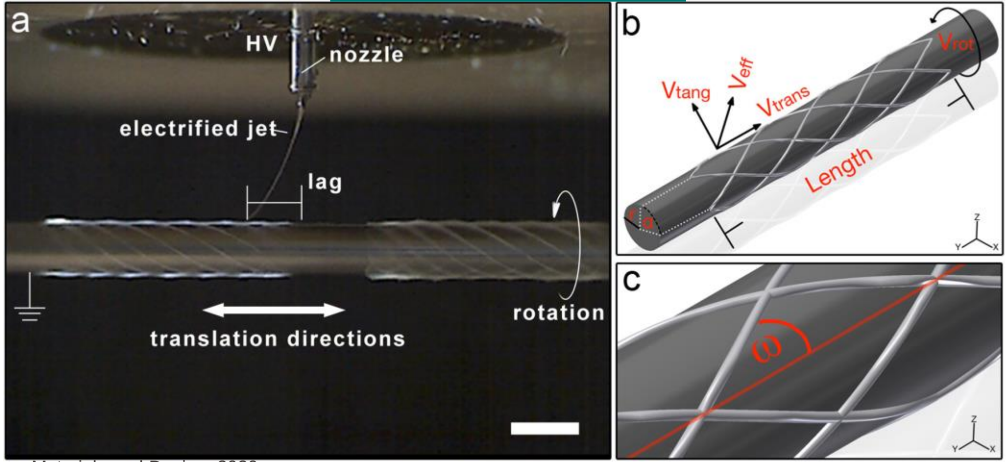



FLAT or PLANAR




TUBULAR




McColl et al, Design and fabrication of melt electrowritten tubes using intuitive software, Materials and Design, 2020
Hrynevich et al. *Small*, 2018, Dimension-Based Design of Melt Electrowritten Scaffolds

# Examples of collector materials

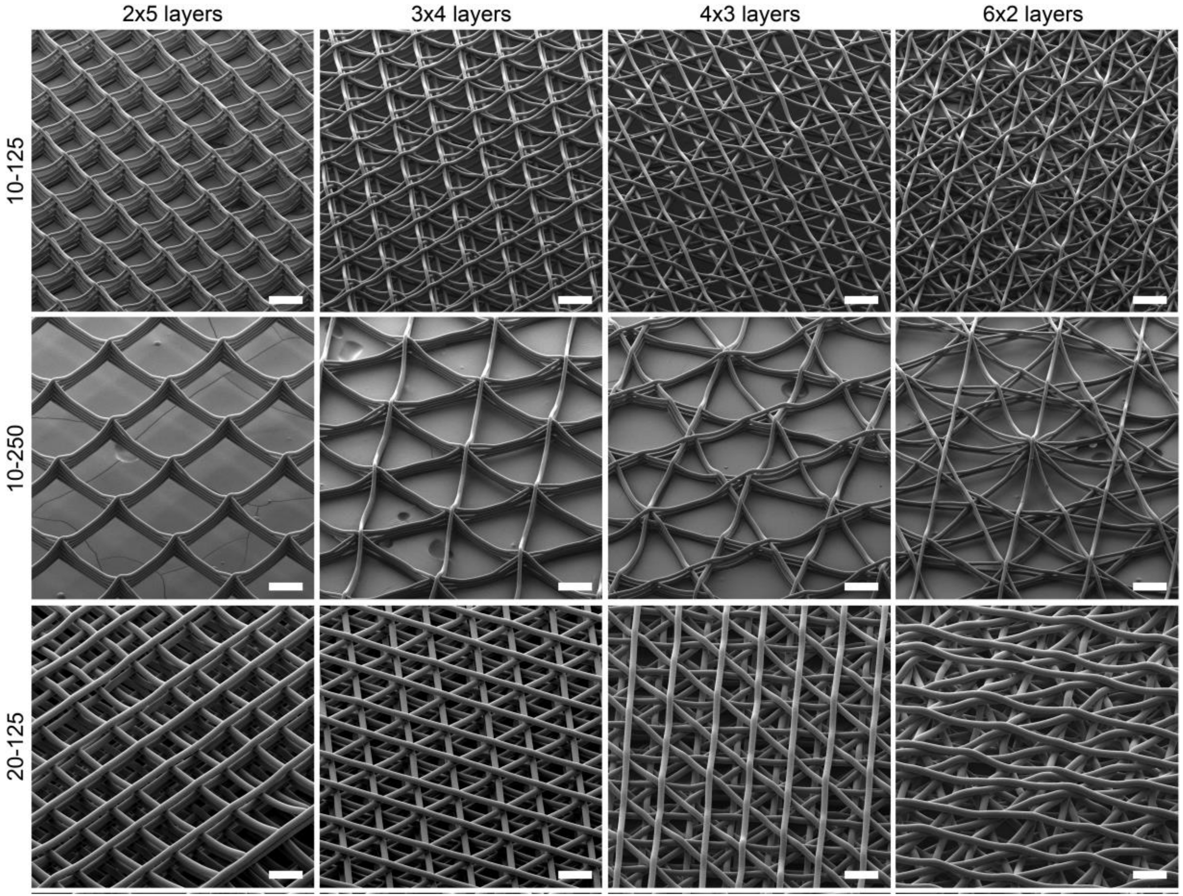
- Metal plate or cyclindrical collectors
- 3D printed PLA or PVA collectors
- Glass substrates
- Glass coated with polymer or metal

