

Plasma technologies for a sustainable future: unique plasma processes for applications in biomedicine and space

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- > World's highest solar radiation (58 million PJ p.a. - 10,000 times greater than our total energy consumption)
- > Abundant land for large-scale solar arrays
- > Plentiful silicon in the form of high-purity quartz to support solar cell manufacture





THE UNIVERSITY OF
SYDNEY

Political will for rapid solar expansion



Australian Government

Australian Trade and Investment Commission

Promoting large-scale investment in solar electricity generation

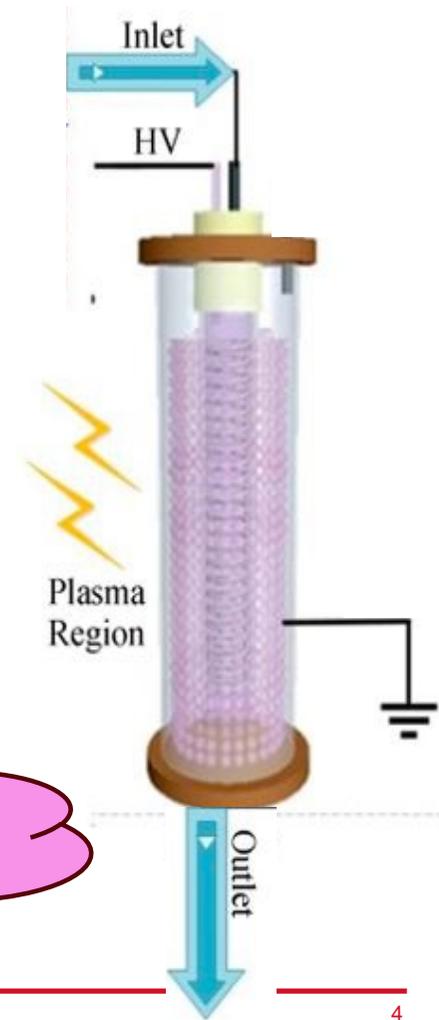
- › “Australia has been a world leader on solar PV research for decades. The same universities that blazed the solar PV trail will step up again to help get utility-scale technology off the ground and help transform Australia into a renewable energy superpower.” (Minister for Climate Change and Energy Chris Bowen)
- › “Australia already has the highest per capita deployment of rooftop solar in the world, and there are several mega-projects in the solar development pipeline.” (CSIRO Senior Principal Research Scientist Dr Chris Vernon)

Power-to-X (PtX) Concept

- › Renewable electricity used to create transportable fuels (e.g. hydrogen; methane; ammonia) using technologies that can be synchronised with intermittent power
- › Crucial for decarbonising hard-to-abate sectors such as long-haul transport
- › Electrolysis of water produces green hydrogen
- › H₂ combined with carbon-based feedstock (e.g. CO₂) can produce a variety of fuels or chemicals with higher energy volume density
- › Conversion process efficiency of electrolysis is currently limited
- › R&D to improve electrolysis cells as well as alternative processes is a priority to enable a global deployment of this technology
- › Plasma combined with catalysts is promising

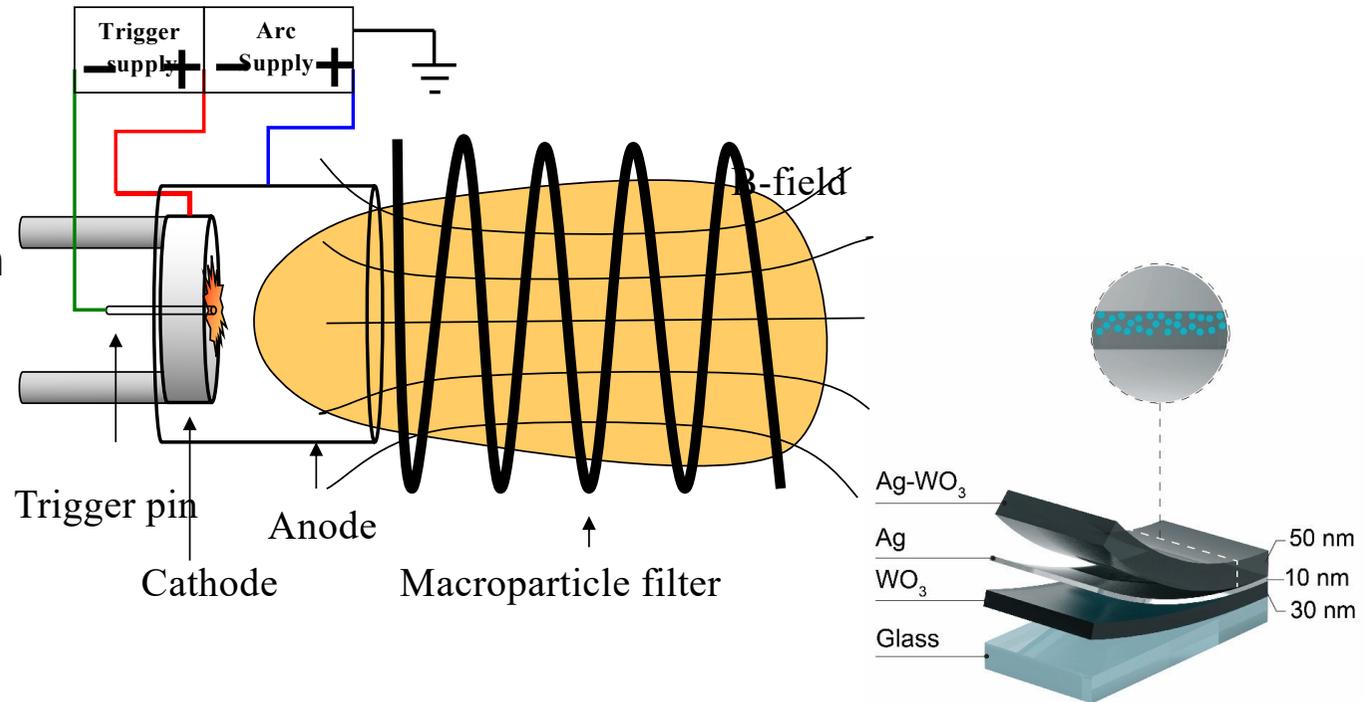


Plasma Power-to-X



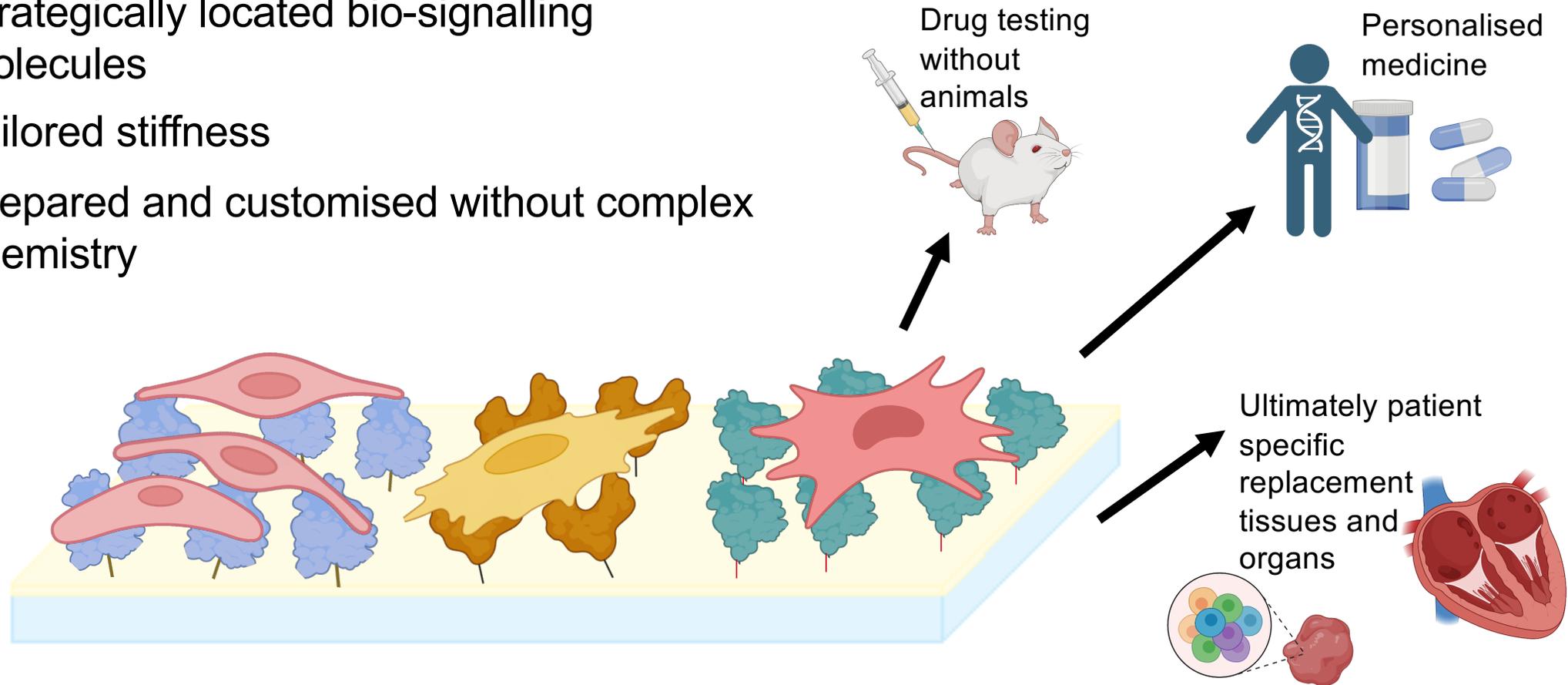
Plasma from Solid Targets: Centre-Triggered Pulsed Cathodic Arc & HiPIMS

