

Electrical failure in microscale silver nanowire networks under voltage pulses



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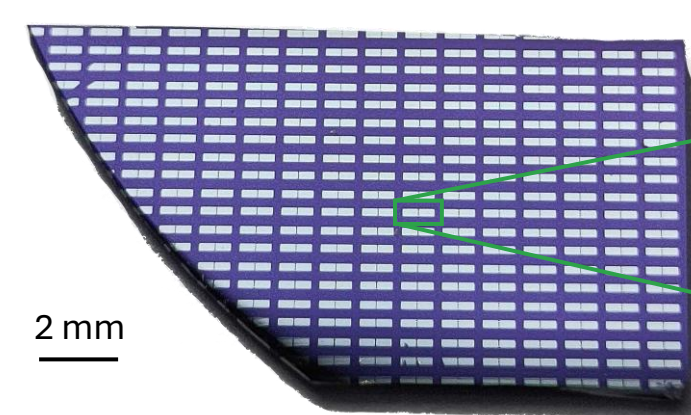
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Experimental details

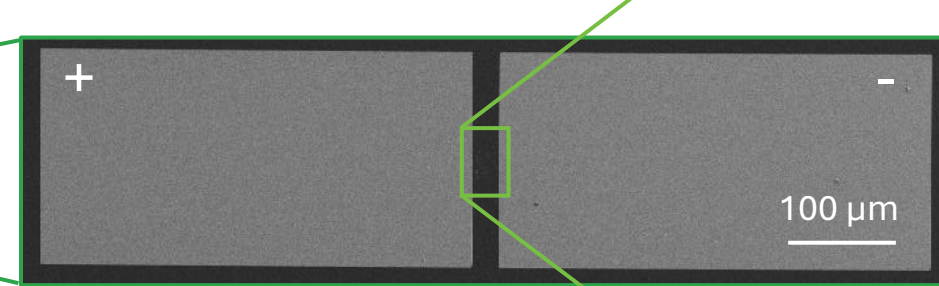
Fabrication :

Overlay lithography on Si/SiO₂ substrate

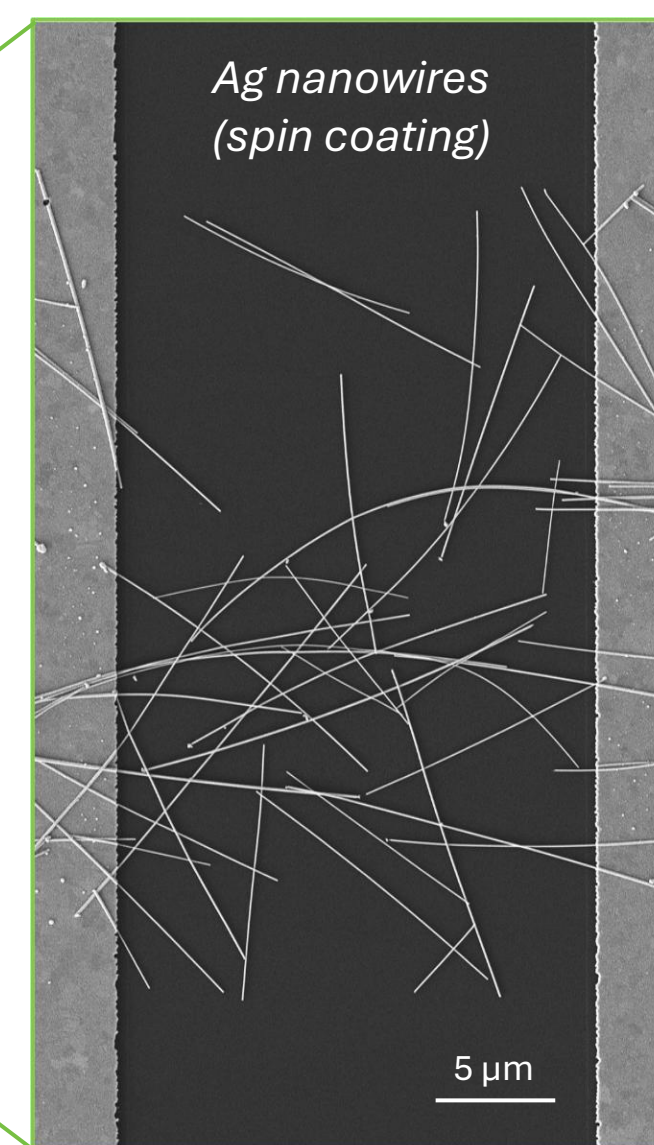


The sample

Ag electrodes
(thermal evaporation)



