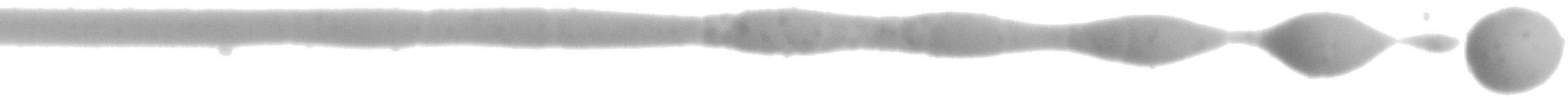


Mapping local failure of silver nanowire networks under electrical stresses

F. Balty [1,2], N. Lejeune [2], M. Rondiat [1], A. Baret [1], A. V. Silhanek [2], N. D. Nguyen [1]

[1] SPIN – Solid state Physics of Interfaces and Nanostructures
[2] EPNM – Experimental Physics of Nanotructured Materials

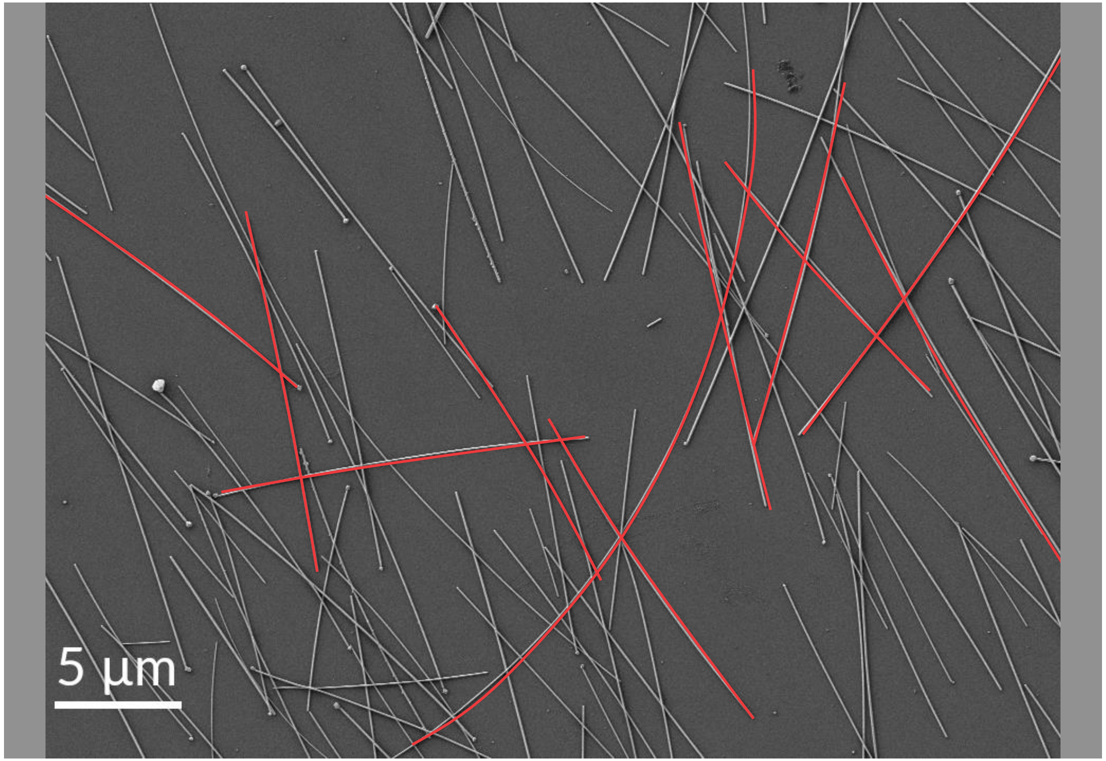
LIÈGE université

EPNM

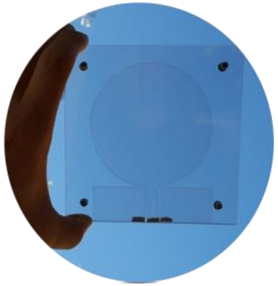
SPIN

E-MRS

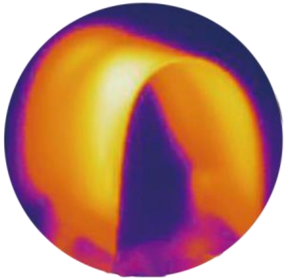
Metallic nanowire networks - Generalities



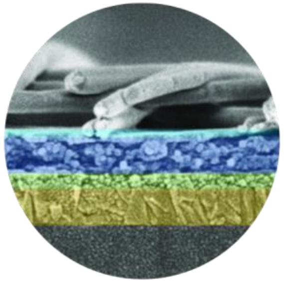
Conductive path between electrodes = « Percolation path » [1]



