



Acrylic on canvas, 61\*46 cm (December 2020)

**Efficient and stable  
 transparent electrodes  
 based on silver nanowire  
 (AgNW) networks:  
 experimental &  
 simulation approaches.**

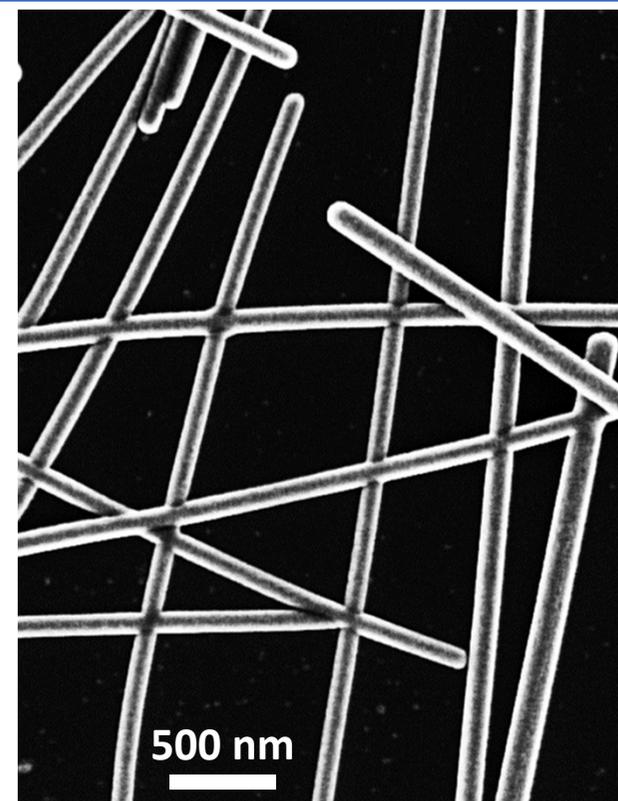
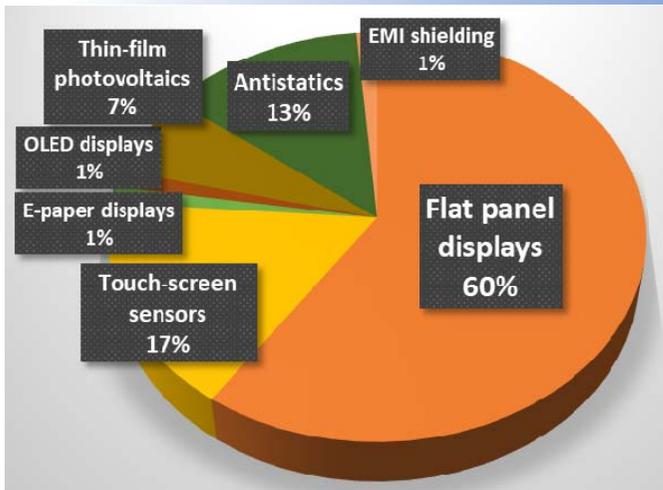


Image by Scanning Electron Microscope (June 2020)

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 C. Sanchez-Velasquez, M. Akbari, J. Resende, V. H. Nguyen,  
 C. Jiménez, D. Muñoz-Rojas, D. Bellet

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# Applications of Transparent Electrodes (TE)



Insight Media (2014)



