Drastic Change in Non-Linear Resistive Materials I(V) Characteristics

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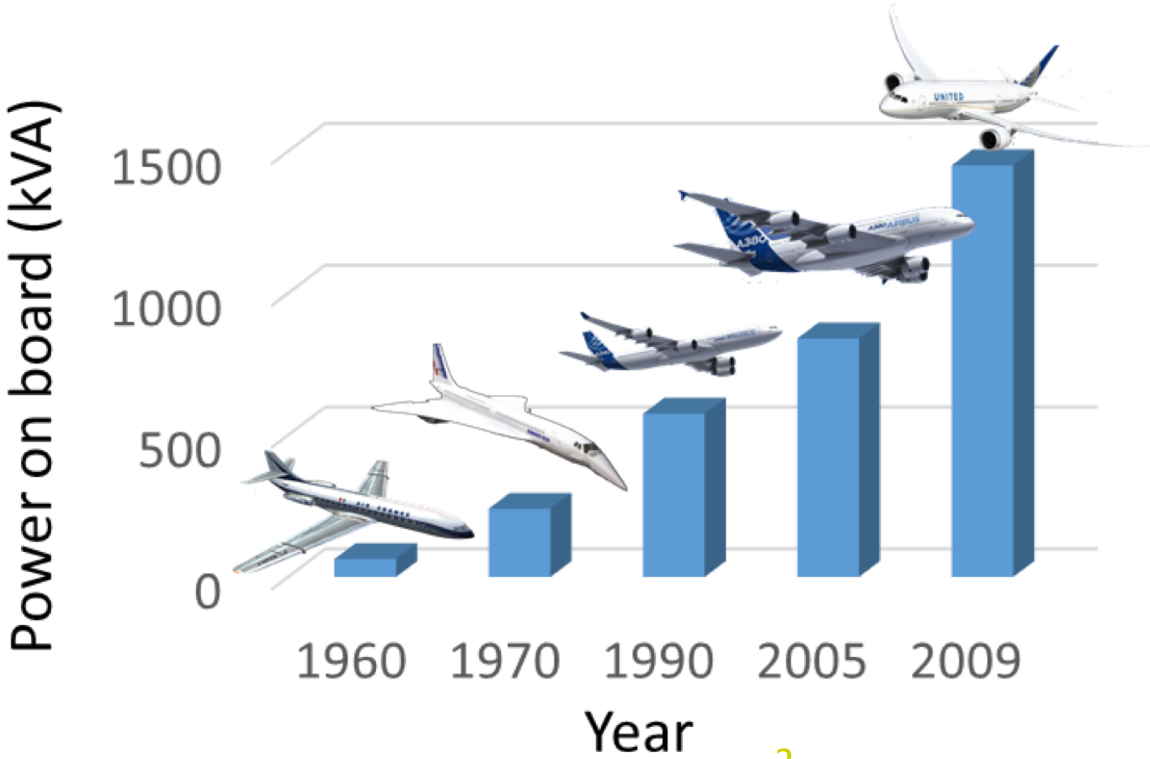
Context - More power on board

- **Clean Sky 2** and **M**ore **E**lectrical **A**ircraft initiatives

- Increasing power installed on board of aircrafts
  - Weight/fuel consumption
  - Operation/maintenance cost
  - Reliability



Current and future trends

- Present: More Electrical Aircraft
  - Replace non-propulsive systems by electrical ones
  - Bleed-less, green taxiing, hydraulic-less, electric braking

Green taxiing
Safran

→ New voltage emerging

115→**230 Vac** and ±**270 Vdc**

Electric braking
Safran

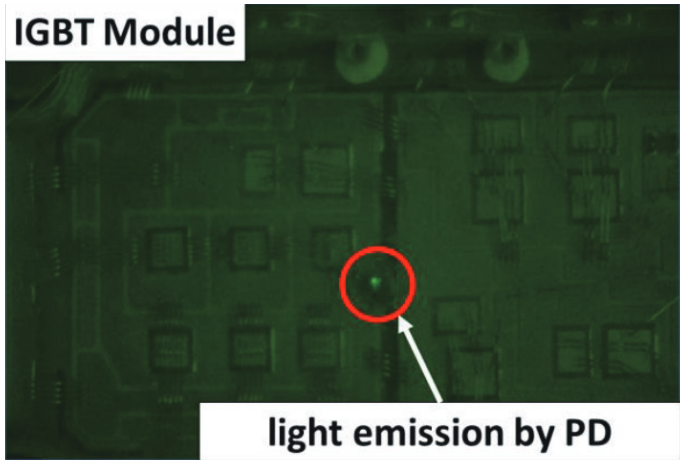
- Next step: Hybrid propulsion ?
  - Airbus E-Fan X (**2 MW** electrical propulsion)
  - Boeing Sugar Volt
  - Zunum

- Higher voltage expected **(3 kV)**

Severe constraints on insulating materials !

Electromechanical chain: **Power module**

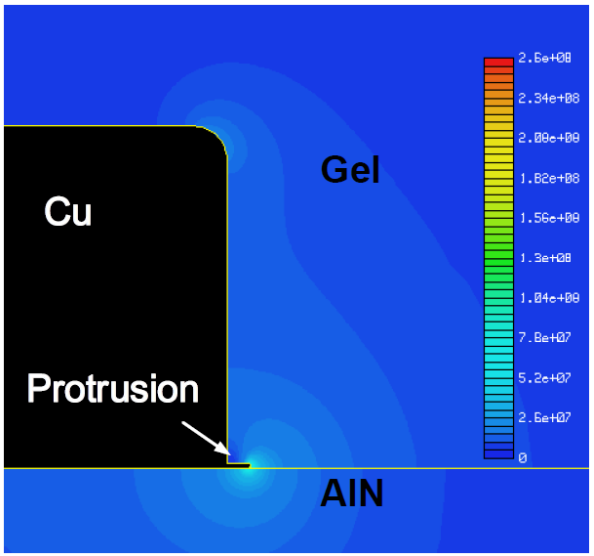
- To increase power densities:
  - Increase voltage



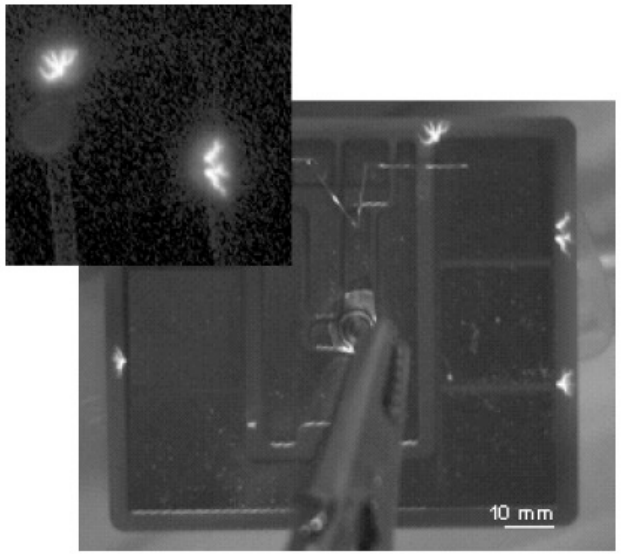
[Maki *et al.*, 17]

High electric field constraint with potentially destructive effect

AMB geometry



[Donzel *et al.*, 12]