- Ablation of solids into plasma by cathodic arc or HiPIMS
- Deposits highly tuneable coatings
- High ion energies produce thrust with high specific impulse
- Sustainable propellants
- In-space refueling while removing debris / mission extension



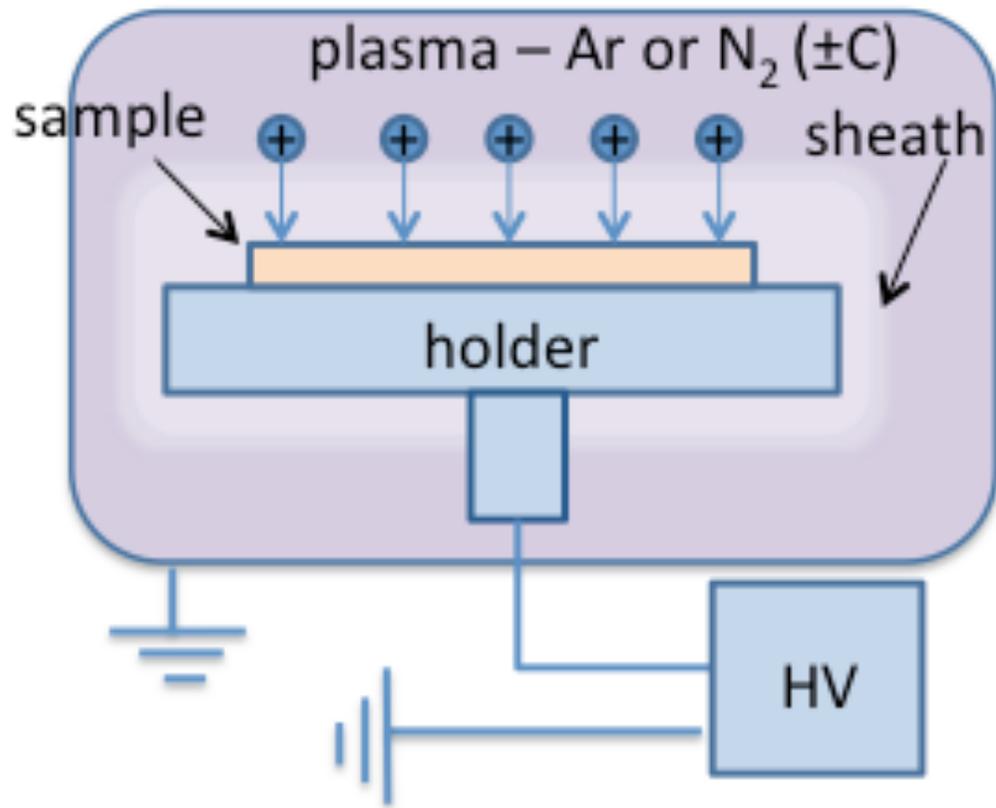
Plasma from organic precursors: Tailorable bio-instructive surfaces and interfaces

- › Strategically located bio-signalling molecules
- › Tailored stiffness
- › Prepared and customised without complex chemistry