Flexible OLED for smartphone, BOE



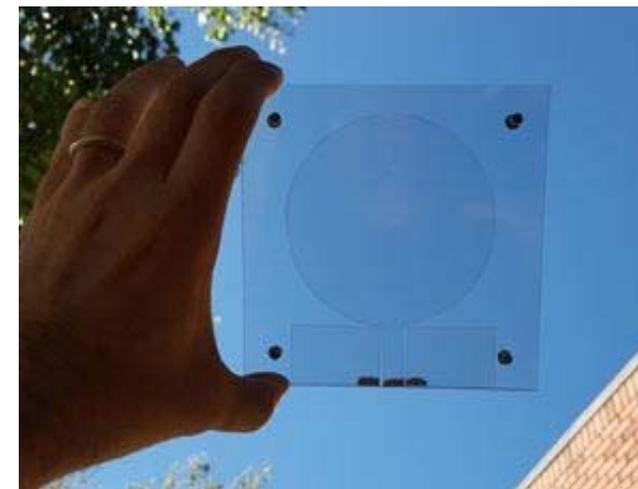
Transparent Heaters, Geomatec



Dye Solar Cell façade, Soloronix



R2R Perovskite Solar Cell, CSIRO



Transparent antenna, MTI

# Transparent Conductive Materials & Figure of Merit

Review: Papanastasiou et al., Adv. Funct. Mater. 30 (2020) 1910225

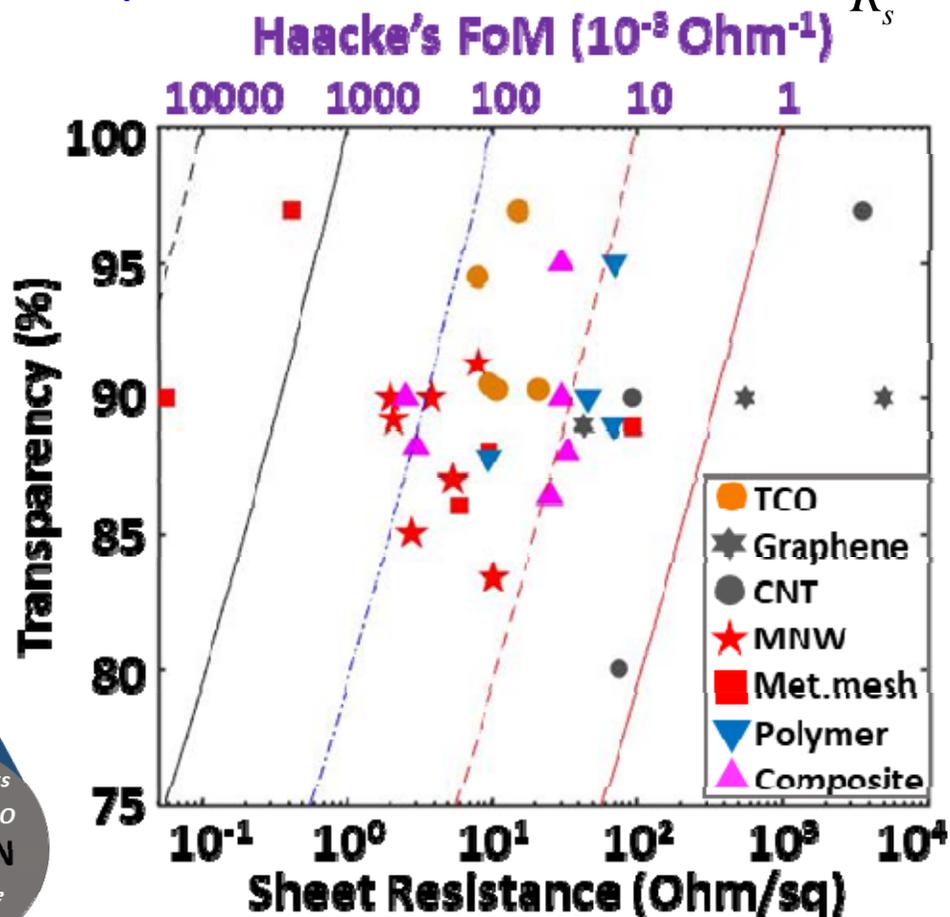
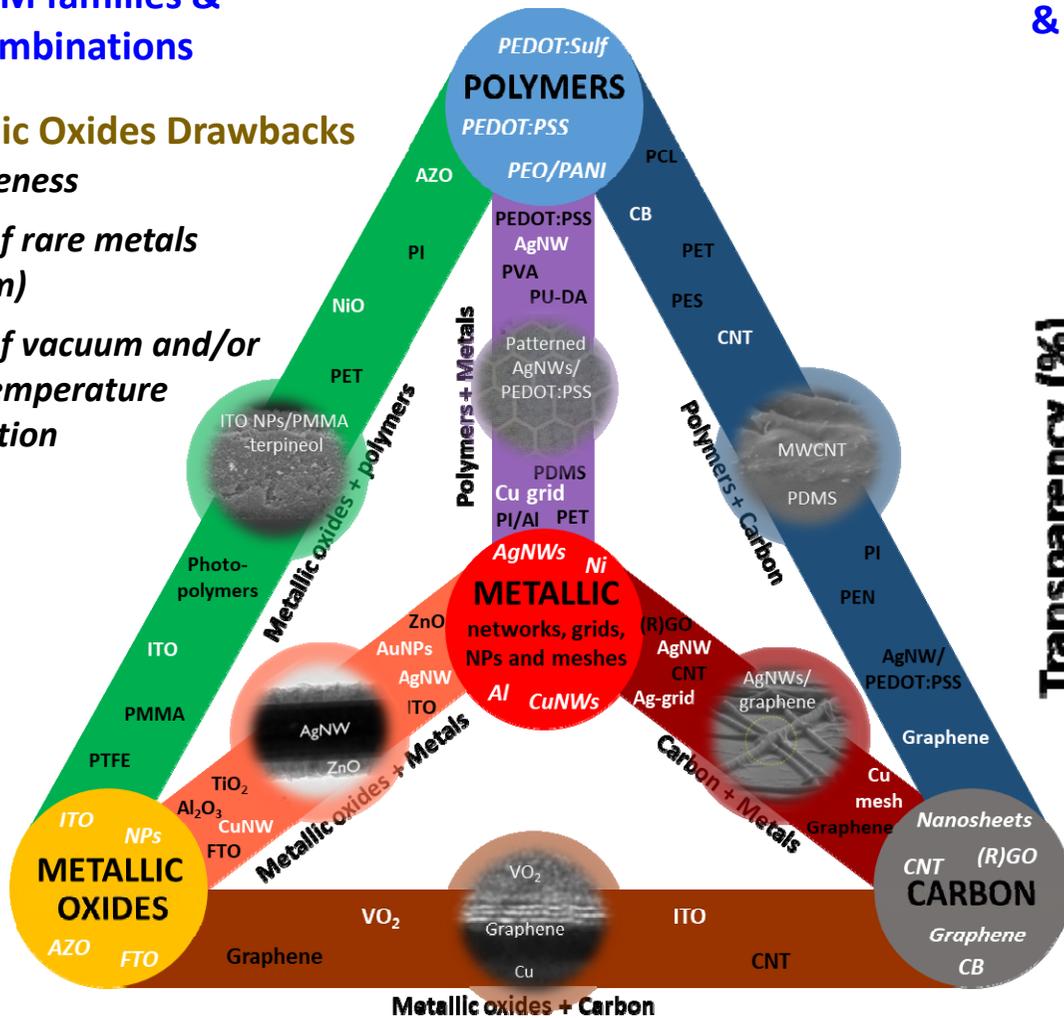
## TCM families & combinations

➤ Performance target & comparison

$$FoM = \frac{T_r^{10}}{R_s}$$

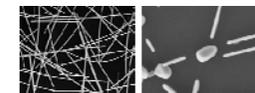
### Metallic Oxides Drawbacks

- Brittleness
- Use of rare metals (Indium)
- Use of vacuum and/or high temperature deposition

