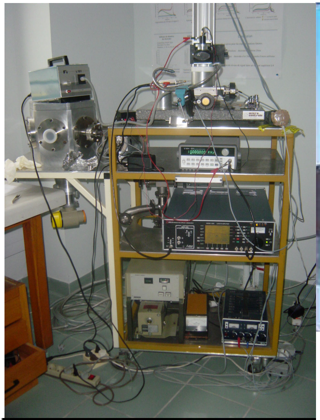
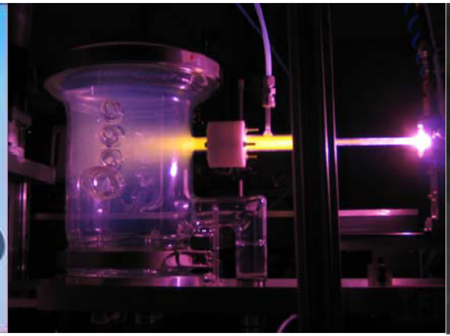
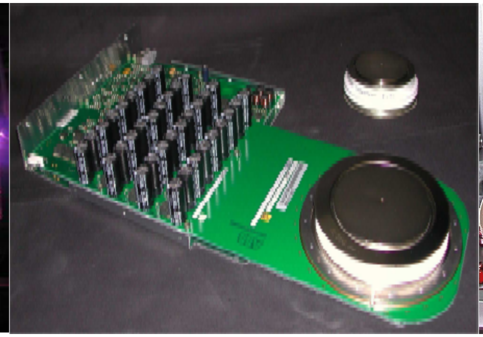
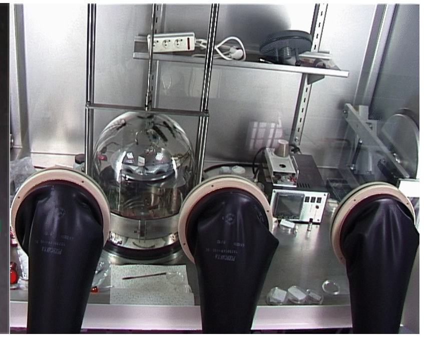
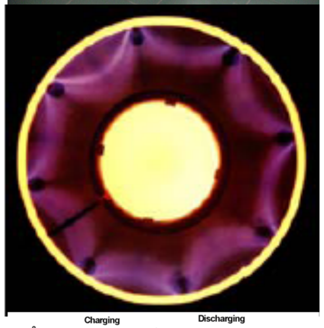
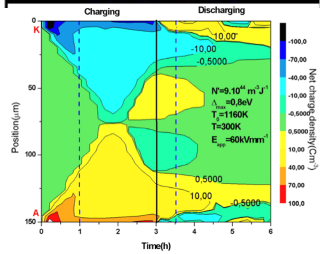


Electrical Polymeric Insulation for Power Electronics: Physical Limits and New Tailored Composite Design Concepts

Sombel Diaham
PhD, Associate Professor, University of Toulouse

24-26 April 2019 – Toulouse, France

Outline

- **Context of HV in power electronics and isolation issues**
  - Passivation of power devices
  - Encapsulation of power modules

- **Electrical degradation in polymers at HV**
  - Space charge
  - Breakdown

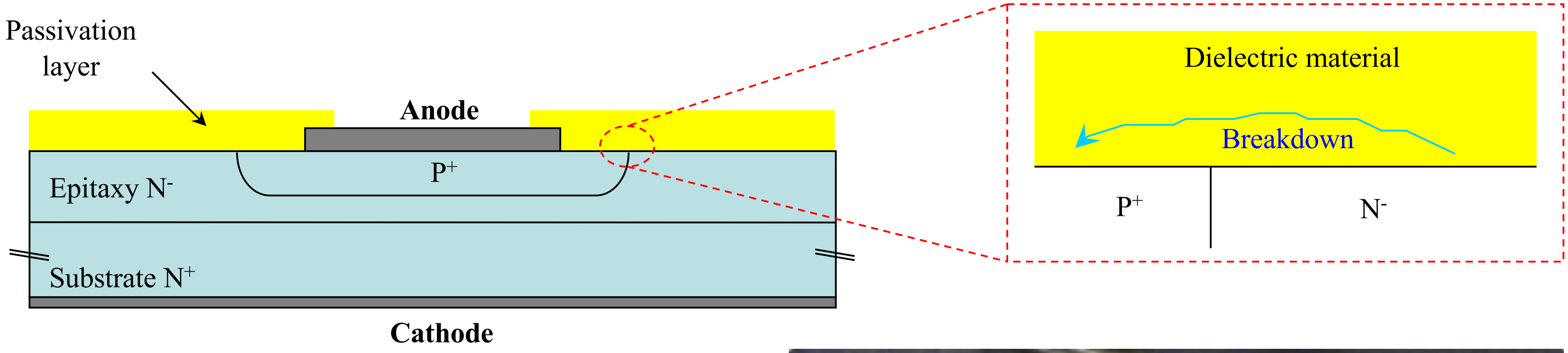
- **Polymer dielectric reinforcement using nanostructuration**
  - Polyimide-based nanocomposites
  - Epoxy-based nanocomposites

- **New field grading materials concepts using electrophoresis**
  - Epoxy-based composites with permittivity gradient