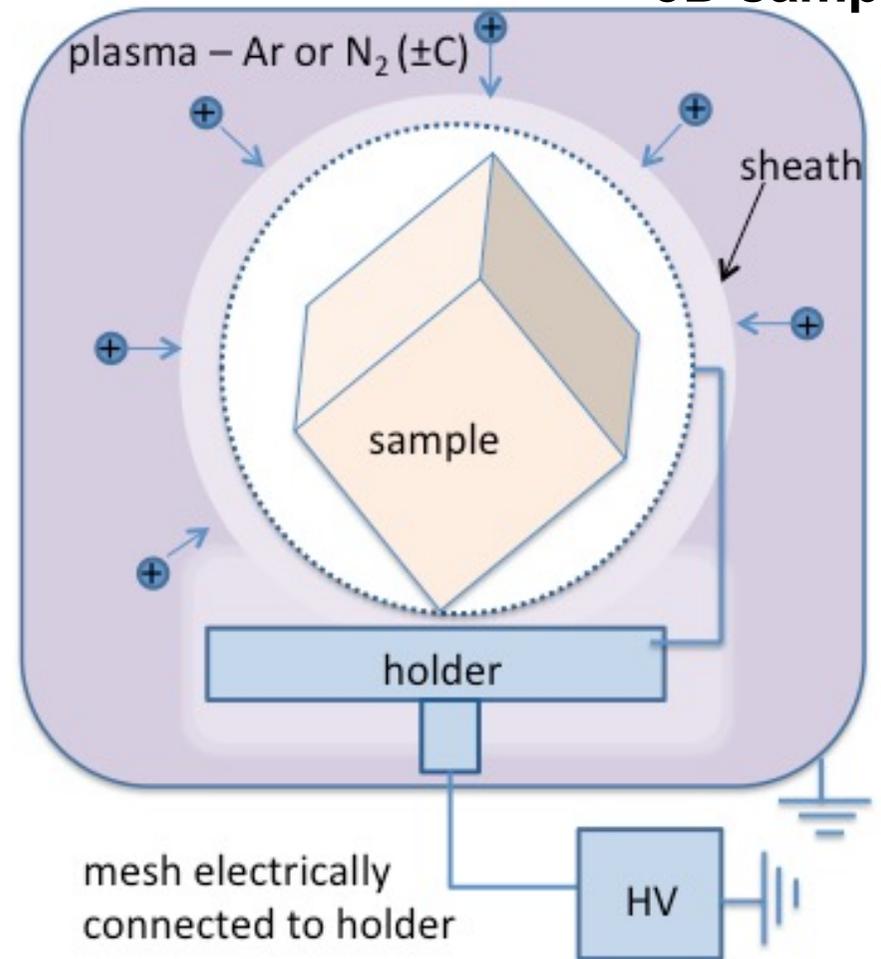
PIII/PIII&D processes

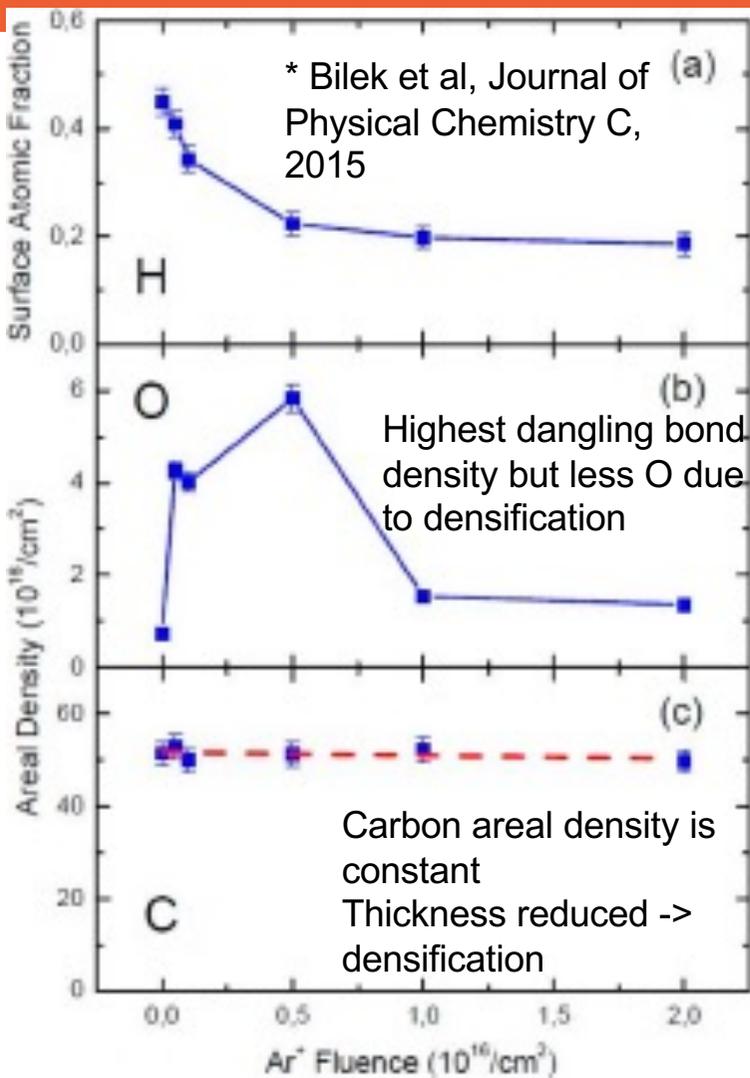
2D sample



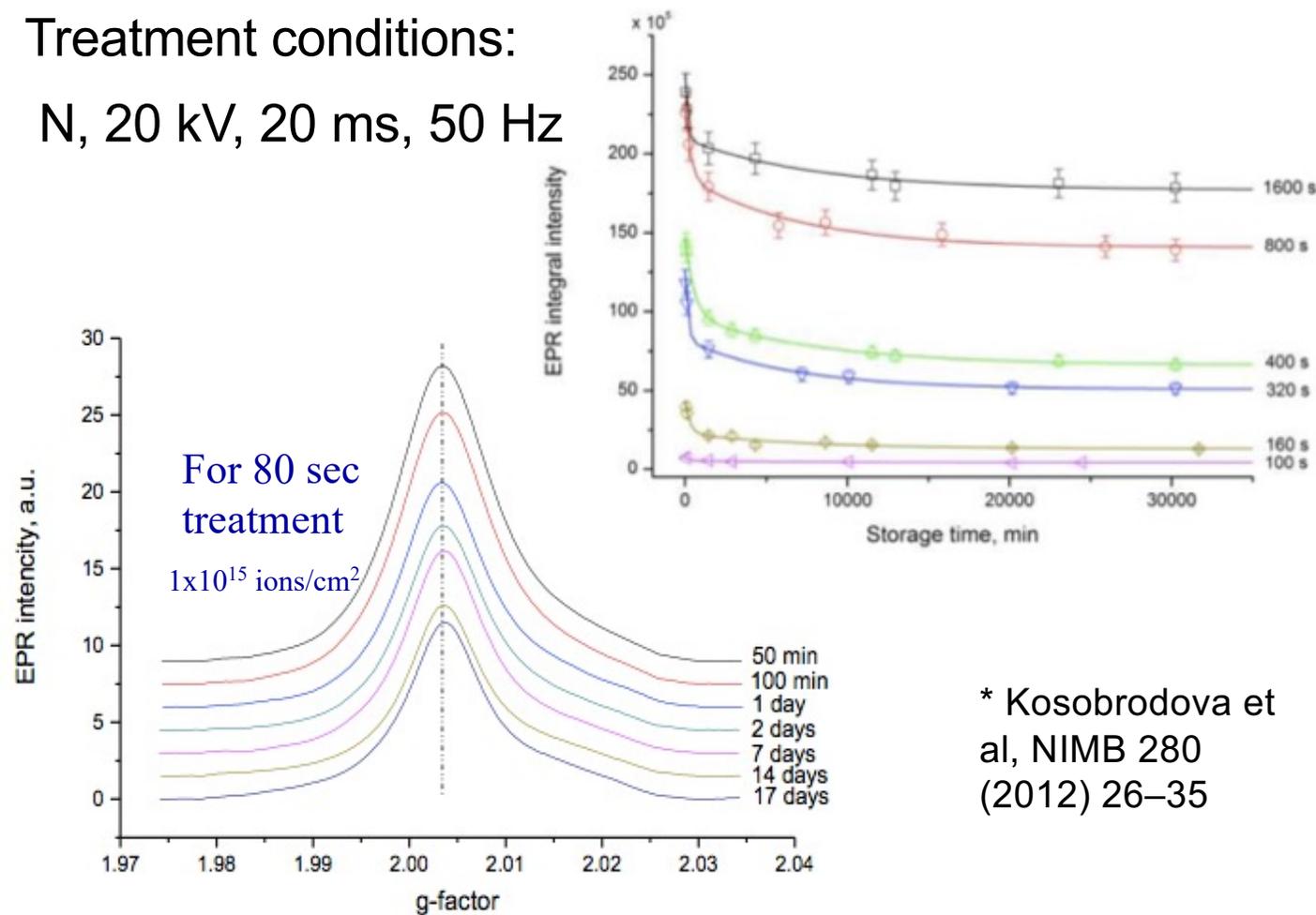
penetration of 20 keV nitrogen ions is about 70-100 nm

3D sample





Treatment conditions:
N, 20 kV, 20 ms, 50 Hz



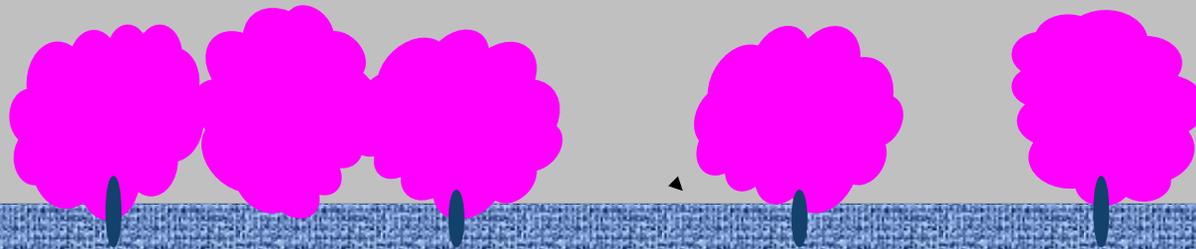
* Kosobrodova et al, NIMB 280 (2012) 26–35

The covalent immobilisation process

Protein molecules in solution

$$N_C = N_{psites} \left(1 - \frac{\tau_p e^{-t/\tau_p}}{\tau_p - \tau_c} - \frac{\tau_c e^{-t/\tau_c}}{\tau_c - \tau_p} \right)$$