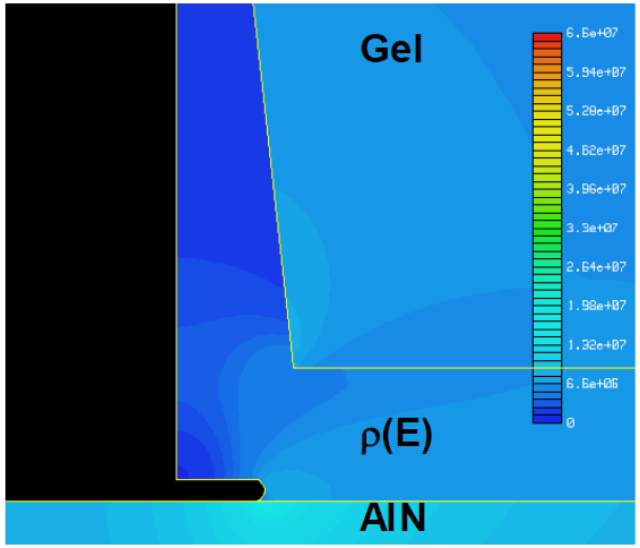


[Fabian *et al.*, 05]

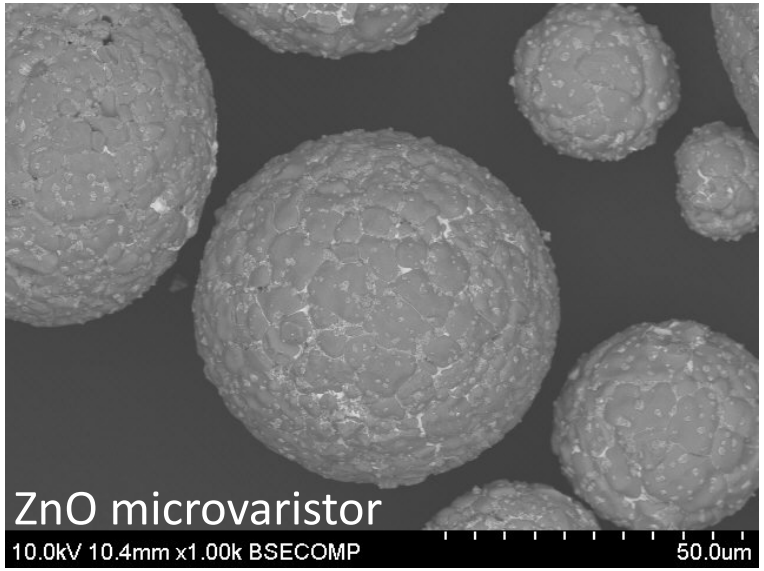
Local field grading methods

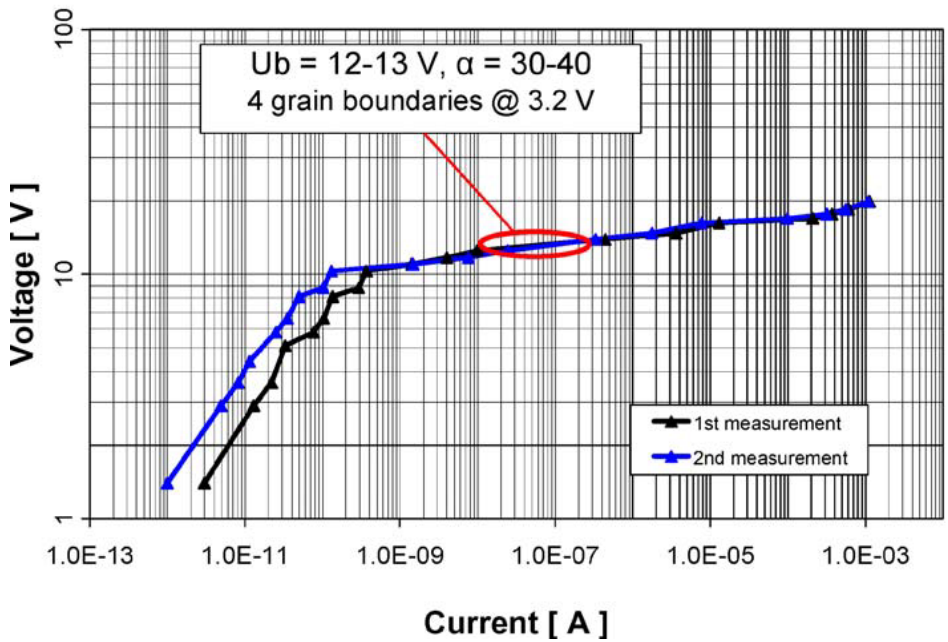
- Field grading categories
  - Permittivity → capacitive grading
  - Resistivity → resistive grading

- ZnO microvaristor
  - High permittivity (bulk ≈ 1000)
  - **Non-linear resistivity**
  - **Complex behavior**



[Donzel *et al.*, 12]



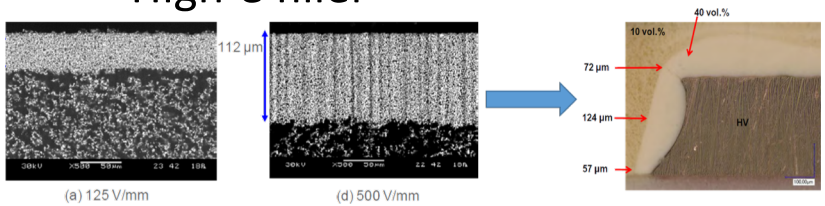


[Greuter *et al.*, 04]

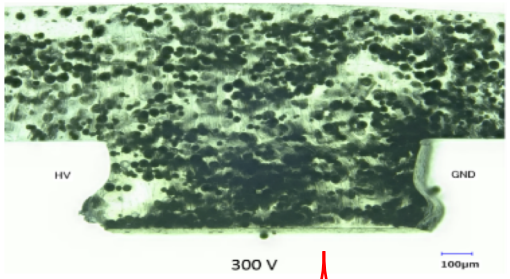
Electrodeposited FGM timeline

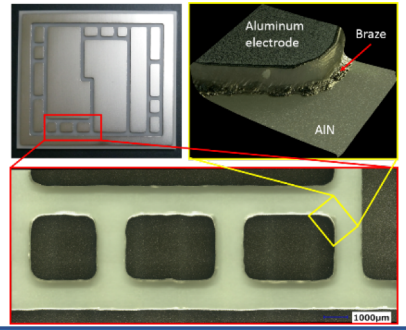
auto-deposition of FGM in area to « cure »

L. Levêque PhD – Laplace
- Proof of concept => Patent
- High-ε filler

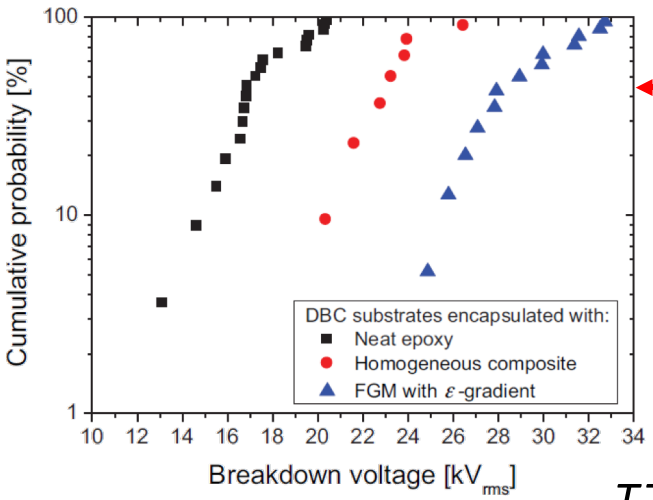


G. Belijar – IRT/Kyutech
- NRM filler (ZnO µvaristor)
- Implementation in AMB

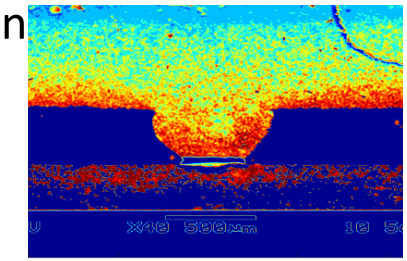




2013 | 2016 | 2017 | 2018 | 2019 | 2020



T.T. Le – IRT/Laplace
- Implementation in active PM (6.5 kV IGBT)
- Impact on partial discharges
- New matrix
- Double-side deposition