Transparent Antenna



Transparent Heater



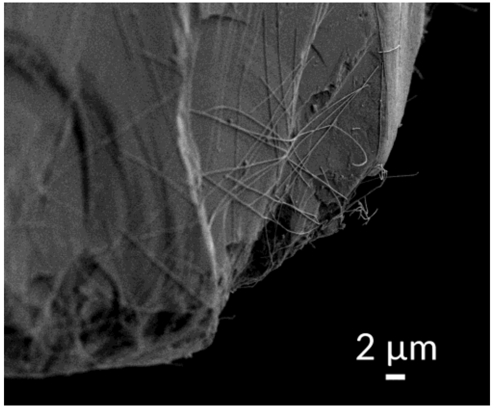
Device integration

Photovoltaic

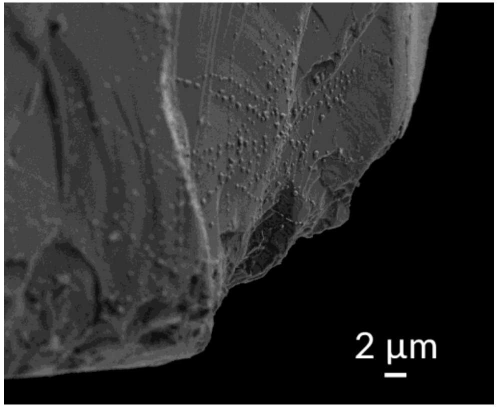
Touch screen

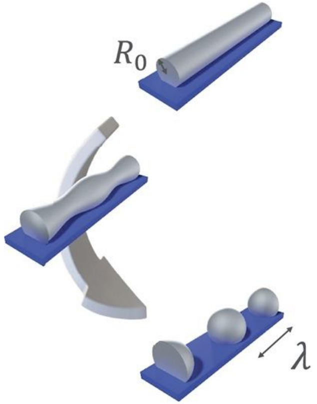
Flexible screen

Metallic nanowire networks - Instabilities



Heating





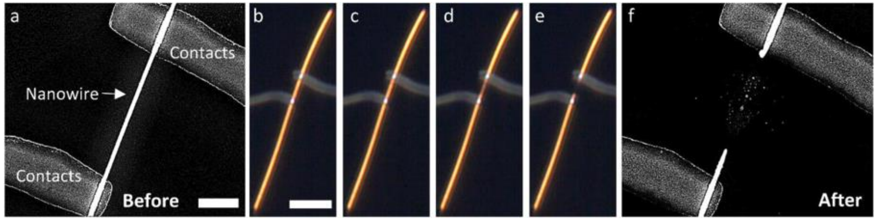
[2]

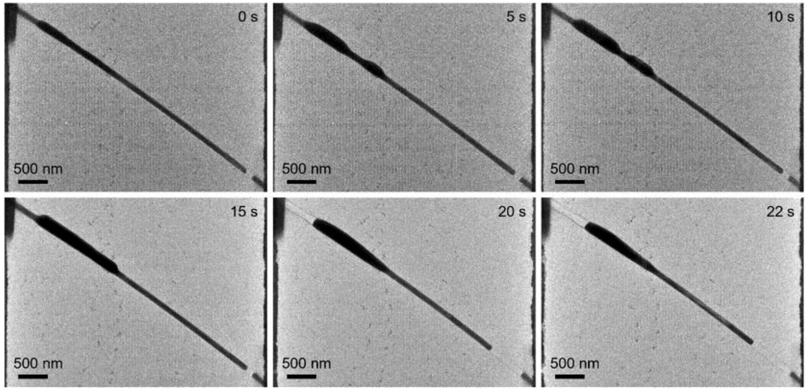
Prone to **instabilities** under a variety of stresses :

- Thermal
- Electrical
- Mechanical
- Chemical
- ...

Electrical instability – Literature

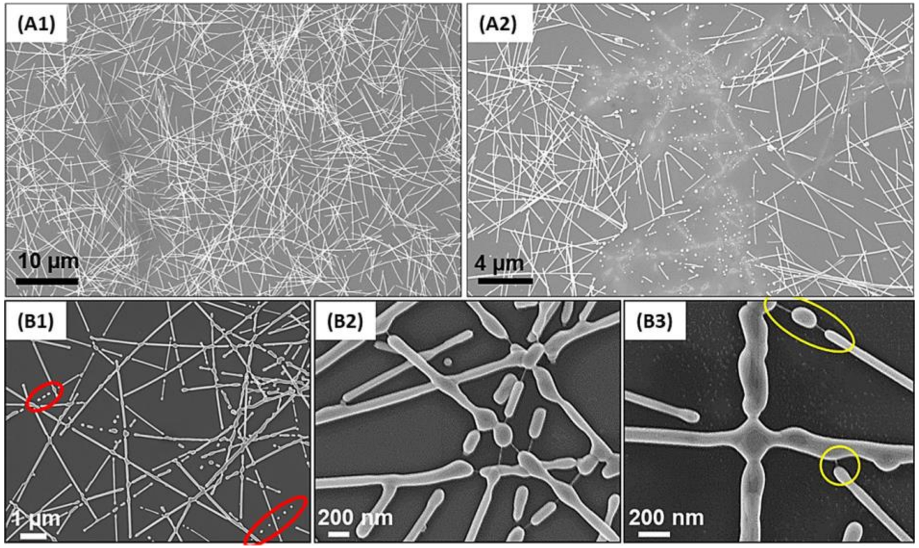
At the nanowire scale





[3-5]