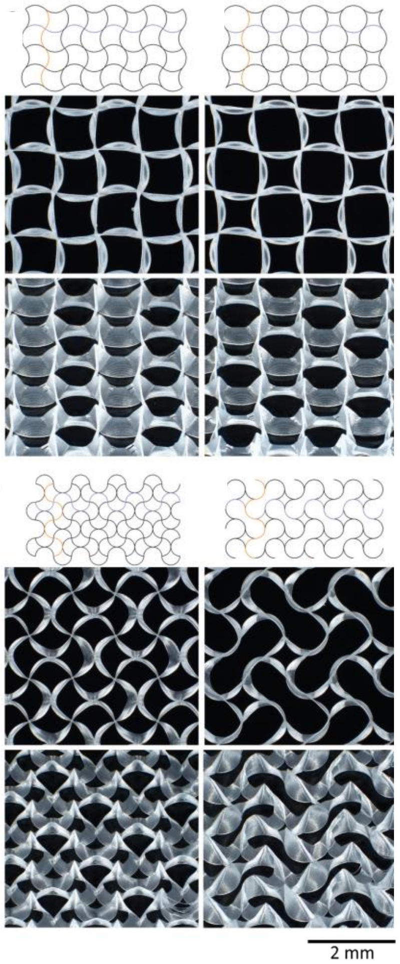
- Key is to have a good grounding and minimal charge build up



McColl et al, Design and fabrication of melt electrowritten tubes using intuitive software, Materials and Design, 2020
Hrynevich et al. *Small*, 2018, Dimension-Based Design of Melt Electrowritten Scaffolds

# Freedom of Design – Poly (Capro-Lactone) (PCL)






- Youssef et all, Tissue Engineering Part C, 2019 (Left) (100 µm)
  Xu et al, Advanced Material Technologies, 2022 (Right)

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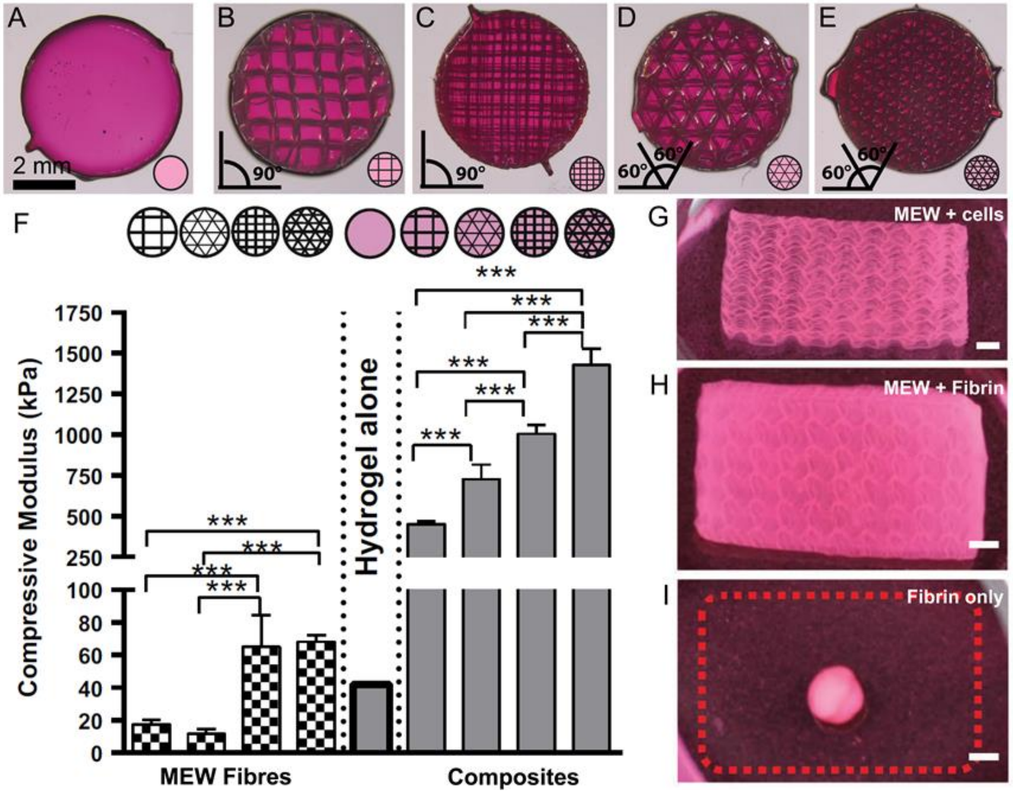
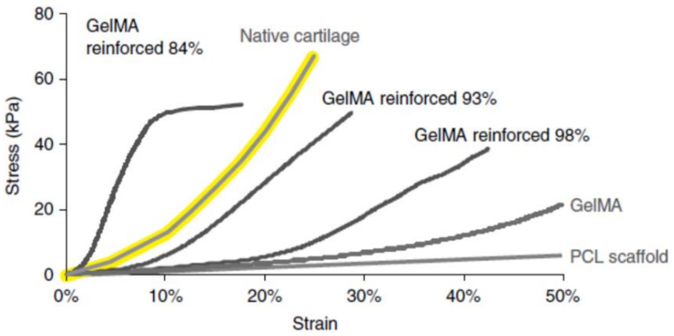
# Reinforcement meshes