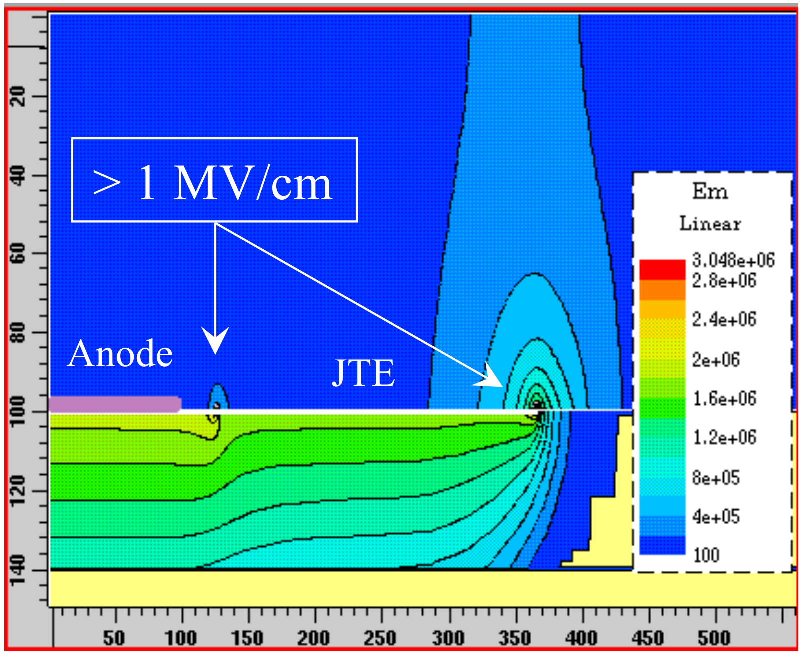
Context: Power conversion

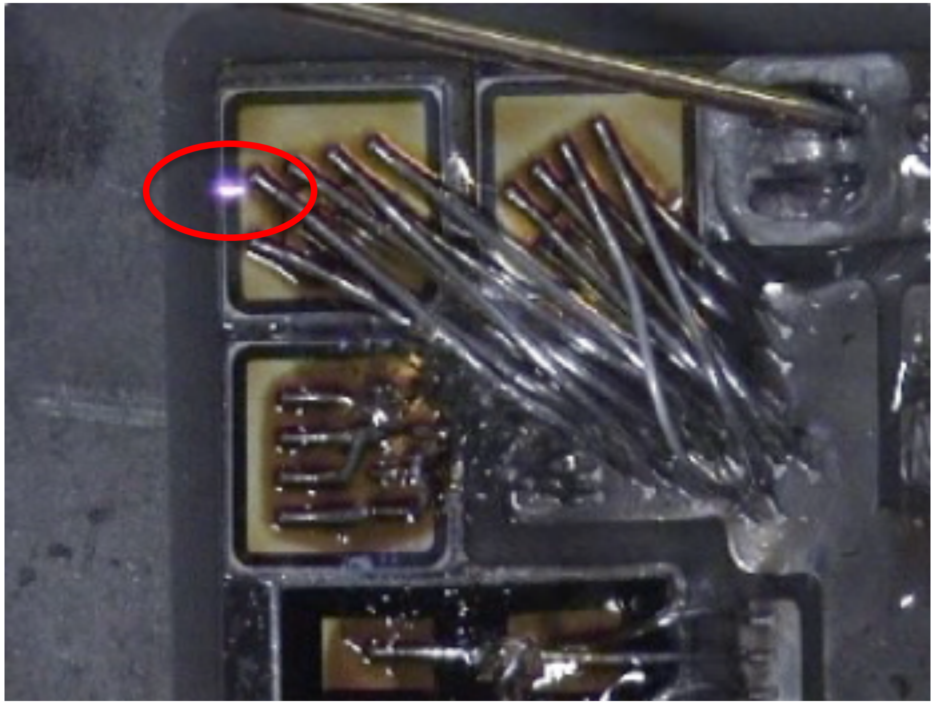
M.-L. Locatelli *et al.*, Proc. of EPE, 2003.

High field consequences on passivation:



Impact of SiC components on field:



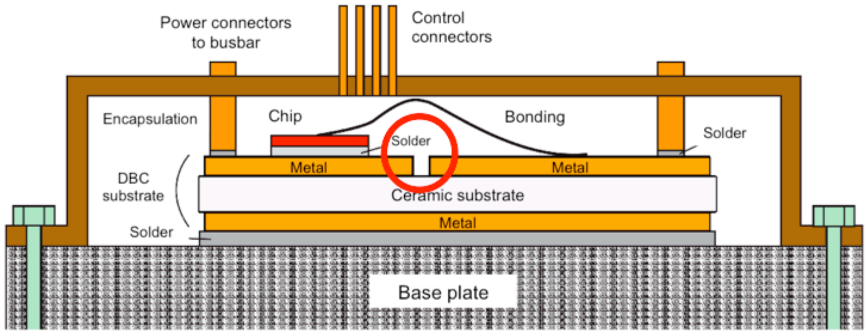


Flashover of the passivation

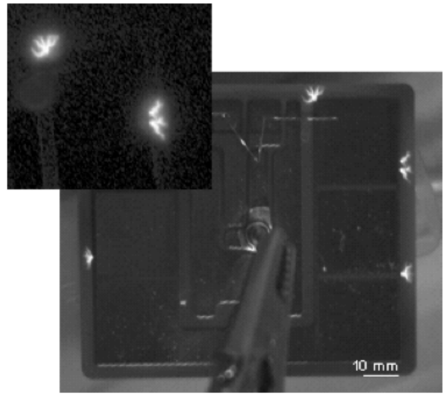
Context: Power conversion

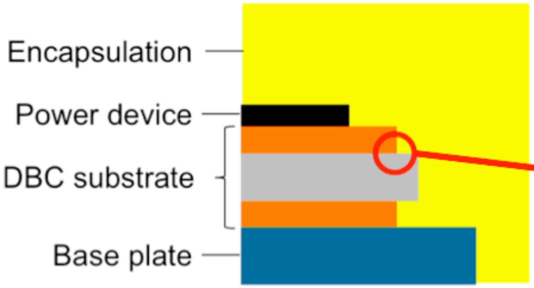
High field consequences on encapsulation:

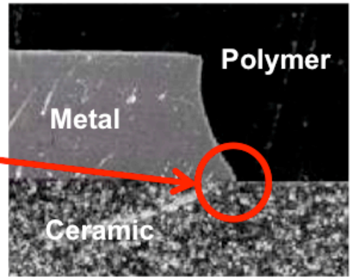
HV power module



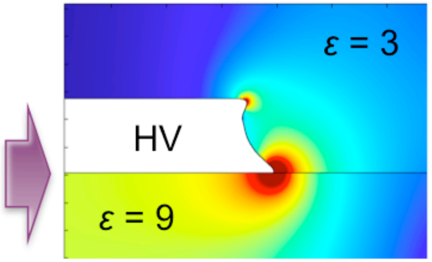
Fabian et al, Proc. IEEE IAC, 2005.