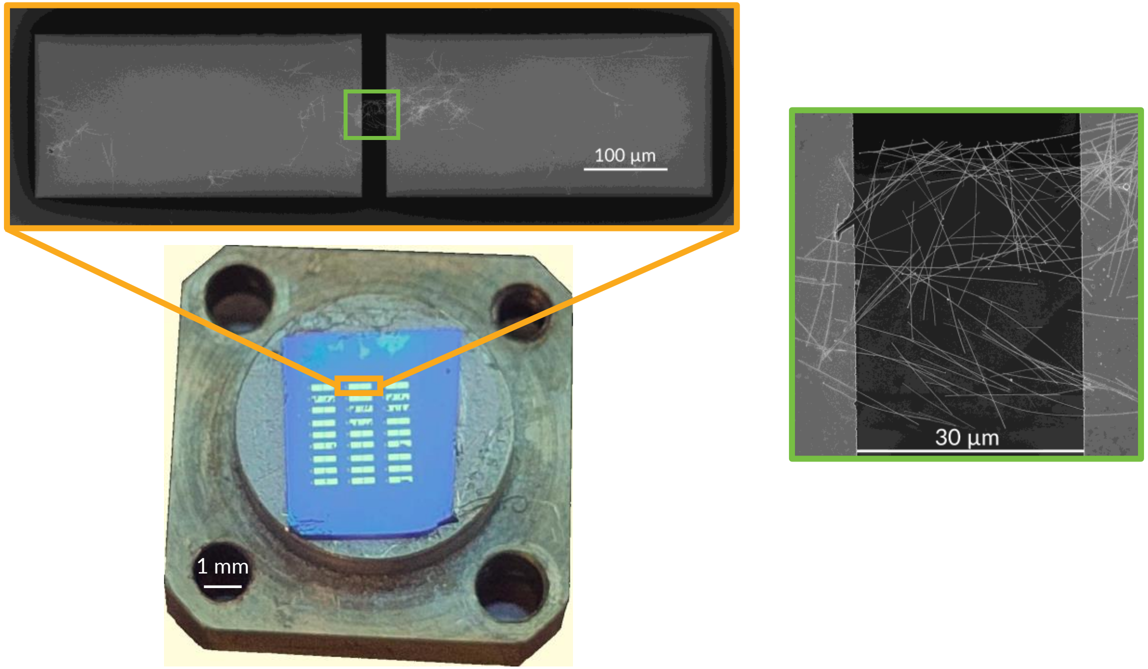
At the network scale

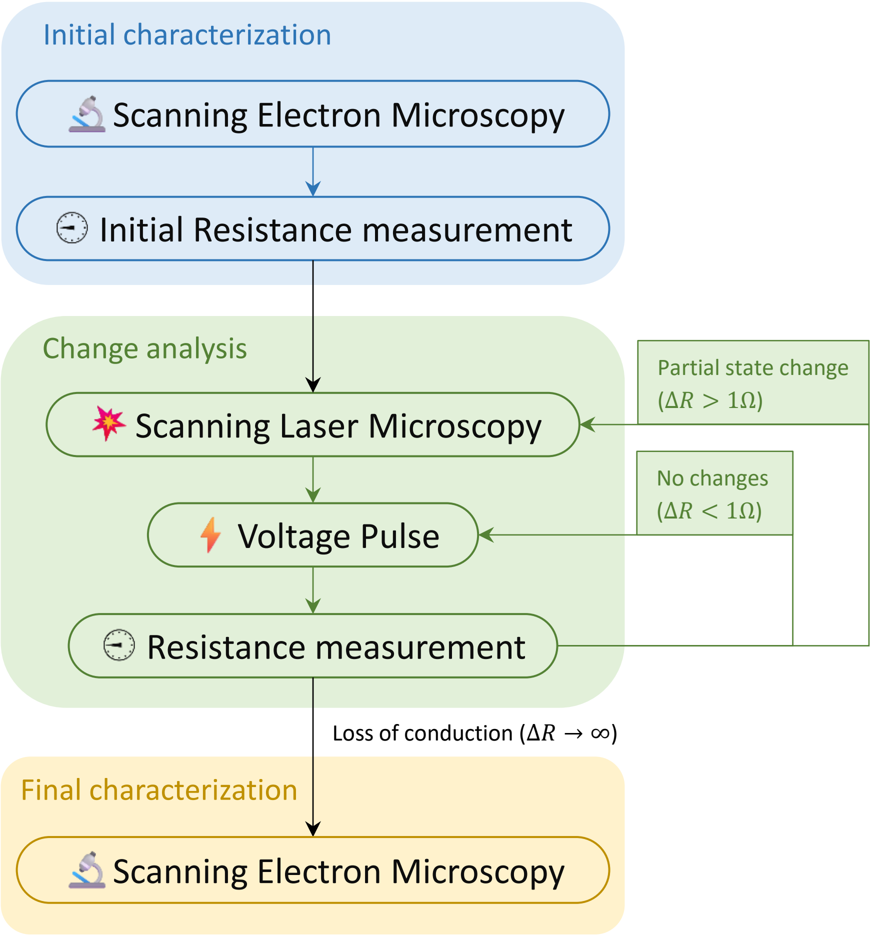


[6-12]

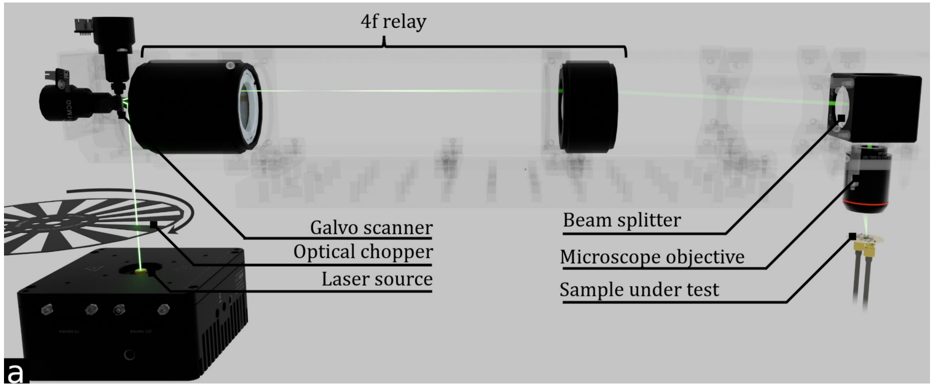
In between ?

