Resistive switching in cluster assembled metallic films

Report 1st Year

10 – 08 - 2018

PhD student: **Matteo Mirigliano**

Tutor: Prof.ssa **C. Lenardi**

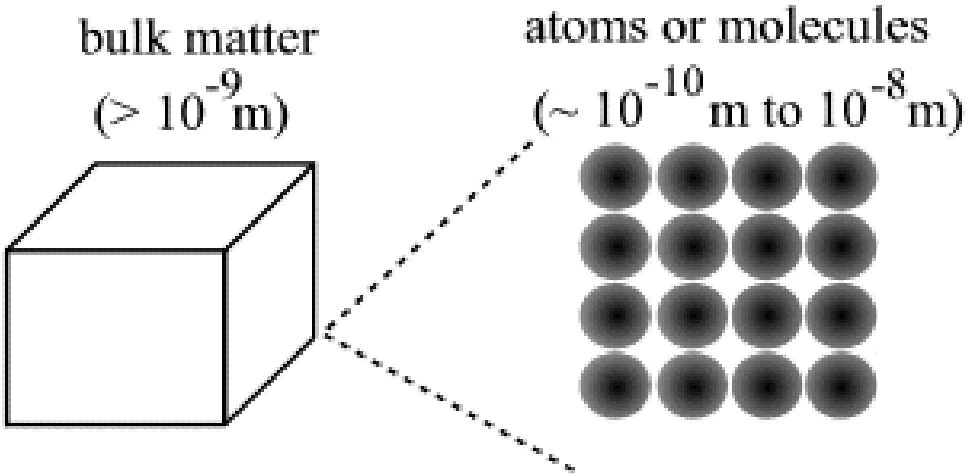
UNIVERSITÀ DEGLI STUDI DI MILANO

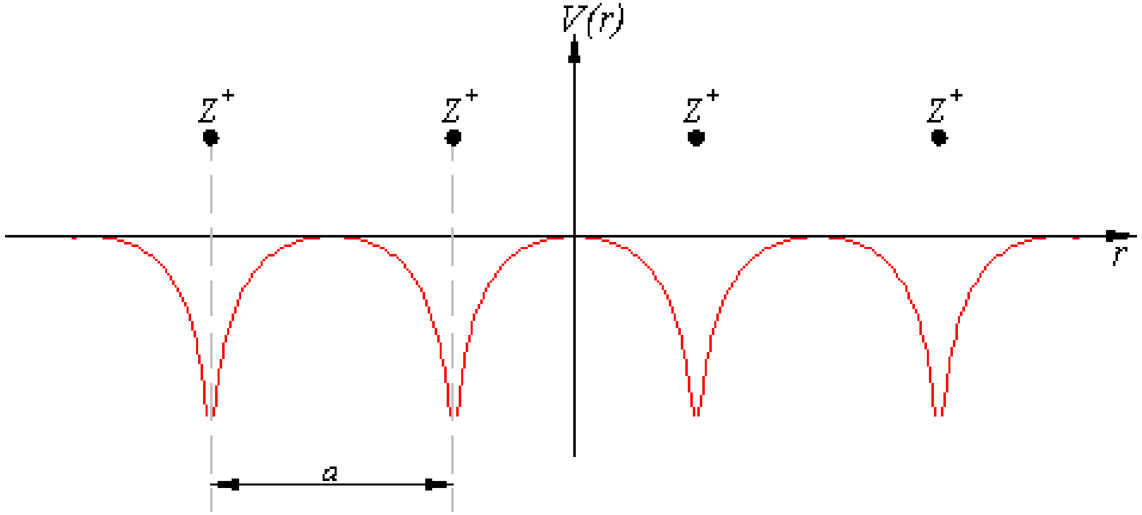
DIPARTIMENTO DI FISICA

Nanostructured metallic thin films

Why are the electrical properties so interesting?

Metallic Bulk Matter → Ohmic conduction

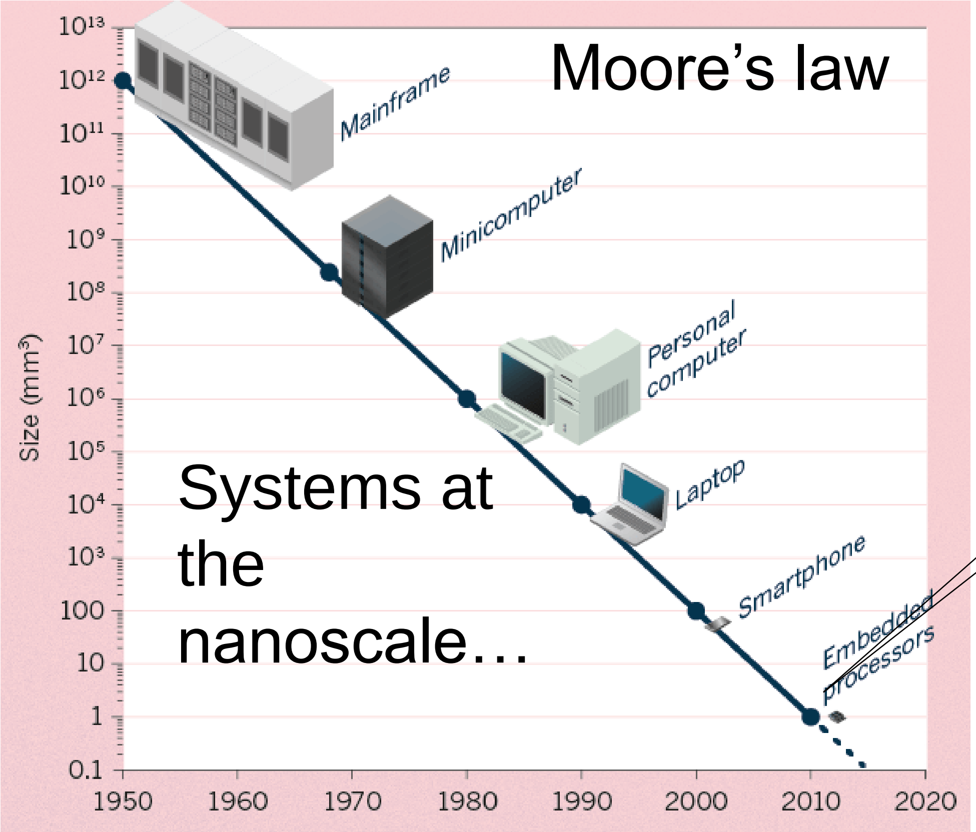


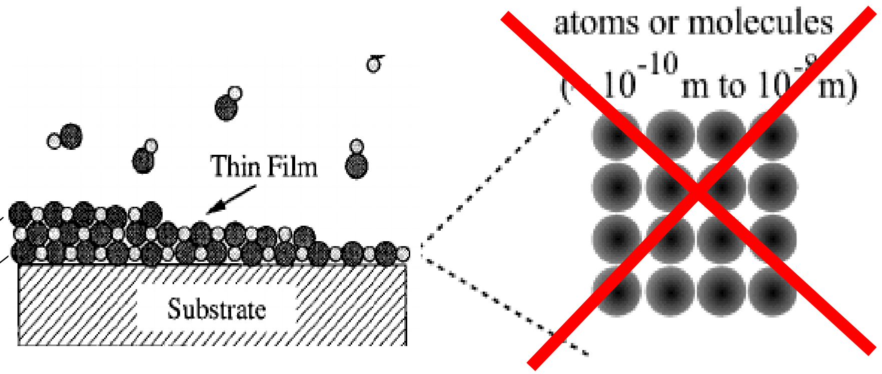


Nanostructured metallic thin films

Why are the electrical properties so interesting?

Thin Films atom-assembled → Anomalous properties

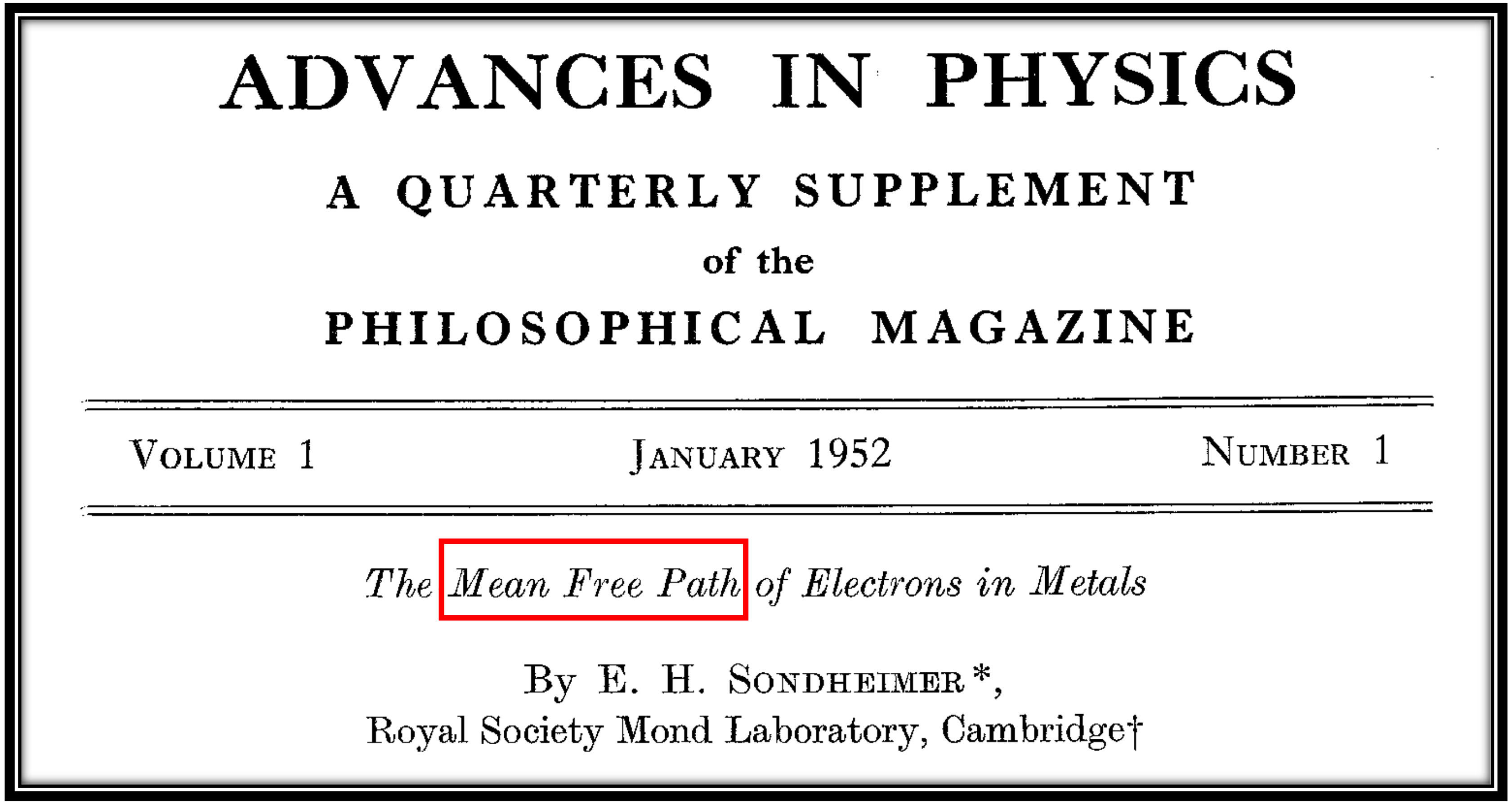




Thickness < 1 μm

- Defects
- Impurities
- Dislocations
- …

Historical background: from the past to the present



ADVANCES IN PHYSICS

A QUARTERLY SUPPLEMENT

of the

PHILOSOPHICAL MAGAZINE

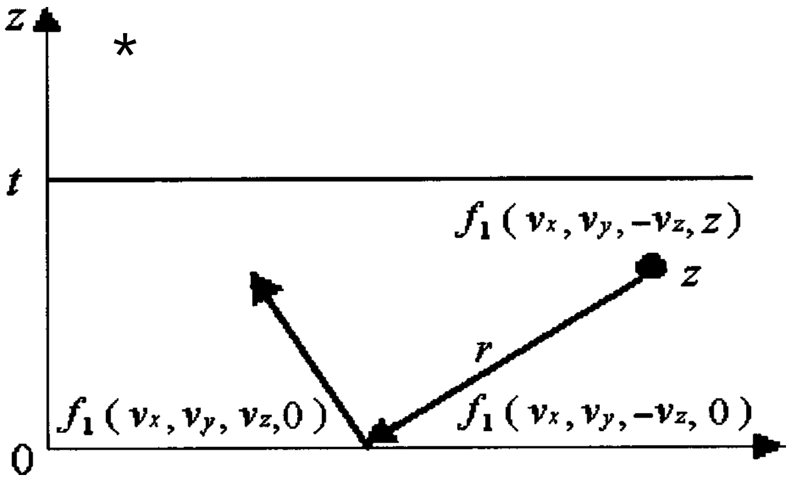
VOLUME 1 JANUARY 1952 NUMBER 1

The Mean Free Path of Electrons in Metals

By E. H. SONDHEIMER*,

Royal Society Mond Laboratory, Cambridge†

Anomalous transport properties due to the submicrometric thickness



Scattering events

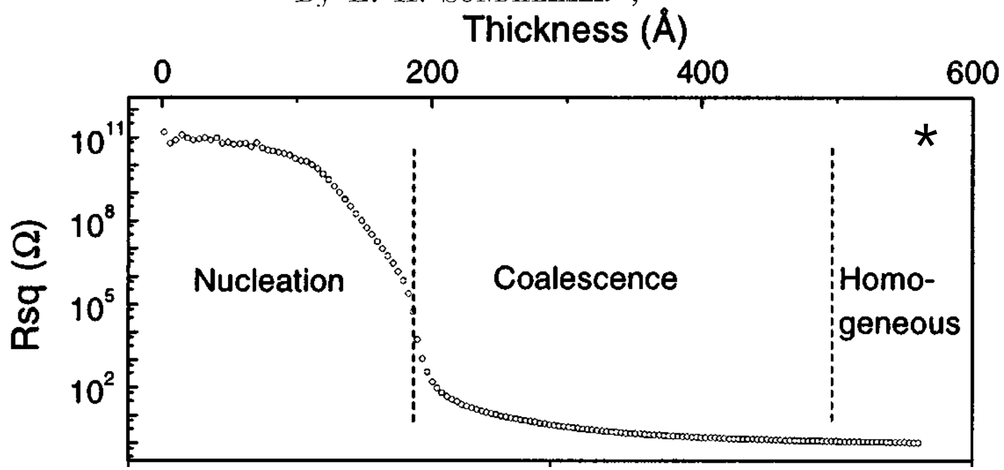
Historical background: from the past to the present