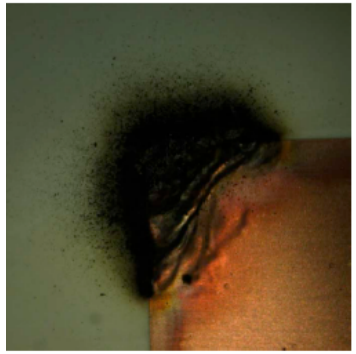


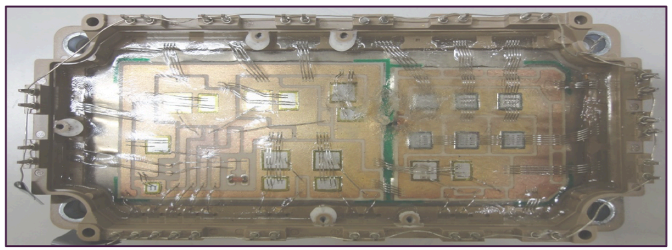
Triple point



Electric field reinforcement due to needle effects and permittivity difference

Z. Li et al., IEEE TDEI, 2010.





At the ‘triple point’:

→ Field reinforcement due to the **tip geometry** and **permittivity difference**

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Electrical degradation in polymers

General scheme

Aging due to charges or to electric field

No cavity

Degradation reaction – molecular scale
Space charge
Hot carrier injection, recombination

Nano-voids

Growth of vacuoles
Electrostatic forces due to charges
Charge mean free path increase
Solid-gas interface

Microcavities

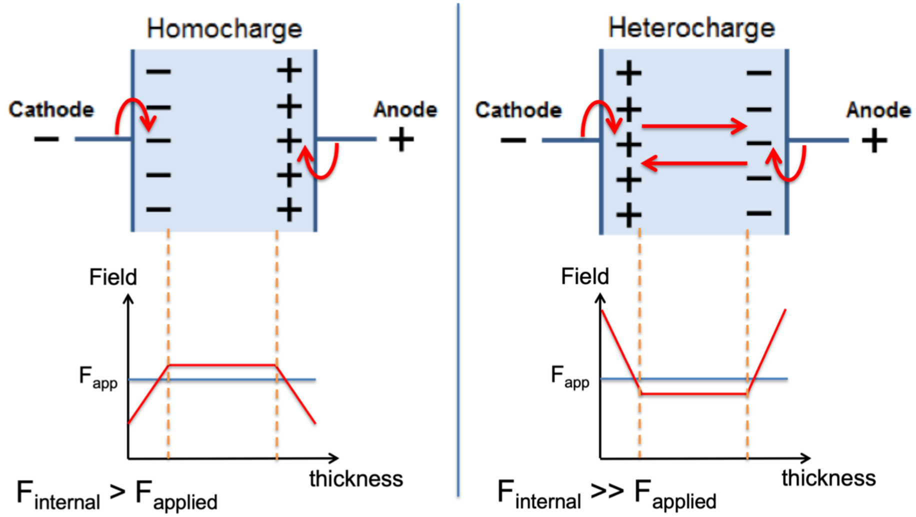
Degradations induced by discharges

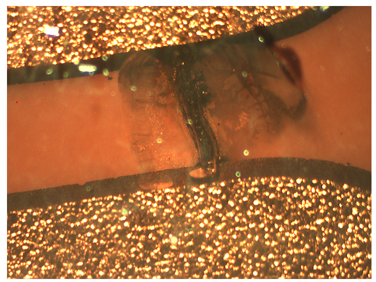
Cavity surface erosion by PD
Chemical degradation due to discharges
UV, reactive species, charges
Thermal effects, …

Treeing

Propagation
Plasma energetic species
Erosion of the dielectric
Electromechanical forces