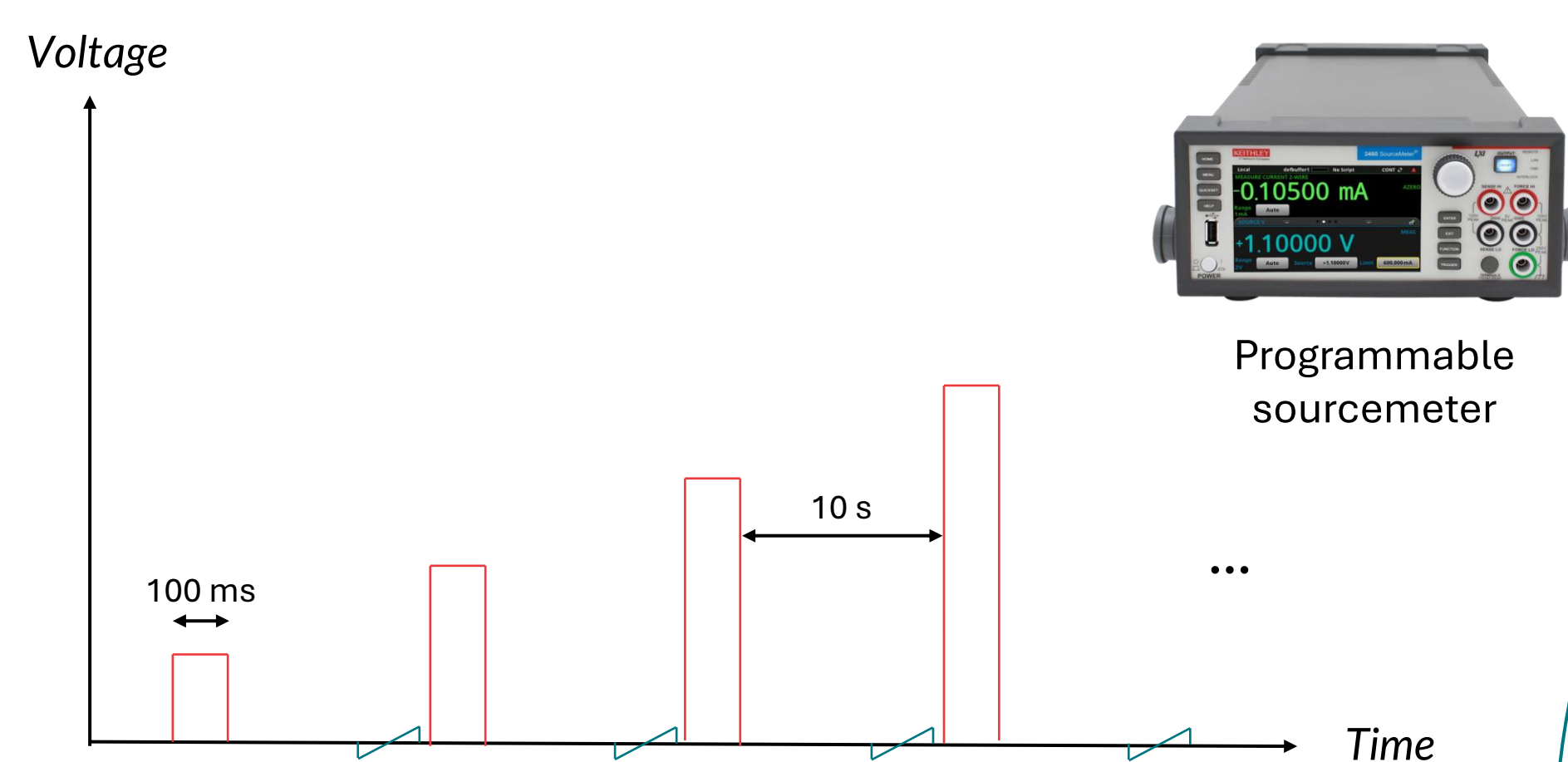
The device



The micro-network

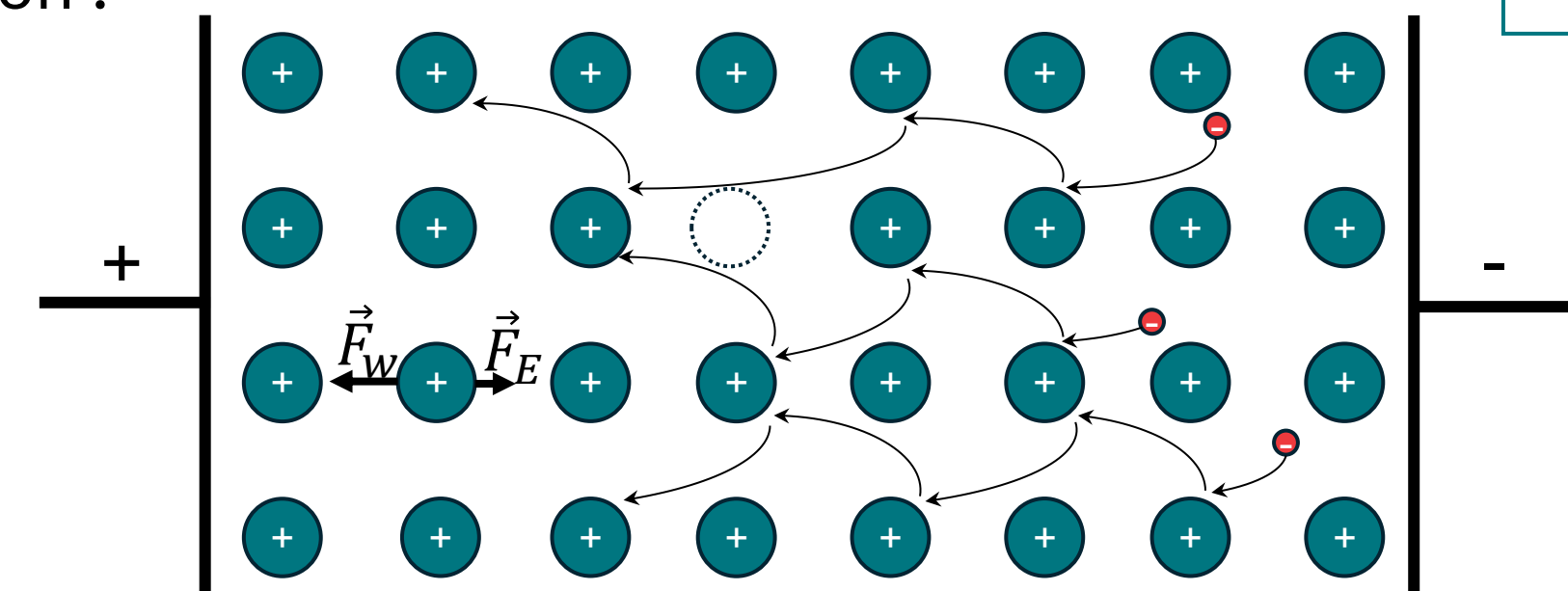
Electrical stresses :

Looping on **ascending pulsed stresses** and **resistance measurements**.



Programmable
sourcemeter

Phenomenon :