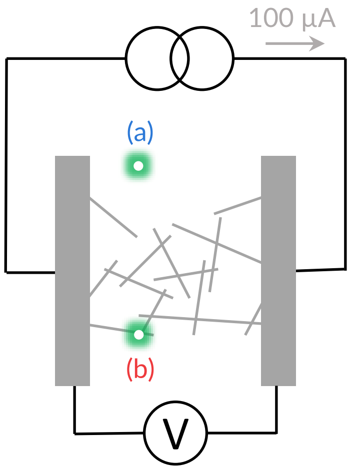
Micro-networks





Scanning Laser Microscopy – Percolation path observation





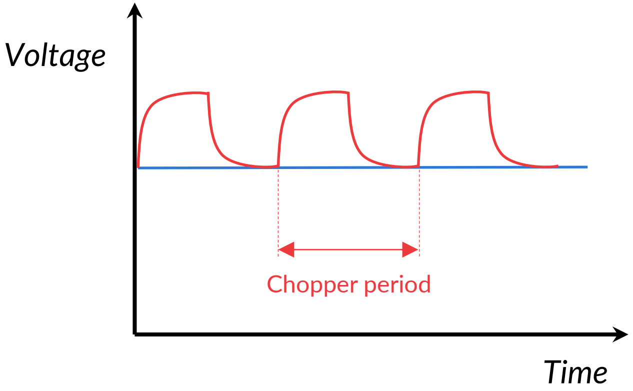
Case (a) : Laser on inactive zone

Case (b) : Laser on percolation path

- Resistivity $\rho \nearrow$ with $T \nearrow$

$$\Rightarrow \quad R \nearrow \left(= \rho \, \frac{l}{S}\right)$$

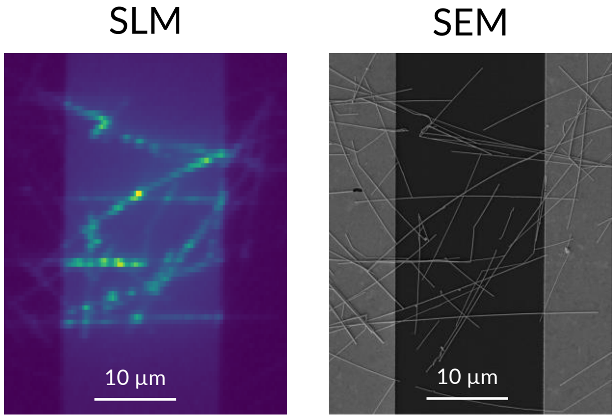
$$\Rightarrow \quad V \nearrow \ (= R\, i)$$



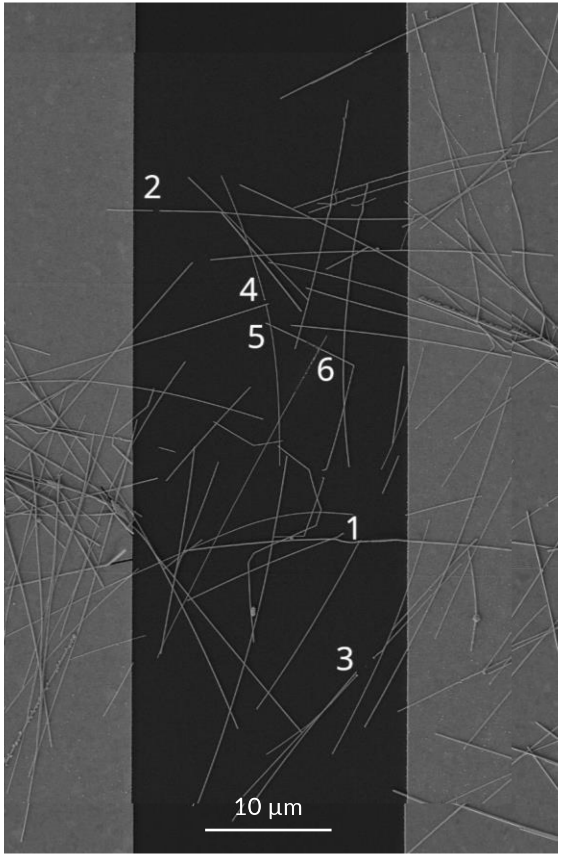
→ No pertubation

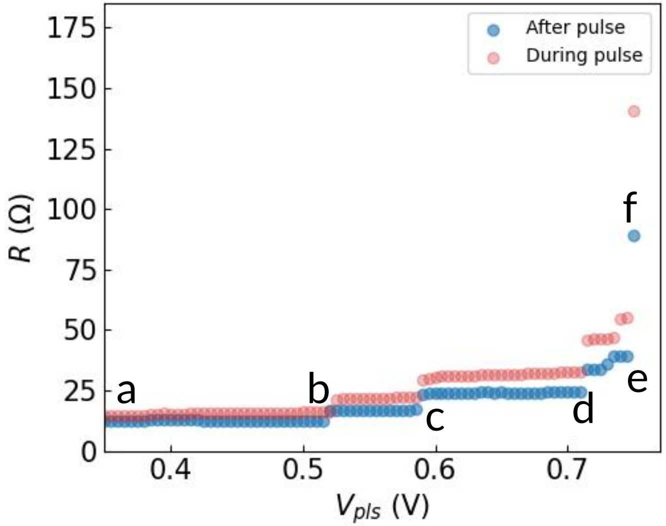
→ Perturbation

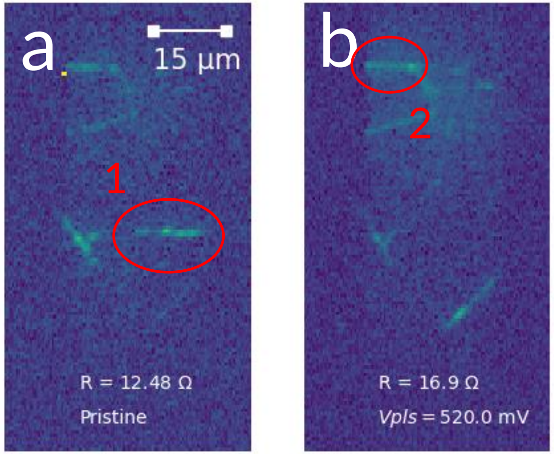
Scanning the whole area :