Breakdown



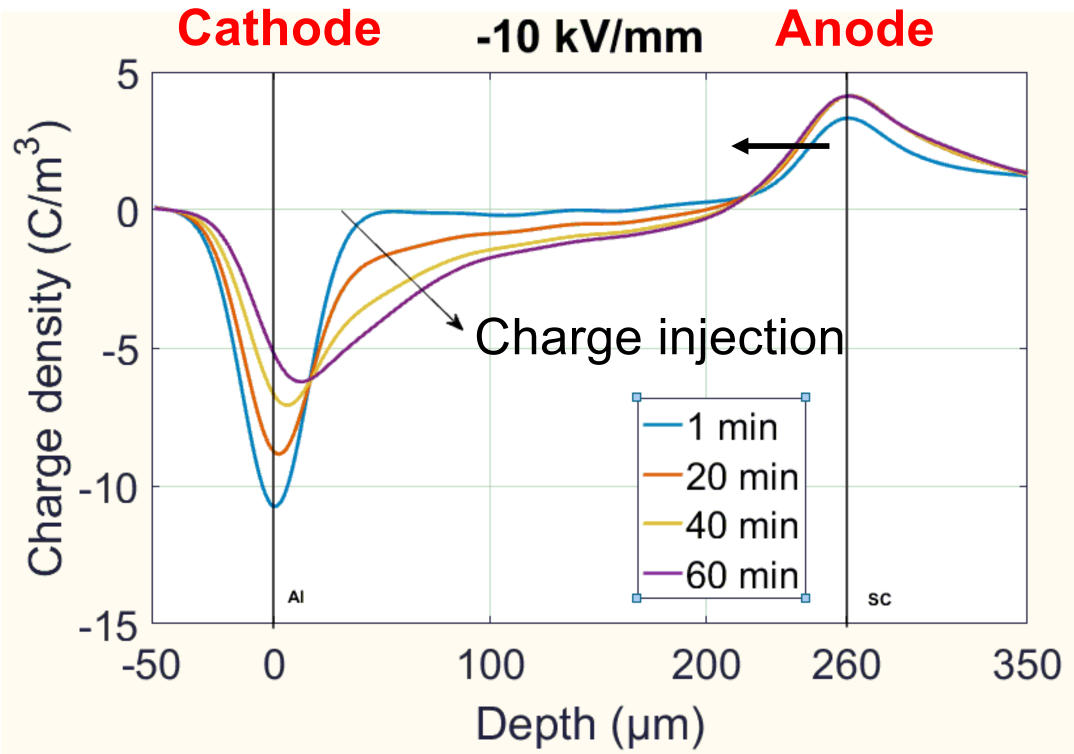


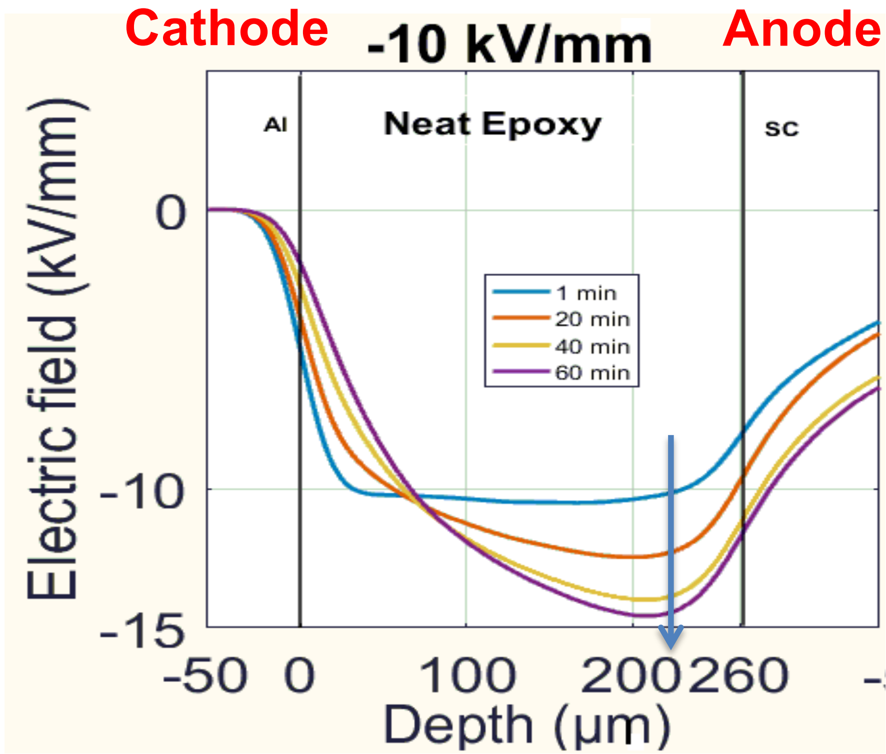
Field reinforcement → Partial discharges → Aging by erosion → Breakdown

Space charge in epoxy

Albani, Master thesis, Laplace, 2018.

PEA method under DC voltage:





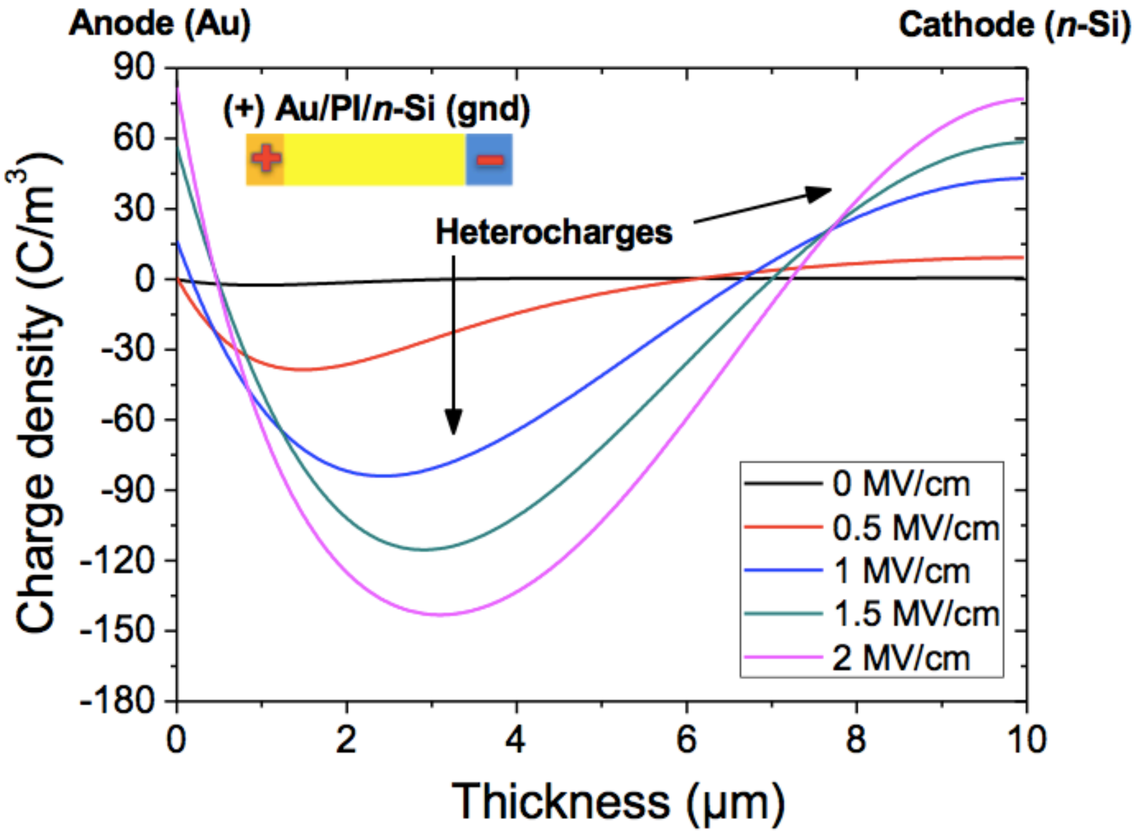
Injection of electrons from the cathode

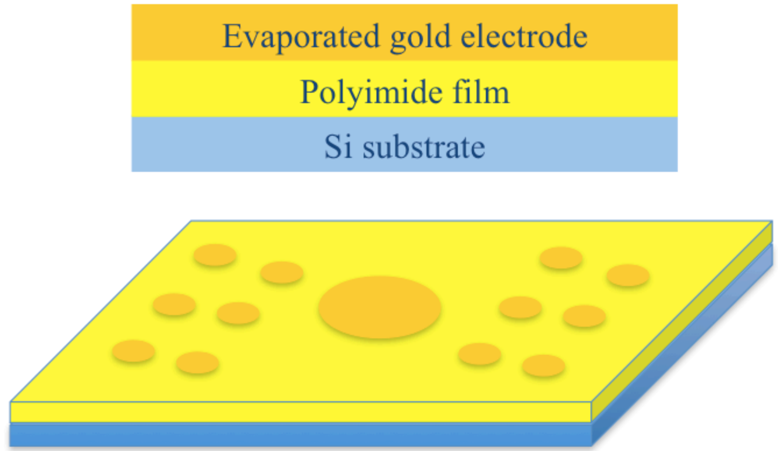
→ Reinforcement of internal field

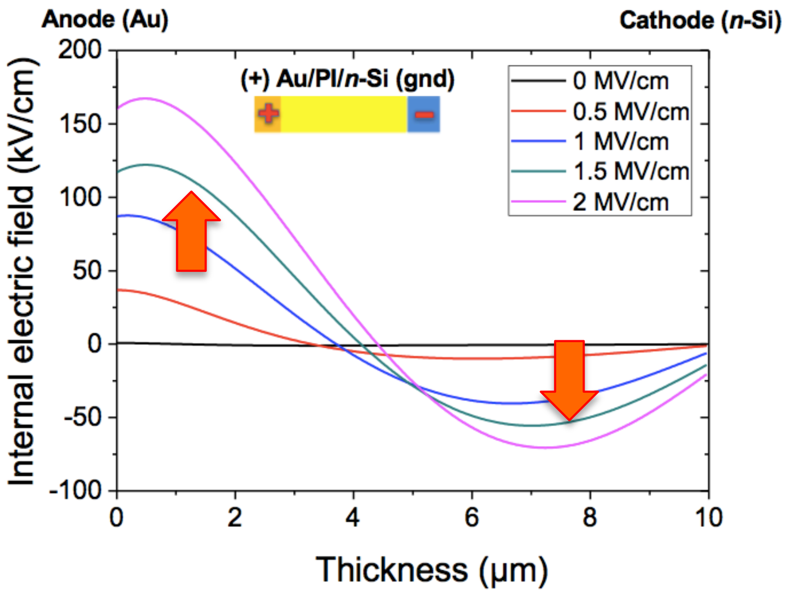
Space charge in polyimide

C.D. Pham et al., Proc. CEIDP, 2011.
M.-L. Locatelli et al., IEEE TDEI, 2017.

LIMM method under short circuit:







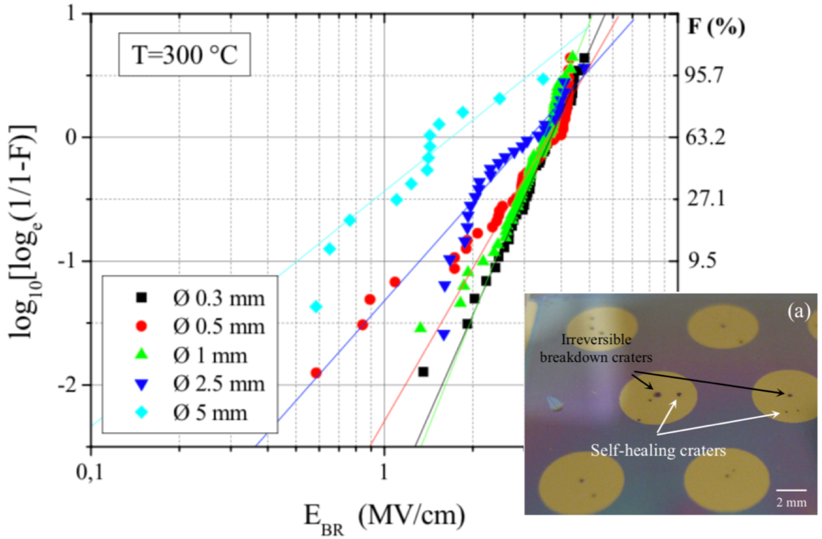
Injection and formation of heterocharges at 'metal / PI' interfaces