VOLUME 81, NUMBER 18 PHYSICAL REVIEW LETTERS 2 NOVEMBER 1998

Bad Metals Made with Good-Metal Components

S. B. Arnason, S. P. Herschfield, and A. F. Hebard

Department of Physics, University of Florida, Gainesville, Florida 32611

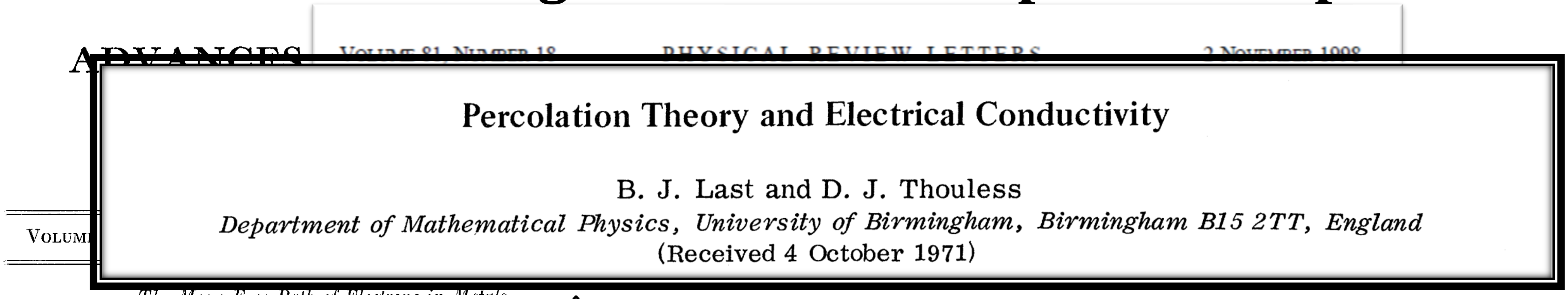


Non linear relation resistance-thickness

- Surface scattering
- Grain boundaries scattering
- …

Anomalous transport properties linked to the morphology

Historical background: from the past to the present

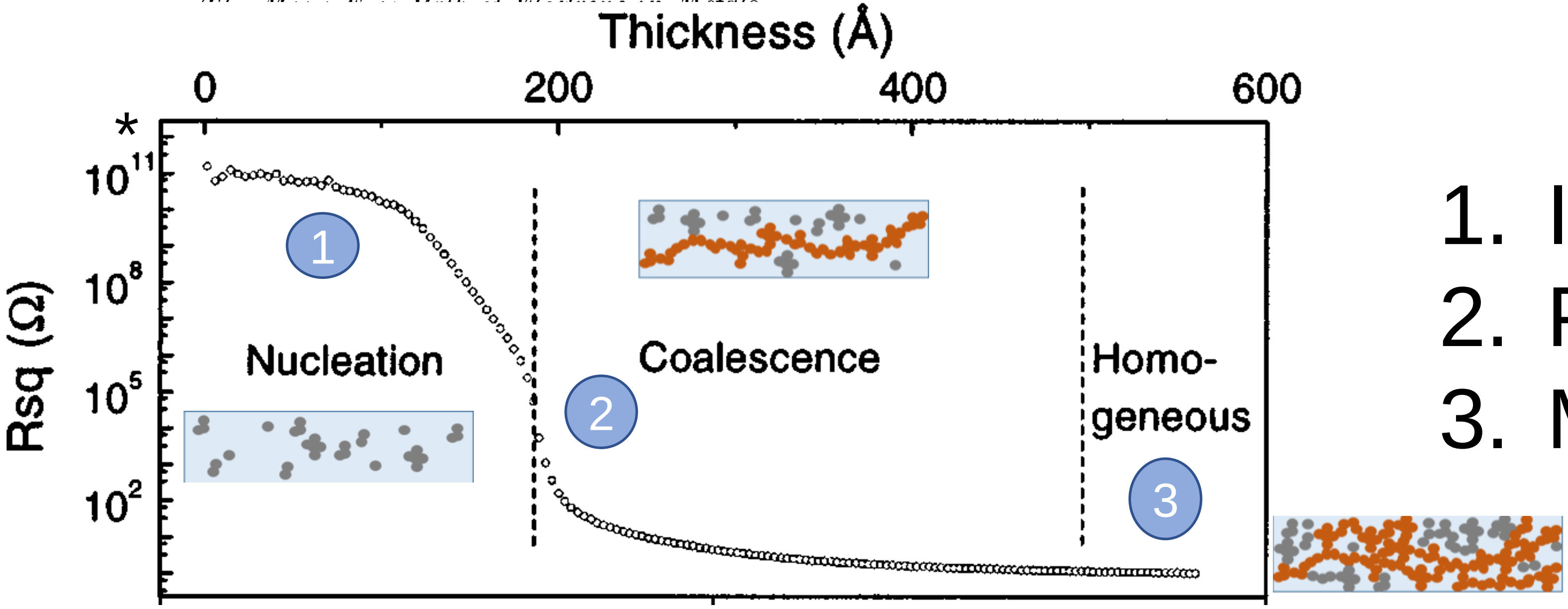


Percolation Theory and Electrical Conductivity

B. J. Last and D. J. Thouless

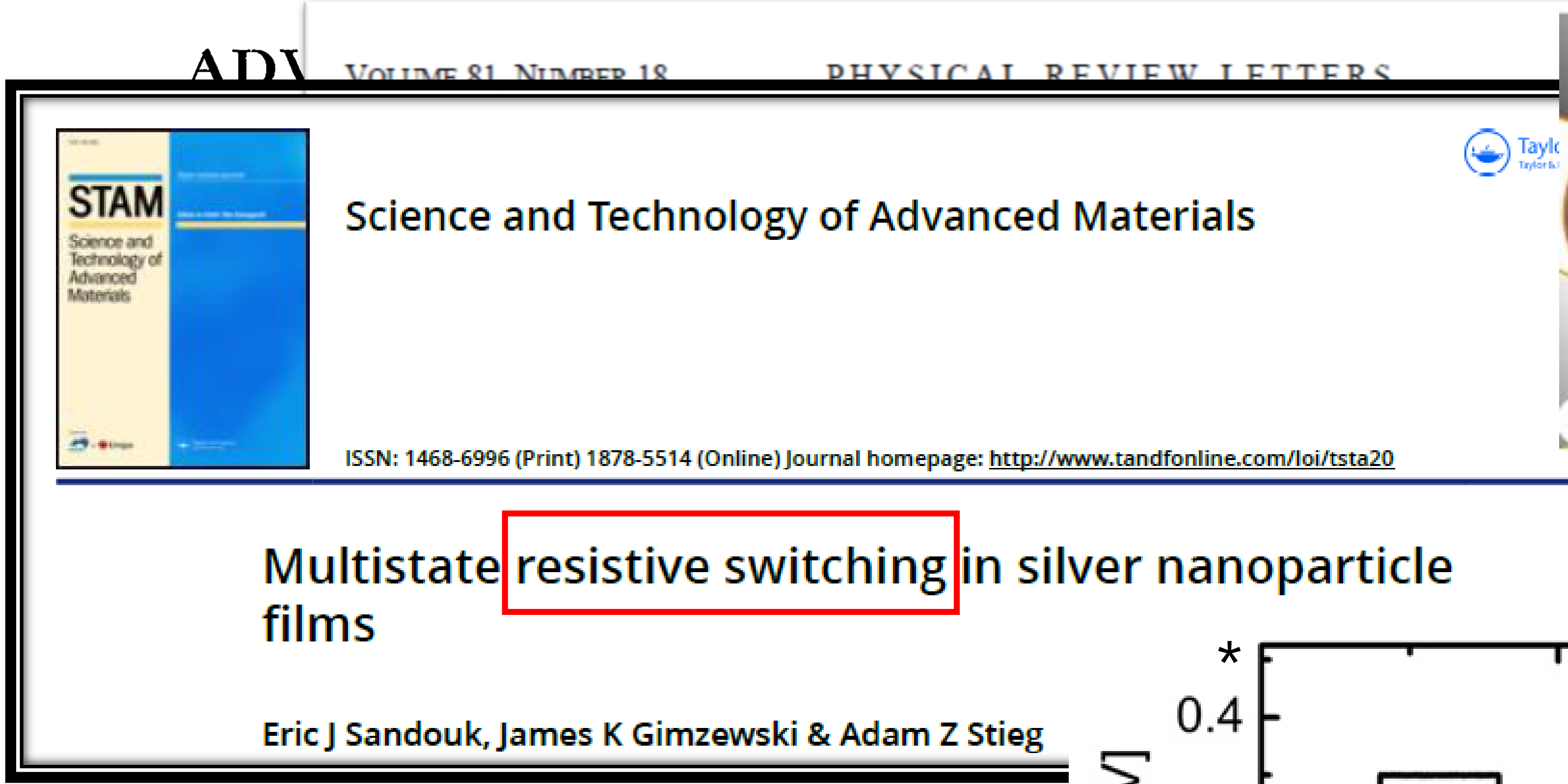
Department of Mathematical Physics, University of Birmingham, Birmingham B15 2TT, England

(Received 4 October 1971)



1. Insulator regime
2. Percolation regime
3. Metallic regime

Historical background: from the past to the present

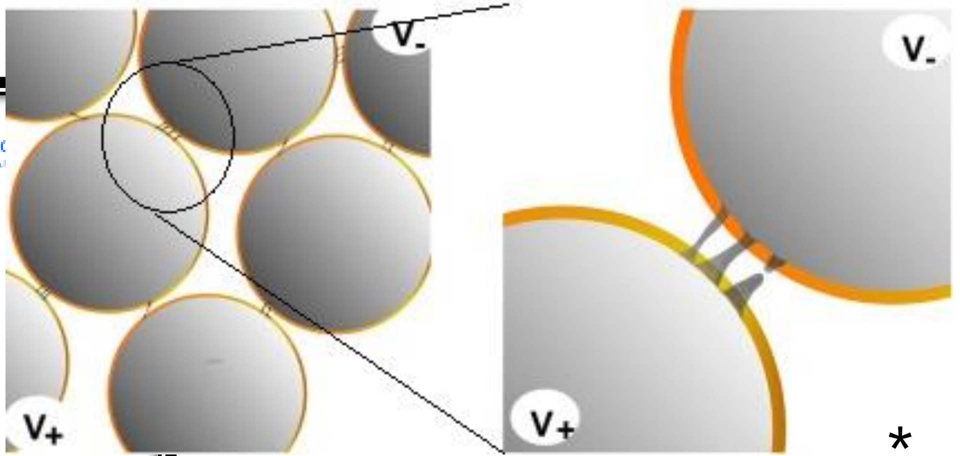

ADV
VOLUME 81, NUMBER 18 PHYSICAL REVIEW LETTERS

Science and Technology of Advanced Materials

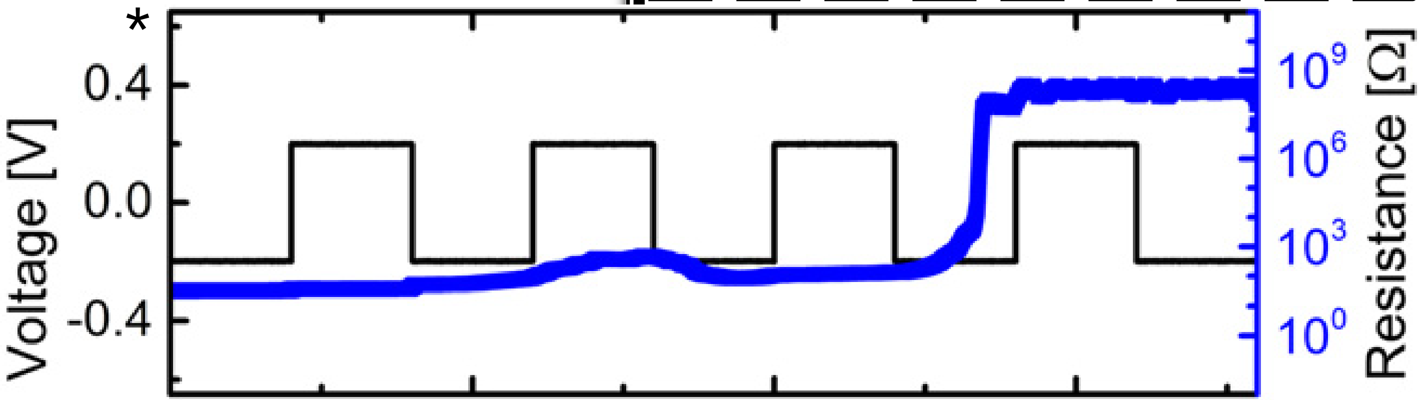
ISSN: 1468-6996 (Print) 1878-5514 (Online) Journal homepage: http://www.tandfonline.com/loi/tsta20

Multistate resistive switching in silver nanoparticle films

Eric J Sandouk, James K Gimzewski & Adam Z Stieg



Percolating film with an insulating phase



In more recent years…

* Sandouk et al., *Sci. Technol. Adv. Mater.*, **16,** 055004 (2015);

Historical background: from the past to the present


nature nanotechnology

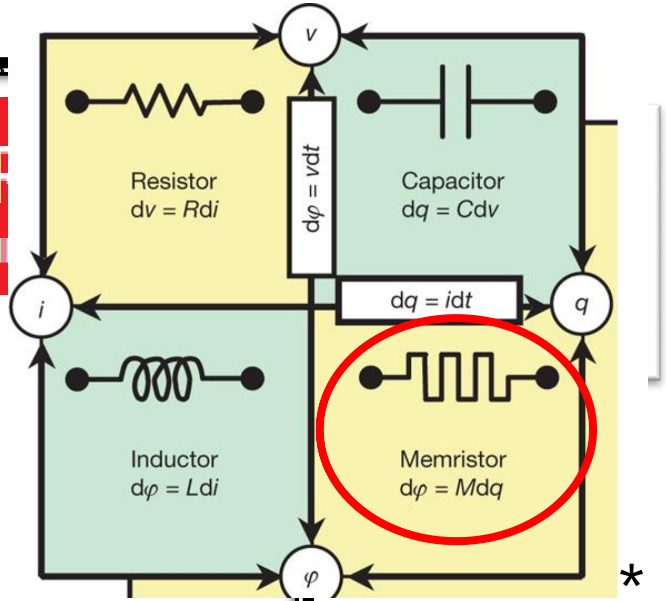
REVIEW AR

PUBLISHED ONLINE: 27 DECEMBER 2012 | DOI: 10.1038/N

Memristive devices for computing

J. Joshua Yang[1], Dmitri B. Strukov[2] and Duncan R. Stewart[3]

Memristive devices are electrical resistance switches that can retain a state of internal resistance based on the history of applied voltage and current. These devices can store and process information, and offer several key performance characteristics that exceed conventional integrated circuit technology. An important class of memristive devices are two-terminal resistance



*

Technological application

Thin films → Memories (RRAM), memrisitve devices logic gates, adaptive systems….

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Why introduce cluster assembled films?