T.T. Le – Laplace
- Breakdown voltage ×2

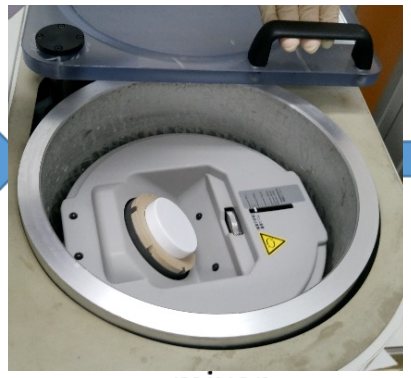
How epoxy/ZnO microvaristor NRM behave under high electric constraint ?

Elaboration process

- Material elaboration: Epoxy / ZnO microvaristor / additives

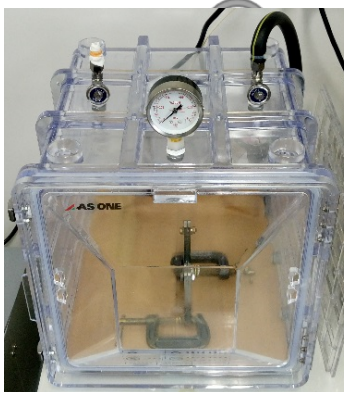
+ Additives

1 min Patm
3 min 0,2 kPa



mixer

Molding

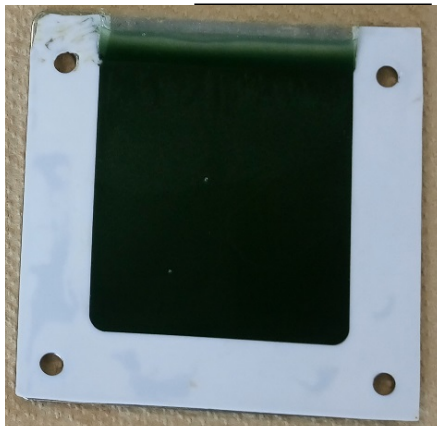


Degasing
15 min

cross-linking

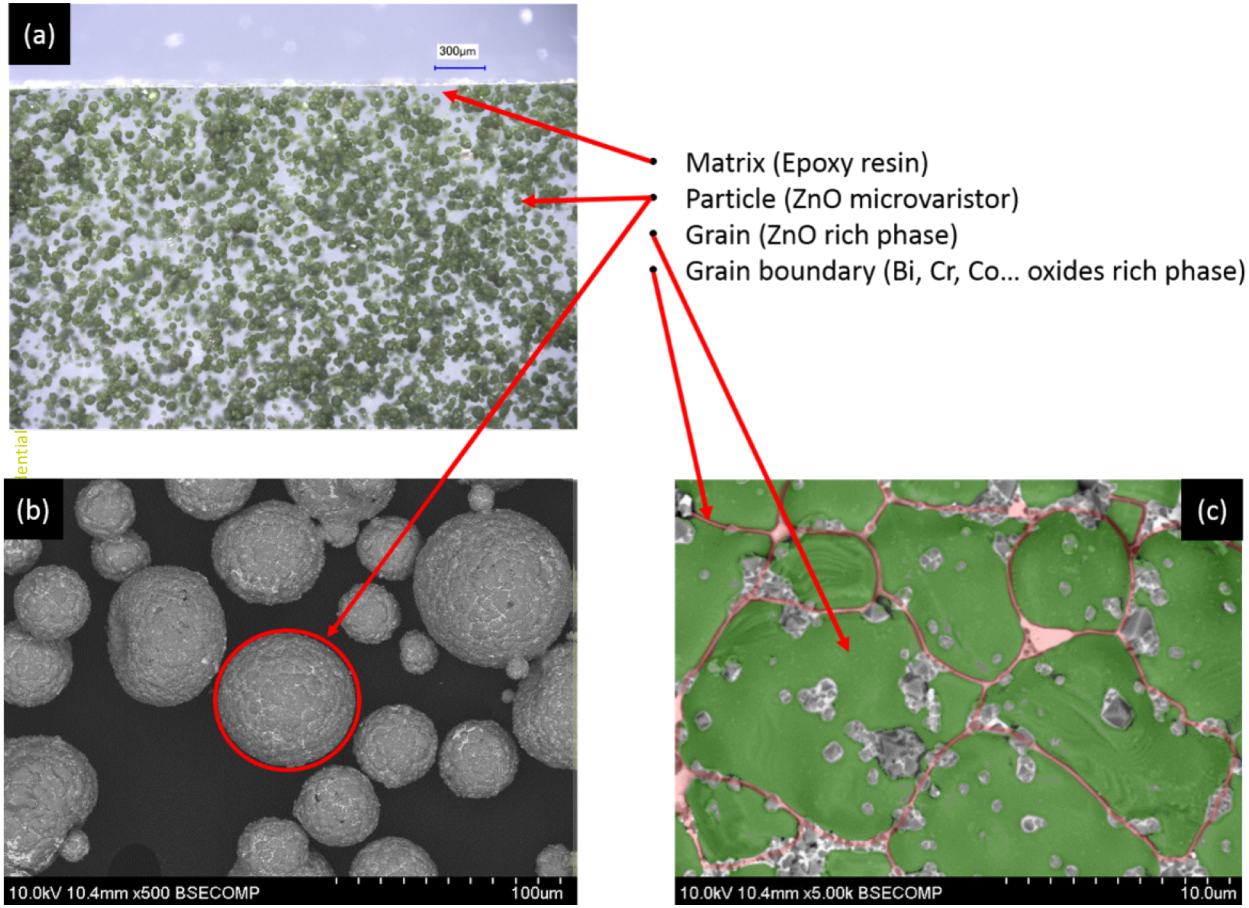
70 °C 3h
150 °C 3h

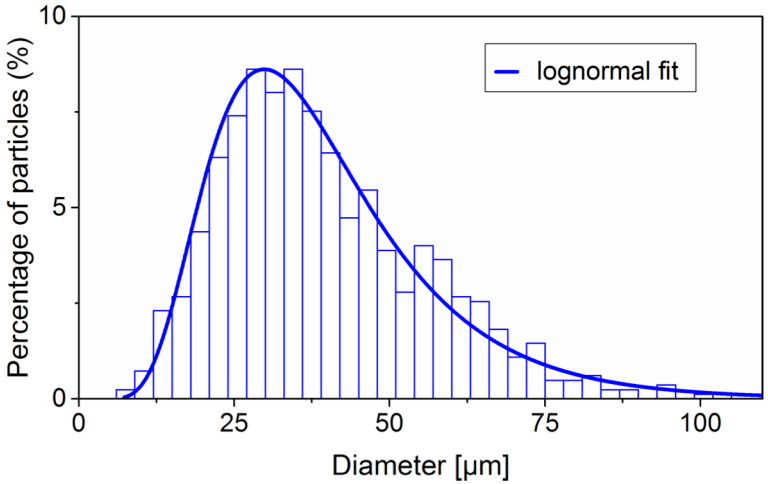
Dimensions :
80x70x0,5 mm



Materials

- Epoxy matrix + Amine type hardener
- ZnO microvaristor (prototype particles); diameter ranging from 10 to 100 µm; filler content from 10 to 50 vol%