Factors affecting mechanics:
- Fiber diameter
- Number of layers
- Orientation of fibers
- Fiber interspacing
- Fiber patterns

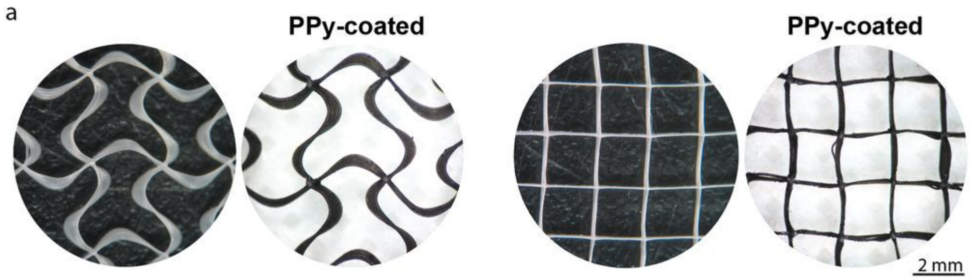
12/03/2025

Visser et al, Reinforcement of hydrogels using three-dimensionally printed microfibres, nature communications, 2015

# Electroconductive Patches

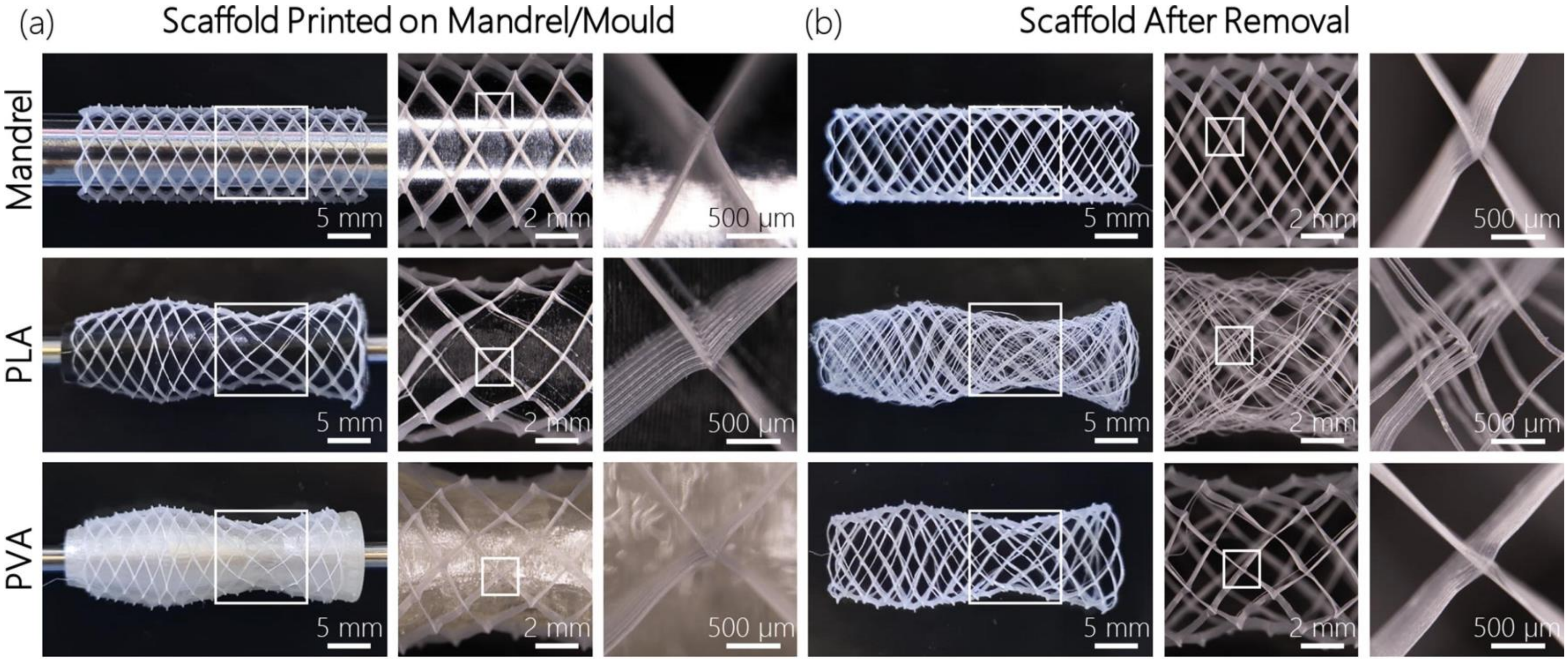






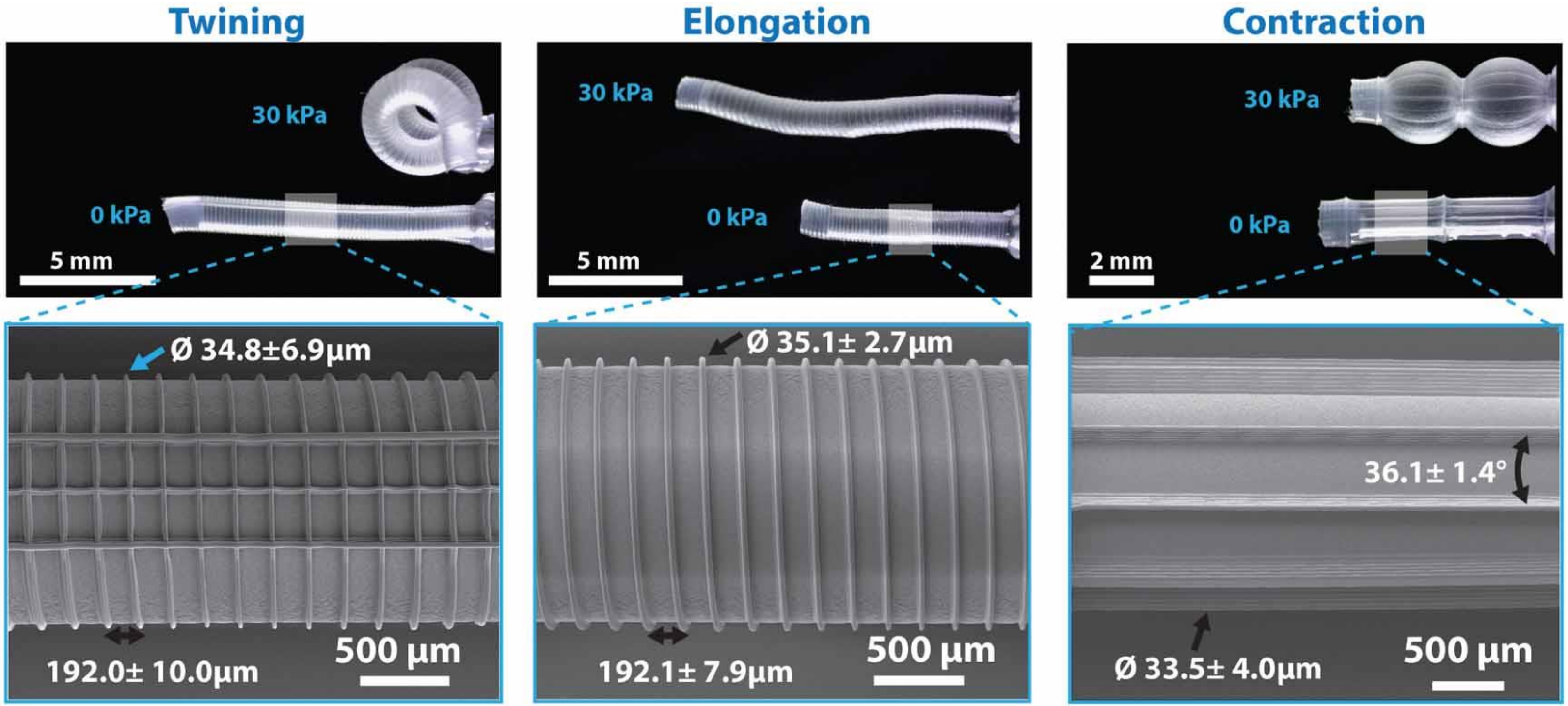

- Cardiac tissue engineering application
- Conduction of electrical impulses
- Mechanical anisotropy due to design freedom