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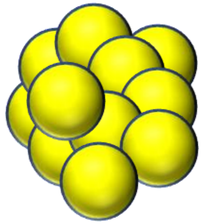
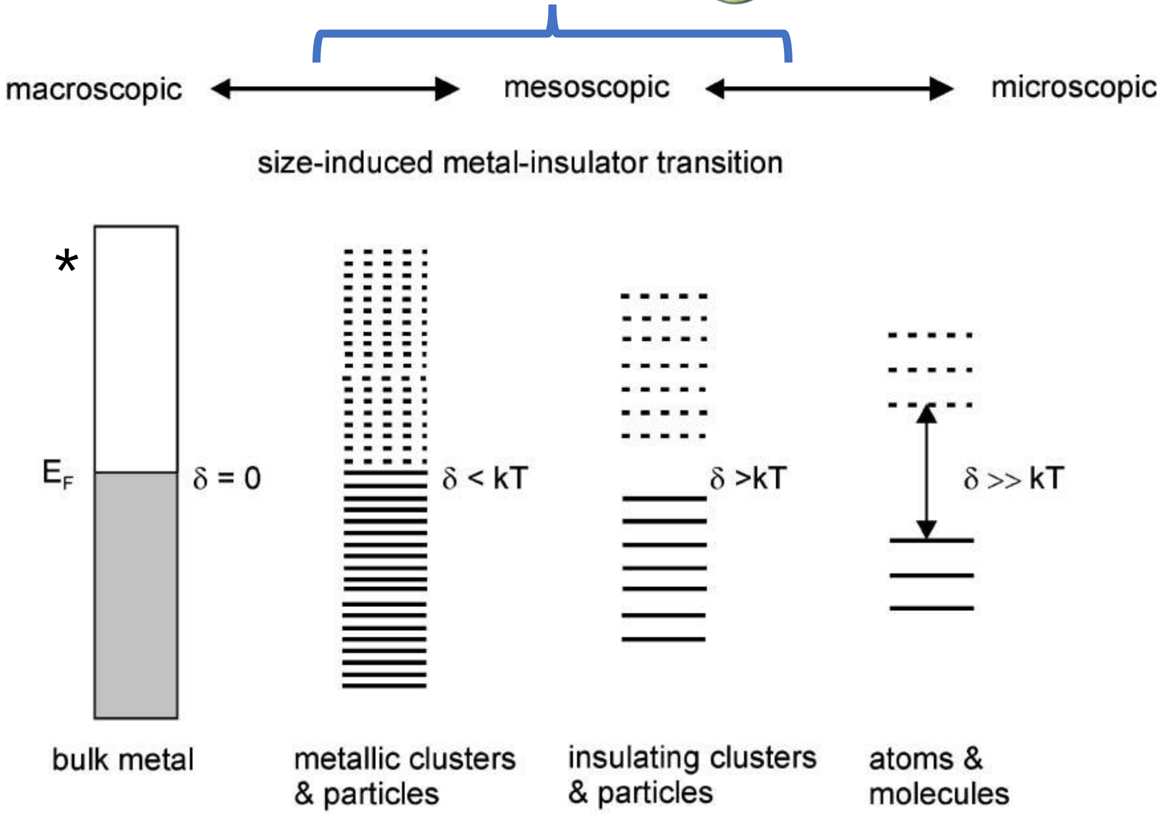
Cluster assembled metallic films

Bridge between bulk and atom like properties

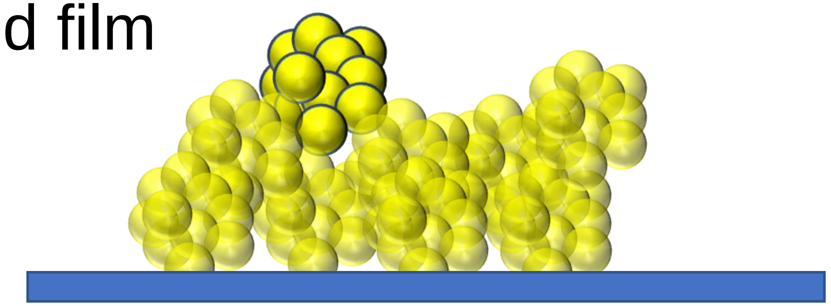


Cluster: aggregate of atoms (from few units to thousands)

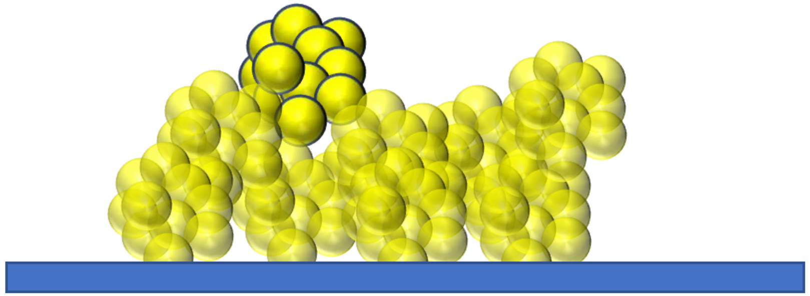


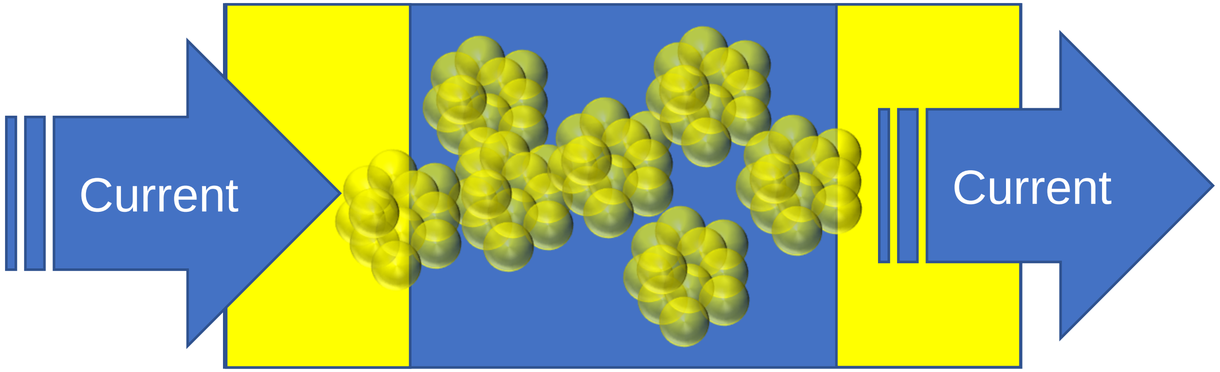
Cluster as building blocks to fabricate film:

- With defects, dislocations…
- Properties different form bulk-like
- Properties different from atomically deposited film



Cluster assembled metallic films

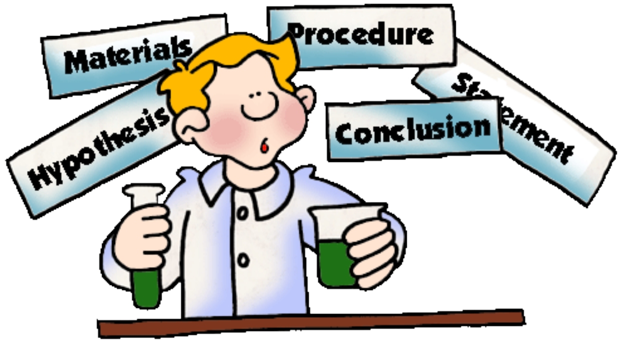




Objectives

- Study the morphology
- Control the growth process
- Understand electrical transport properties