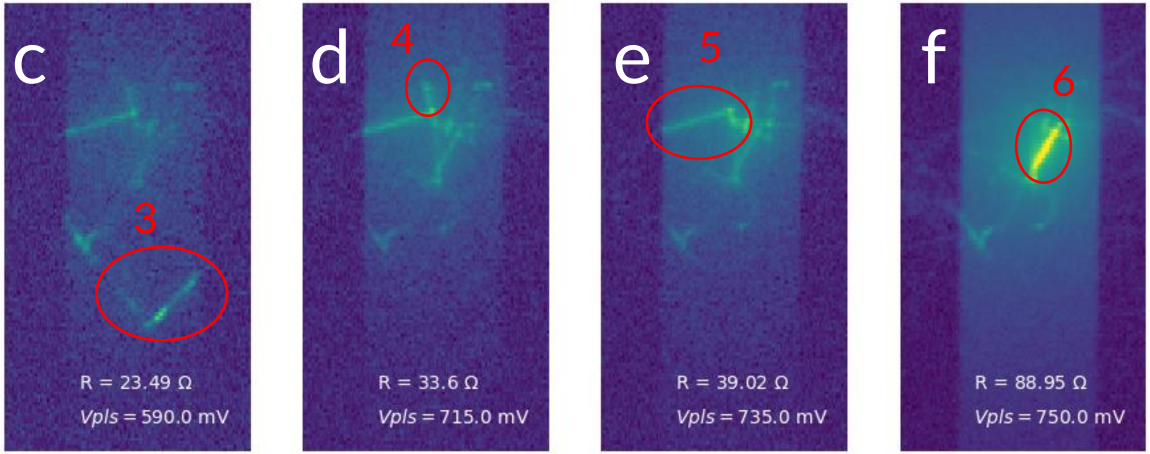


Results

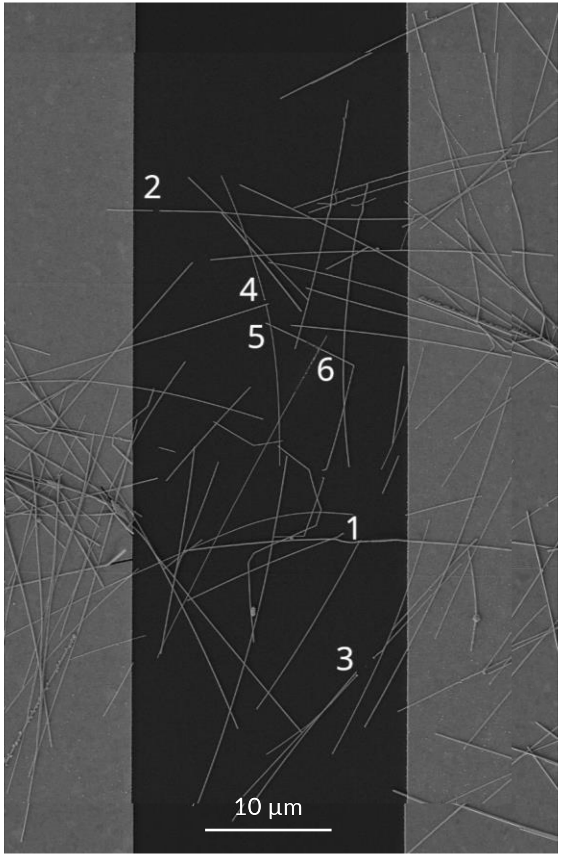

2
4
5
6
1
3
10 µm

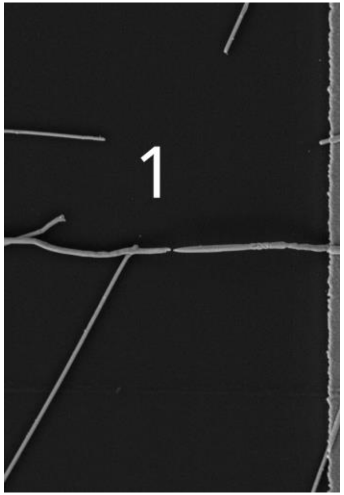

175
150
125
100
75
50
25
0
R (Ω)
0.4
0.5
0.6
0.7
V_{pls} (V)
After pulse
During pulse
a
b
c
d
e
f

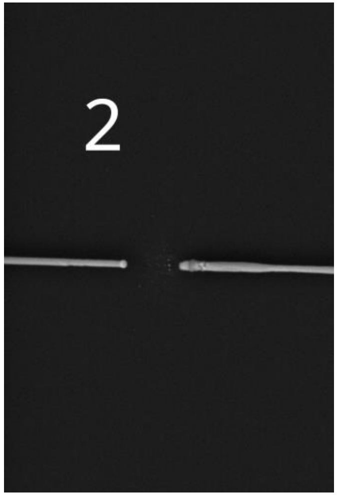

a
15 µm
1
R = 12.48 Ω
Pristine
b
2
R = 16.9 Ω
Vpls = 520.0 mV

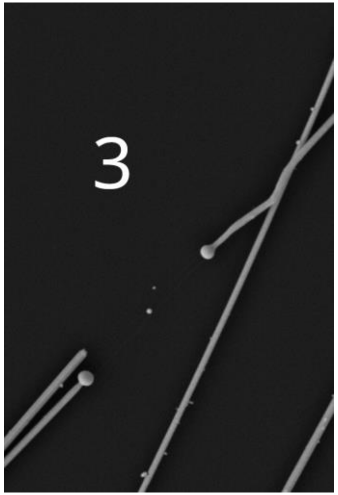

c
3
R = 23.49 Ω
Vpls = 590.0 mV
d
4
R = 33.6 Ω
Vpls = 715.0 mV
e
5
R = 39.02 Ω
Vpls = 735.0 mV
f
6
R = 88.95 Ω
Vpls = 750.0 mV