# Tubular (poly vinyl alcohol)




Brooks-Richard et al, Dissolvable 3D printed PVA moulds for melt electrowriting tubular scaffolds with patient-specific geometry, Materials & Design, 2022

# Tubular for Soft Robotics (poly caprolactone)

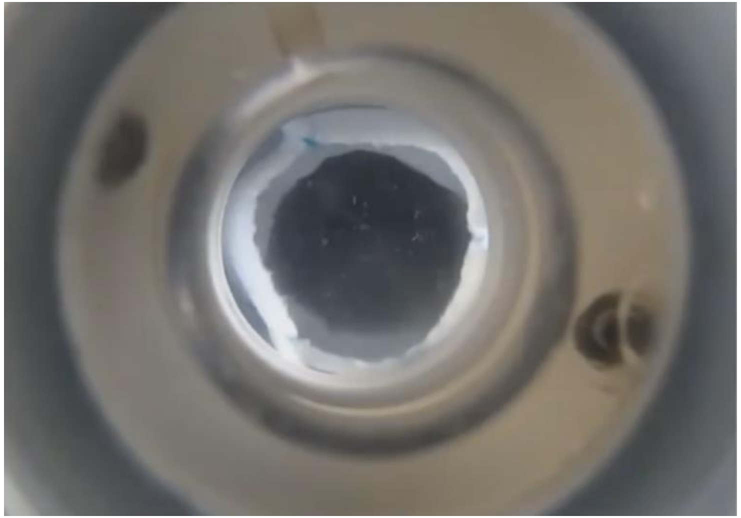



Bas et al, Ultrafast, miniature soft actuators, Multifunctional Materials, 2021

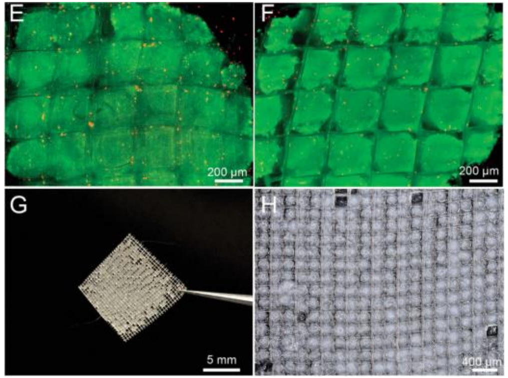
# Melt Electrowriting

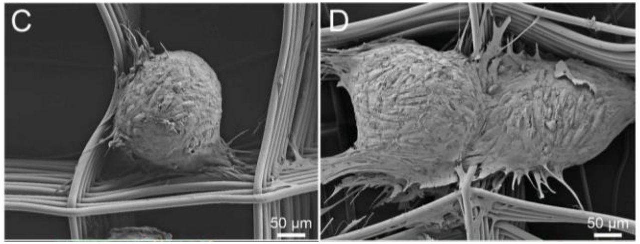


- Artificial heart valve:
  - Designed after mech. properties of heart valve
  - Printed via MEW from PCL
  - Shown in bioreactor
- Sheet-like Tissue Constructs:
  - 13 – 15 µm fibre
  - 7 – 8 µm catching fibres for spheriods

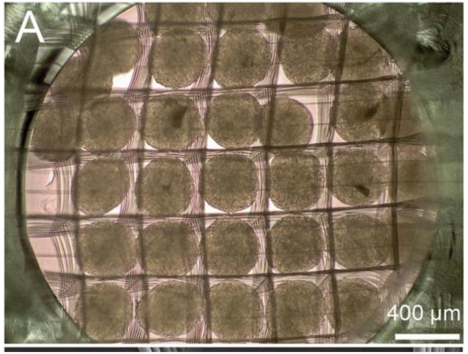


Saidy *et al.*, *Small* **2019**, *15* (24), 1900873.
https://youtu.be/s79VhOGqSwo?si=DvhR1B3iufGJMw3j