Experimental methods



Gain a deeper insight into the methods can be used…

1. Cluster metallic film fabrication
2. Morphology investigation
3. Electrical transport properties investigation

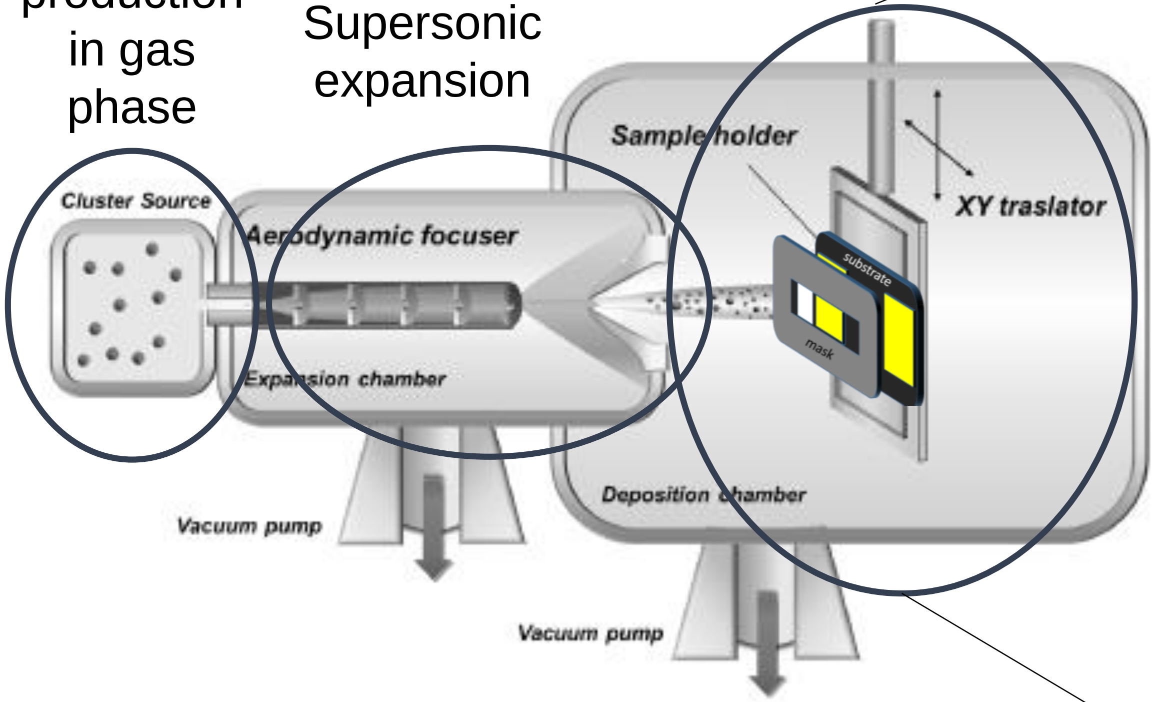
Experimental methods

Supersonic Cluster Beam Deposition

Cluster production in gas phase

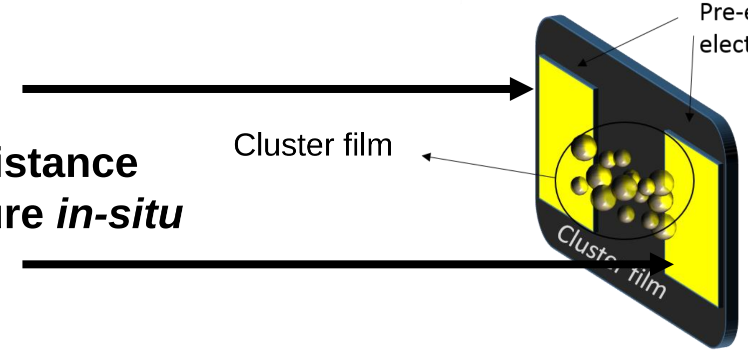
Supersonic expansion

Cluster deposition

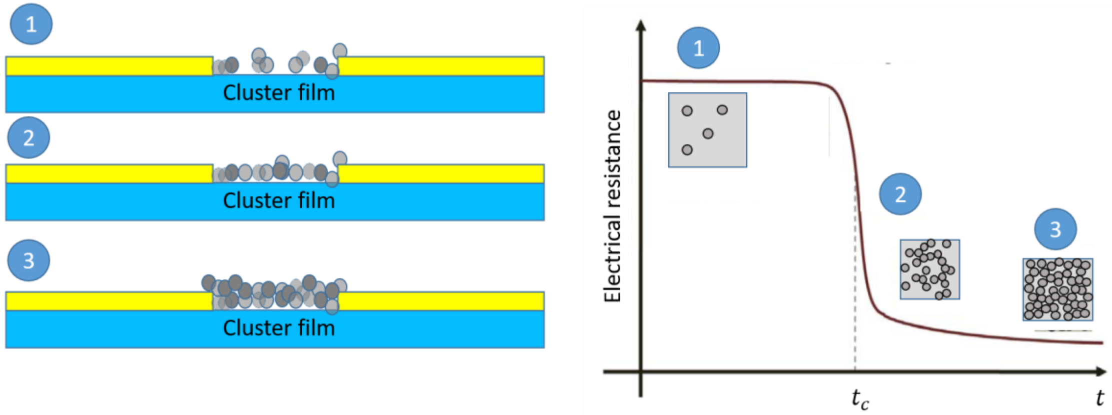


1. Cluster metallic film fabrication
2. Morphology investigation
3. Electrical transport properties investigation

Resistance measure *in-situ*

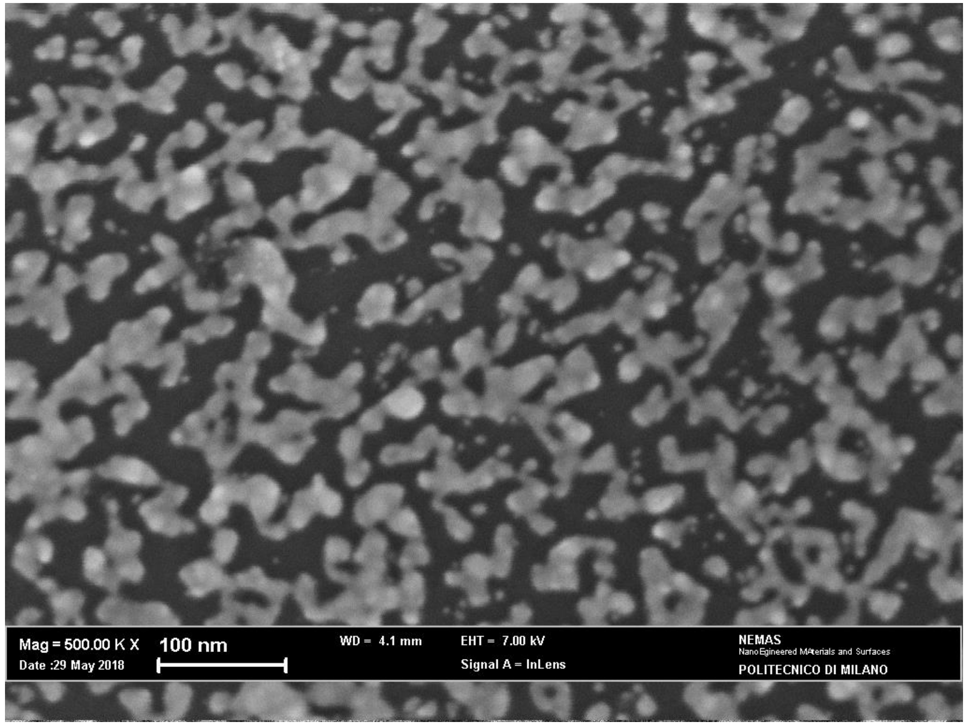


Percolation Curve



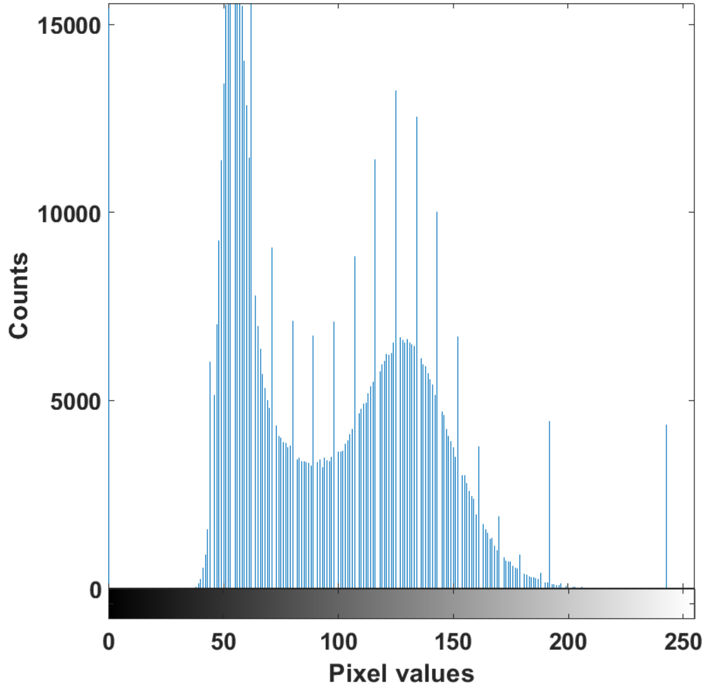
Experimental methods

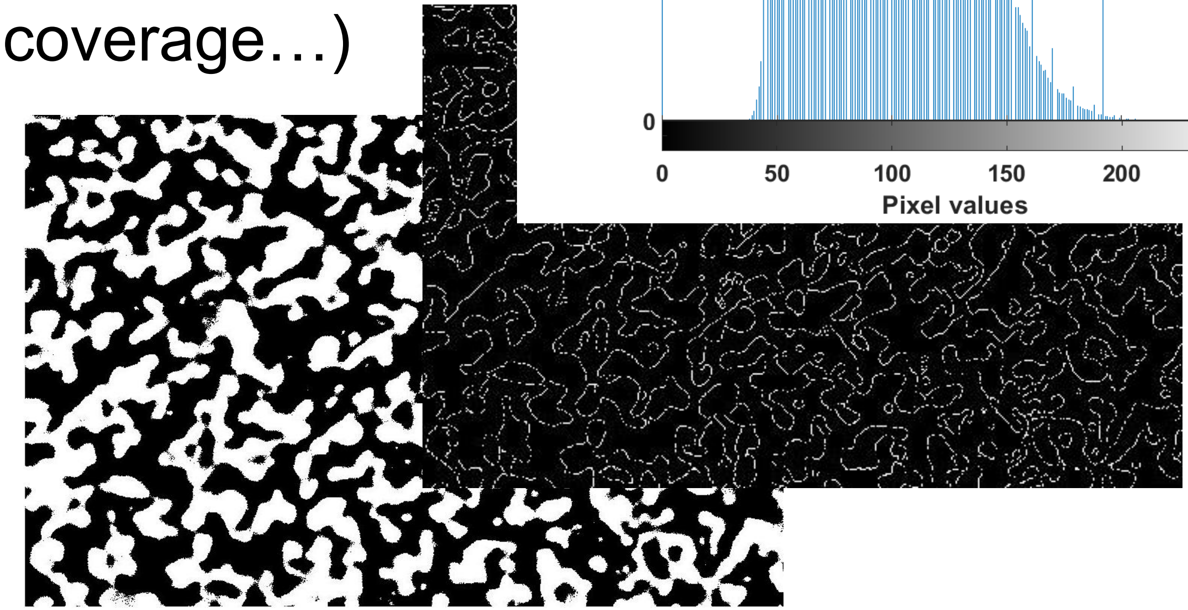
AFM, SEM…



Some image processing…

…geometrical properties analysis (island size, coverage…)

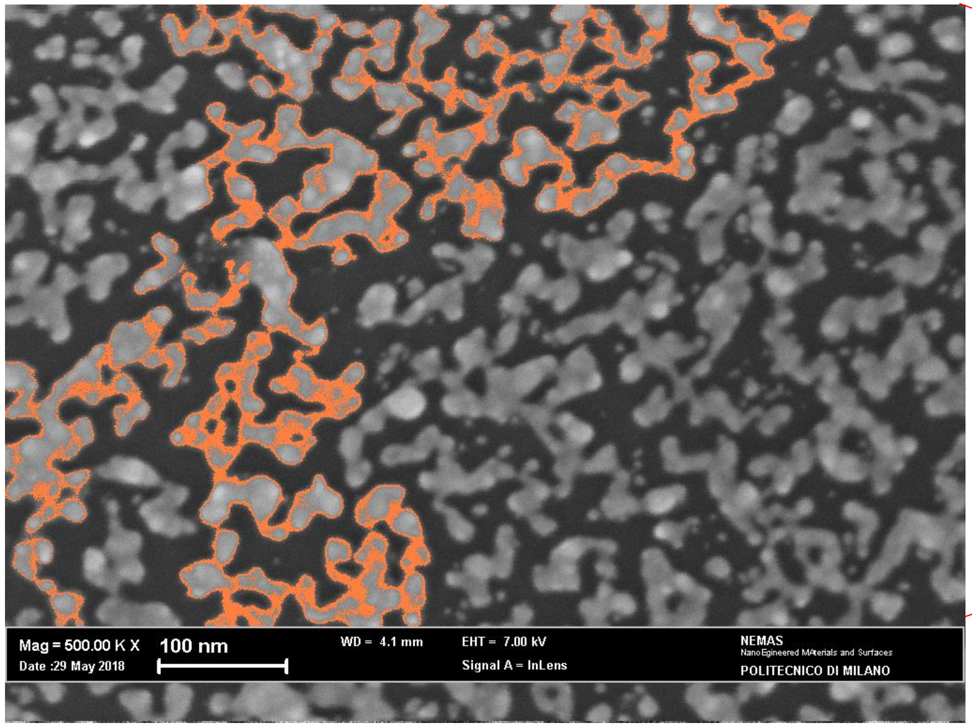


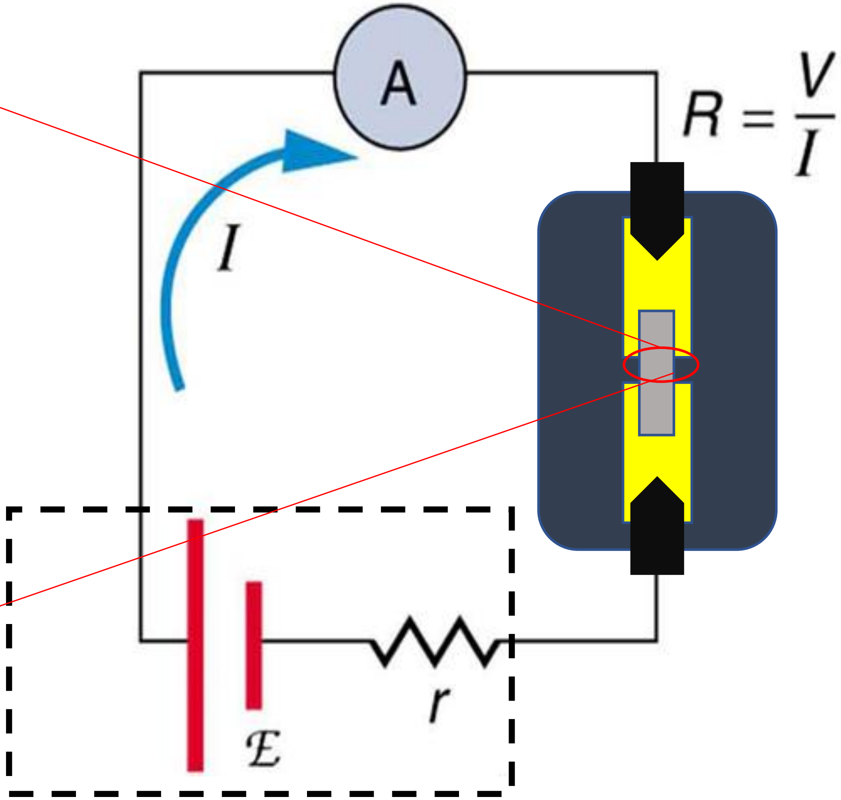


1. Cluster metallic film fabrication
2. Morphology investigation
3. Electrical transport properties investigation

Experimental methods

Voltage-Current measurement



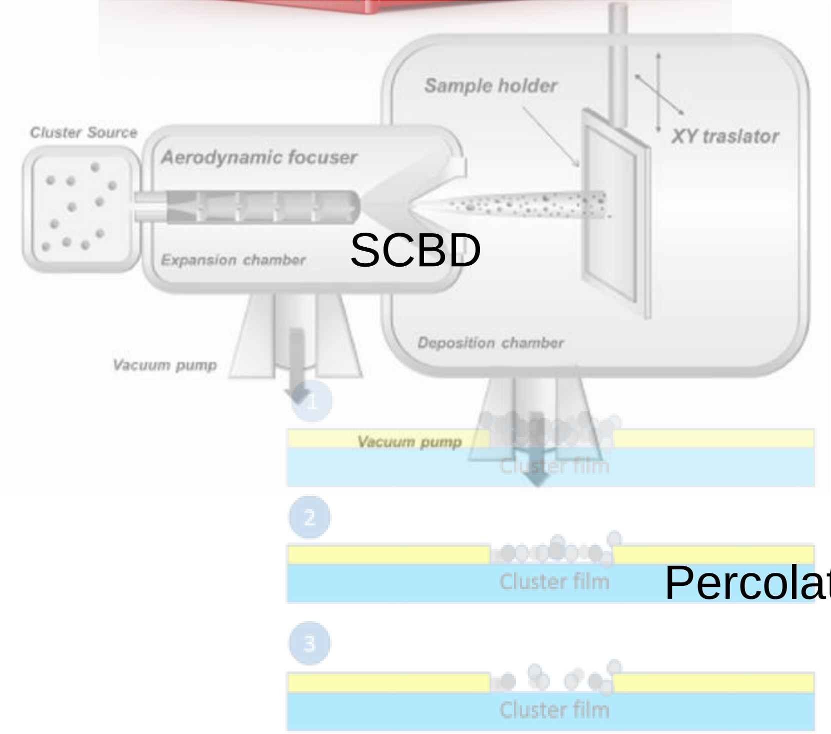


Electrical properties under the application of an external bias

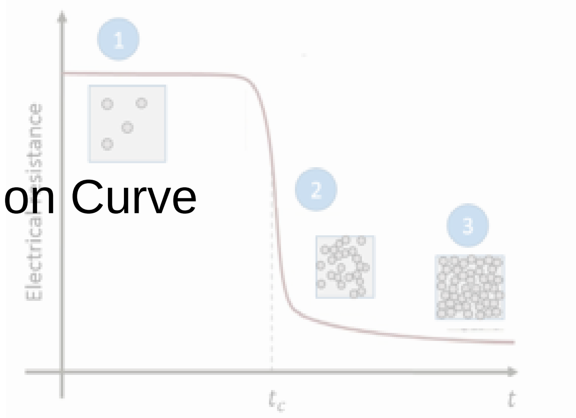
1. Cluster metallic film fabrication
2. Morphology investigation
3. Electrical transport properties investigation