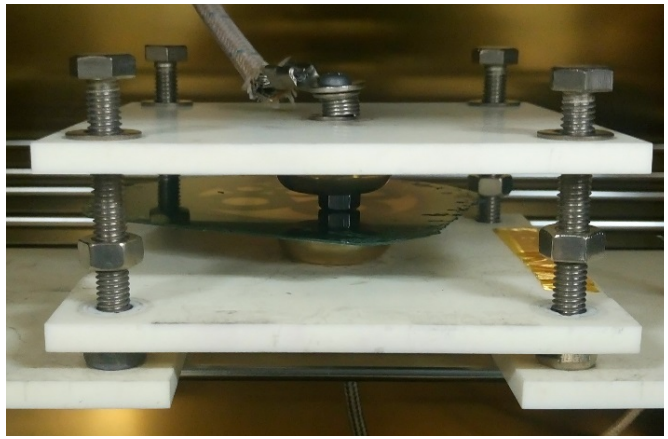


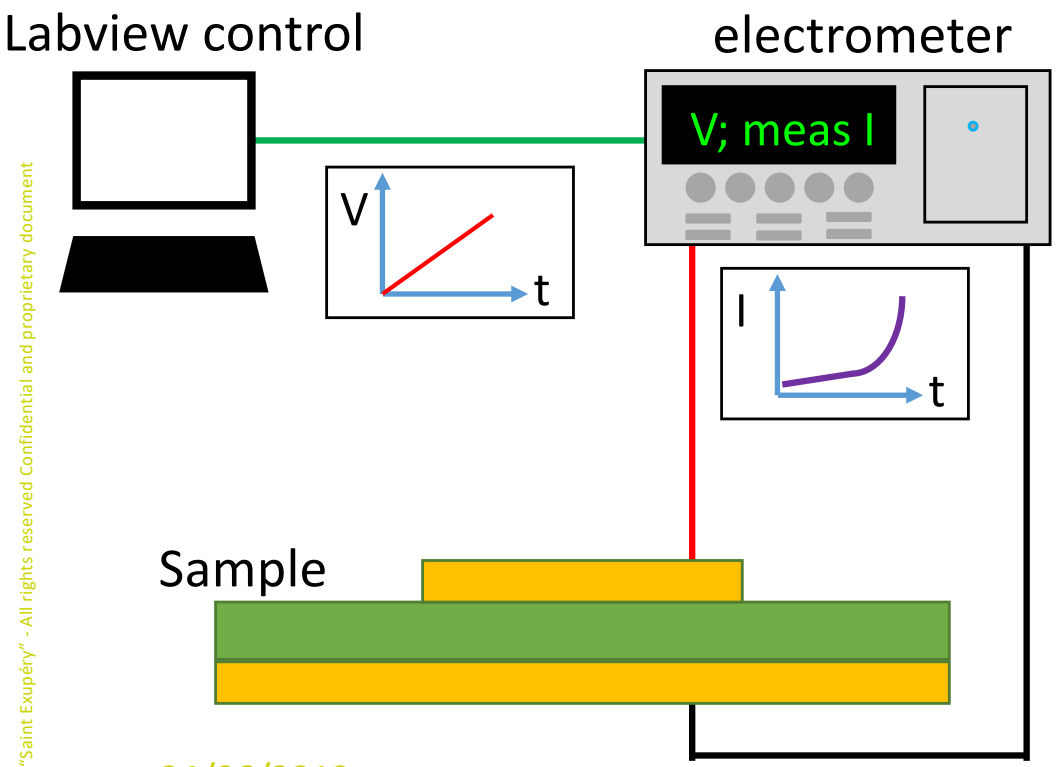


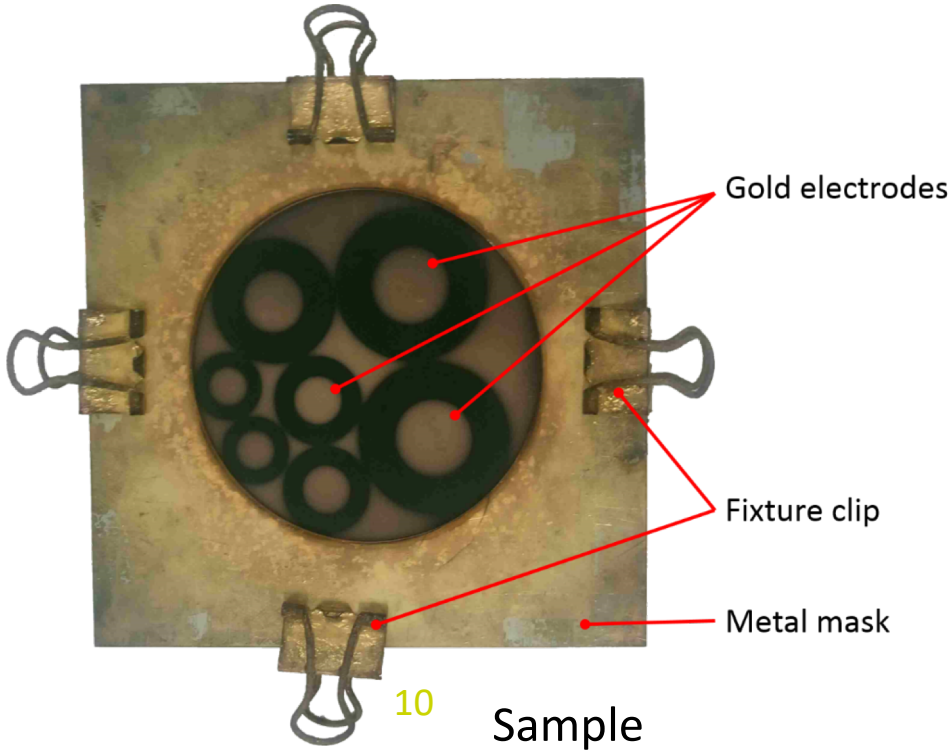
I(V) characterization: Setup

- DC voltage ramp
  - Vmax = 1000 V
  - Imax = 1 mA
  - Slope = 17 V/s => max cycle duration 60 s