Electromigration

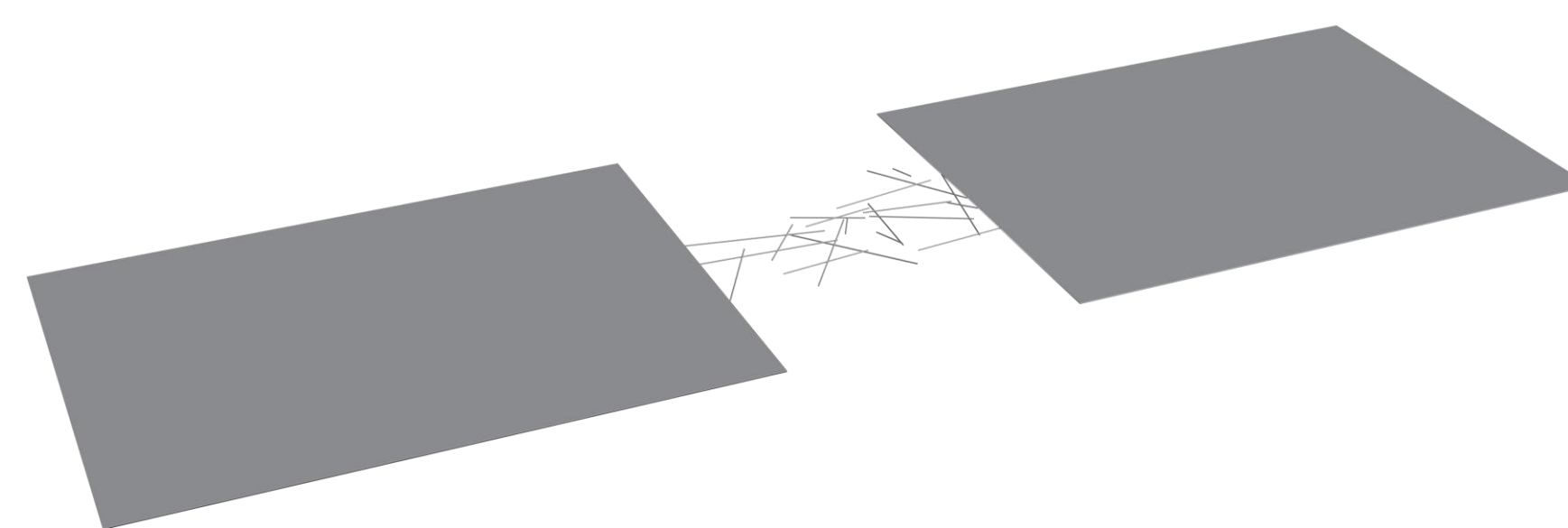
A **bias** applied to a conductor induces **forces** on the **ions** forming the crystal lattice.

- $\vec{F}_E \triangleq$ the **electrical force** from the electrical field,
- $\vec{F}_W \triangleq$ the “**electron wind**” force, from repeated collisions with moving electrons.

At high current densities, wind forces become significant and can displace ions, especially near defects. This phenomenon is known as **electromigration**.

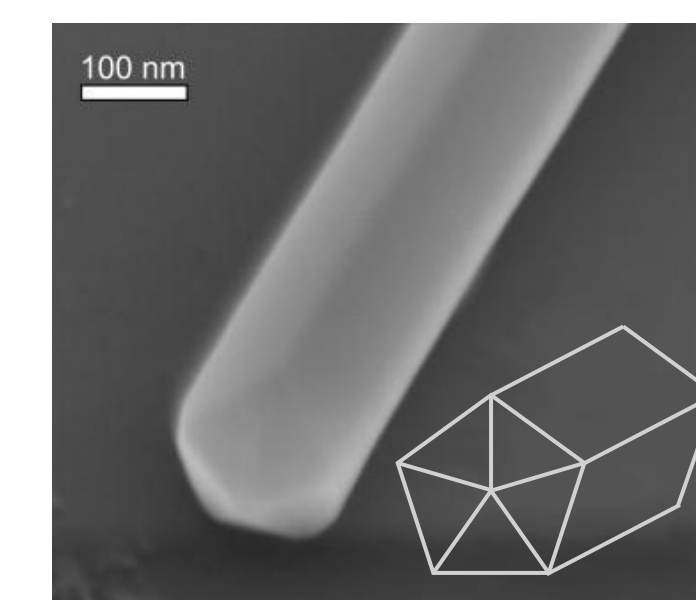
Overview

How do nanowire networks fail under electrical stresses ?