with this new tools in mind…

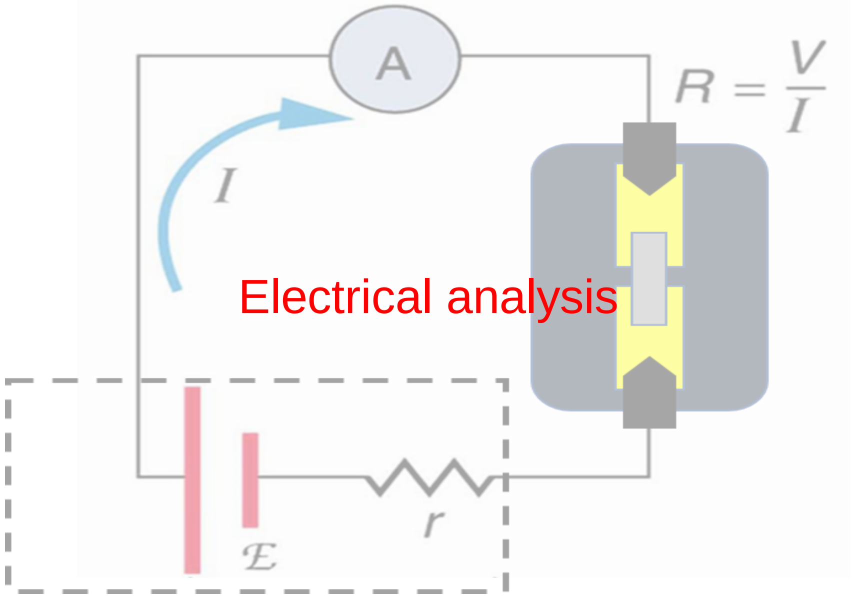
…now we are going to see some data…



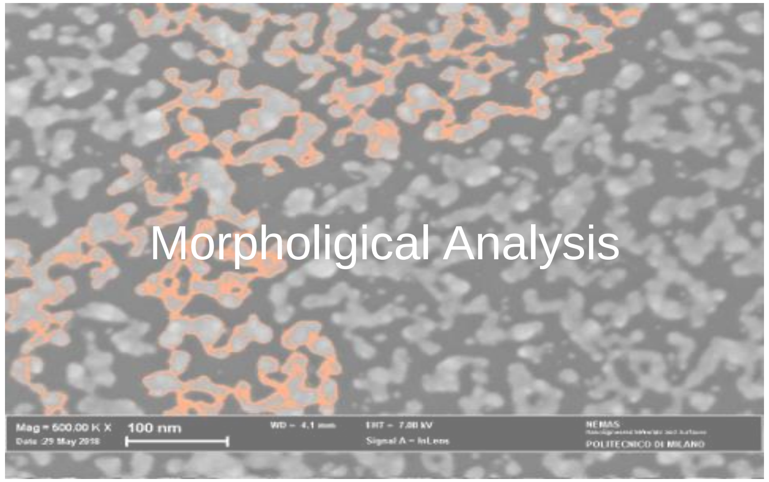
SCBD



Percolation Curve

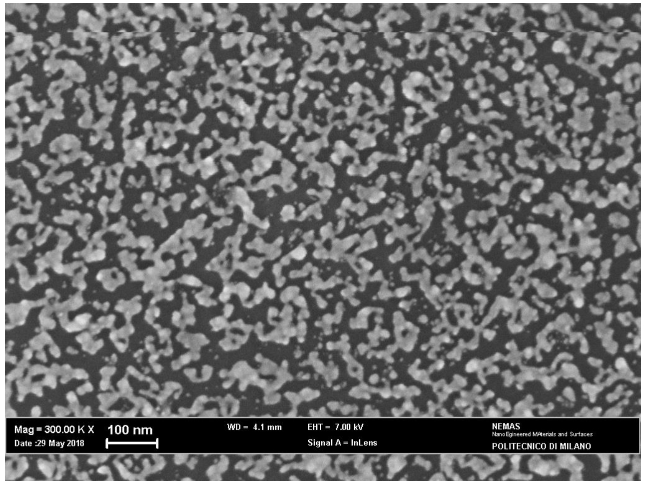


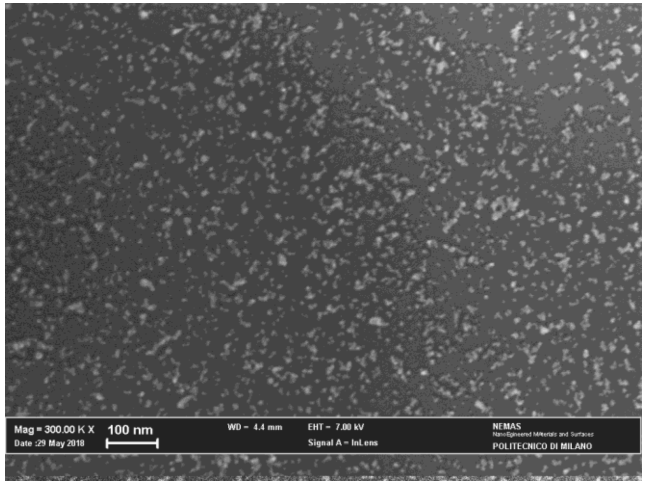
Electrical analysis

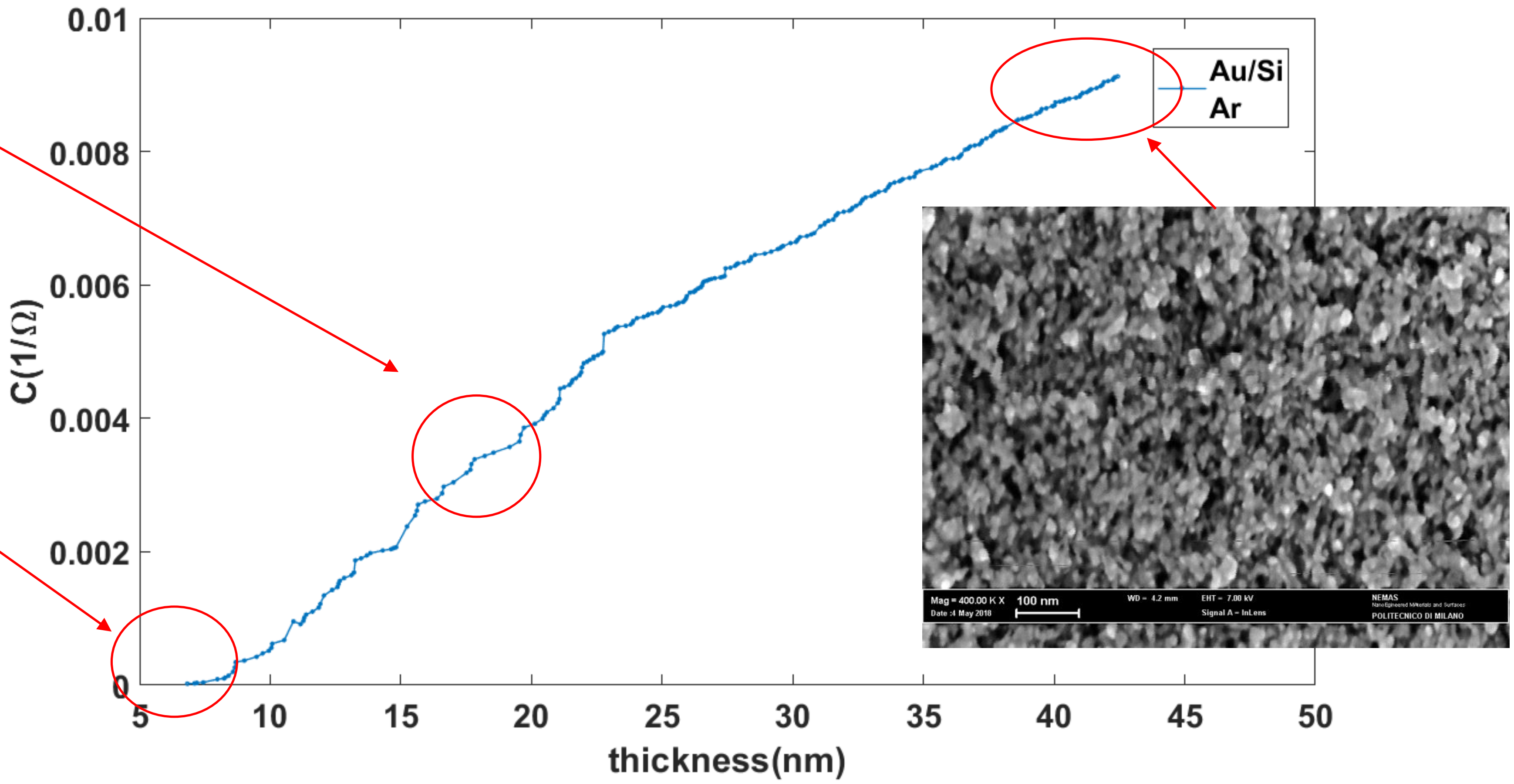


Morpholigical Analysis

Percolation Curve

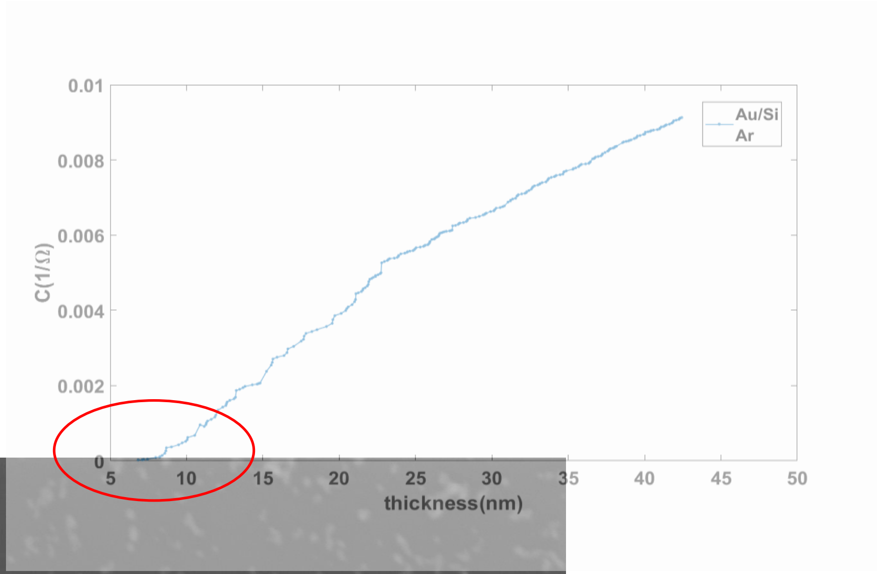


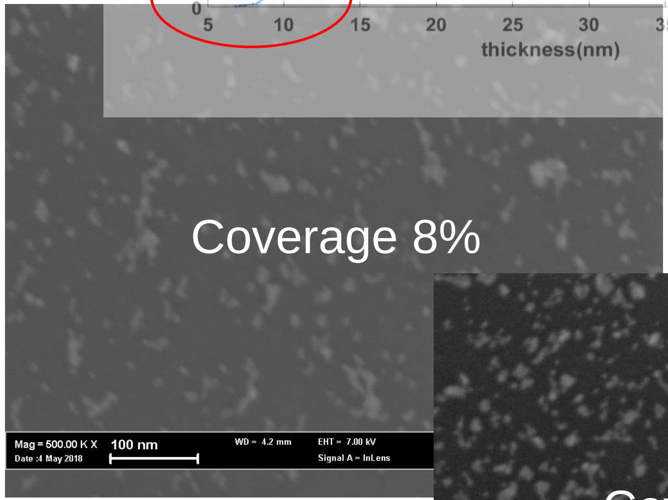


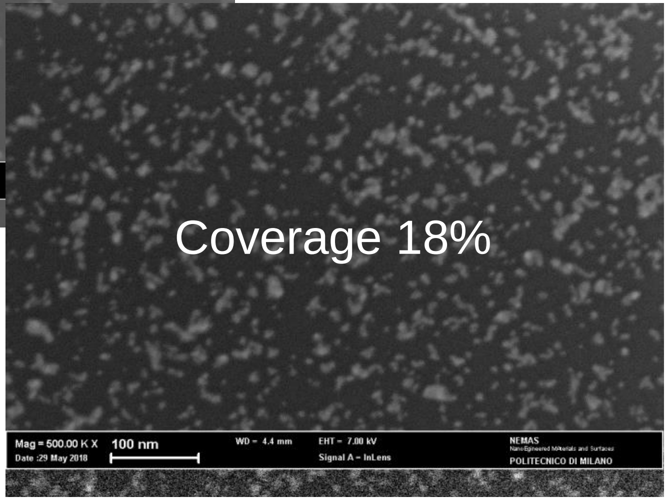


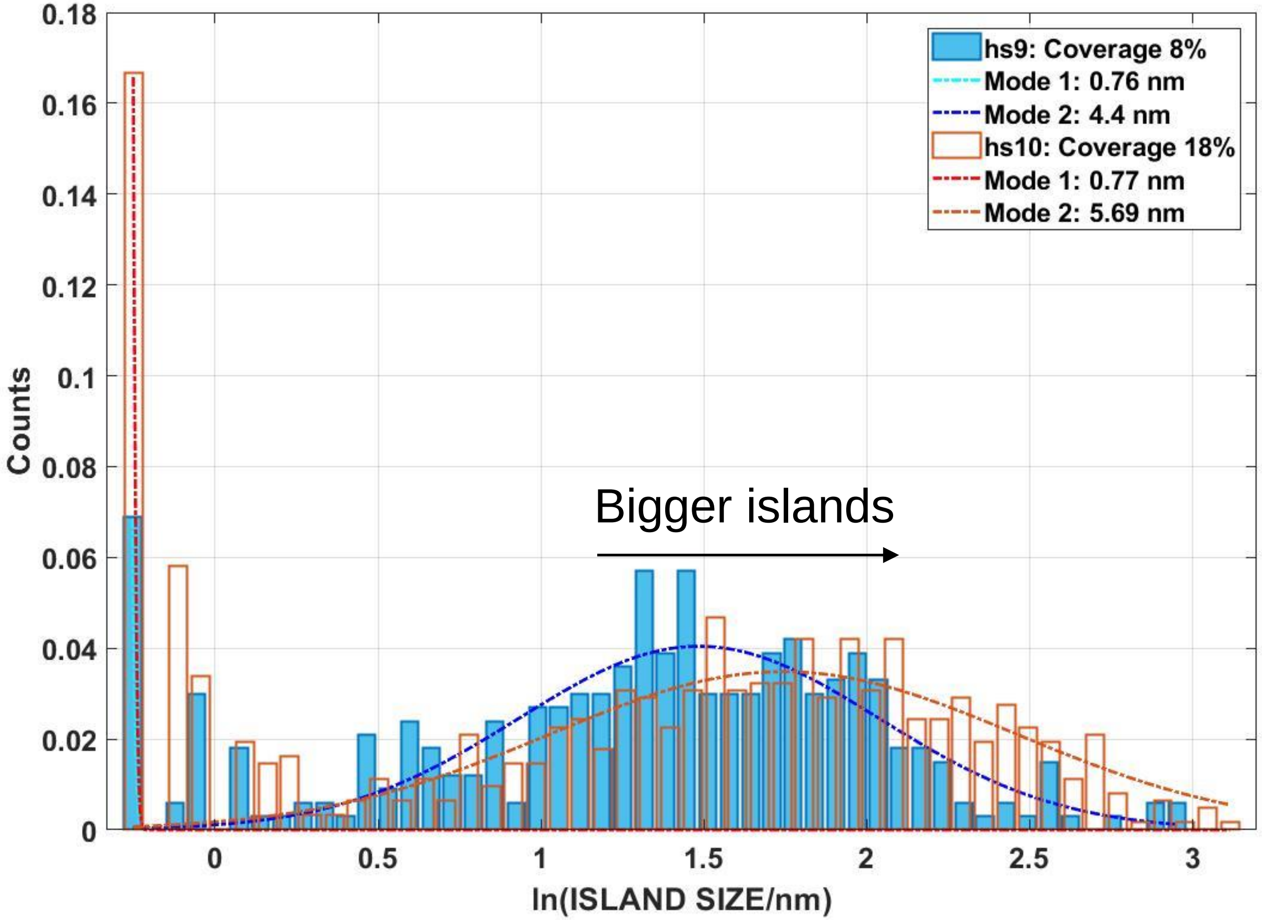
Native Island Size Distribution

Growth in the first stages



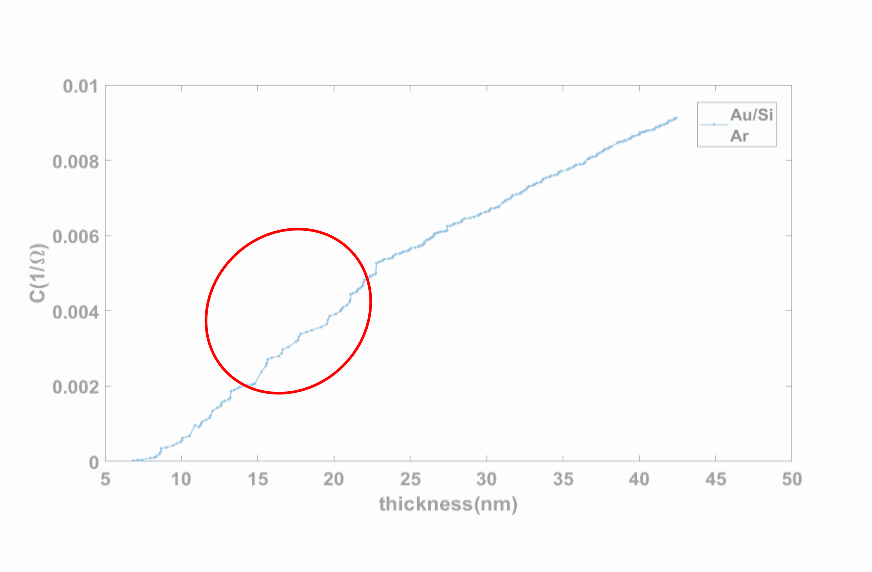


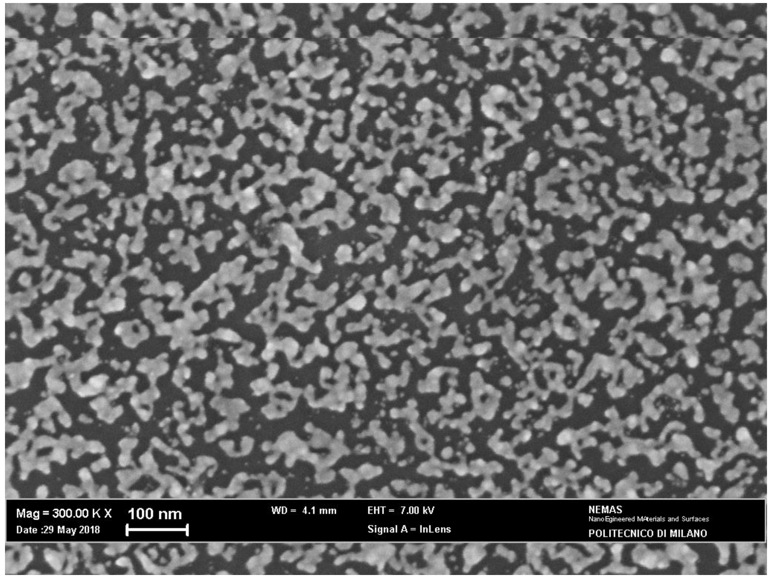


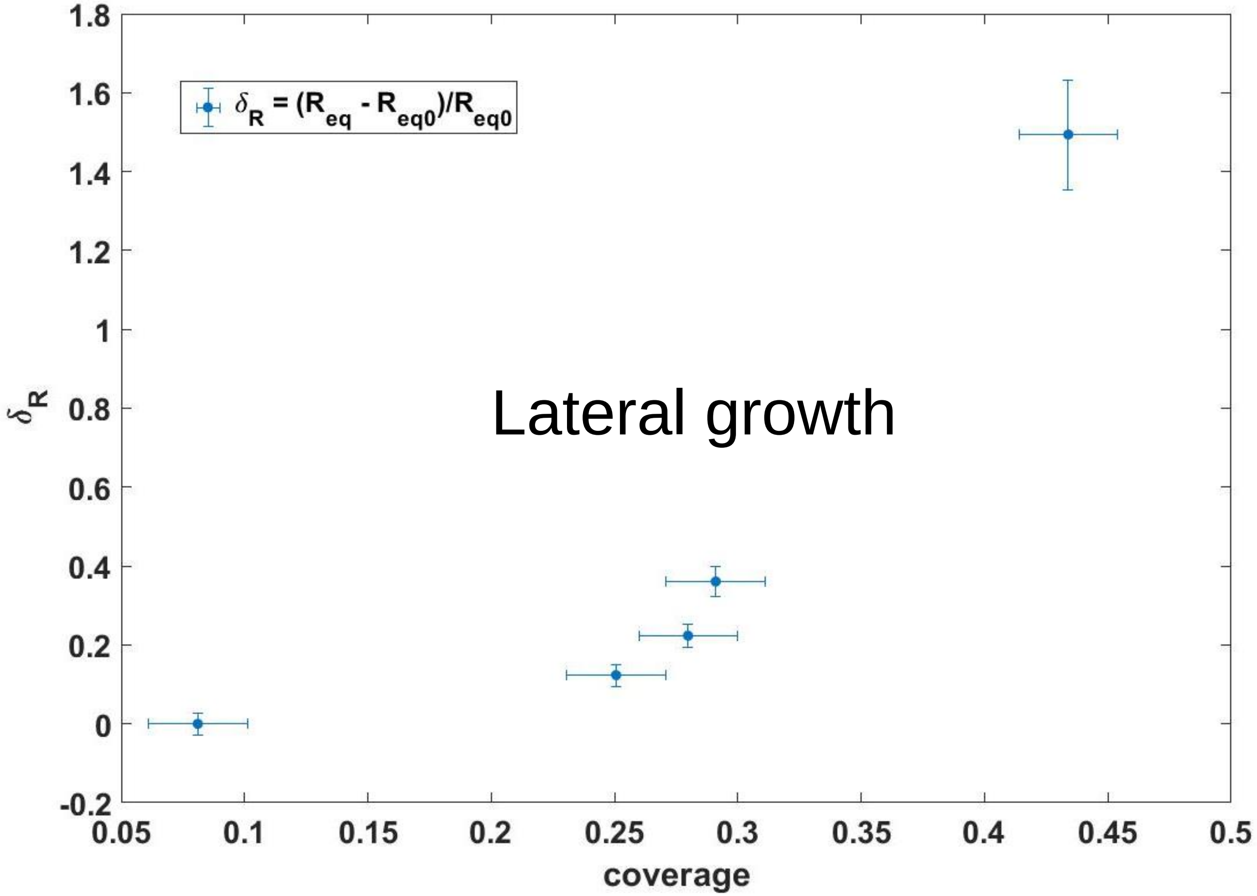


Percolation Threshold