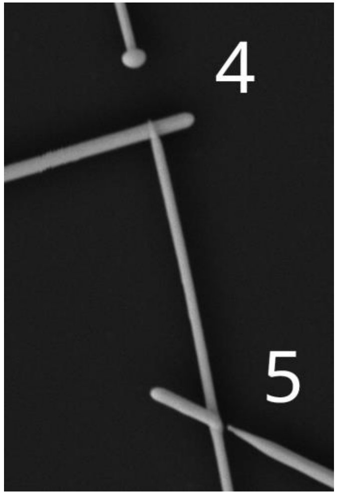
Results

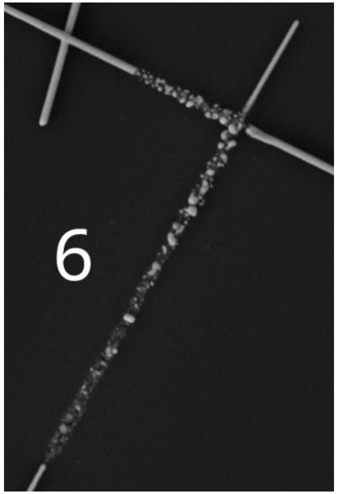








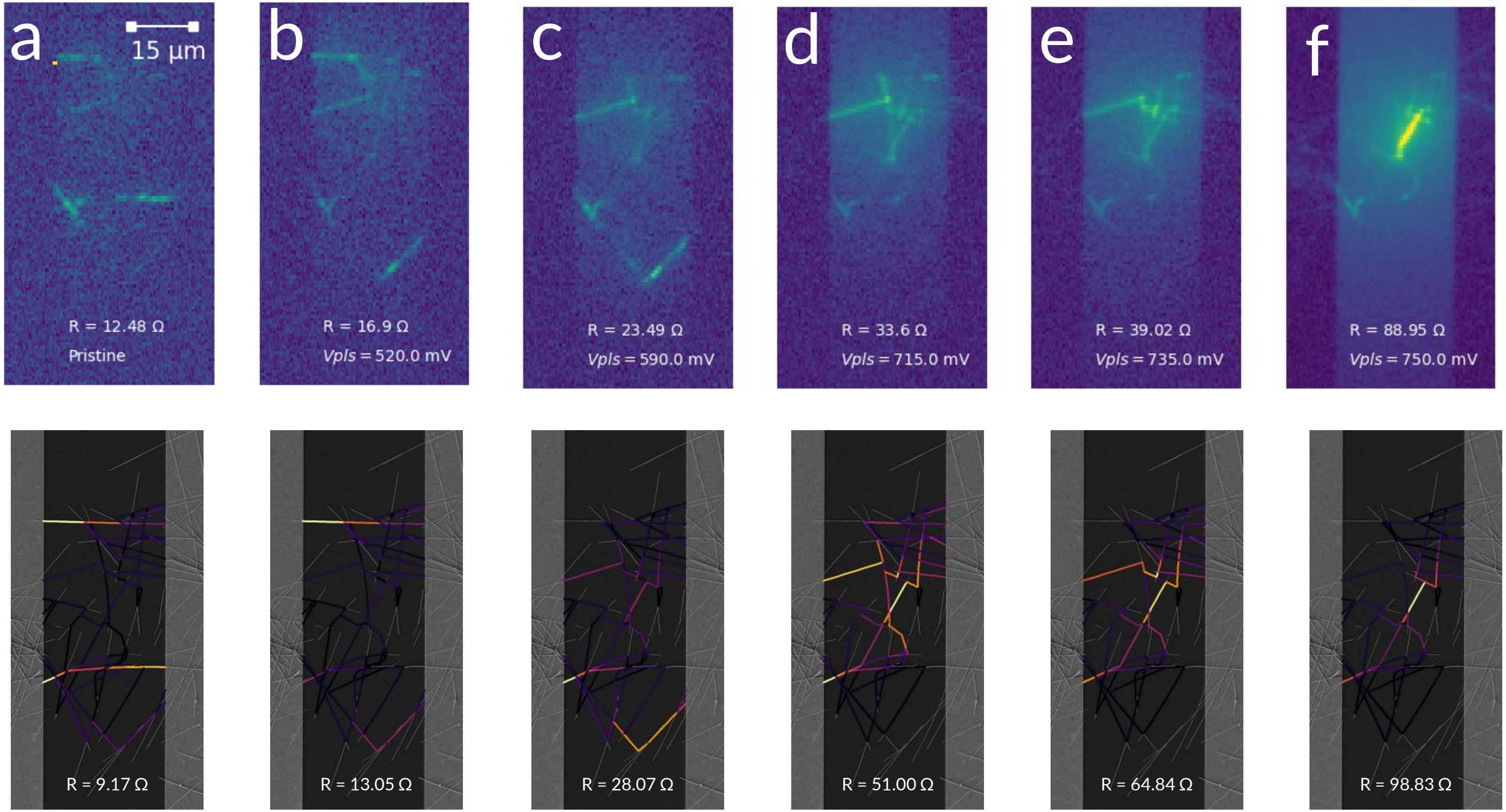




Comparison with digital twin simulation

Scanning Laser Microscopy

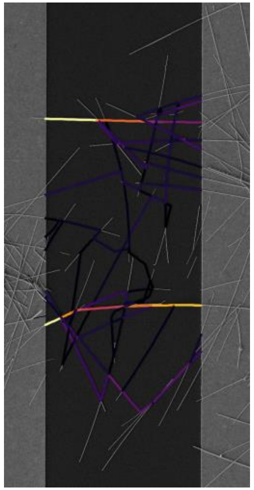
Colormap of the **simulated currents** (arbitrary units)