Sample holder

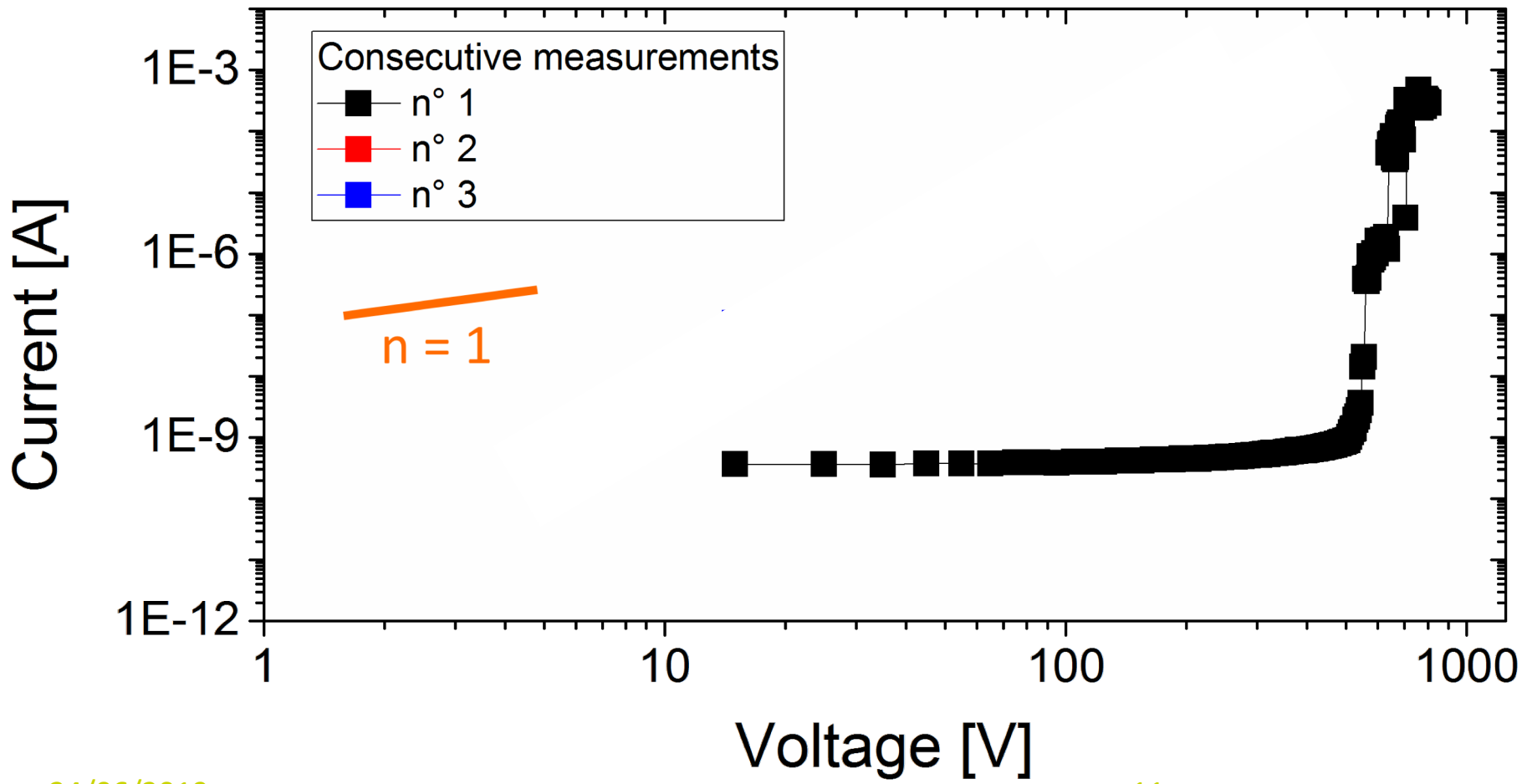






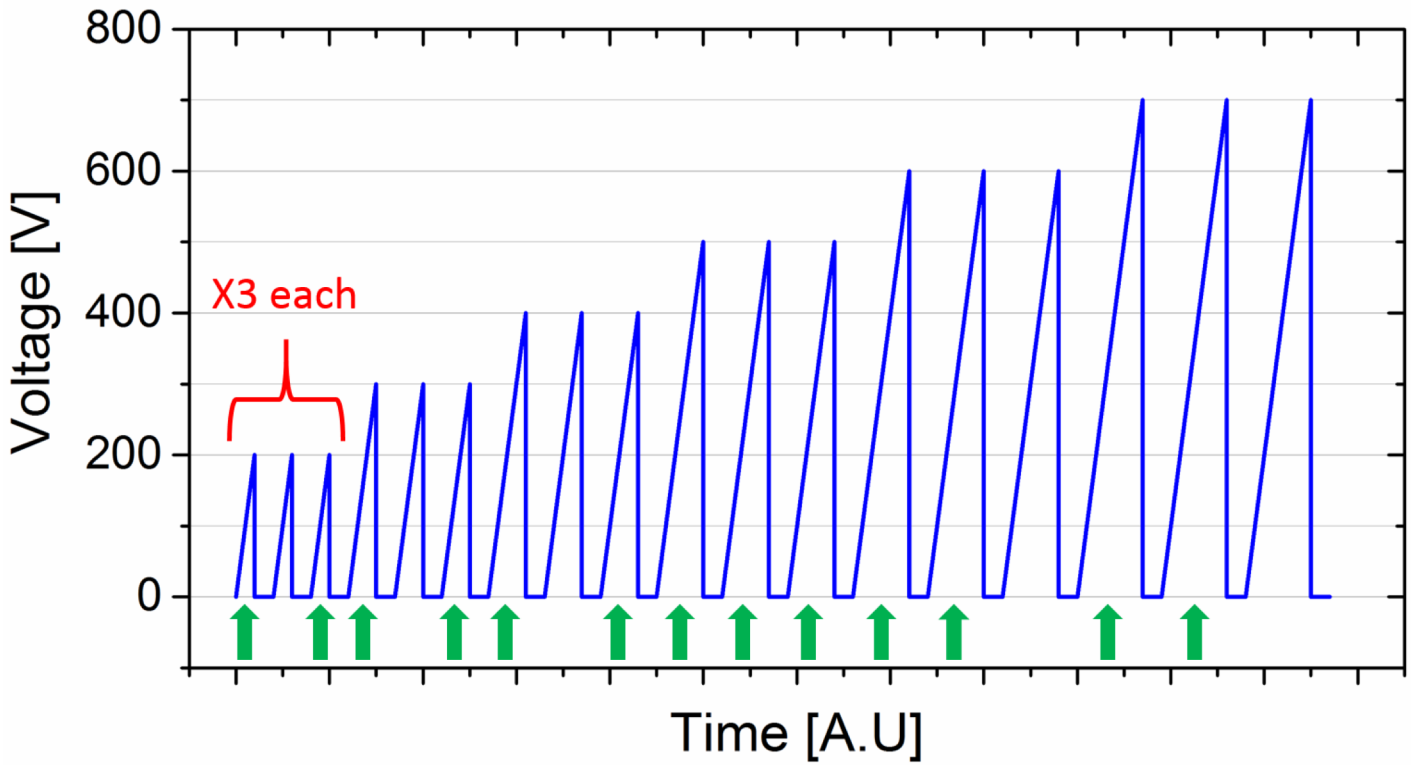
FGM I(V) characteristics

- Consecutive measurements:



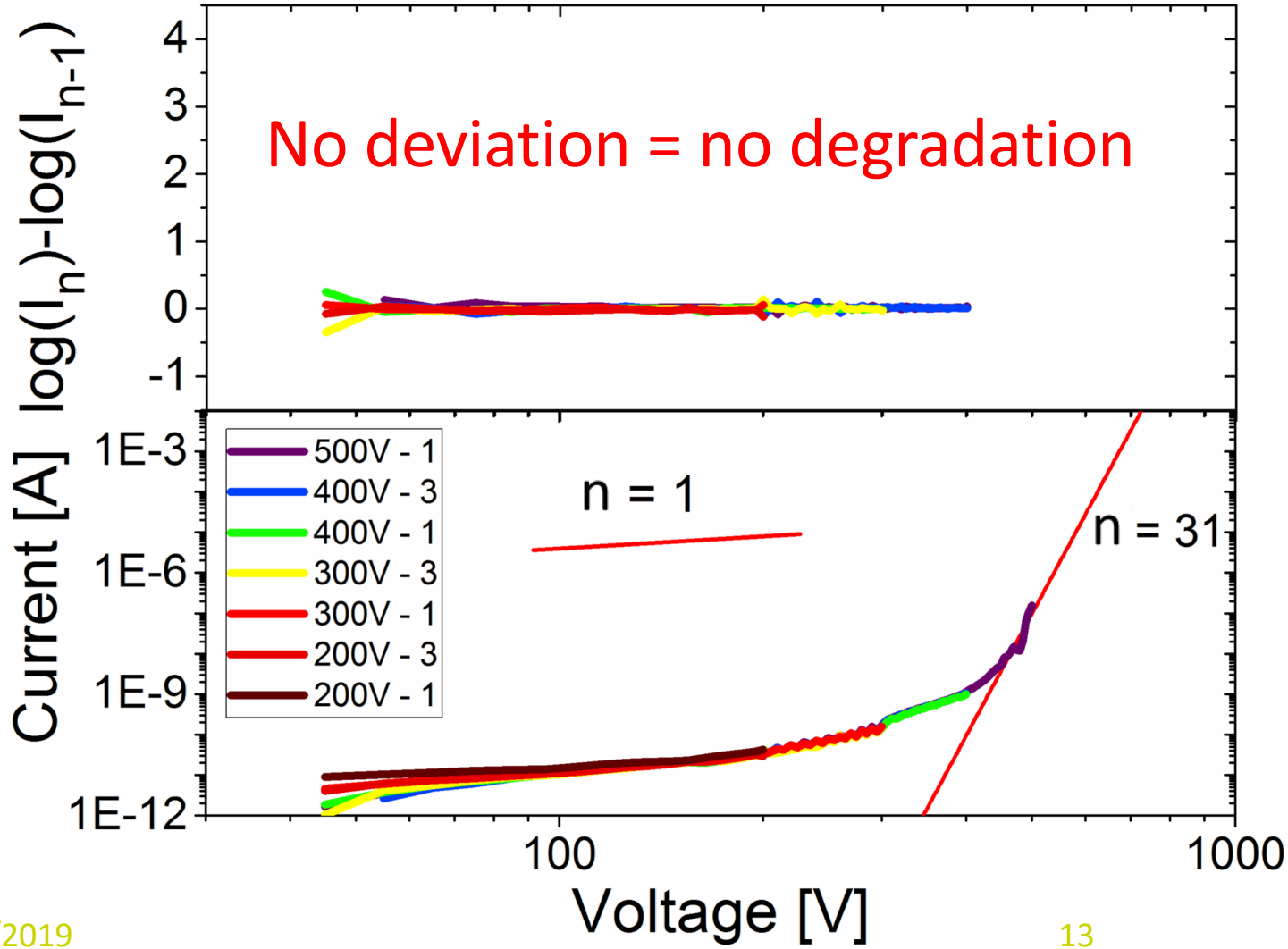
Understanding the degradation process

- Consecutive measurements: increasing voltage



I(V) under the degradation threshold

- Epoxy/ZnO 50 vol%



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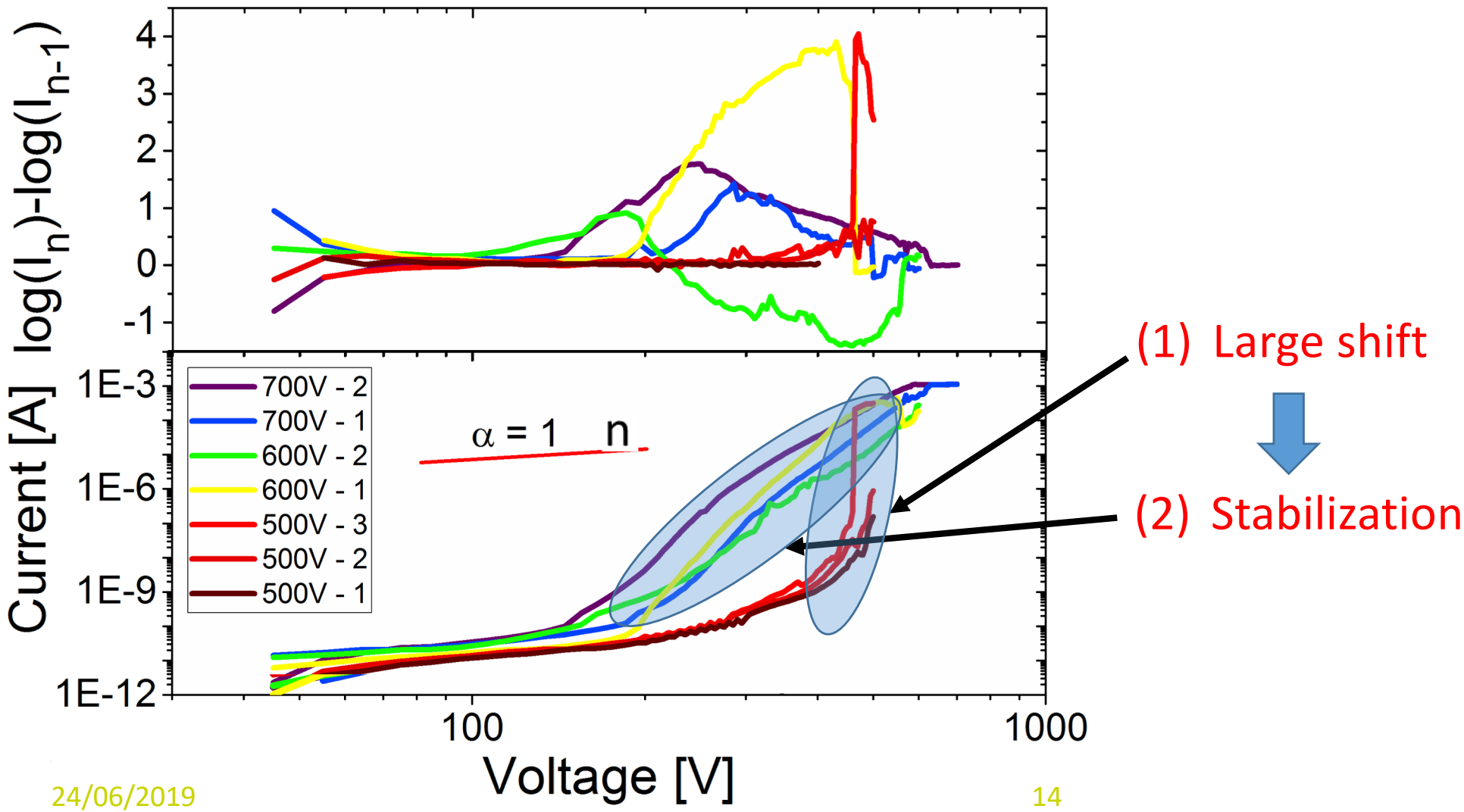
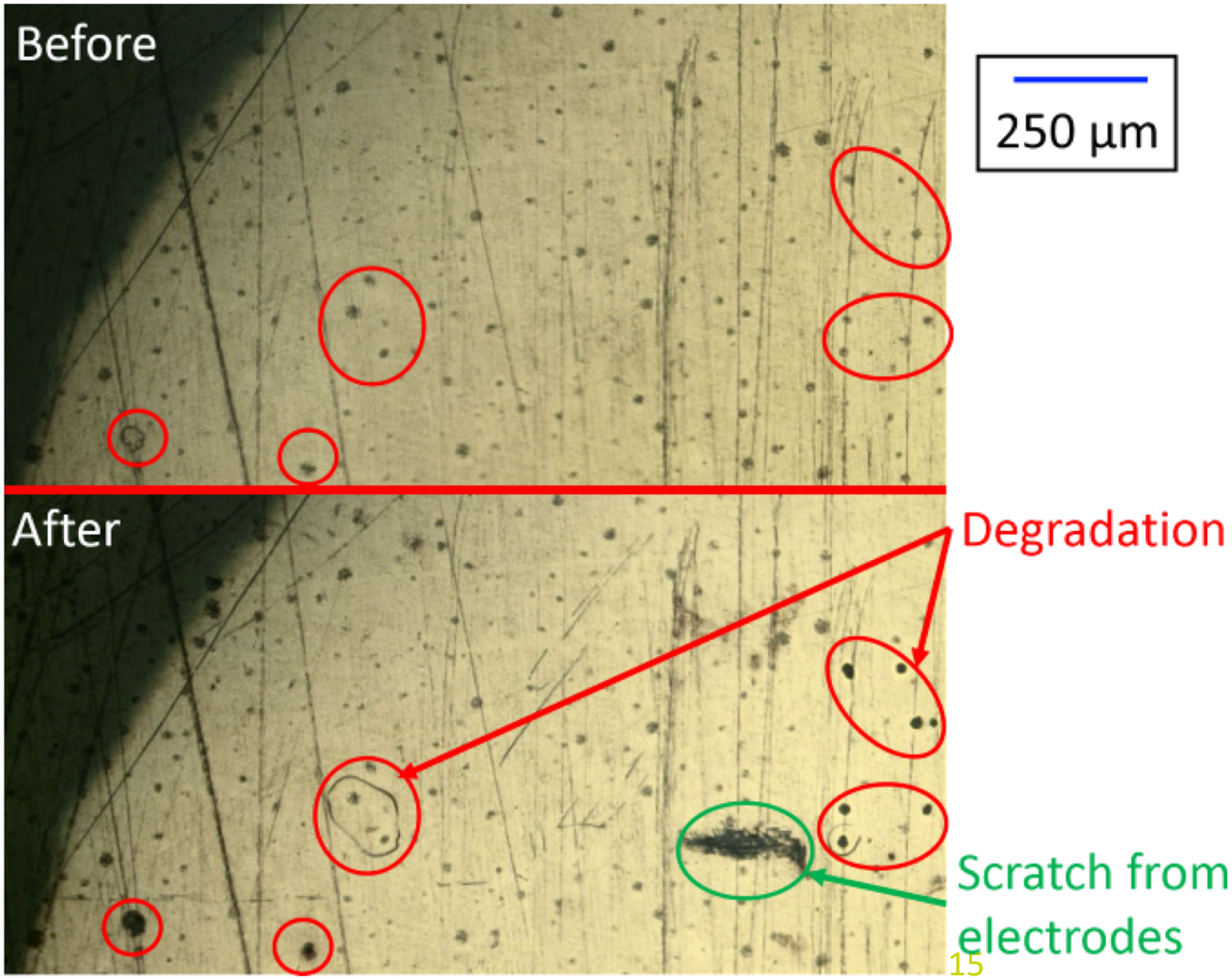