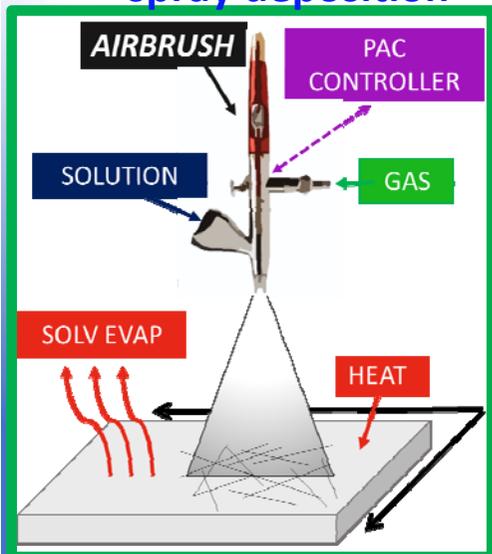


$L_{NW}$  5-150  $\mu$ m  
 $D_{NW}$  10-150 nm

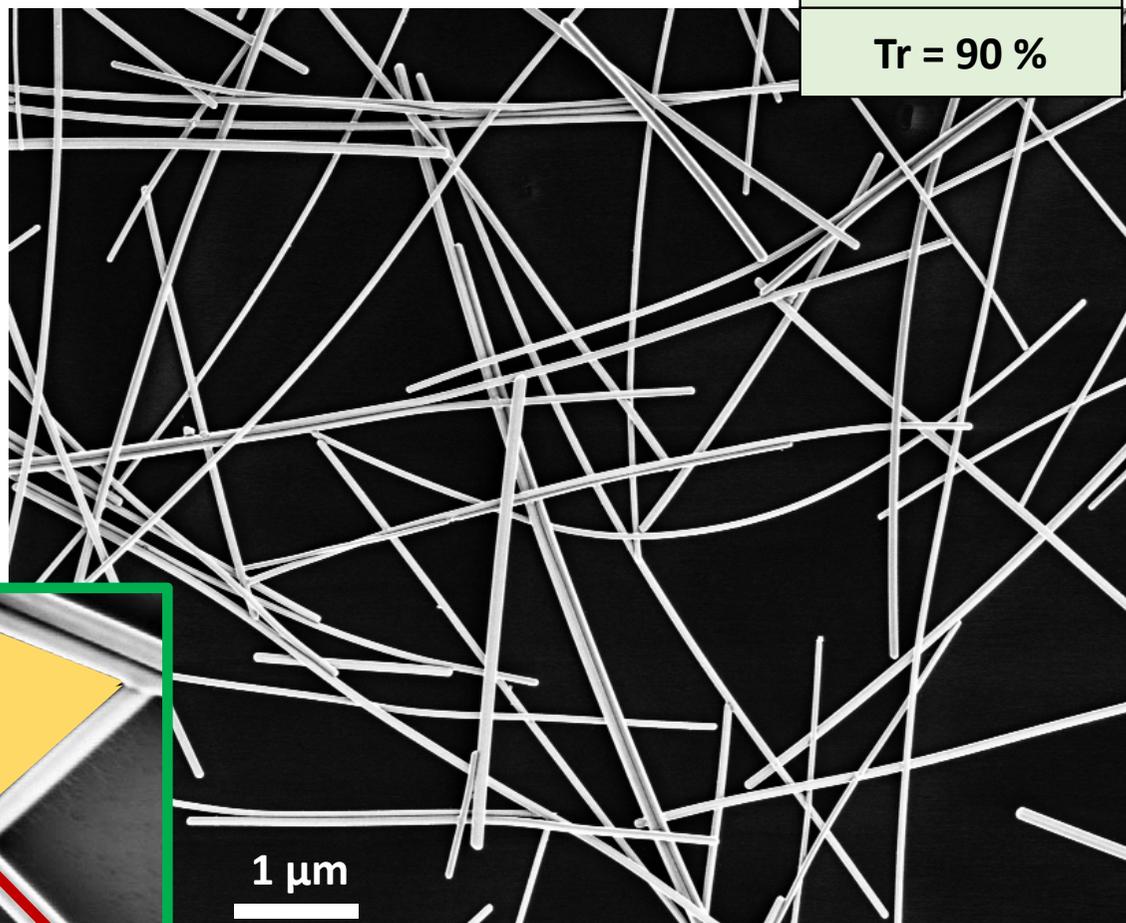
# From AgNWs to AgNW Networks



## AgNWs suspension spray deposition



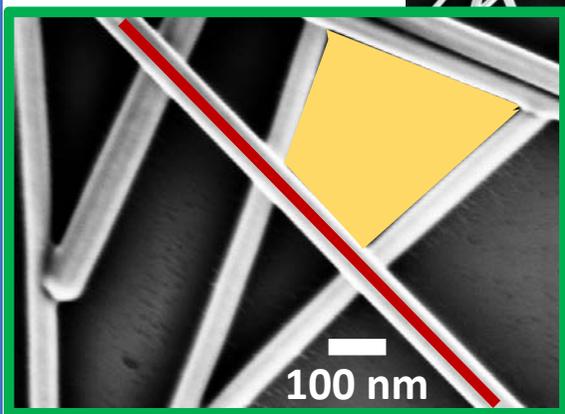
## SEM



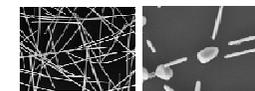
$R_{sh} = 5 \Omega/sq$   
 $Tr = 90 \%$



Samples size 10\*10 cm<sup>2</sup>

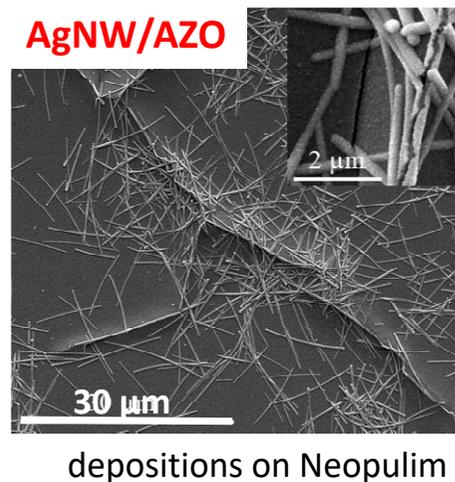