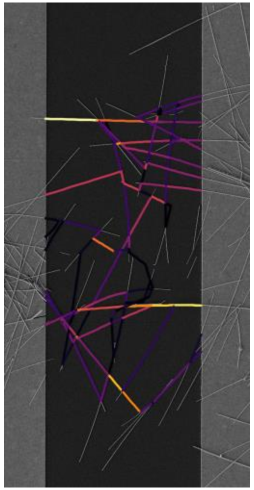
(Similar simulations : [1])

Simulation as a tool to interpret

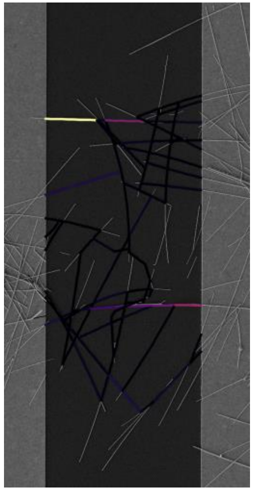
Numerical investigation on a variety of parameters :



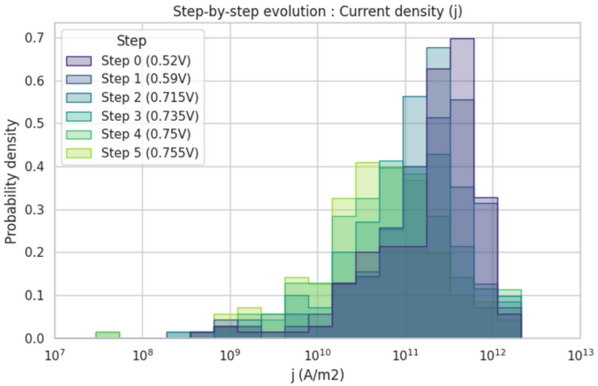
Current I

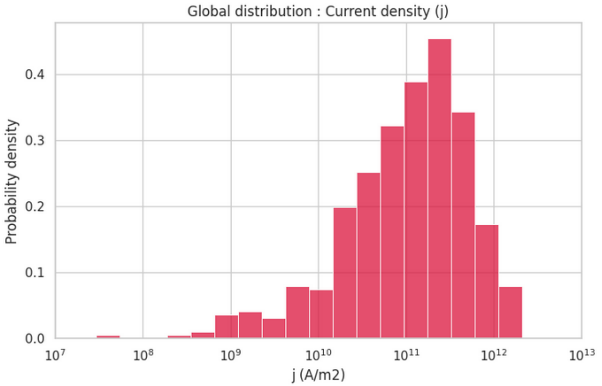


Current density j



Dissipated power P

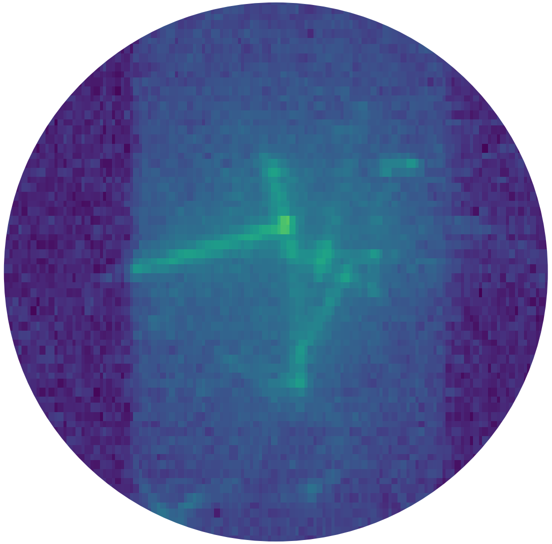




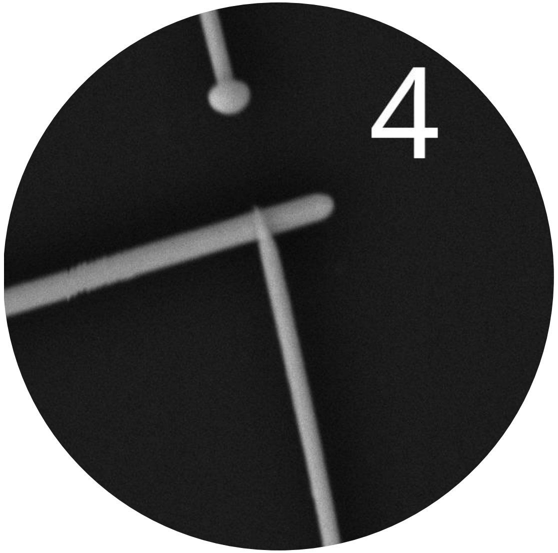
Preliminary results :

- Order of magnitude of stresses comparable to literature results
- Variety of failure morphology
- Stochastic failure – not always the NW with largest stress