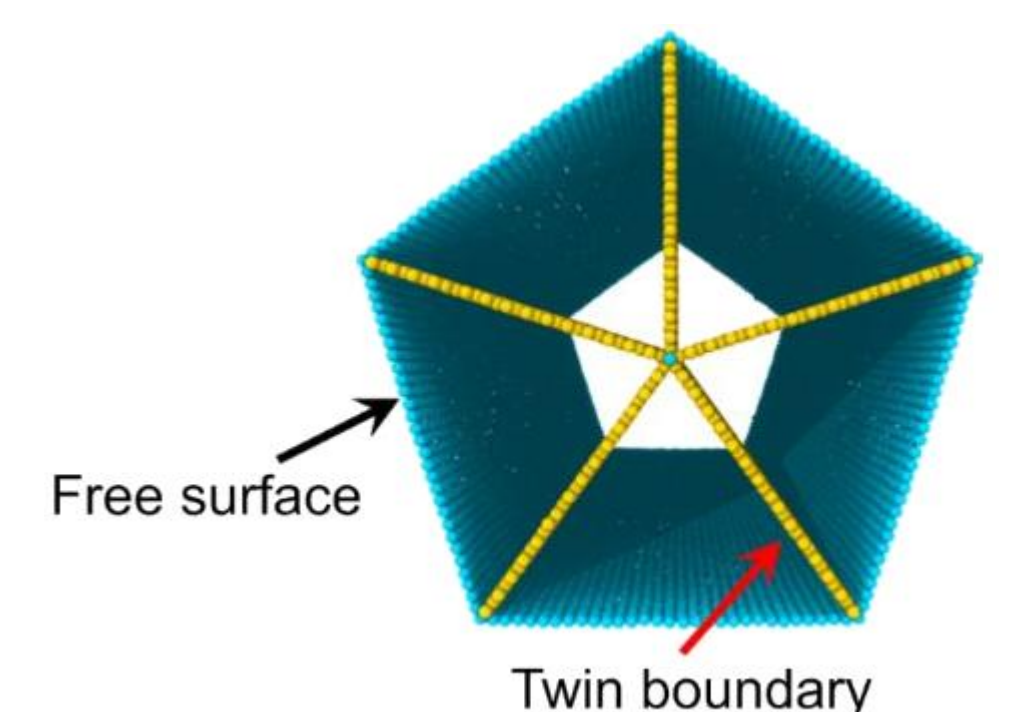


Few-wire networks as a platform to study **failure mechanisms**

Defects in polyol-grown AgNWs :



[1]