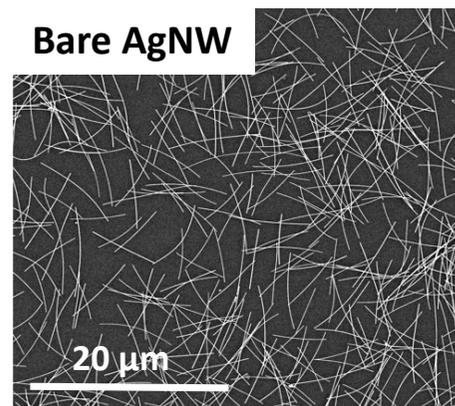
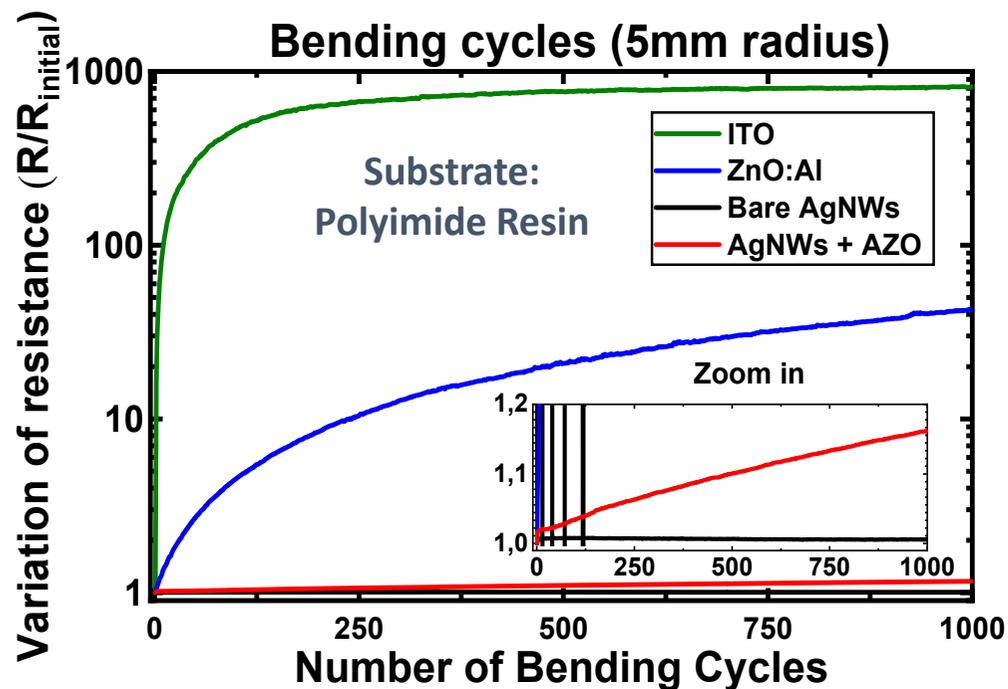


# AgNW versus TCO: flexibility

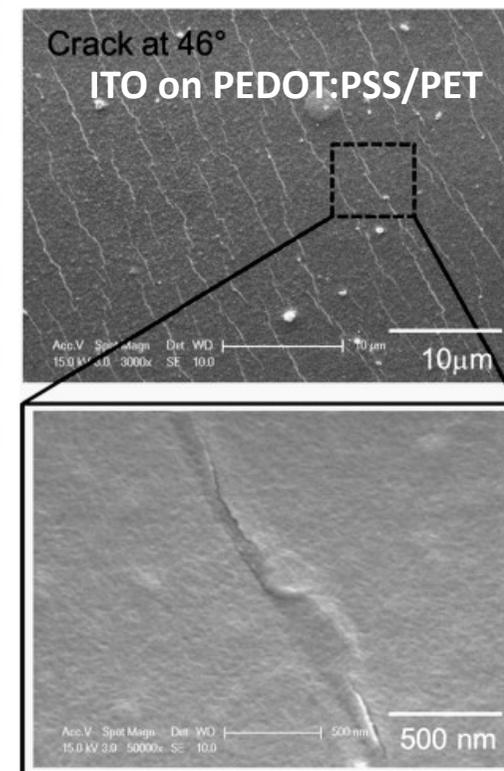


Nguyen, Resende, Papanastasiou et al., *Nanoscale* 11 (2019) 12097

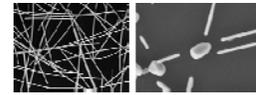
➤ SEM after bending



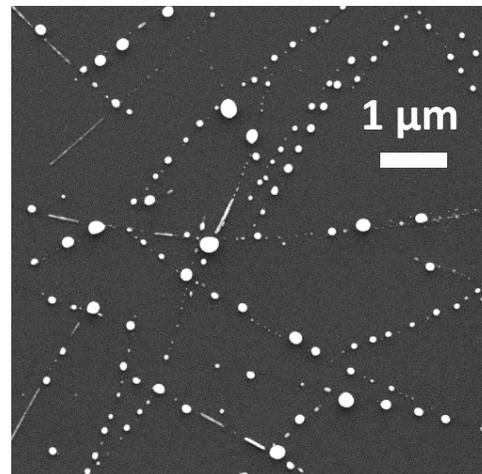
Jung et al, *Thin Solid Films* 550 (2014) 435