$$\tau_p = f(v_p, n_p, S_p)$$



Mobile free electrons in interlayer

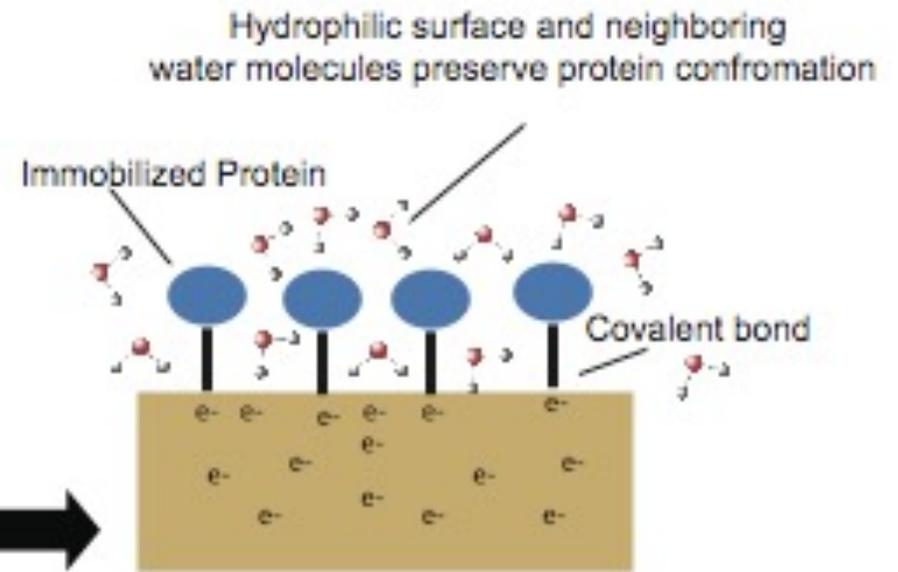
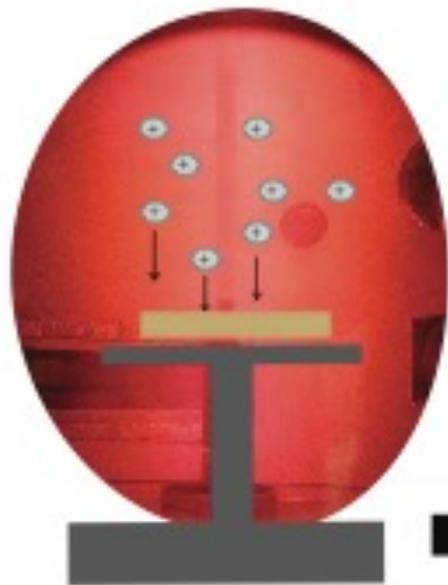
$$\tau_c = f(v_c, n_c, S_c)$$

* Bilek MMM, et al., *PNAS.*, 108:14405-14410, (2011)

Embedded radicals enable covalent biomolecule immobilisation

Contact with Biomolecule Solution

Diagram by Stacey Hirsh



Plasma process

Spontaneous Covalent Coupling

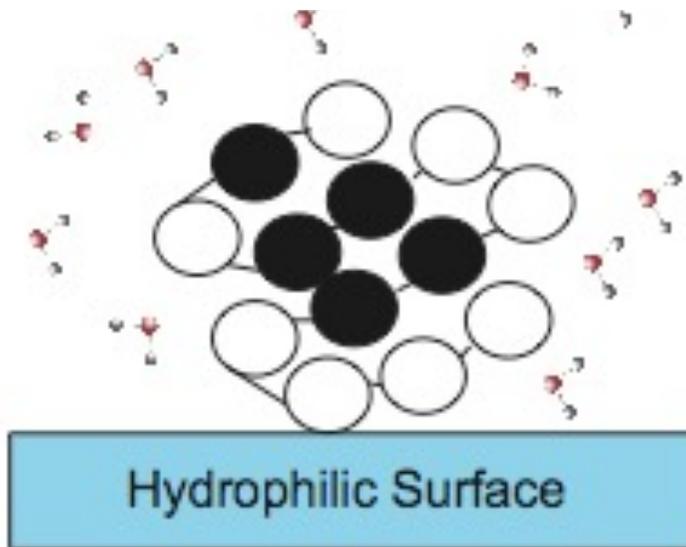


* Bilek MMM, et al., *PNAS*, 108:14405-14410, (2011)

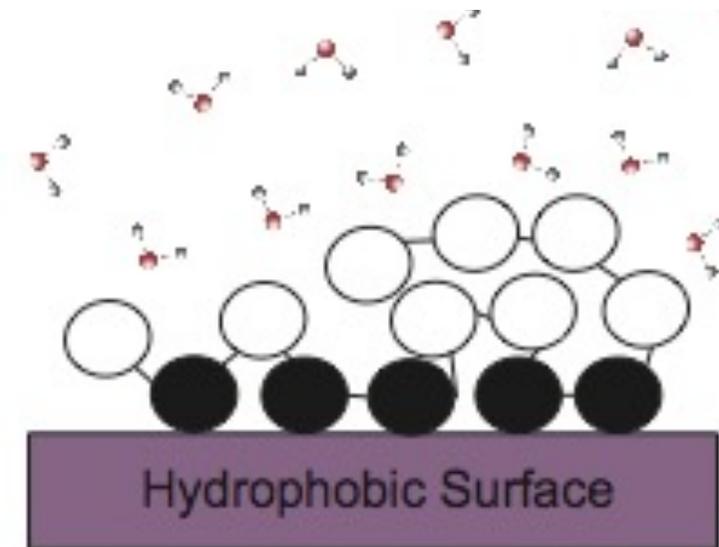


Ion implanted layers combine:

- 1) Retention & stabilisation of protein conformation
- 2) Strong, irreversible attachment



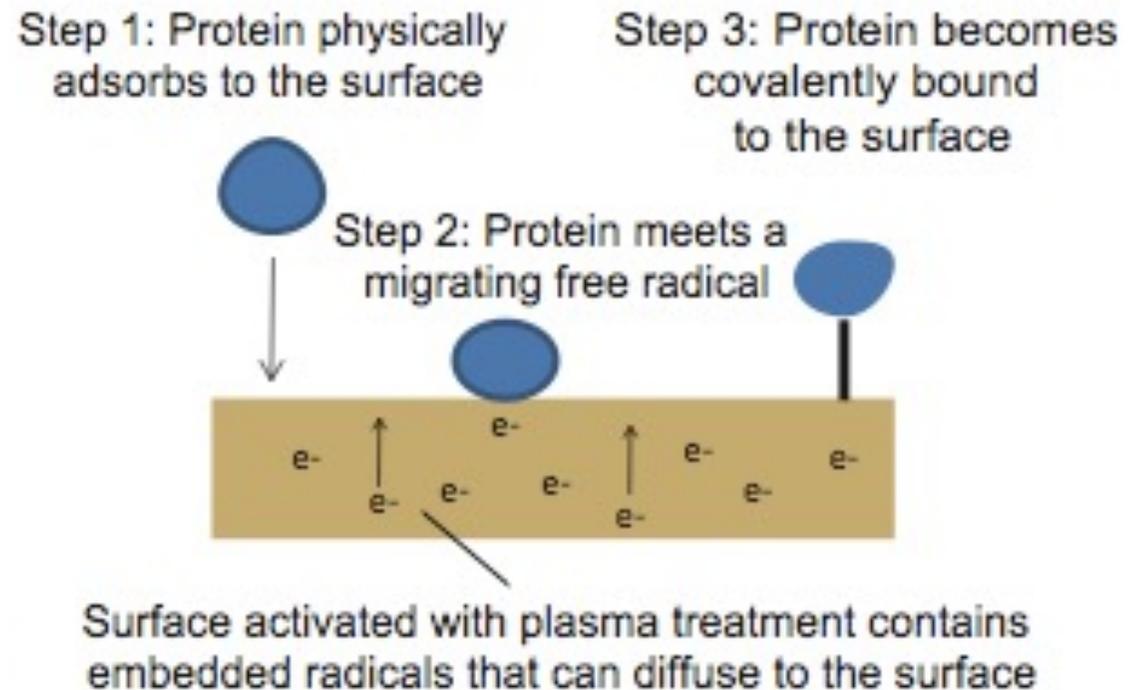
- ◆ Retains protein conformation
- ◆ Low attachment strength



- ◆ Protein denaturation
 - ◆ Strong attachment
-

Radical Induced Covalent Coupling

- › Protein immobilisation on physical contact
- › No toxic chemicals or solvents
- › Rapid covalent attachment
- › Binds all macromolecules
- › No additional reagents needed
- › pH is a free parameter



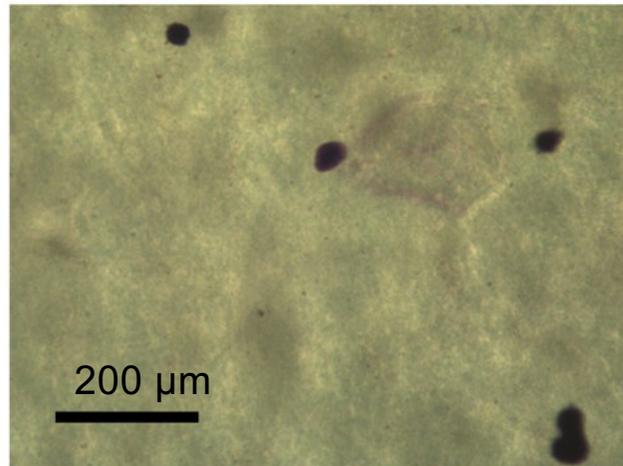
Plasma modified surfaces with immobilised molecules mimic in-vivo environments for cells