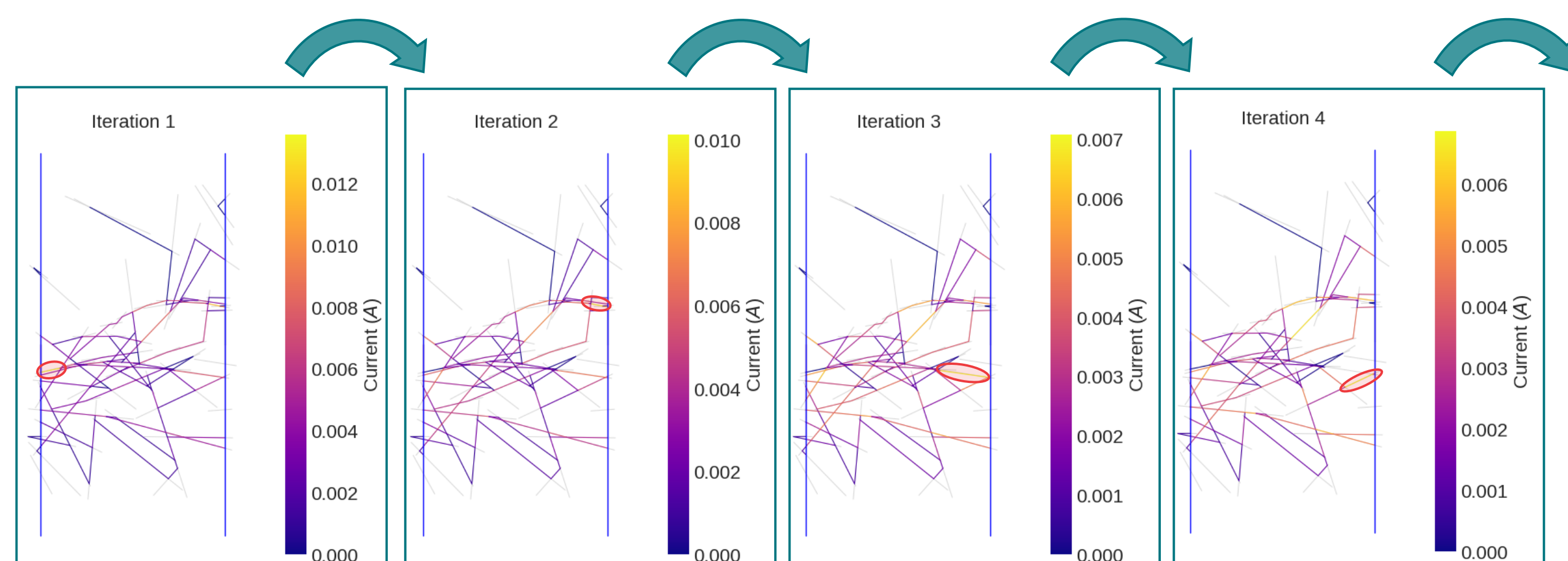
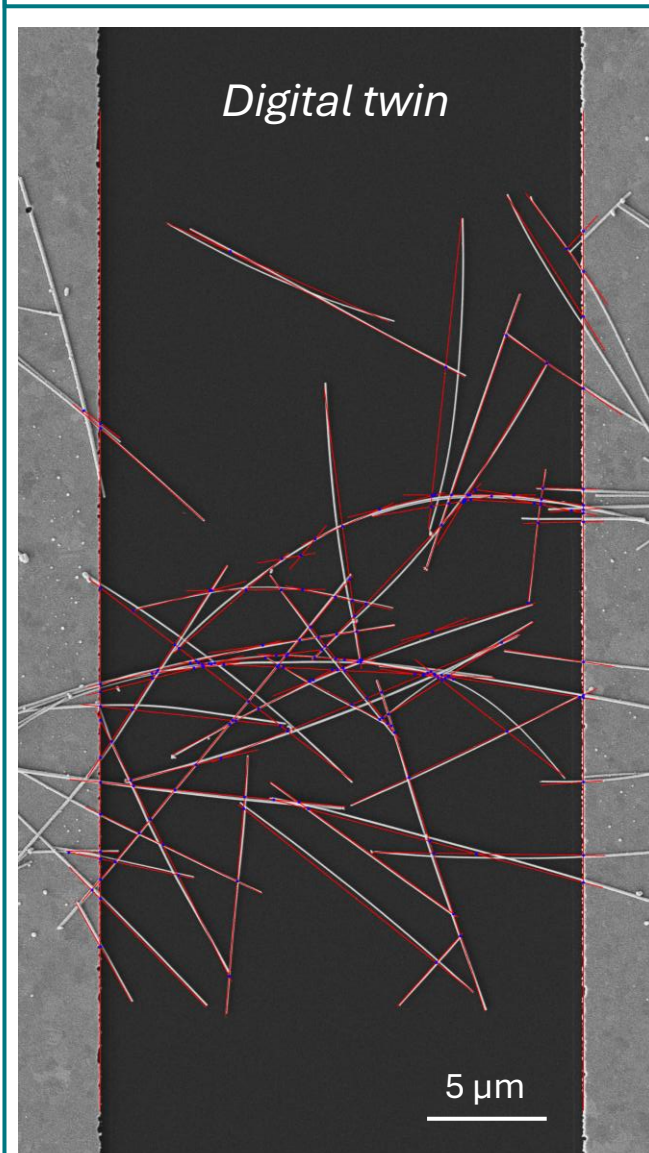


[2]

Simulations

Protocol for prediction of failures :