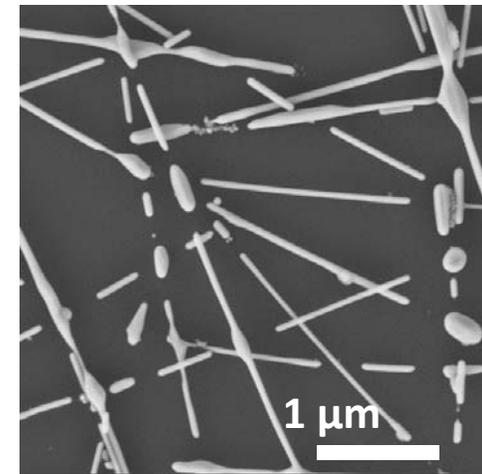
# AgNW Networks Limitations



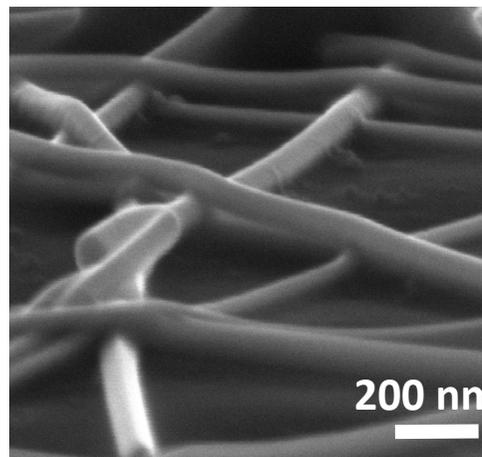
*Spheroidization  
of AgNW network  
under thermal stress*



*Local degradation  
of AgNWs  
under electrical stress*



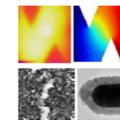
*Surface roughness  
of AgNWs*



**Assess & improve  
stability**

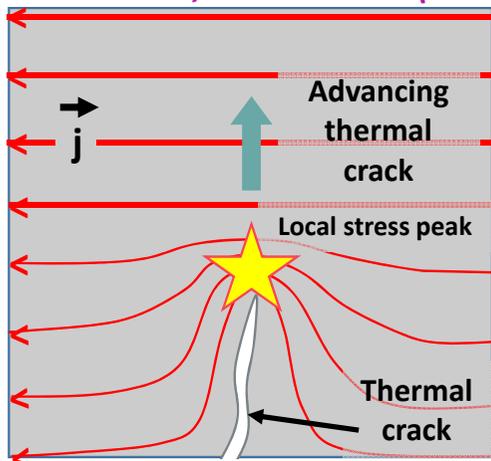
- *electrical*
- *thermal*
- *mechanical*
- *chemical*

# Degradation under electrical stress

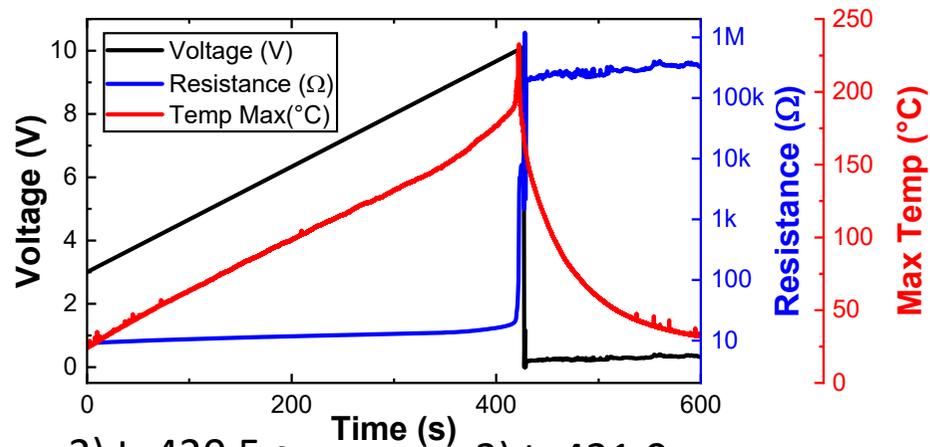


➤ Voltage stress (0.5 V/min) and spatial distribution of Temperature by IR imaging

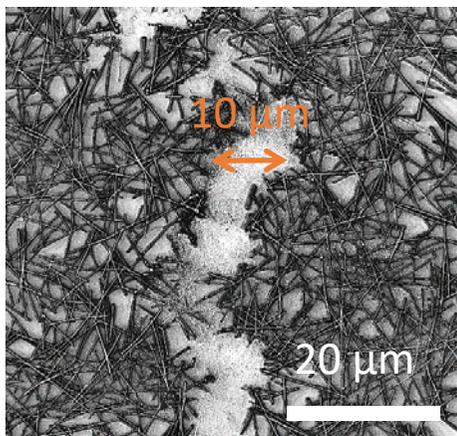
*Sannicolo et al., ACS Nano 12 (2018) 4648*



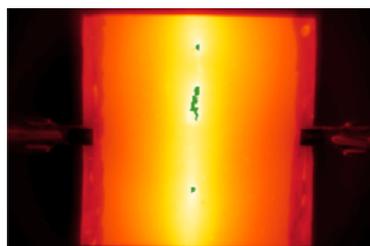
In collaboration with



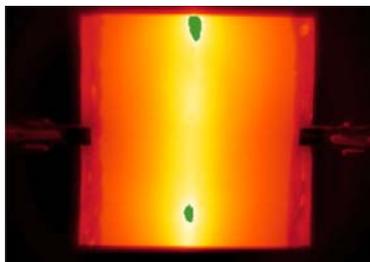
*Charvin, Resende, Papanastasiou et al., Nanoscale Advances 3 (2021) 675-681*