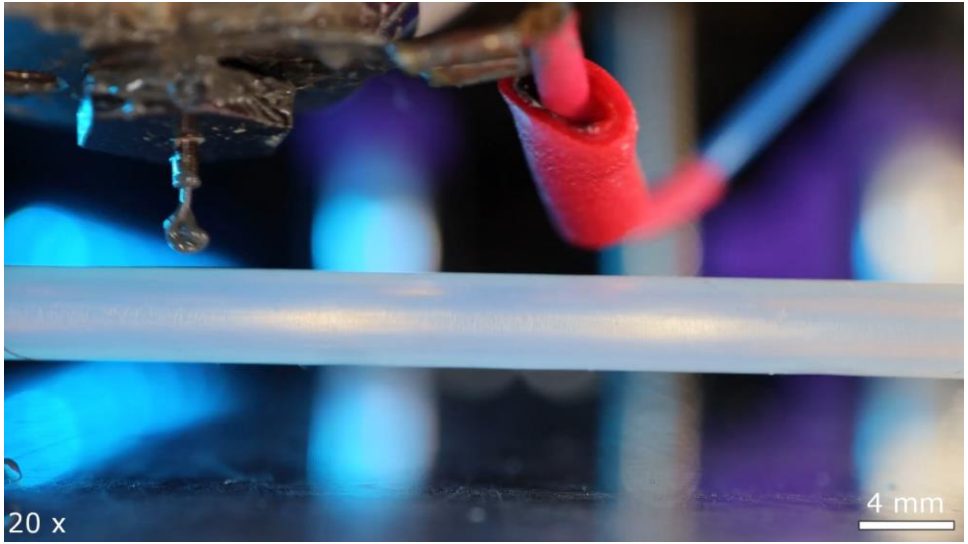




McMaster *et al.*, *Advanced Healthcare Materials* **2019**, *8* (7), 1801326.



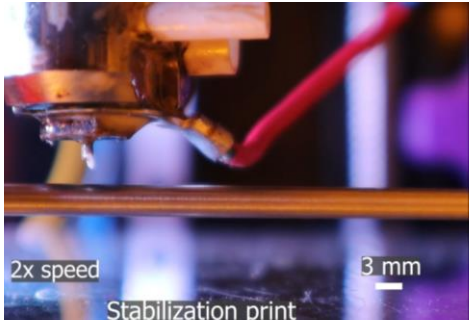
# Materials in MEW
# Metal filled filament

Successful fabrication of multi-layer scaffold in < 8 min

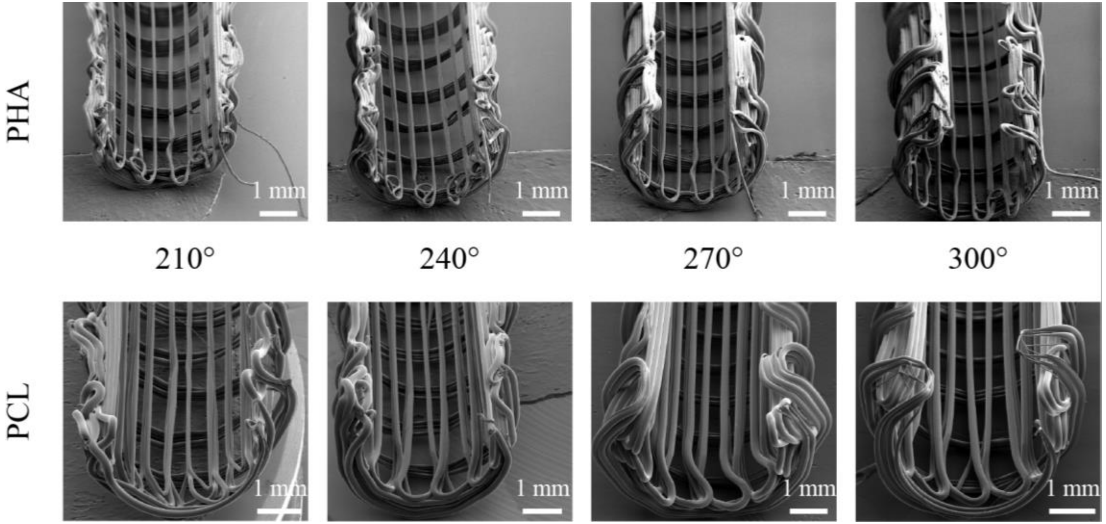




- Menke *et al*., work in progress at LMIS1.

# Materials in MEW Poly(hydroxyalkanoate)




- Biodegradable polymer
- Fibre diameter: 26.1 ± 8 µm
- Printing of novel design → theta tubes