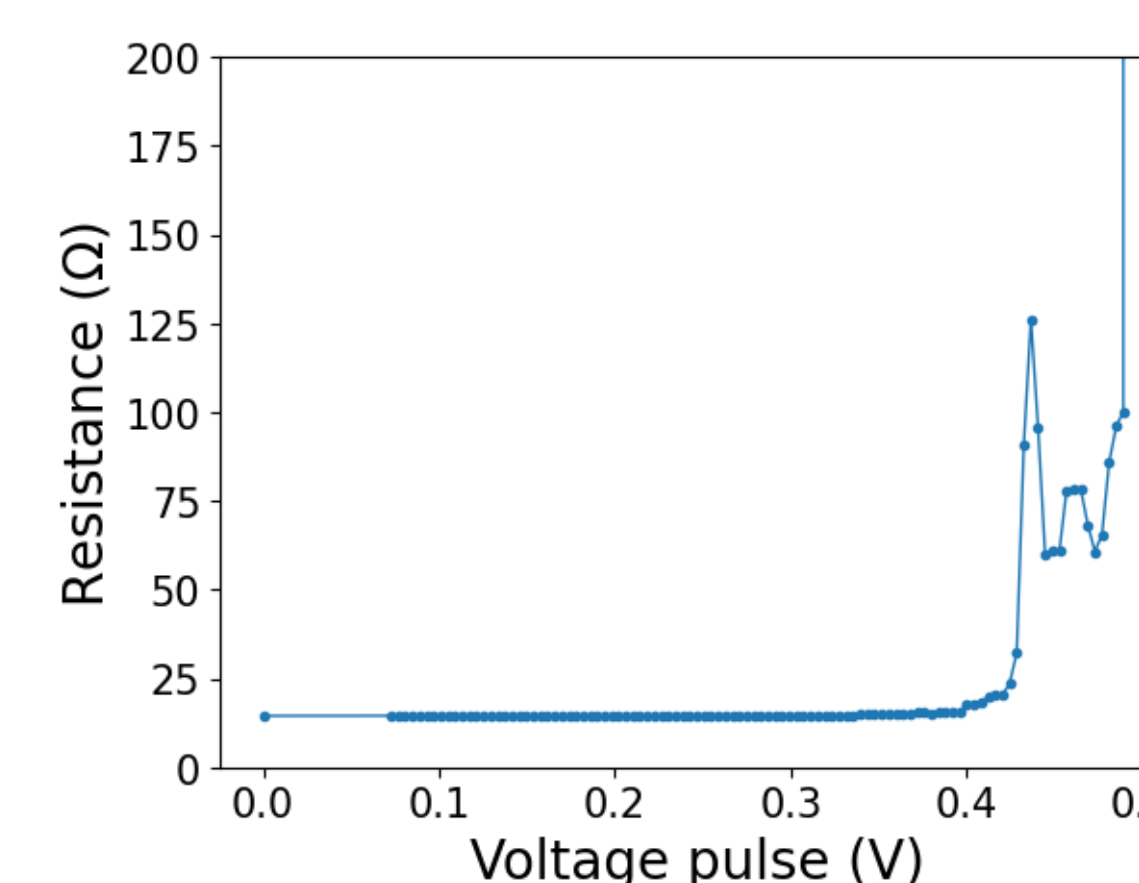
- Draw a digital twin of the micro-network
- Find intersections
- Produce a resistor-based equivalent circuit
- While percolating path exists :
 - Apply a 1V bias (arbitrary choice)
 - Using Kirchhoff laws, computes the current map
 - Remove the wire with maximal current from the circuit



Morphological characterization :