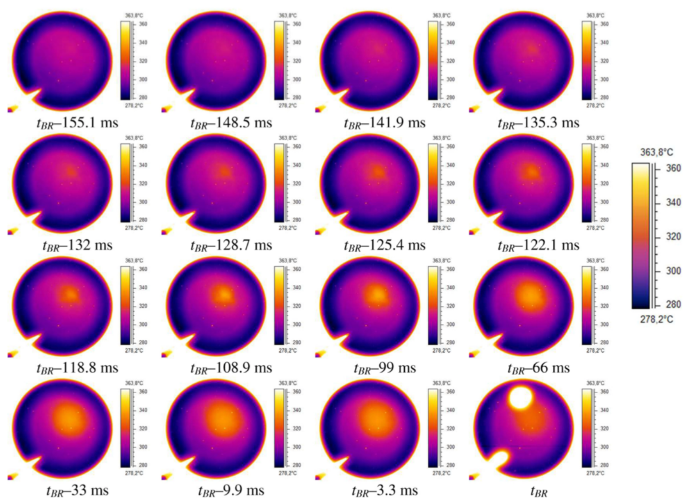
→ Reinforcement of internal field

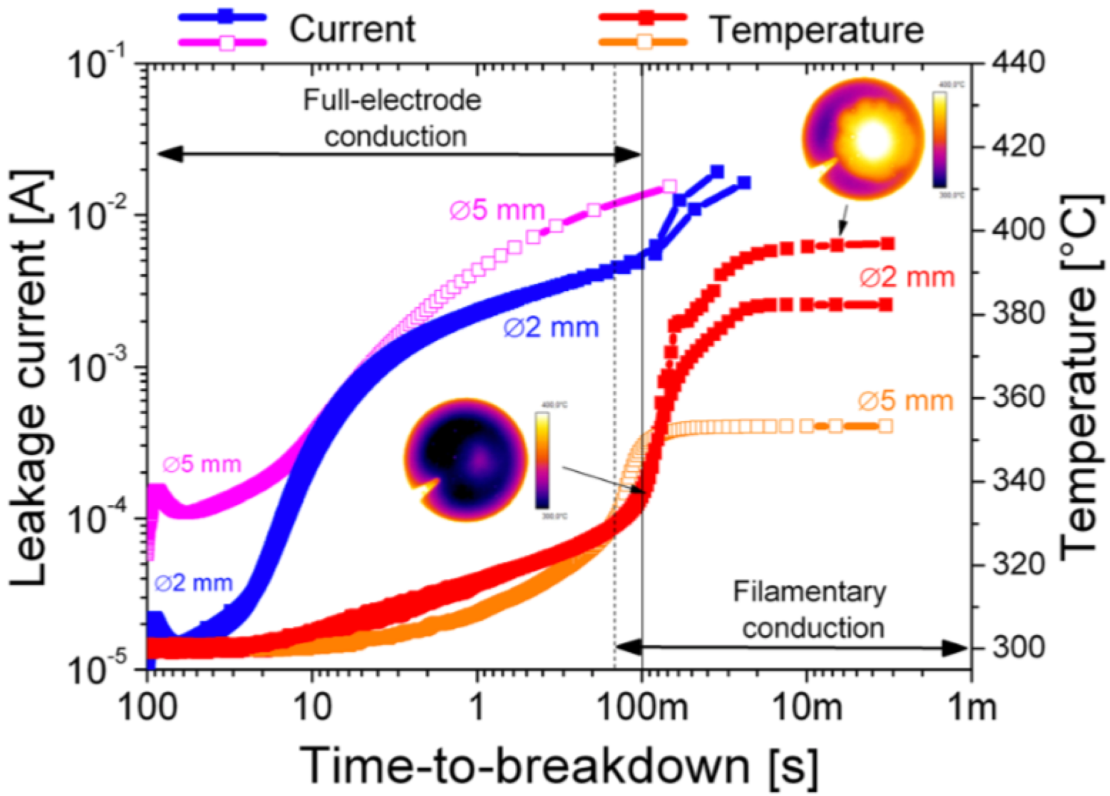
Breakdown mechanism

Diaham *et al*, IEEE TDEI, 2010.
Diaham *et al*, Appl. Phys. Lett., 2017.

Thermal breakdown in polyimide :







Thermal runaway from a threshold field > 1 MV/cm

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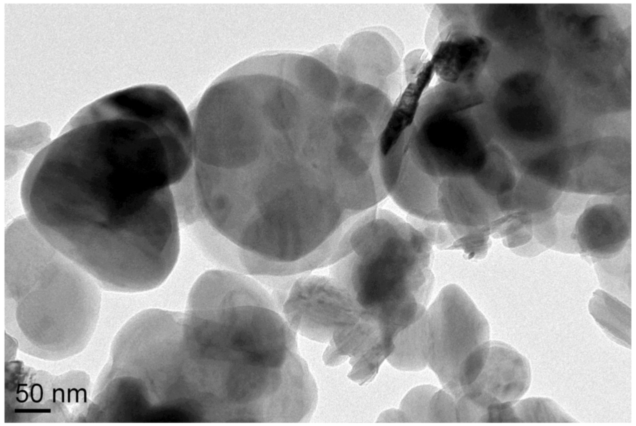
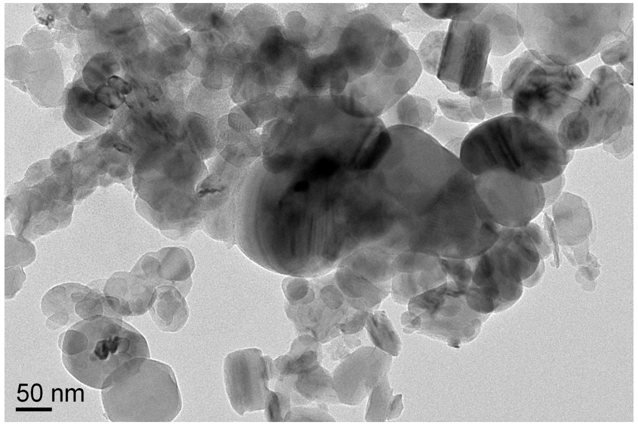
Nitride nanoparticles

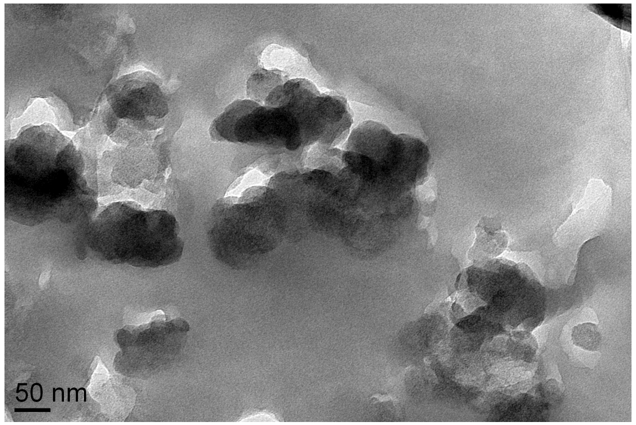
Boron nitride (BN)