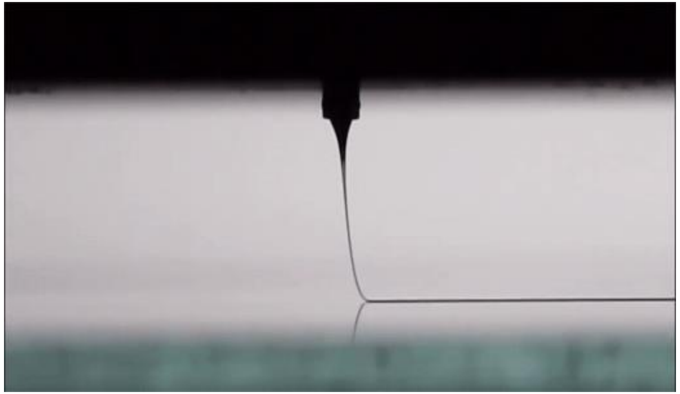


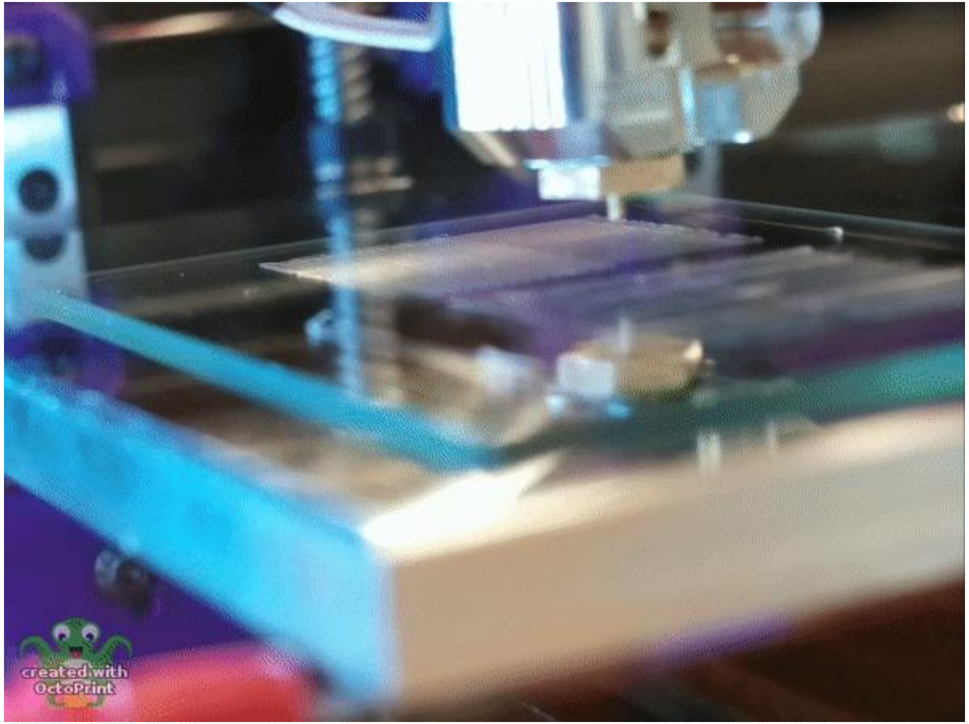

Menke *et al*., manuscript in preparation.

# Take away

- Comparison of FDM with Melt Electrowriting (MEW)
- MEW and High voltage
- Critical Translational speed (CTS)
- Parameters required to control characteristics of polymer fibers
- Variety of polymers processable using MEW
- Types of collectors
- Some applications of flat and tubular scaffolds