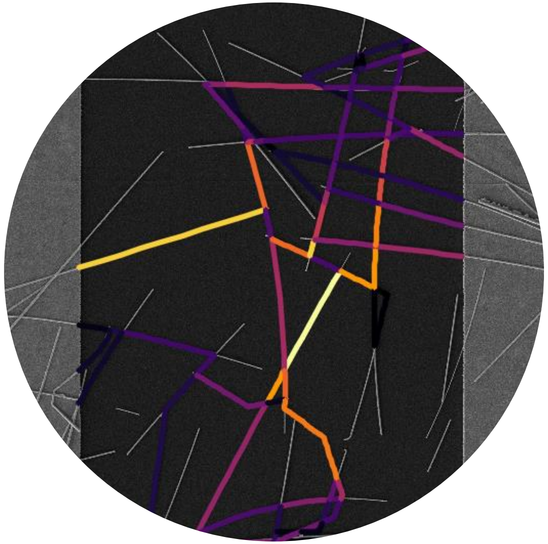
Take-home message



SLM is a spatially-resolved demonstration of the flow of current

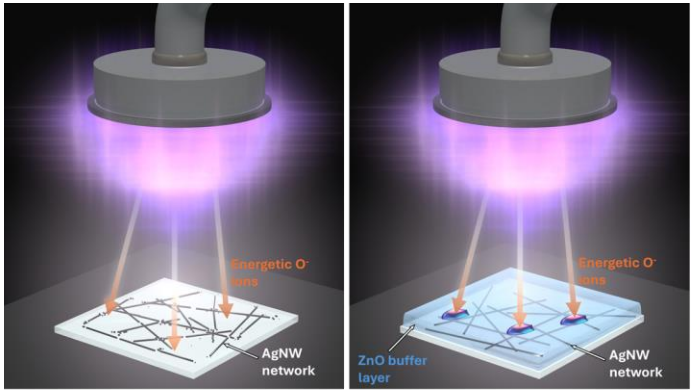


It allows to reconstruct the failure timeline of AgNW micro-network



Combined with simulations, it gives access to a large dataset

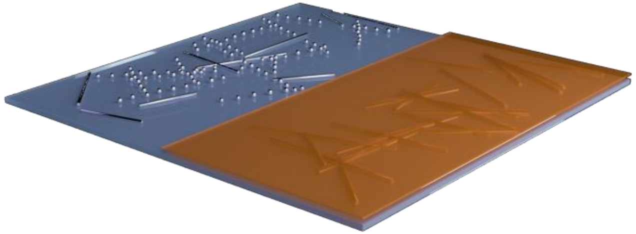
Other presentations from our group



RF sputtering of metal oxides on nanostructured silver electrodes : degradation mechanisms and stabilization strategies

A. Baret, A. Khan, S. Akin, L. Teulé-Gay, D. Bellet, A. Rougier, N. D. Nguyen

Thursday 28/05, 15:00, Room ETOILE A



Enhancing the Stability of Silver Nanowire Networks with TiO_2 *Thin Films*

A. Baret, R. Zaghdoudi, F. Balty, Q. Binstok, D. Ndemekong, M. Georges, N. D. Nguyen

Thursday 28/05, 16:30-18:30, Poster session Room ETOILE

References

[1] D. P. Langley, M. Lagrange, N. D. Nguyen, and D. Bellet, “Percolation in networks of 1-dimensional objects: comparison between Monte Carlo simulations and experimental observations,” *Nanoscale Horizons*, vol. 3, pp. 545–550, Aug. 2018.

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[4] M. Waliullah and R. A. Bernal, “Current density at failure of twinned silver nanowires,” *Nanotechnology*, vol. 33, p. 305706, July 2022.

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[7] C. Mayousse, C. Celle, A. Fraczkiewicz, and J.-P. Simonato, “Stability of silver nanowire based electrodes under environmental and electrical stresses,” *Nanoscale*, vol. 7, pp. 2107–2115, Jan. 2015. 145 citations (Crossref) [2023-10-20].

References

[8] M. Lagrange, T. Sannicolo, D. Muñoz-Rojas, B. G. Lohan, A. Khan, M. Anikin, C. Jiménez, F. Bruckert, Y. Bréchet, and D. Bellet, "Understanding the mechanisms leading to failure in metallic nanowire-based transparent heaters, and solution for stability enhancement," *Nanotechnology*, vol. 28, p. 055709, Dec. 2016.

[9] T. Sannicolo, N. Charvin, L. Flandin, S. Kraus, D. T. Papanastasiou, C. Celle, J.-P. Simonato, D. Muñoz-Rojas, C. Jiménez, and D. Bellet, "Electrical Mapping of Silver Nanowire Networks: A Versatile Tool for Imaging Network Homogeneity and Degradation Dynamics during Failure," *ACS Nano*, vol. 12, pp. 4648–4659, May 2018.

[10] K. Wang, Y. Jin, X. Wang, B. Qian, J. Wang, and F. Xiao, "Investigation into the failure mechanism of silver nanowire network film under electrical stress," in *2020 IEEE 70th Electronic Components and Technology Conference (ECTC)*, pp. 1218–1224, June 2020.

[11] K. Wang, Y. Jin, and F. Xiao, "Long-term electrically stable silver nanowire composite transparent electrode under high current density," *Journal of Materials Science: Materials in Electronics*, vol. 32, pp. 20919–20935, Aug. 2021.

[12] N. Charvin, J. Resende, D. T. Papanastasiou, D. Muñoz-Rojas, C. Jiménez, A. Nourdine, D. Bellet, and L. Flandin, "Dynamic degradation of metallic nanowire networks under electrical stress: a comparison between experiments and simulations," *Nanoscale Advances*, vol. 3, no. 3, pp. 675–681, 2021.