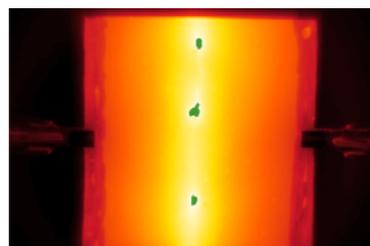
1) t=420.0 s



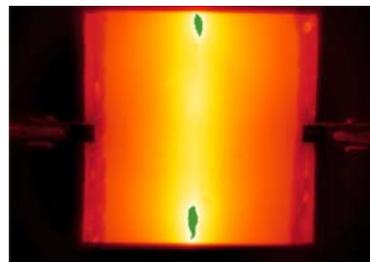
4) t=421.5 s



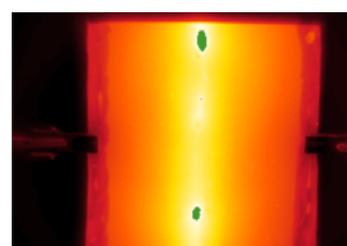
2) t=420.5 s



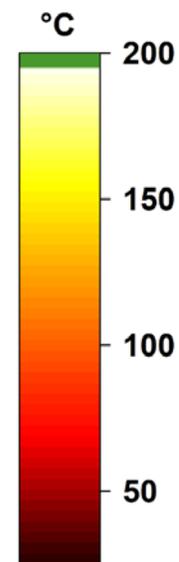
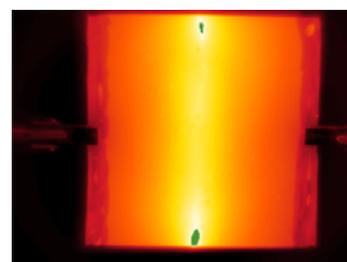
5) t=422.0 s



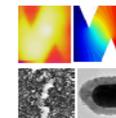
3) t=421.0 s



6) t=422.5 s

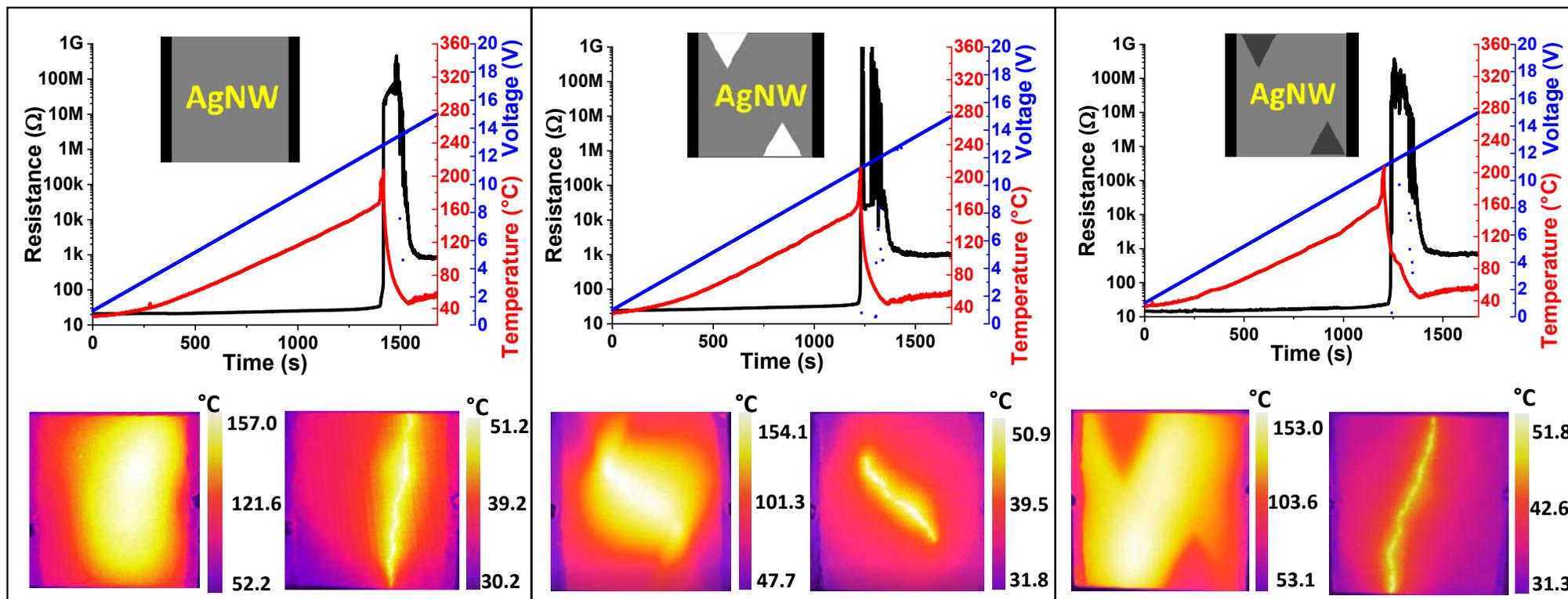


# Failure of non-homogenous networks



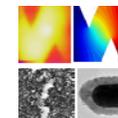
Papanastasiou et al., submitted

➤ Voltage stress (0.5 V/min) and spatial distribution of Temperature by IR imaging