Growth in the first stages

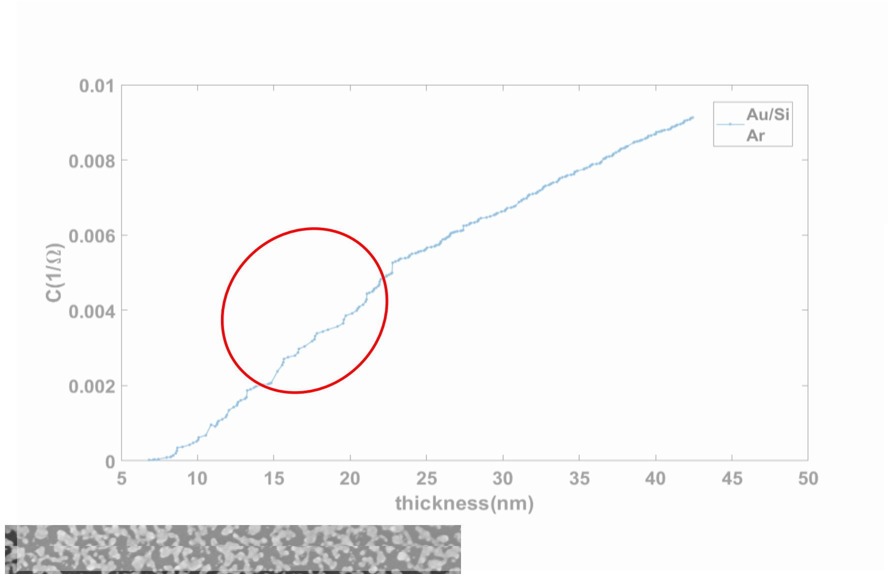


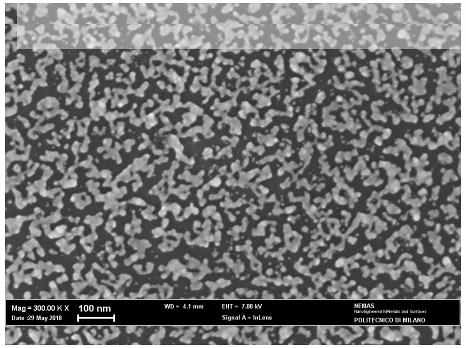




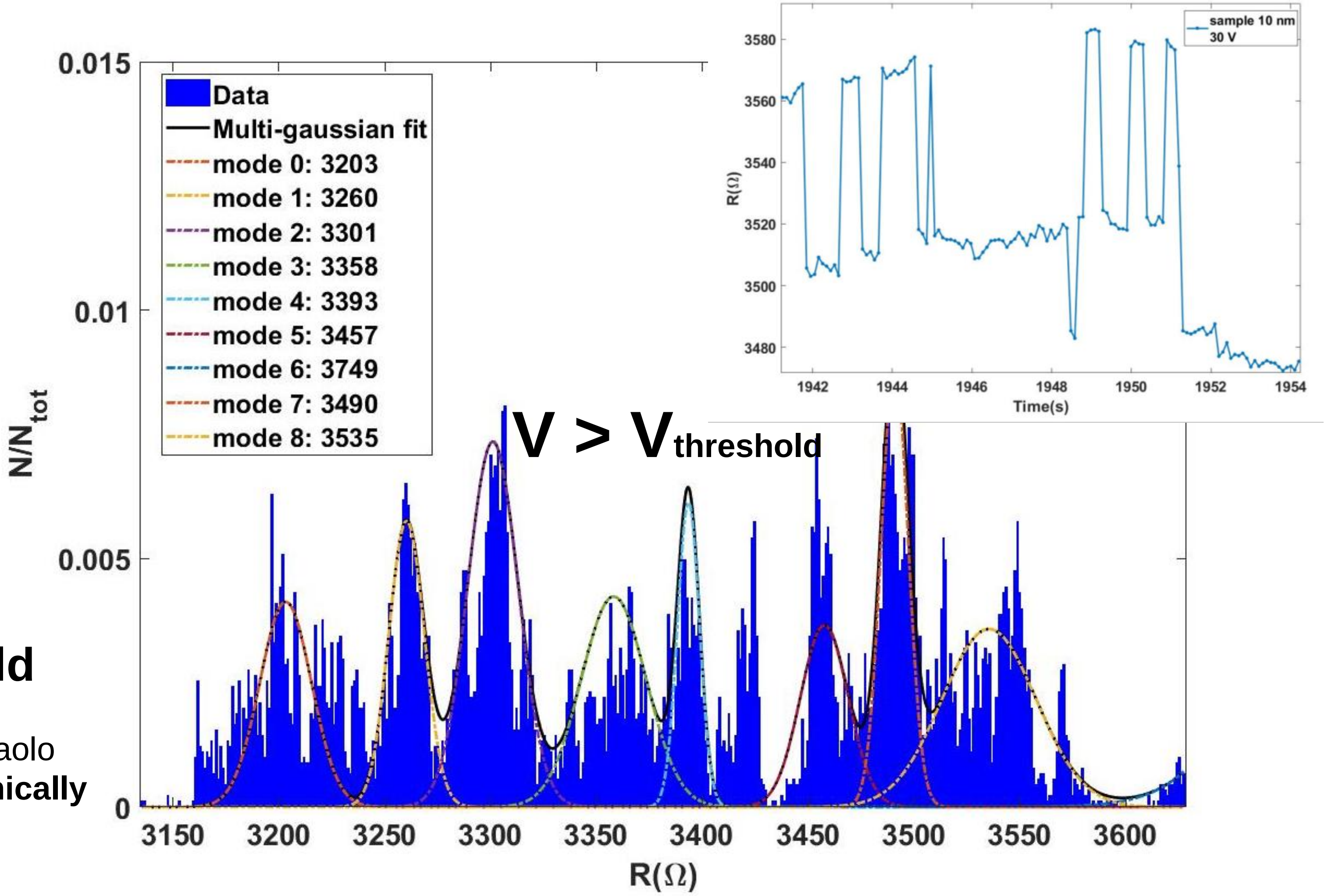
Percolation Threshold

Electrical properties





Switching behaviour

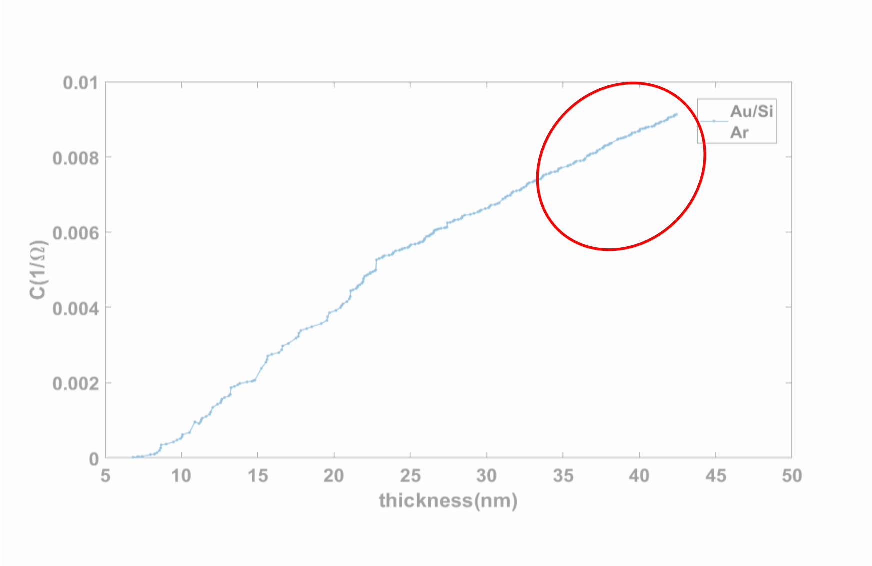


…News on **Physics World**

Chloé Minnai, Matteo Mirigliano, Simon A Brown and Paolo Milani: **The nanocoherer: an electrically and mechanically resettable resistive switching device based on gold clusters assembled on paper,** *Nano Features* (2018)

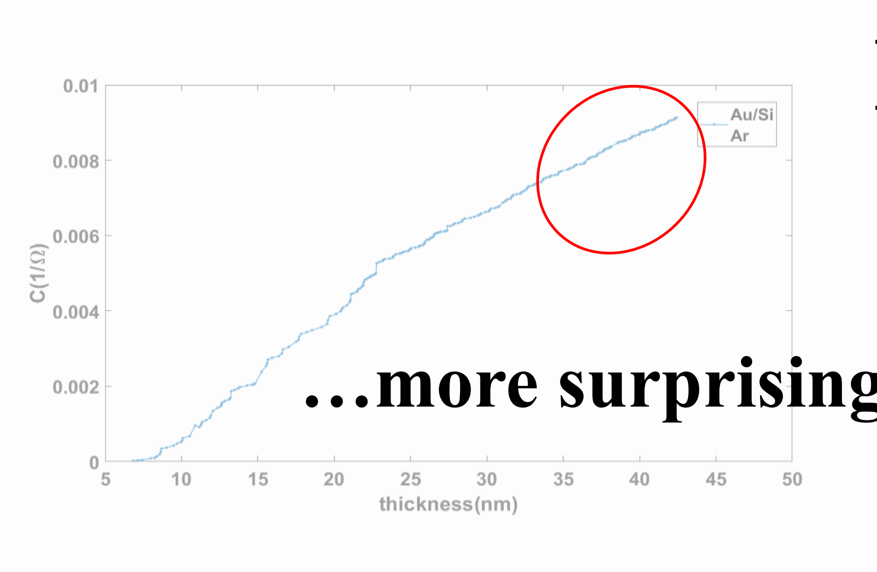
Beyond the Percolation Threshold

Morphology

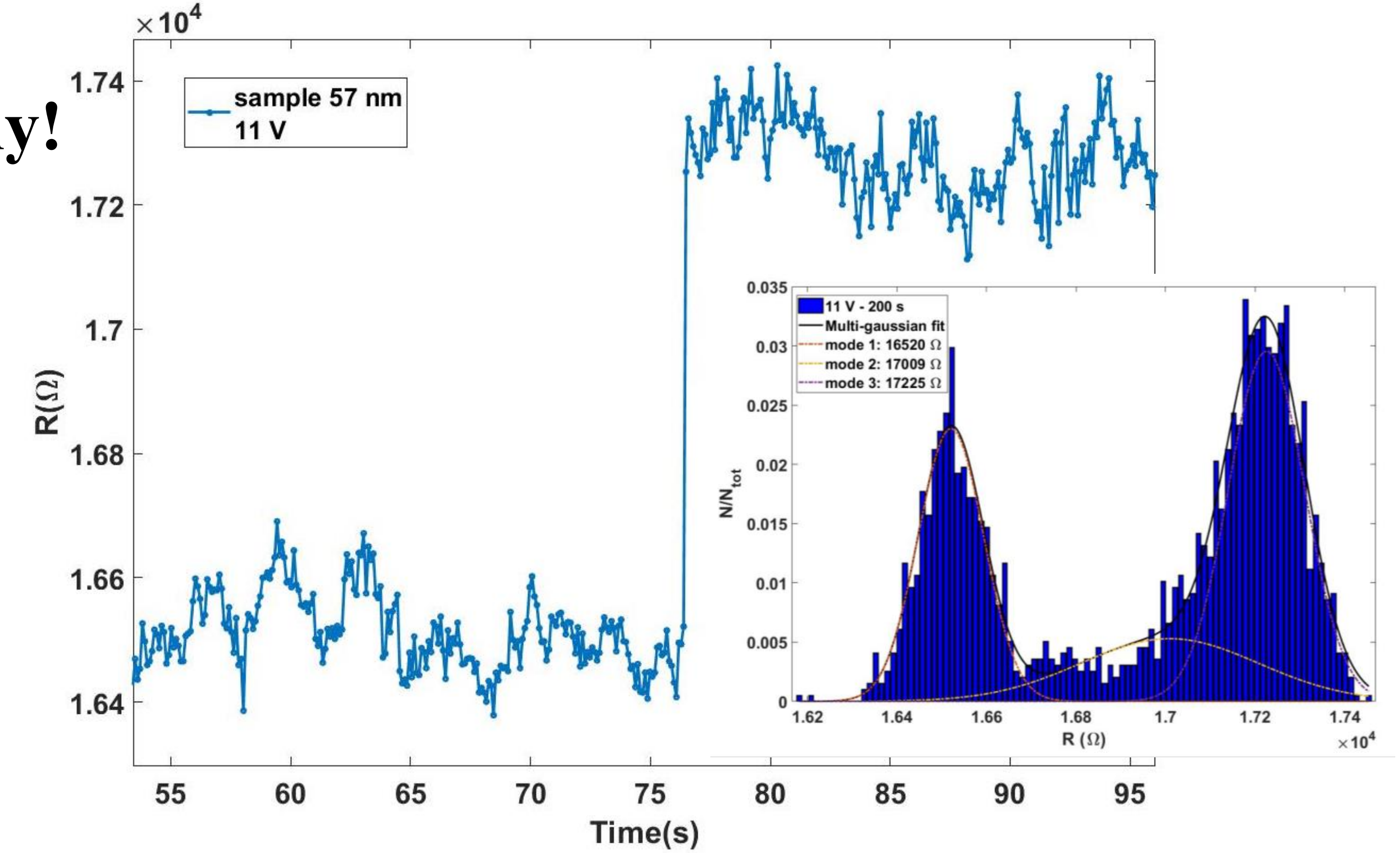


Beyond the Percolation Threshold

Electrical properties

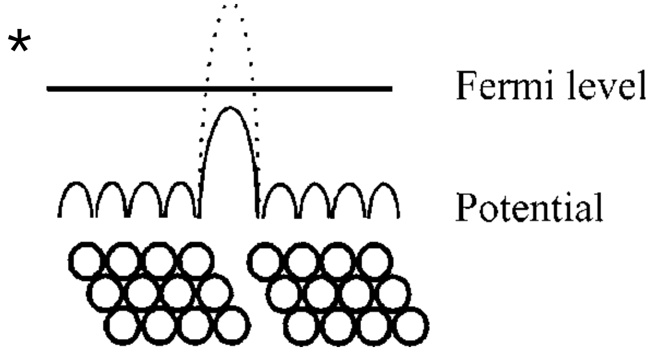


…more surprisingly!