Human dermal fibroblasts spread surfaces coated with collagen (BSA blocked)

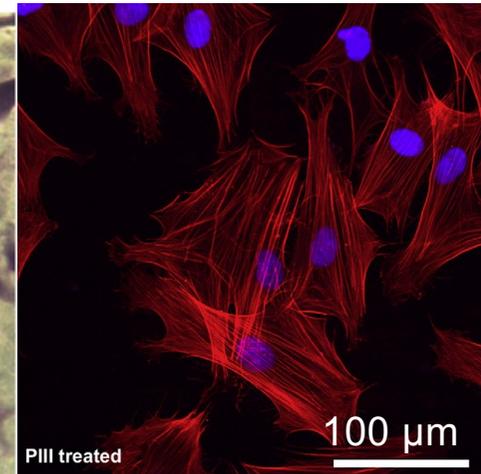
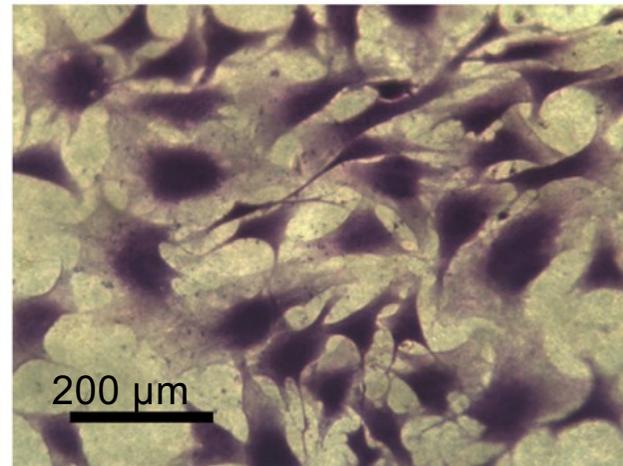
Collagen amounts same on both surfaces as measured by ELISA

* Bax DV, et al.,
Biomaterials 31
(2010) 2526–2534

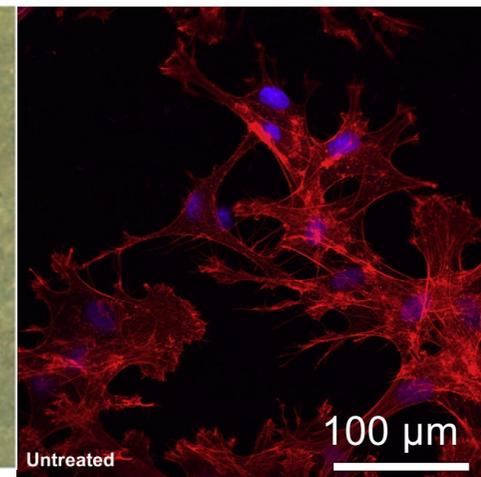
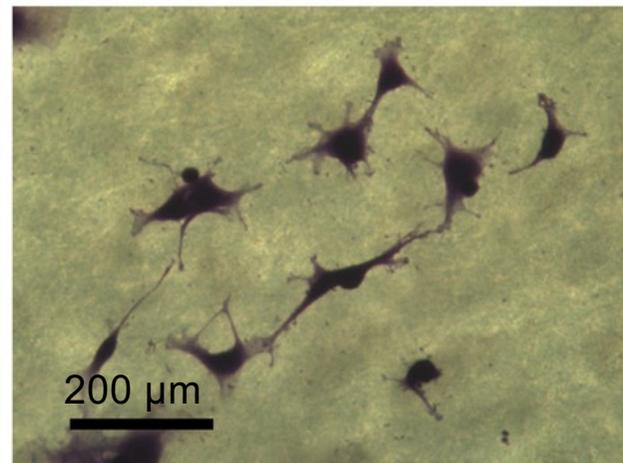
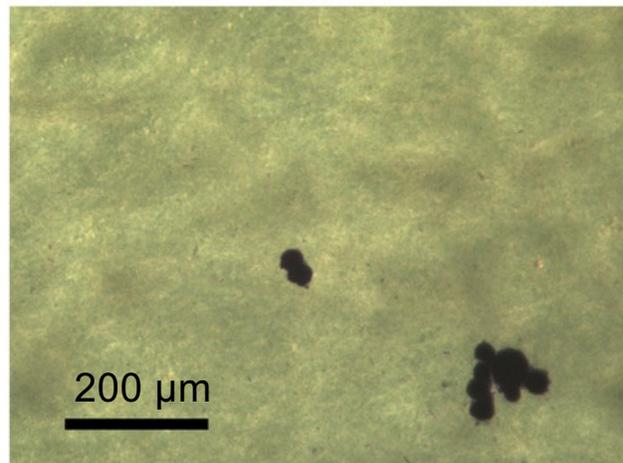
PIII treated



20µg/ml Collagen



Untreated

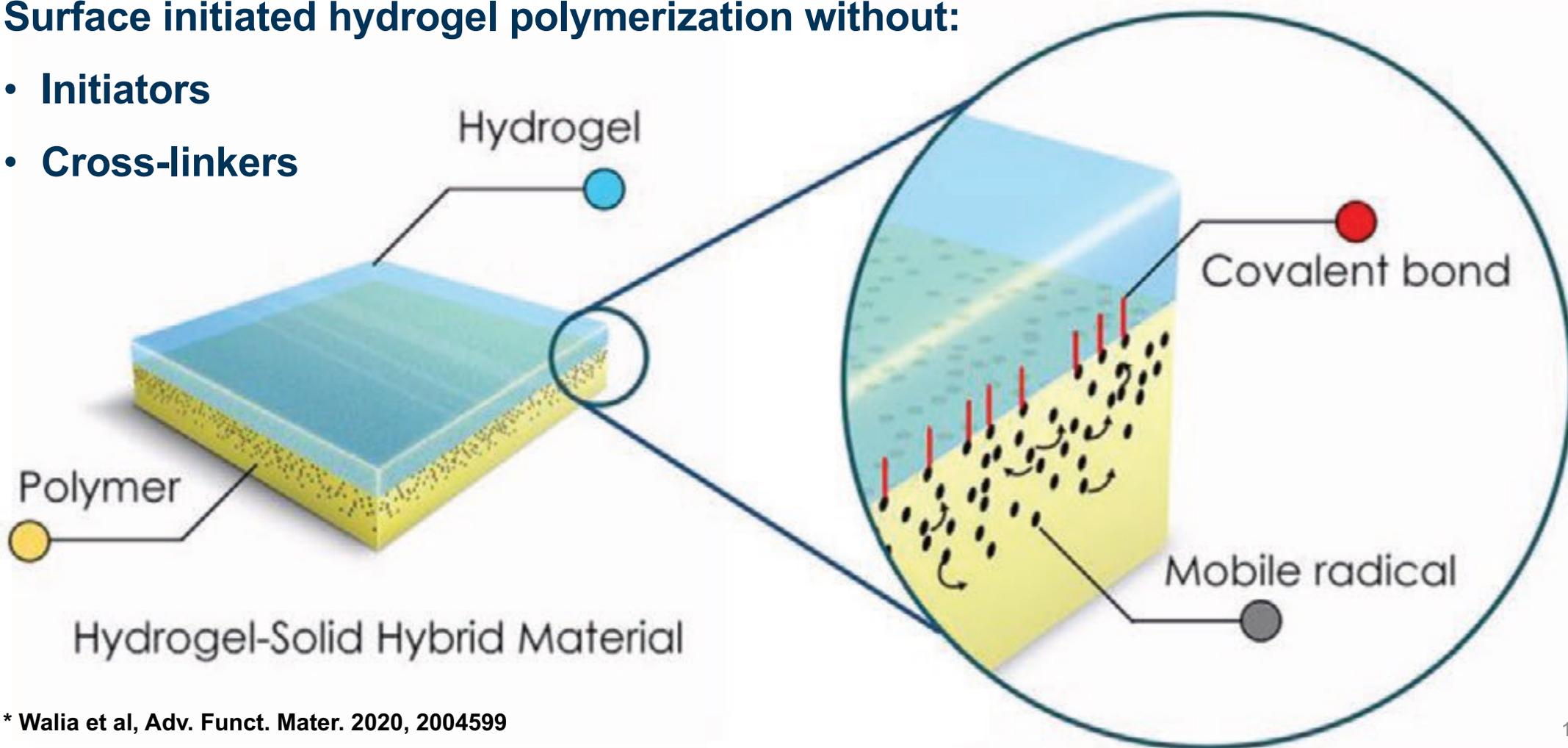




Hydrogel coating covalent attachment enabled by surface-embedded radicals

Surface initiated hydrogel polymerization without:

- Initiators
- Cross-linkers

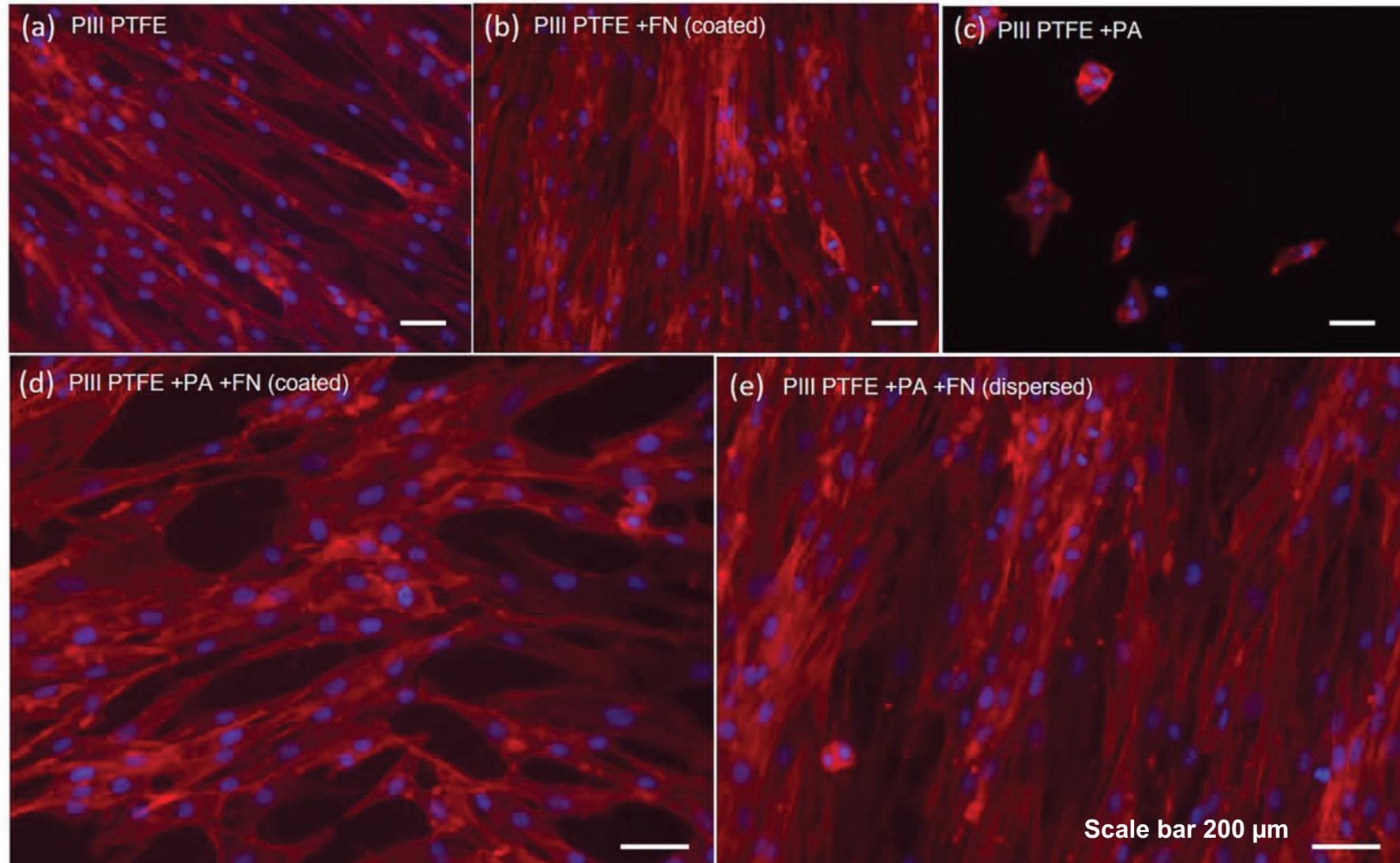


* Walia et al, Adv. Funct. Mater. 2020, 2004599

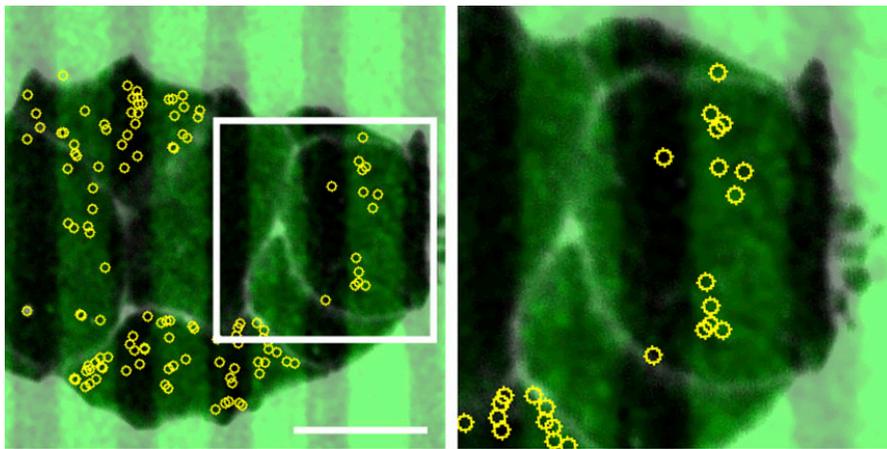
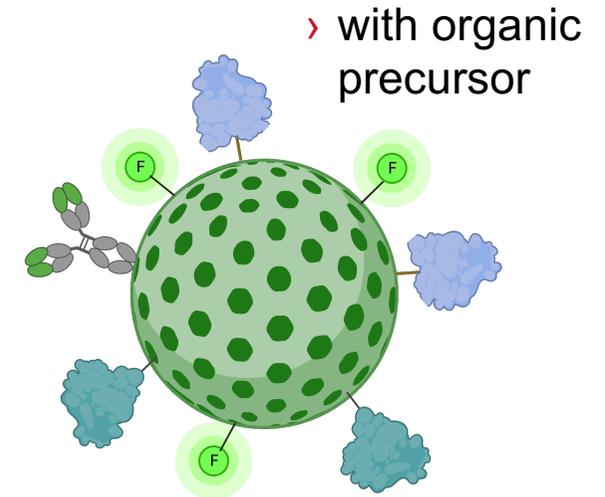
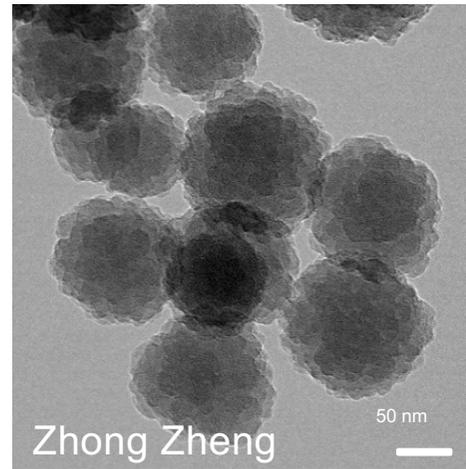
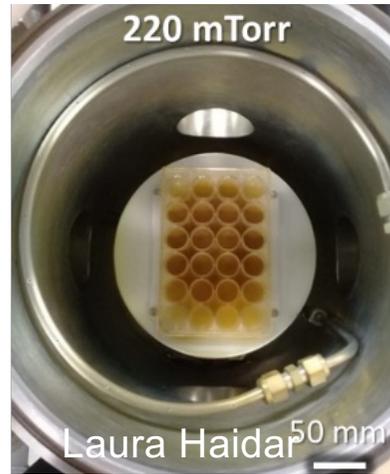
**Hydrogel
immobilized with
adhesion
molecules
facilitates cell
growth just like
native ECM**