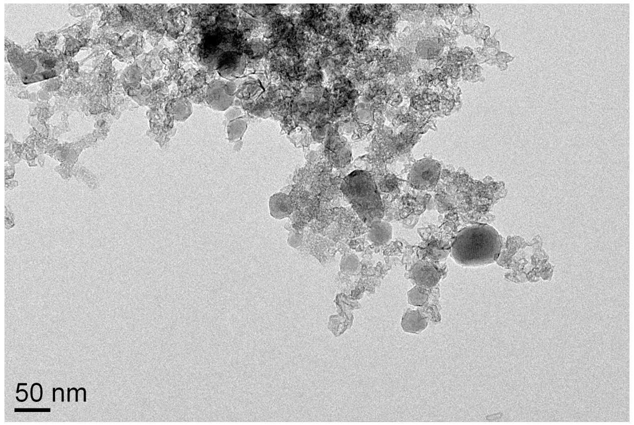
***h*-BN (120 nm)**



***h*-BN (60-100 nm)**

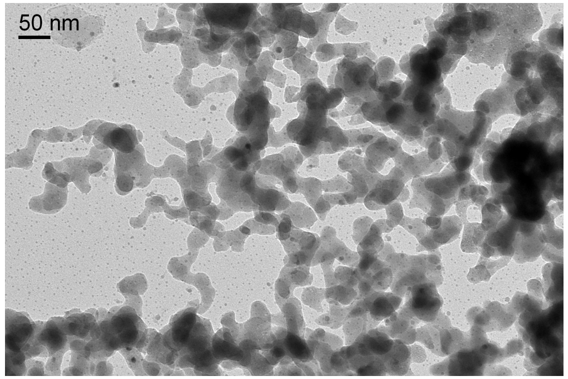


***t*-BN (95 nm)**



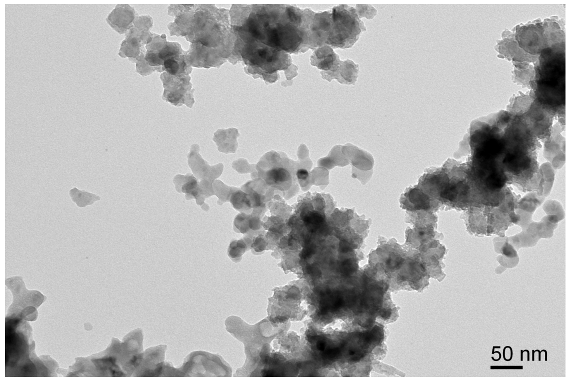
***w*-BN (35 nm)**

Silicon nitride (Si_3N_4)



20 nm

Aluminum nitride (AlN)