*Failure at lower voltage or faster degradation*

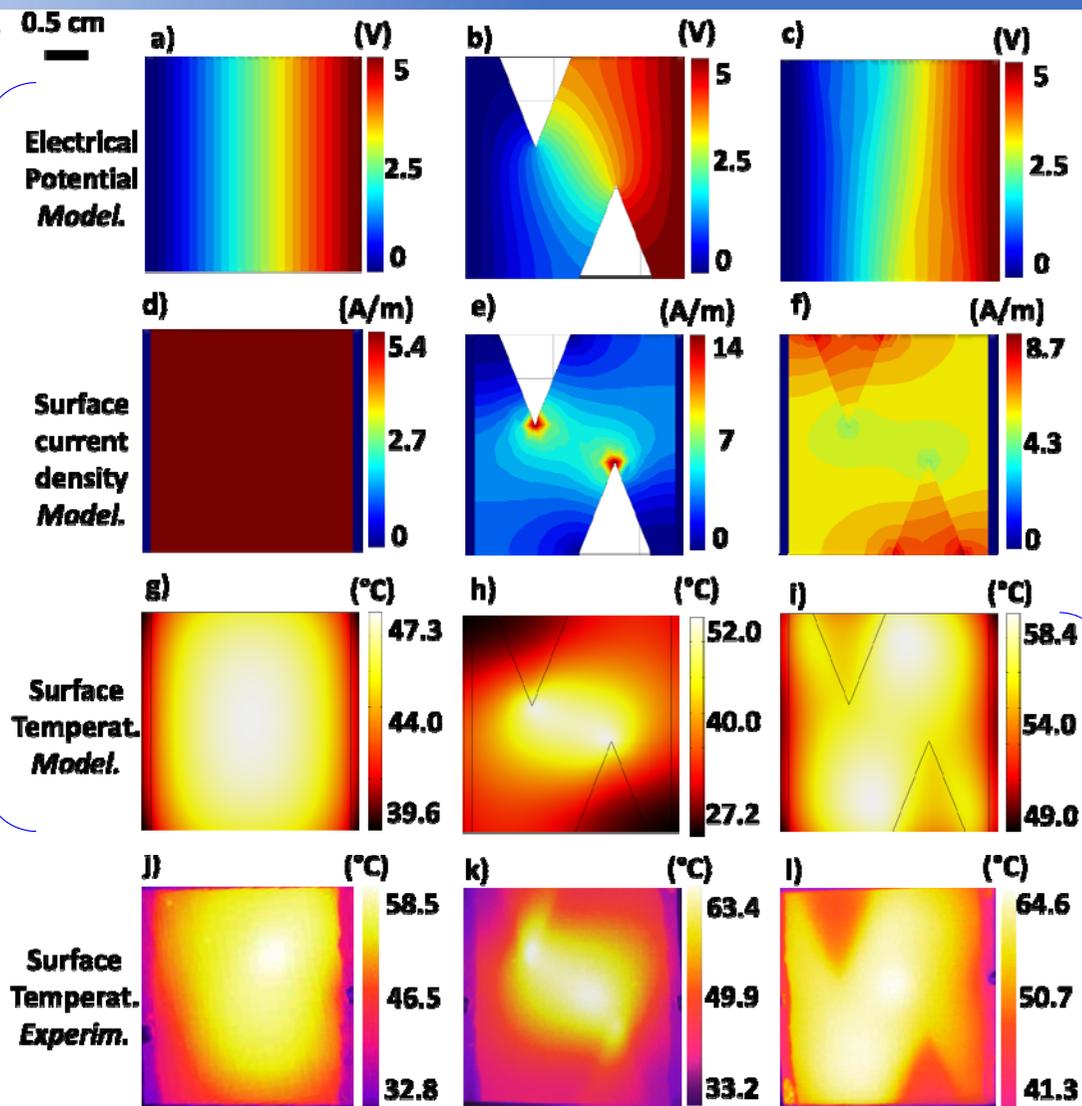
# Modeling of non-homogeneous networks



Papanastasiou et al., submitted

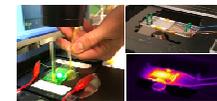
➤ COMSOL simulation of Ag thin films

COMSOL

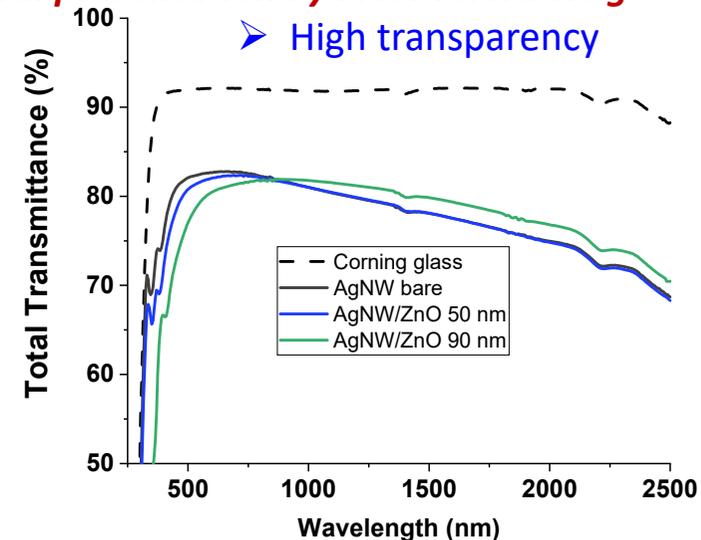
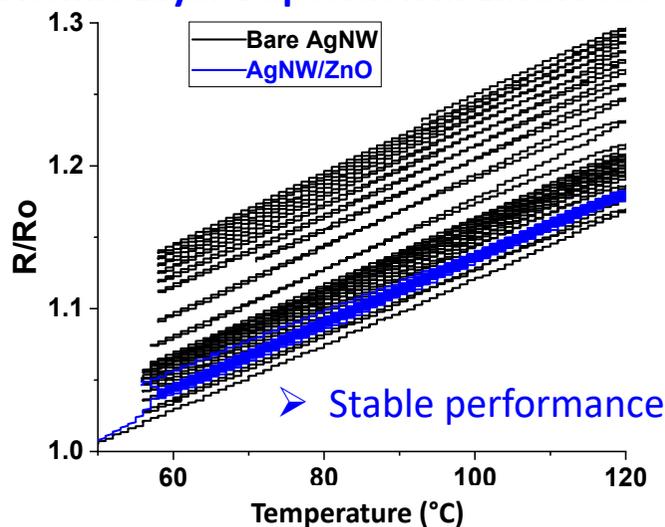
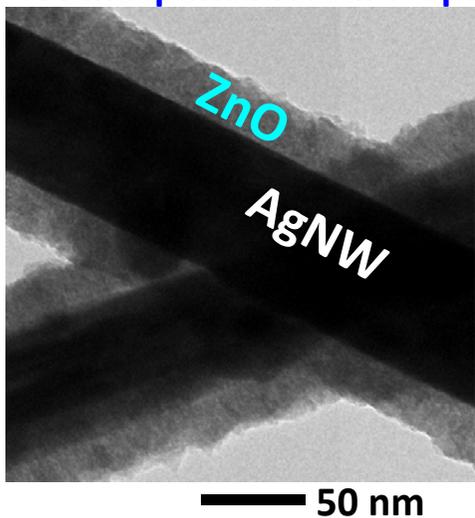