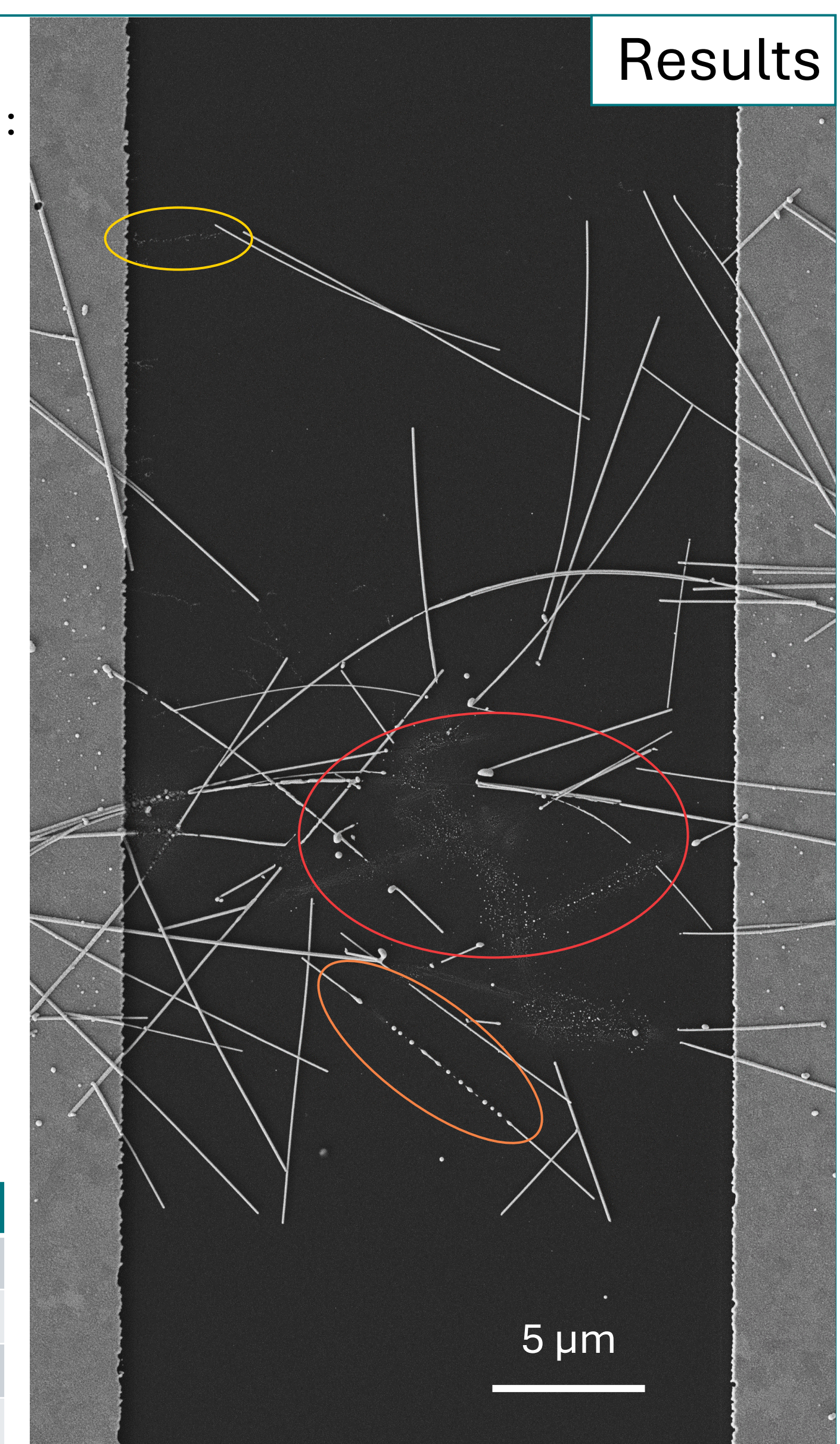
- Explosion-like instabilities
- Spheroidization-like instabilities
- Dendrite formation

Quantitative results :



Mean breaking current density (A/cm ²)	Reference
$3.1 \cdot 10^6$	[3]
$1.63 \cdot 10^6$	[4]
$(10 \pm 3) \cdot 10^7$	[5]
$(6 \pm 3) \cdot 10^7$	This work

Results



Take-home message

- Modelling few-wire AgNW networks bridges experiments and simulations, enabling failure prediction in more complex systems.
- Digital twin circuits help extract key parameters, such as junction resistance and critical current density driving electrical failures.
- In complex systems, multiple failure mechanisms may coexist and interact.
- Further works includes :
 - *In-situ* microscopy to resolve the chronology of failure events.
 - 3D structural characterization to refine thermal modelling at the wire–substrate interface.

References :

- [1] S. Vlassov *et al.*, Materials Chemistry and Physics **143** (3), 1026-1031 (2014).
- [2] S. Vlassov *et al.*, Journal of nanotechnology **10**, 2468-2476 (2019).
- [3] M. Lagrange *et al.*, Nanotechnology **28** (5), 055709 (2017).
- [4] N. Charvin *et al.*, Nanoscale advances **3**, 675-681 (2021).
- [5] M. Waliullah *et al.*, Nanotechnology **33** (30), 305706 (2022).

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