Discussion

At the origins of the non linear behaviour and the switching mechanism in our metallic systems

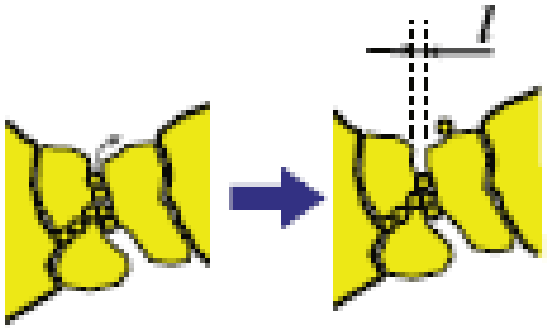


- **Presence of defects, grain boundaries…**

  Different conduction mechanisms: tunnelling…

- **Electromigration effects**

  Joule heating, atom rearrangements….



"As grains are growing and restructuring, there is the possibility for grain boundary potentials to alter in both height and width so to either increase or decrease the resistance"

Durkun, Schneider,Welland J. Appl. Phys., **86** (1999)

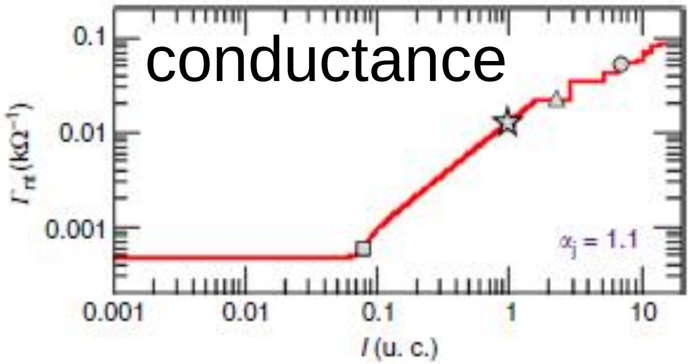
…is this all?

*Durkun and Welland, Phys. Rev B, **61** (2000)

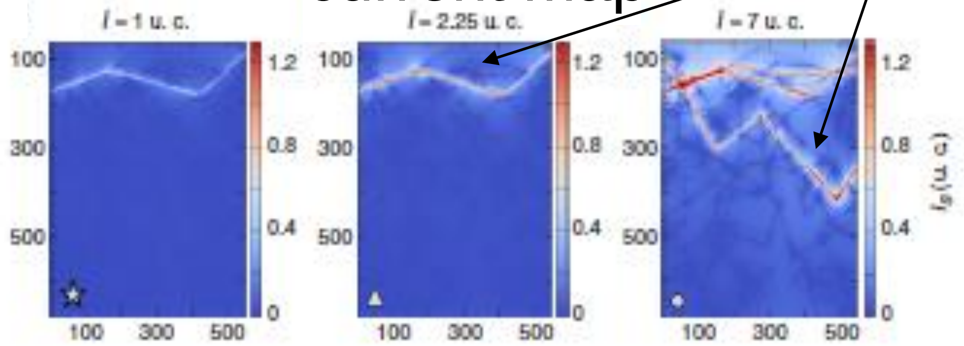
Discussion

*Metal nanowire random network

conductance



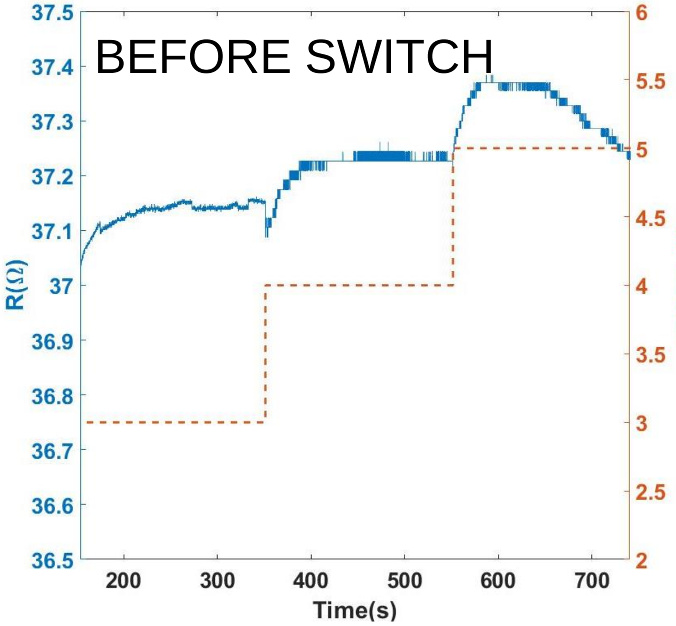
current map

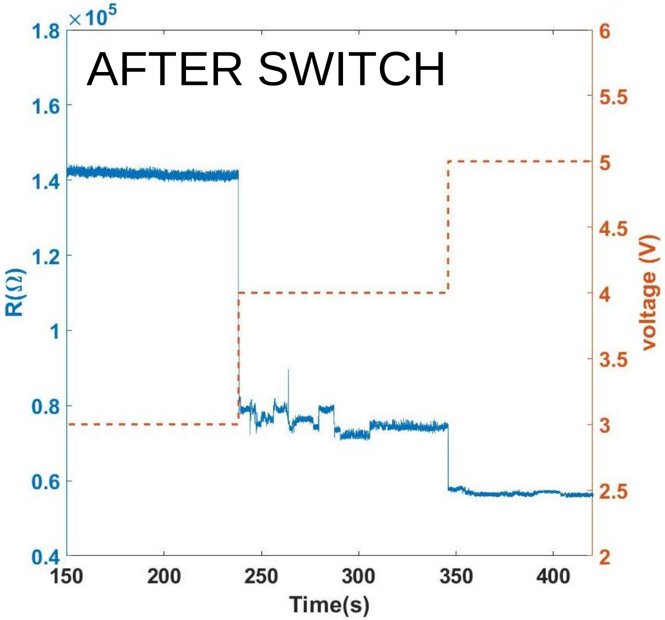


Complex behaviour

Can the disorder be exploited? That's the question…

Current paths at different current source in a similar system…





- Complex switch patterns…
- Correlated local phenomena…
- …adaptive behaviour

Conclusions

Cluster assembled metallic films

Fundamental point of view

- Organization of the matter at the nanoscale
- Growth morphology
- Understanding of physical properties like electrical transport

Applications

- Non linear electrical properties
- Switching mechanism in metallic films

Conclusions

Cluster assembled metallic films

- Organization of the matter at the nanoscale
- Growth morphology
- Understanding of physical properties like electrical transport
- Non linear electrical properties
- Switching mechanism in metallic films

Perspectives

- Deepest study of switching behaviour
- Exploiting such a complex phenomena
- Further study on local electrical and morphological properties of thicker films (AFM)

This is highly multidisciplinary project

Thanks to:

- Prof. A. Pullia (UNIMI)
- Prof. A. Podestá (UNIMI)
- Dr.ssa Francesca Borghi
- Dr.ssa Chloé Minnai
- Prof. Simon Brown (Canterbury University, NZ)
- Prof. Luciano Colombo (Universitá di Cagliari)
- Prof. Davide Galli (UNIMI)

Thanks for attention!