➤ Comparison between simulations and experimental results at 5 volts

# Enhanced stability by oxide thin coatings



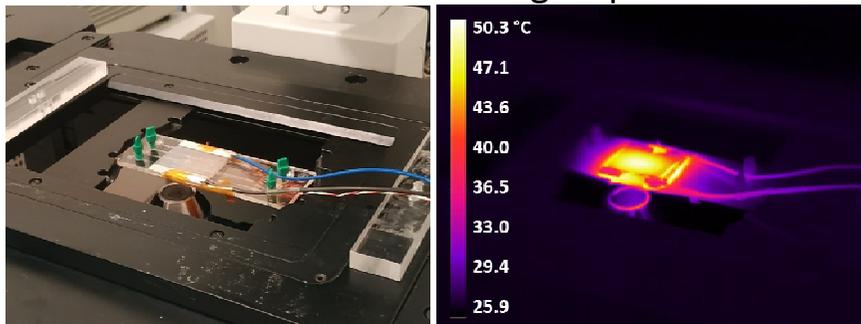
Atmospheric Pressure- Spatial Atomic Layer Deposition in LMGP. See oral presentation by Fidel Toldra-Reig



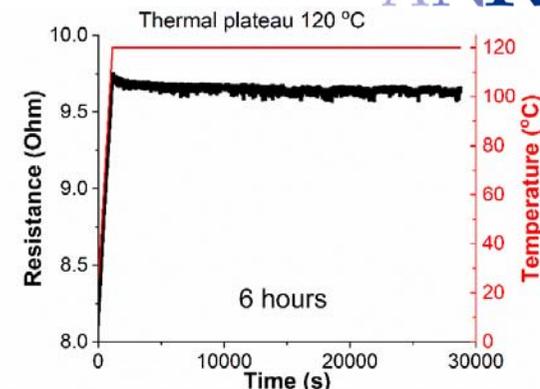
Optimized, stable technology → Integration into devices

Transparent Heaters for in-situ biomedical observations

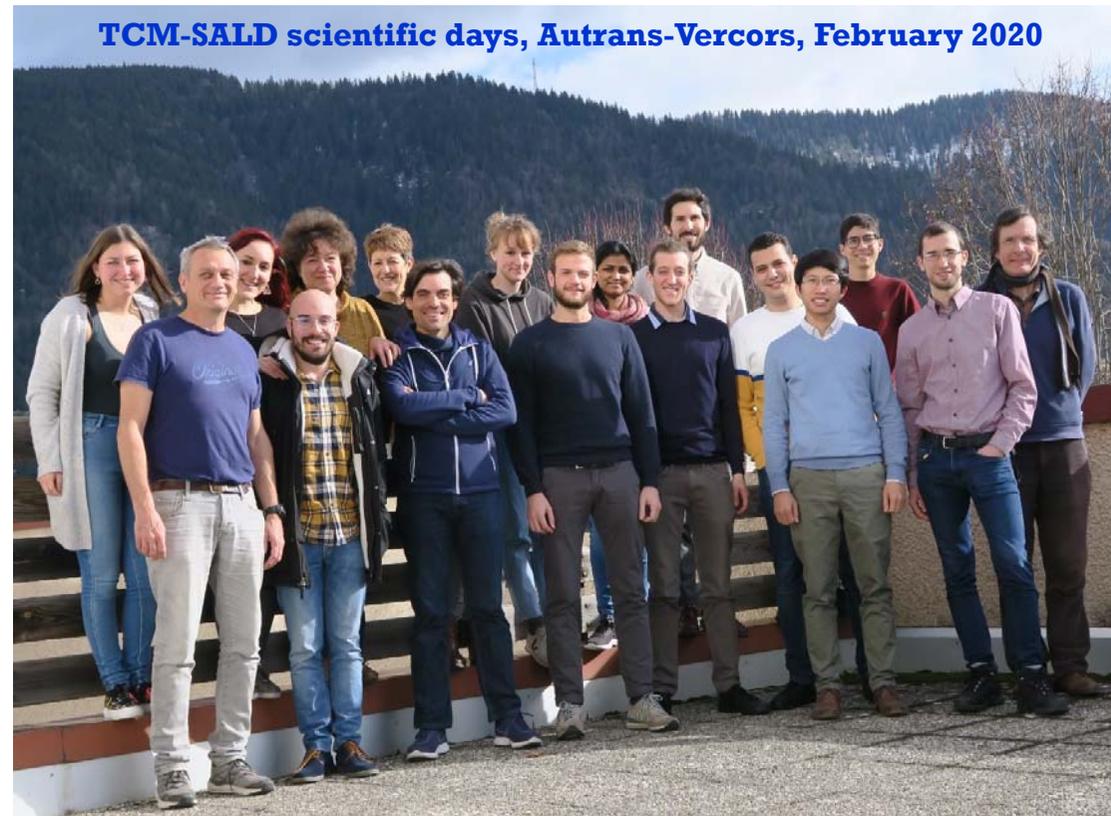
Collaboration with the bio-group of LMGP



Flexible, transparent electrodes for OPV



# ..questions?



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Auvergne-Rhône-Alpes

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CARNOT  
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Agence Nationale de la Recherche  
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MARIE CURIE