* *Walia, et al, Adv.
Funct. Mater. 2020,
2004599*

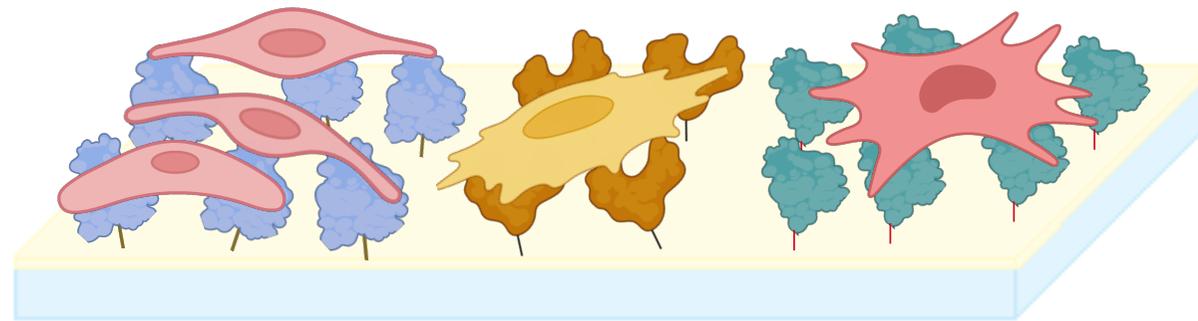
- *Bingyan Liu*
- *Jiayan Shao*



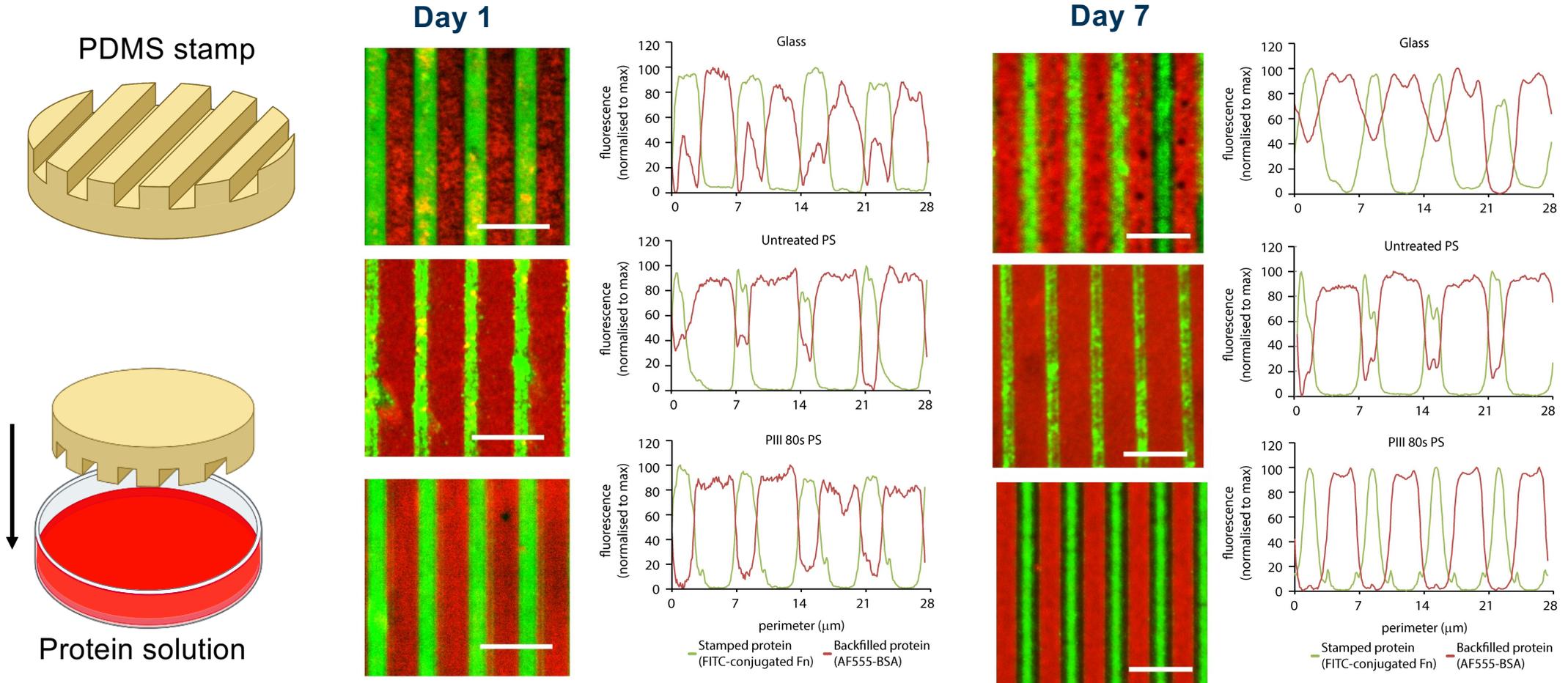
Simple plasma deposition processes yield radical laden surface coatings and nanoparticles



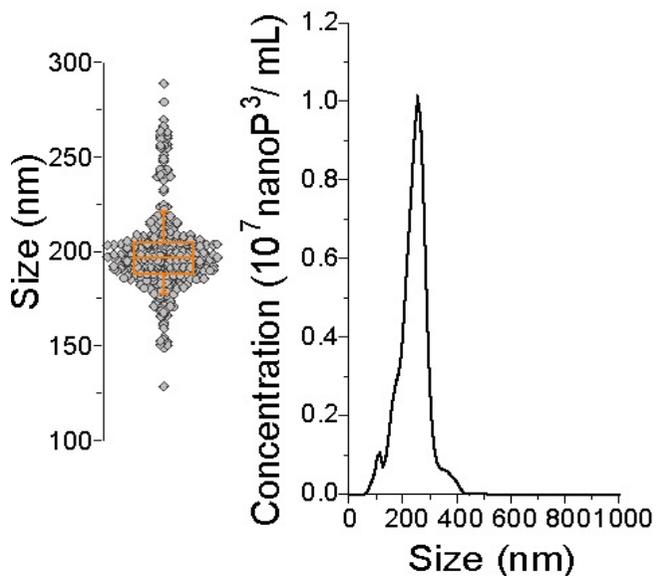
> with ion bombardment



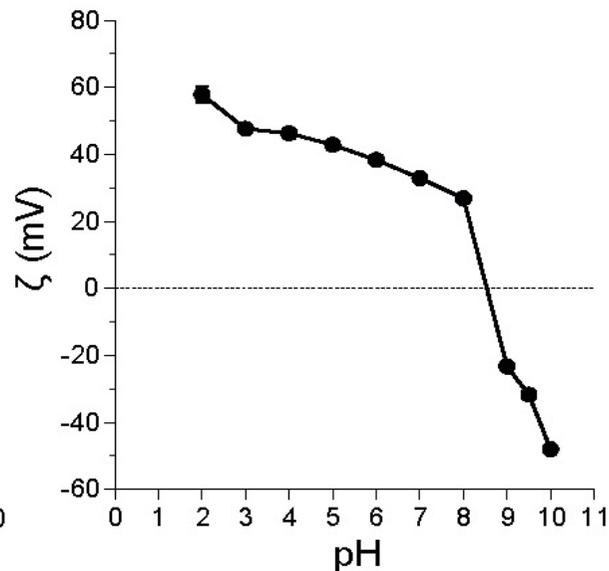
Stable biomolecule patterns for localized control of cell responses



Plasma synthesised nanoparticles have tunable size, surface charge and enter cells

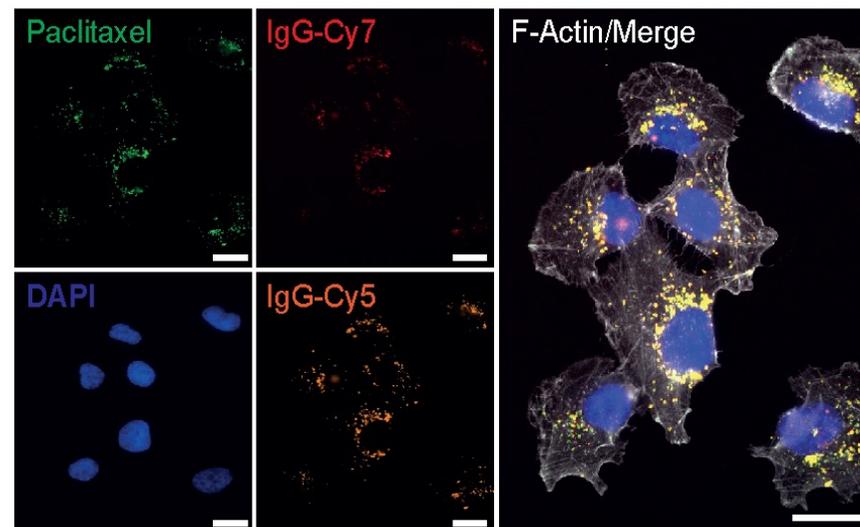
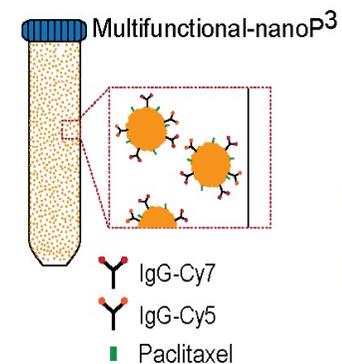