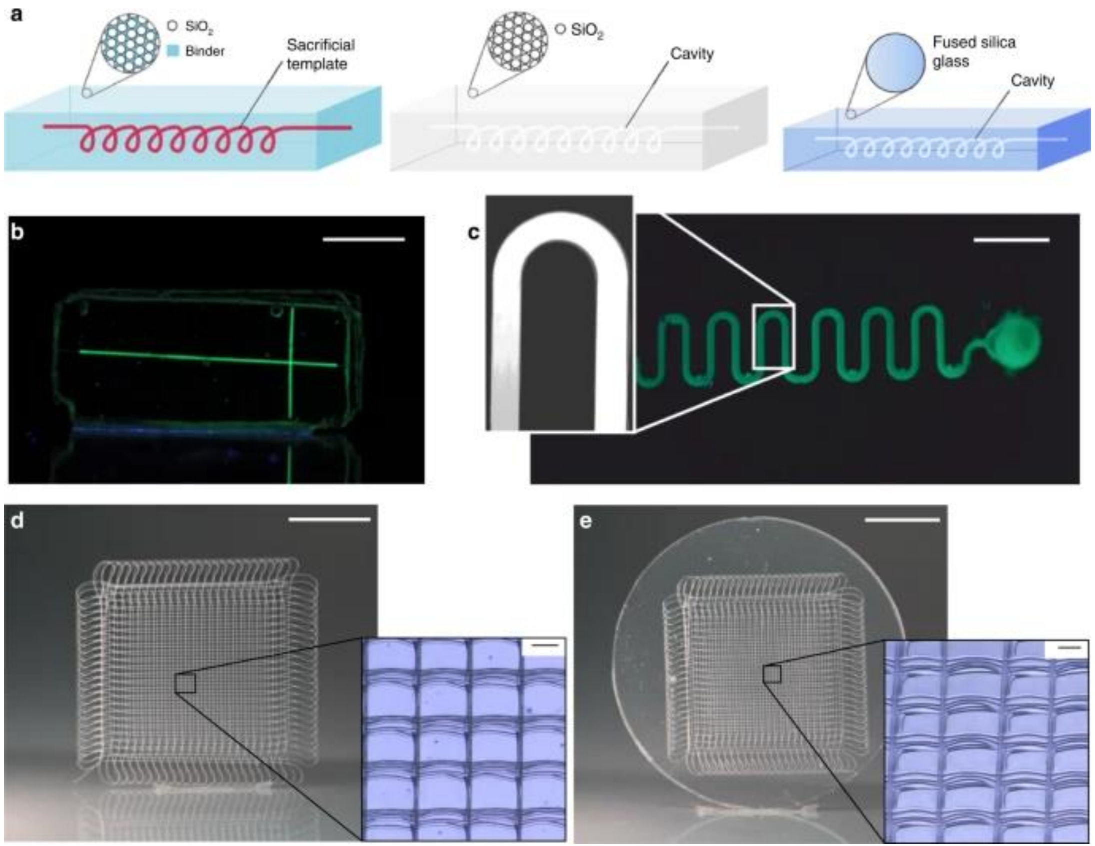
# Conversion to MEW






Thanks to Taavet Kangur for this slide

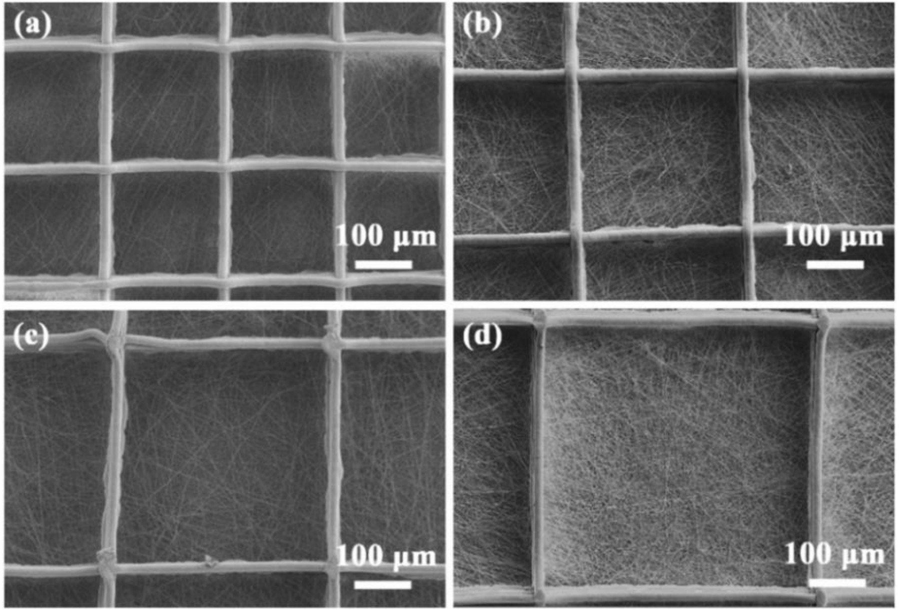
# Sacrificaial Template

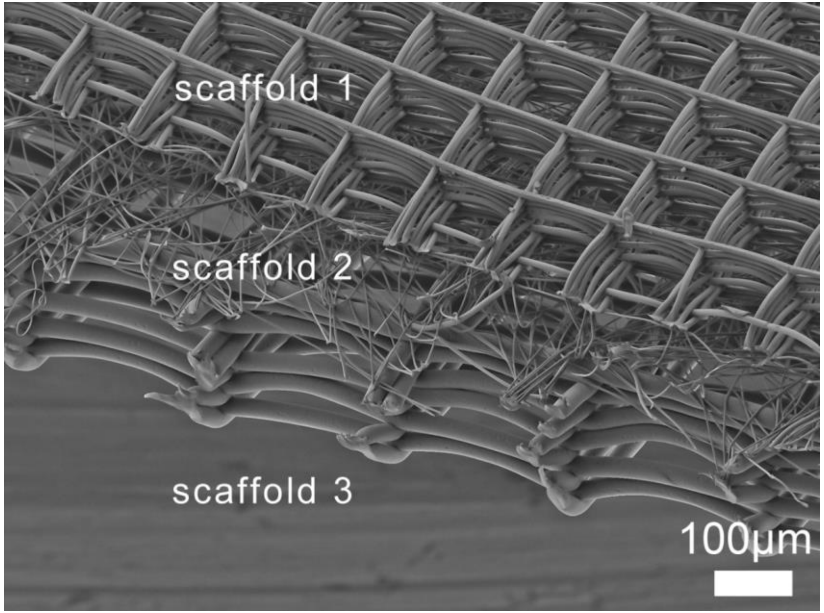





Kotz et al, Fabrication of arbitrary three-dimensional suspended hollow microstructures in transparent fused silica glass, nature communications, 2019

# Hybrid Manufacturing






Du et al, Highly directional water transport membrane made from a hybrid manufacturing approach: Unleashing the power of melt electrowriting, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2022
Hrynevich et al. *Small*, 2018, Dimension-Based Design of Melt Electrowritten Scaffolds