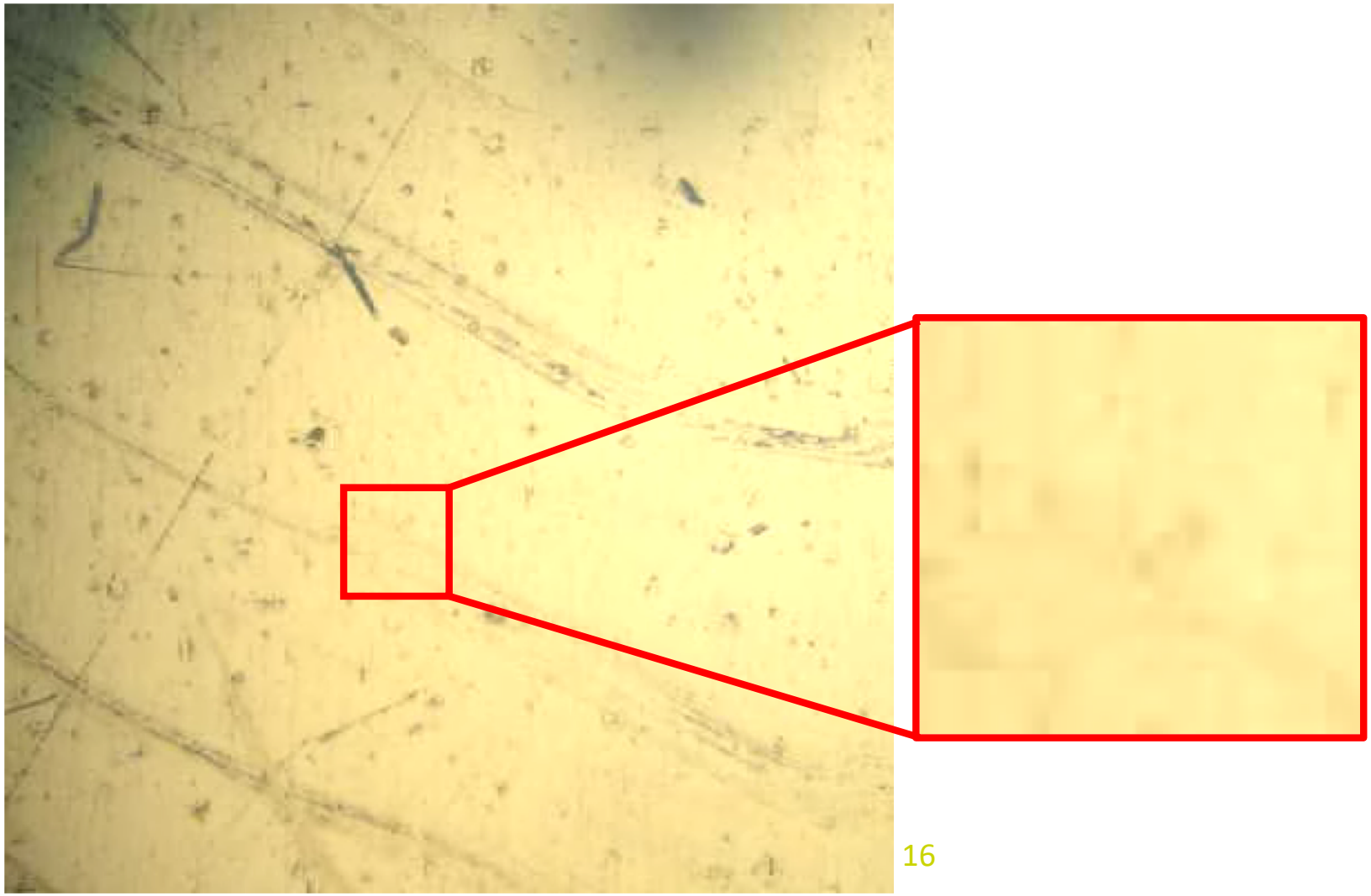
Degradation mechanism

- Optical microscopy of the composite surface



Degradation mechanism

- Online optical microscopy of the composite surface during voltage application



Proposed degradation mechanism

- Hypothesis:

(a) Voltage < $Vthresh_1$

(b) Voltage = $Vthresh_1$

J_{local} increase

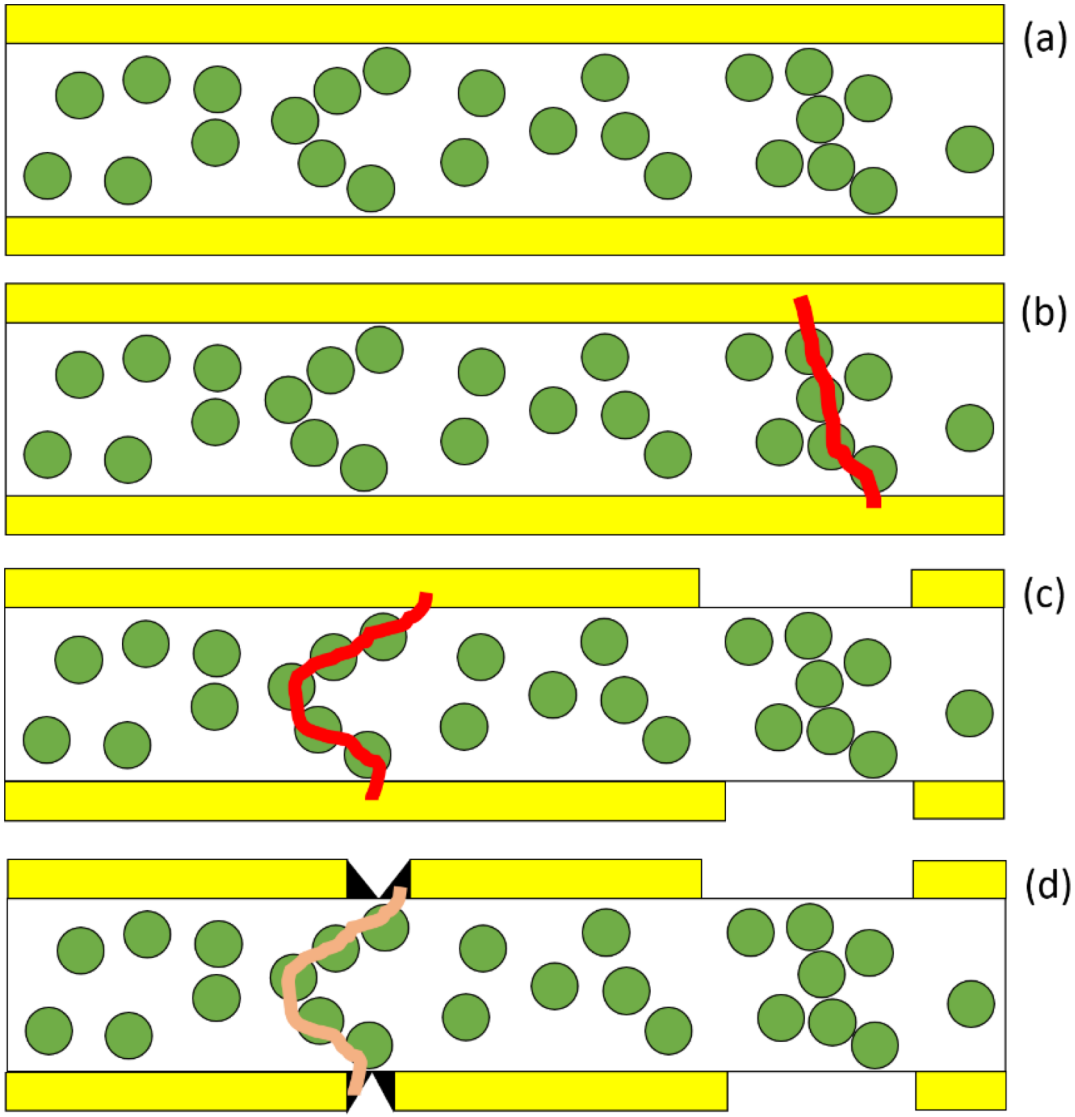
Self-healing of the « defect »

(c) Voltage = $Vthresh_2$

(d) Voltage> $Vthresh_2$

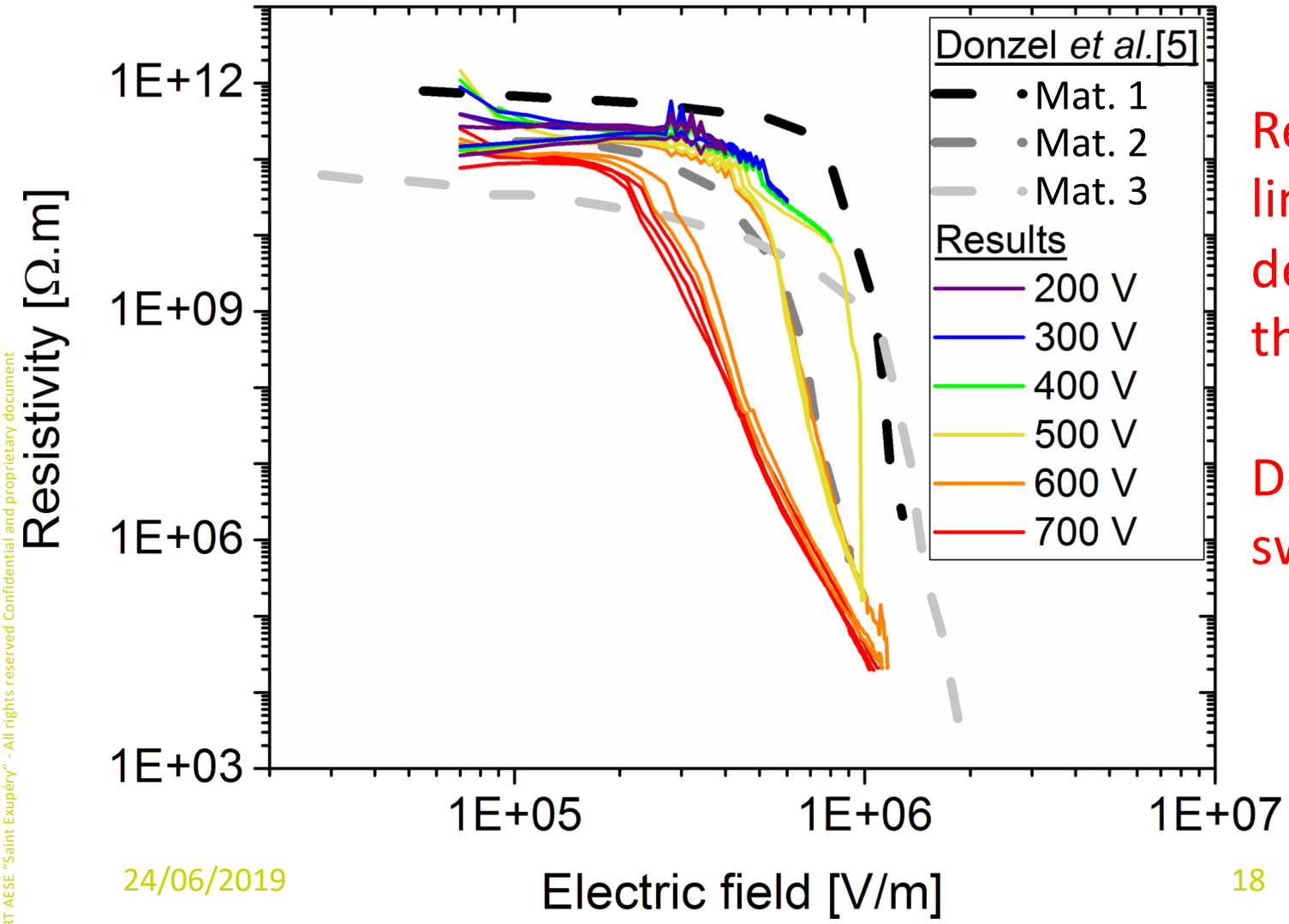
Partial self healing

Still participating to current increase



Impact on NRM properties

- Comparison with literature



Reduced non-linearity above the degradation threshold

Decrease of the switching field

Conclusion

- Large modification of the non-linear I(V) characteristics above the degradation threshold
- Impact of the electrode might not be negligeable for NRM characterisation
- Mandatory to perform successive characterization of such materials

Thank you for your attention