Controllable mean size with narrow distribution



Zeta potential varies from positive to negative with pH of the solution

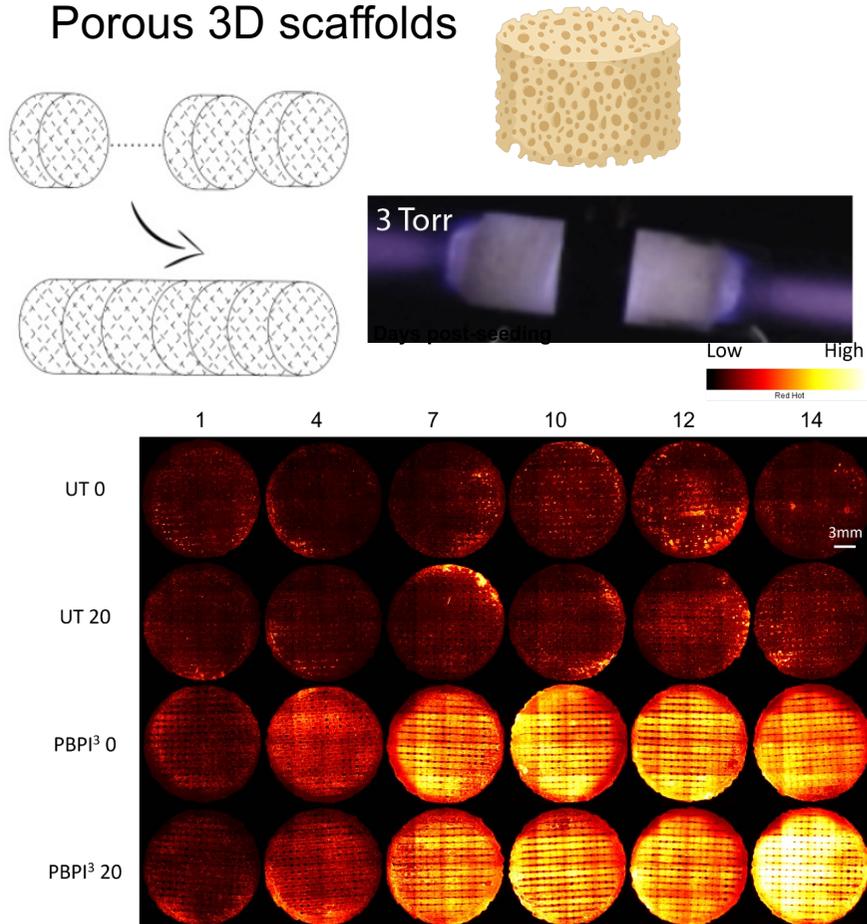
Molecular cargo is bioactive & transported into cells



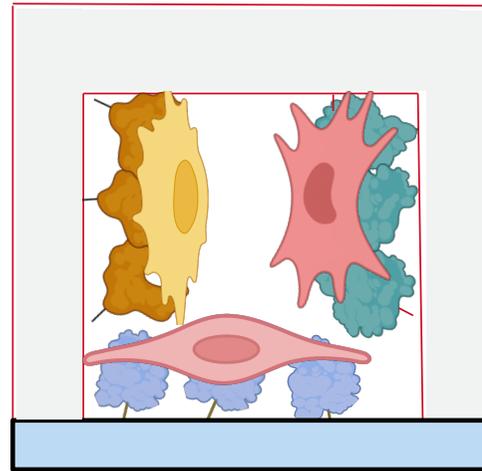
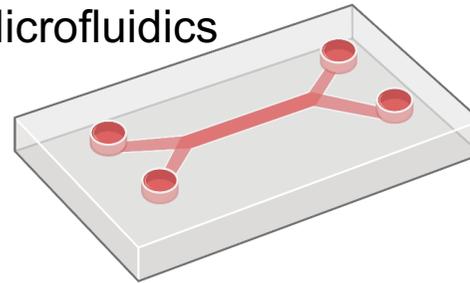
Scale bar is 20 μ m

Bio-instructive surfaces for biomedicine in complex geometries

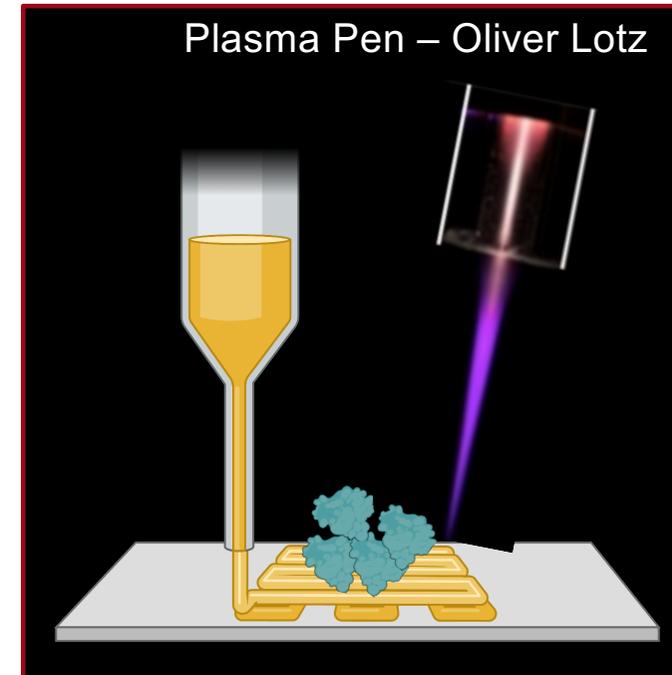
Porous 3D scaffolds



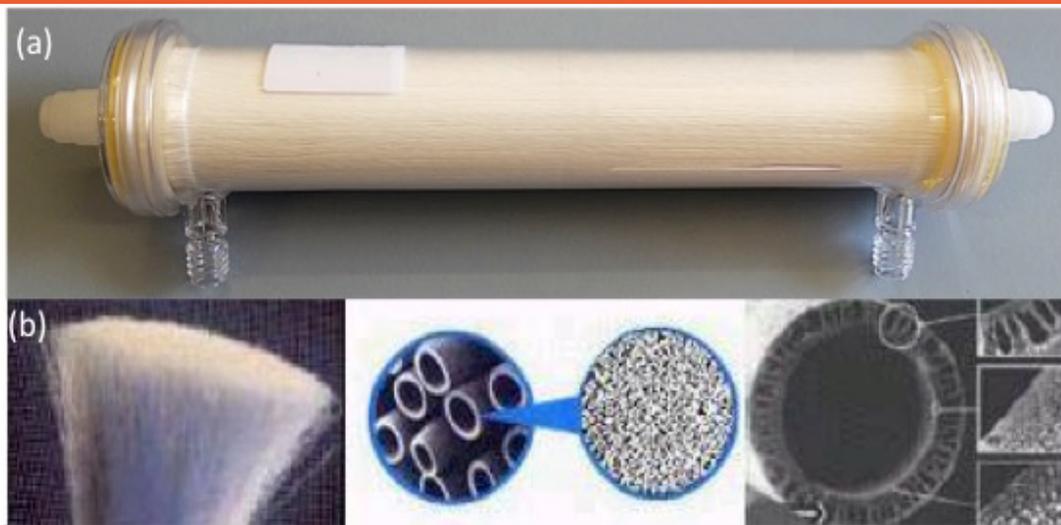
Microfluidics



3D Bioprinting



Surface activation of 3D porous structure - dialysis cassette



Hollow fibre cassette: ~10,000 fibres; 200 μm diam; 10-50 nm pores