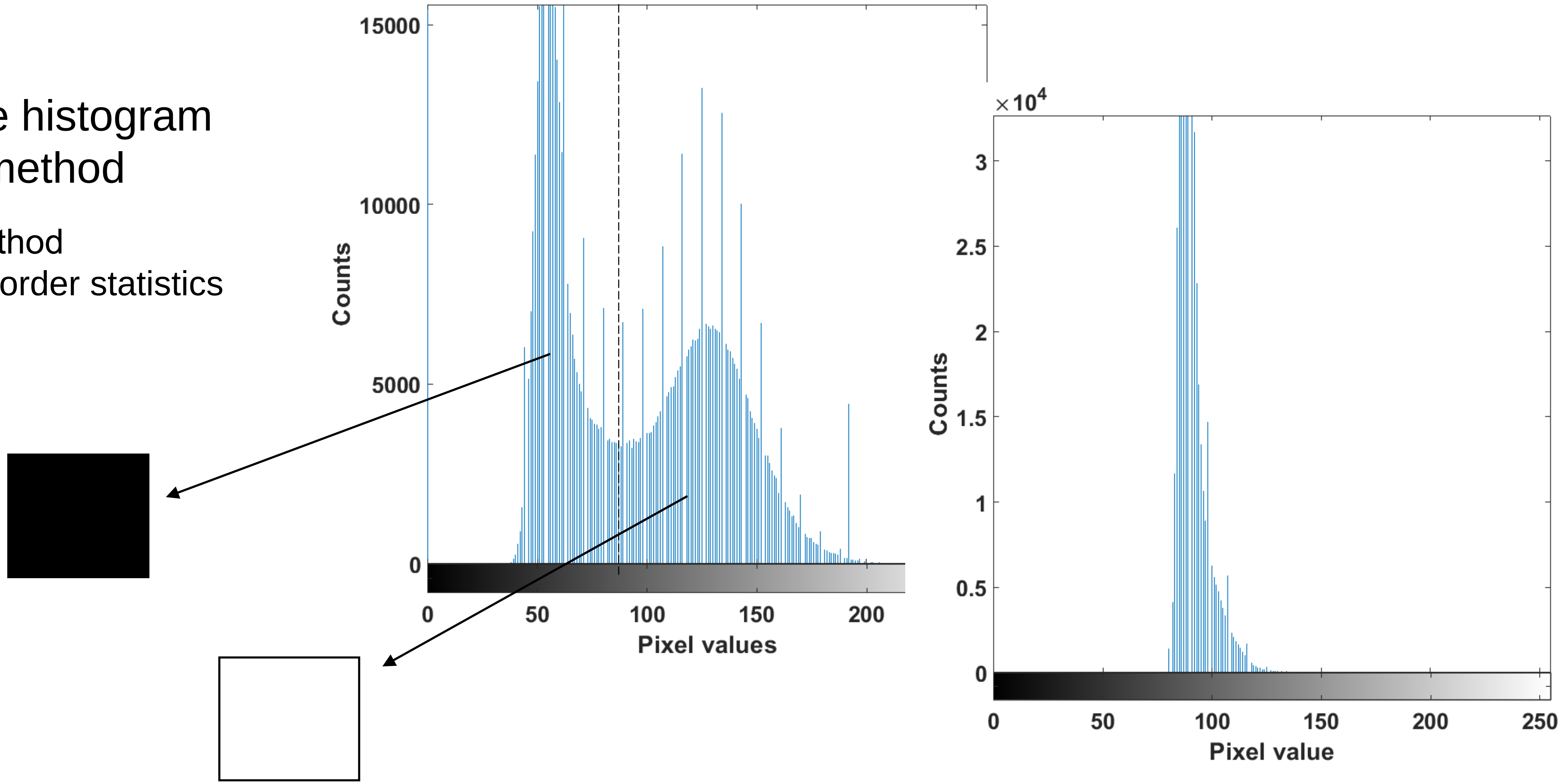
SLIDE DI RISERVA

Experimental methods

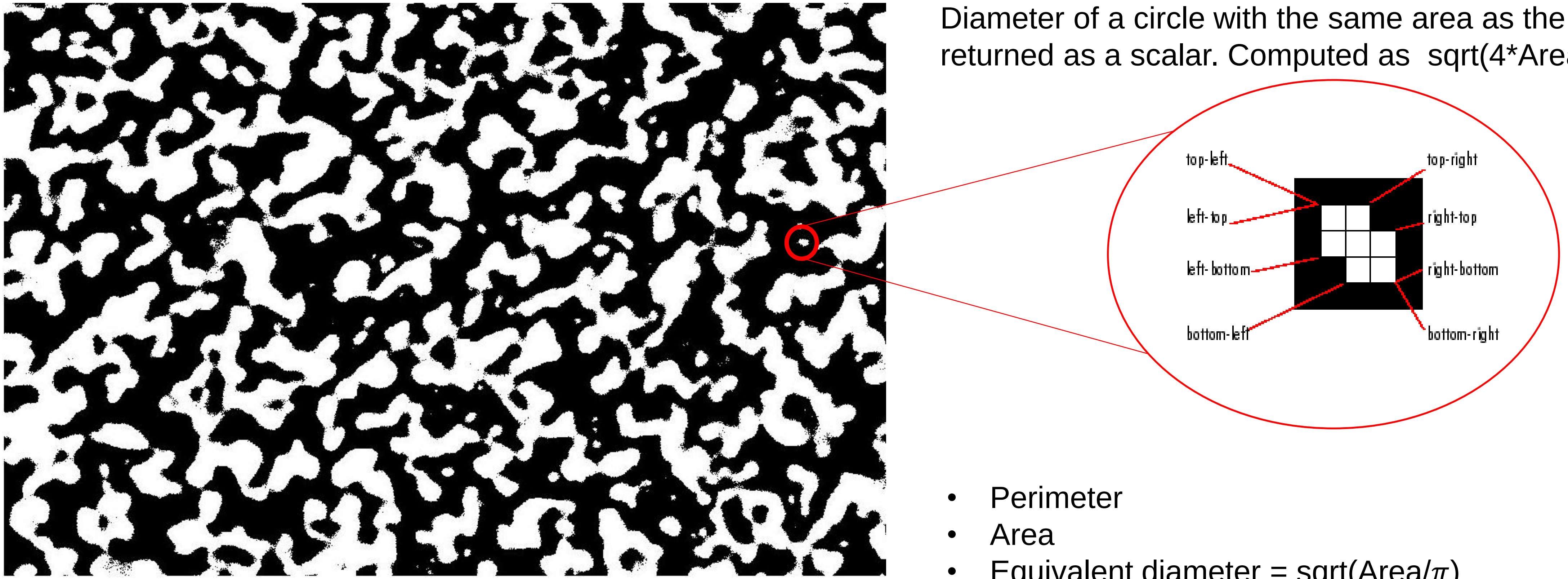
Image processing

Thresholding method

1. Analyse the histogram
2. Choose a method
   - Otsu’s method
   - Local first order statistics
   - …



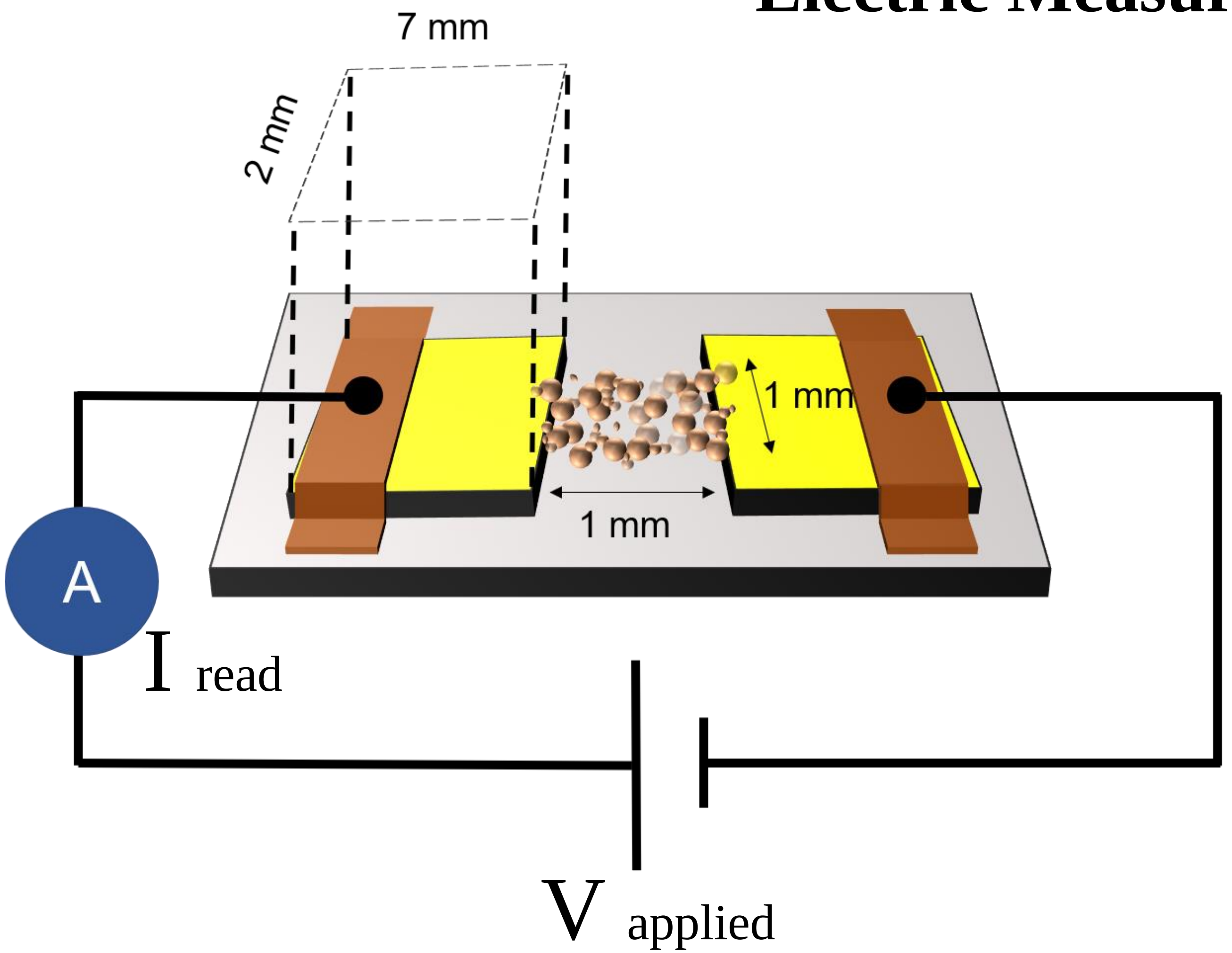
Experimental methods
Image processing



Diameter of a circle with the same area as the region, returned as a scalar. Computed as sqrt(4*Area/pi).

- Perimeter
- Area
- Equivalent diameter = sqrt(Area/π)

Experimental methods
Electric Measurements



Scheme of the device under test

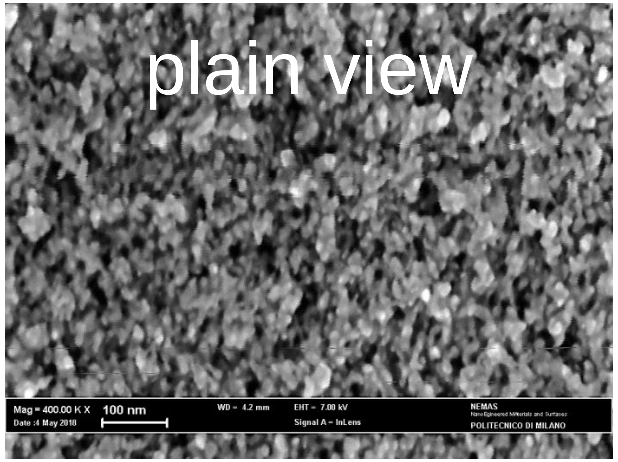
Two probes method

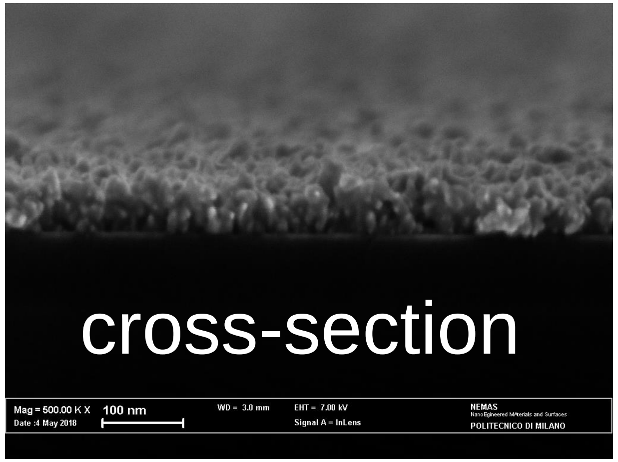
$$V = R\,I$$

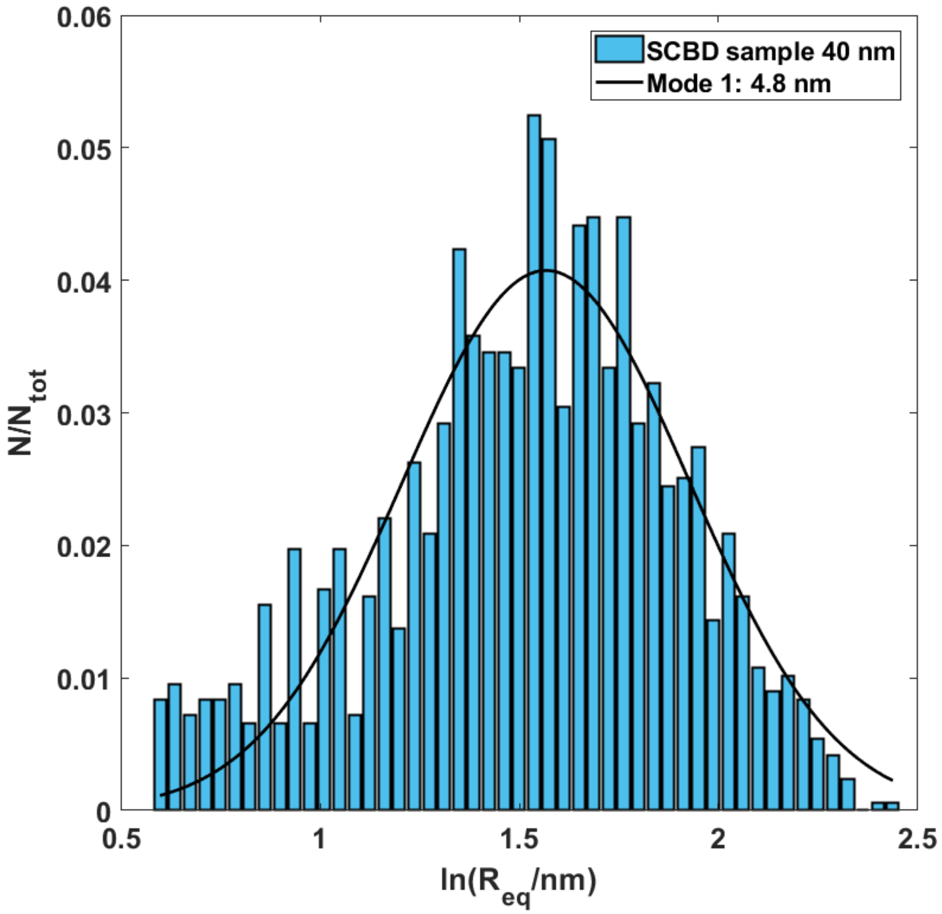
V: voltage
R: resistance
I: current

Beyond the Percolation Threshold

Granulometry



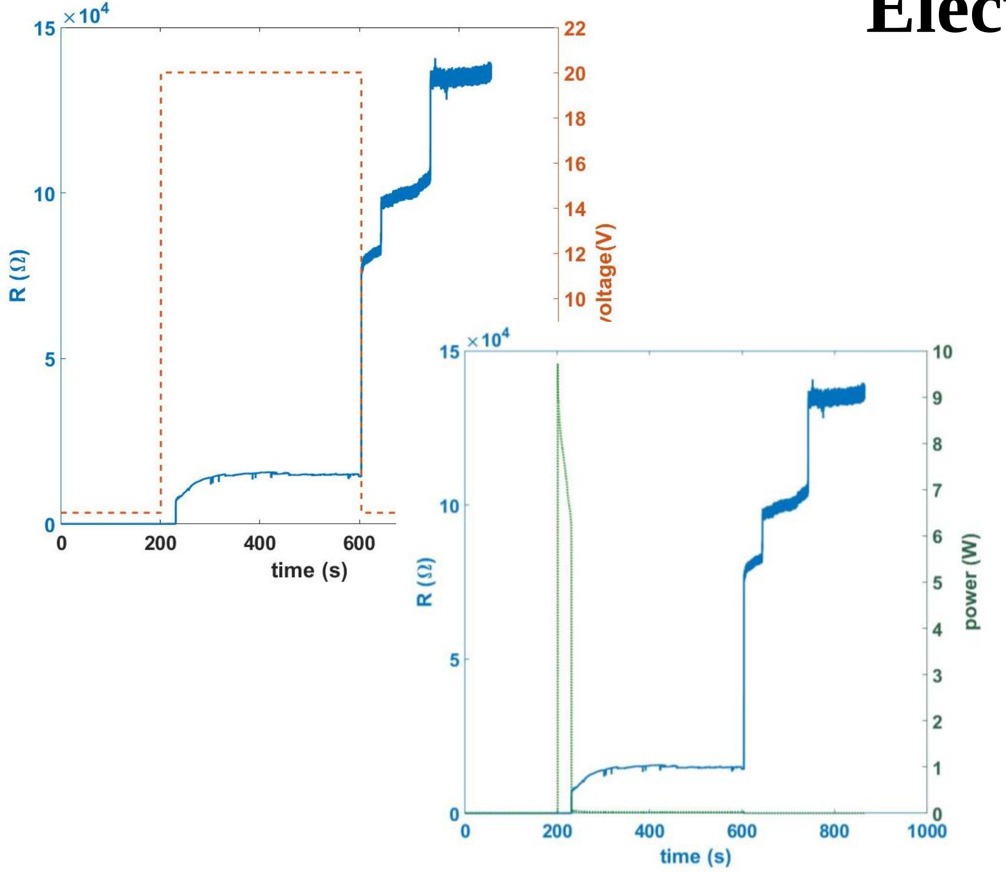


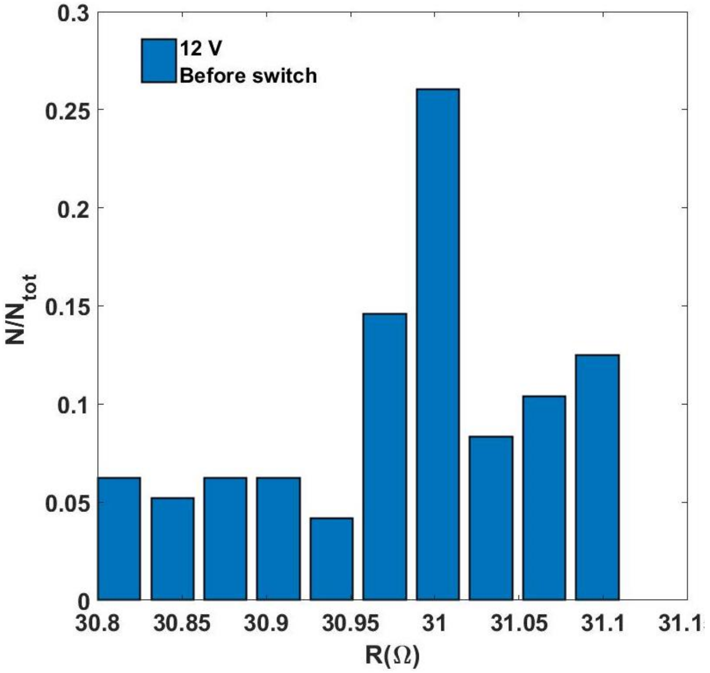


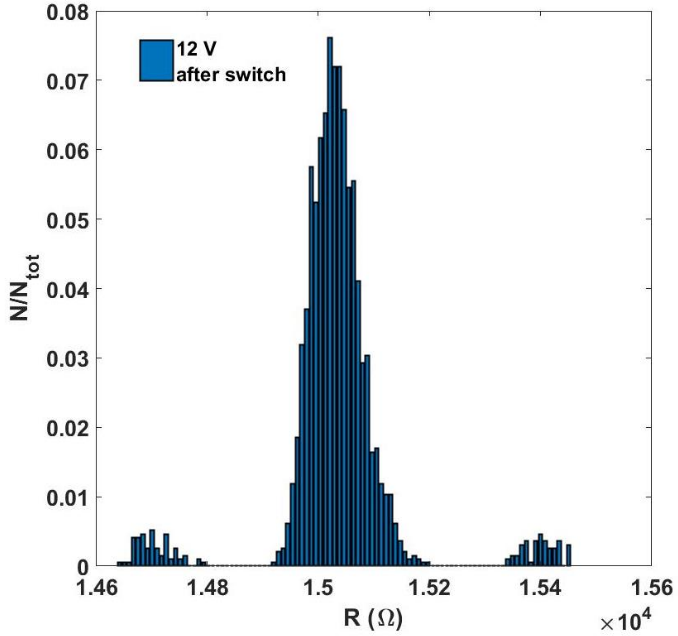
Segmentation under same constraints on curvature radius

Beyond the Percolation Threshold

Electrical properties







Before switch

After switch

low – high – low → voltage