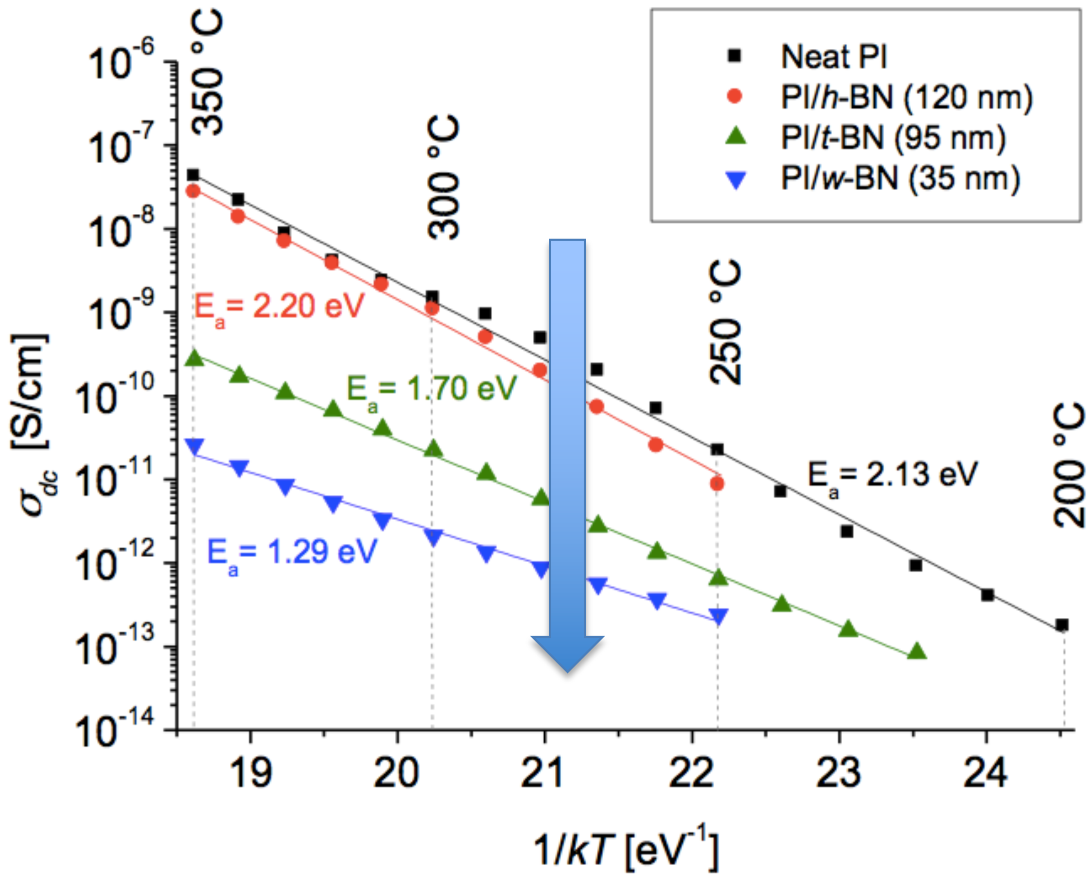
40 nm

DC conductivity

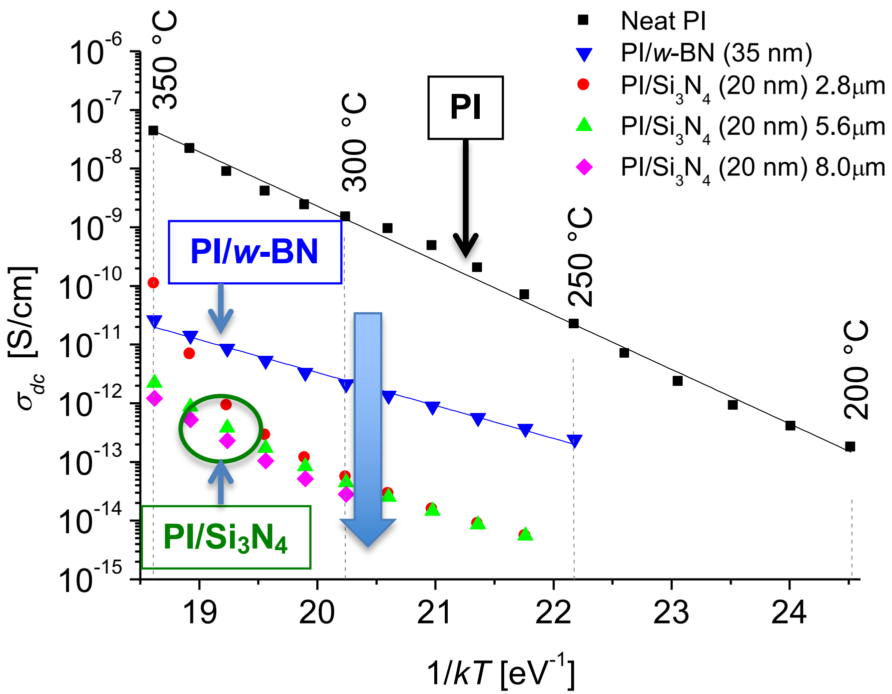
Diaham et al, J. Phys. D.: Appl. Phys., 2015.
Diaham et al, Proc. IEEE NMDC, 2017.

Polyimide-based nanocomposites:

Nanoparticules BN



Nanoparticules Si_3N_4

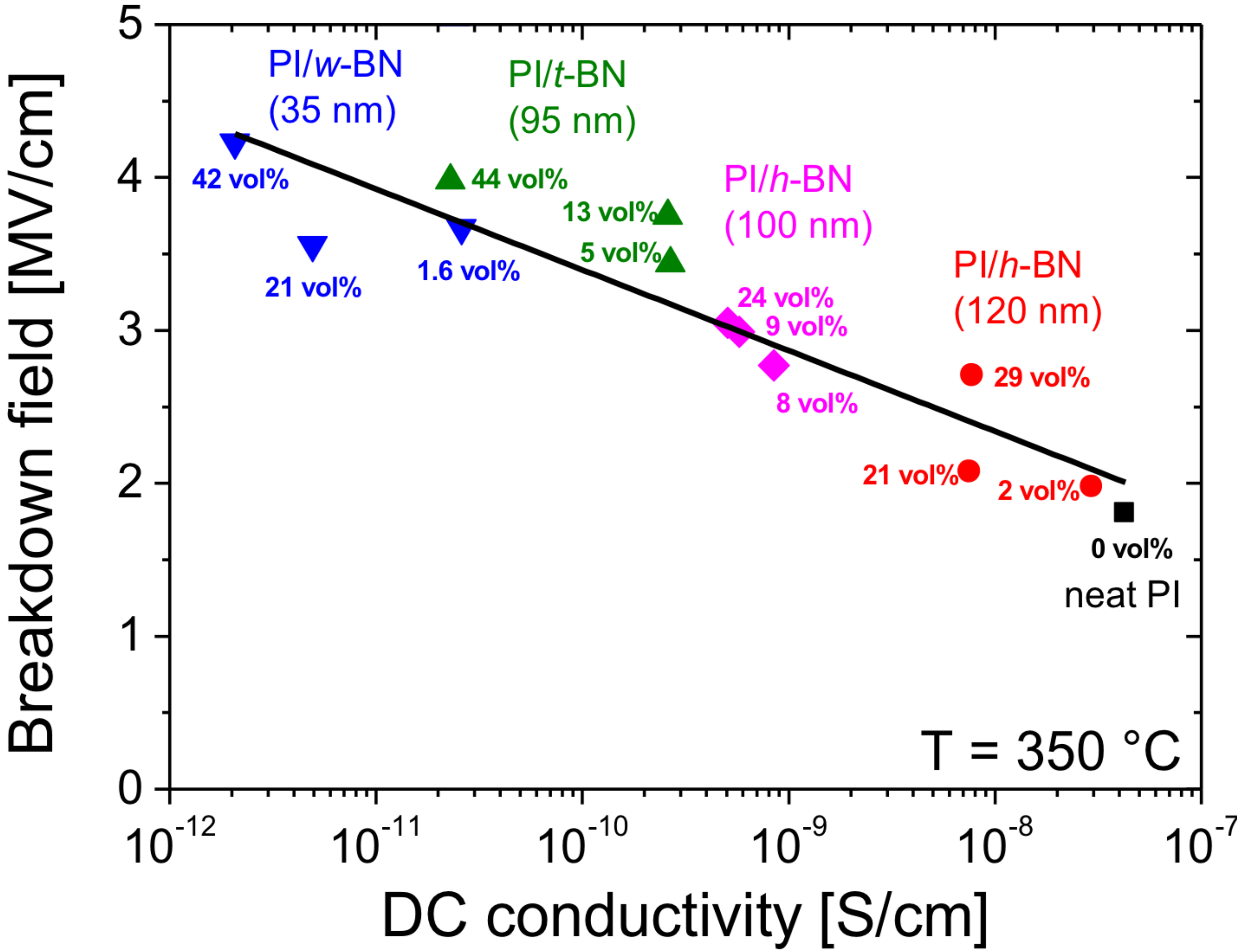


Decrease of E_{act} → Changing in the conduction mechanism with small BN
Smaller Si_3N_4 allows decreasing down to 2 orders of magnitude more

DC breakdown

Diaham et al, IEEE TDEI, 2019.

Relation between 'breakdown/conductivity':

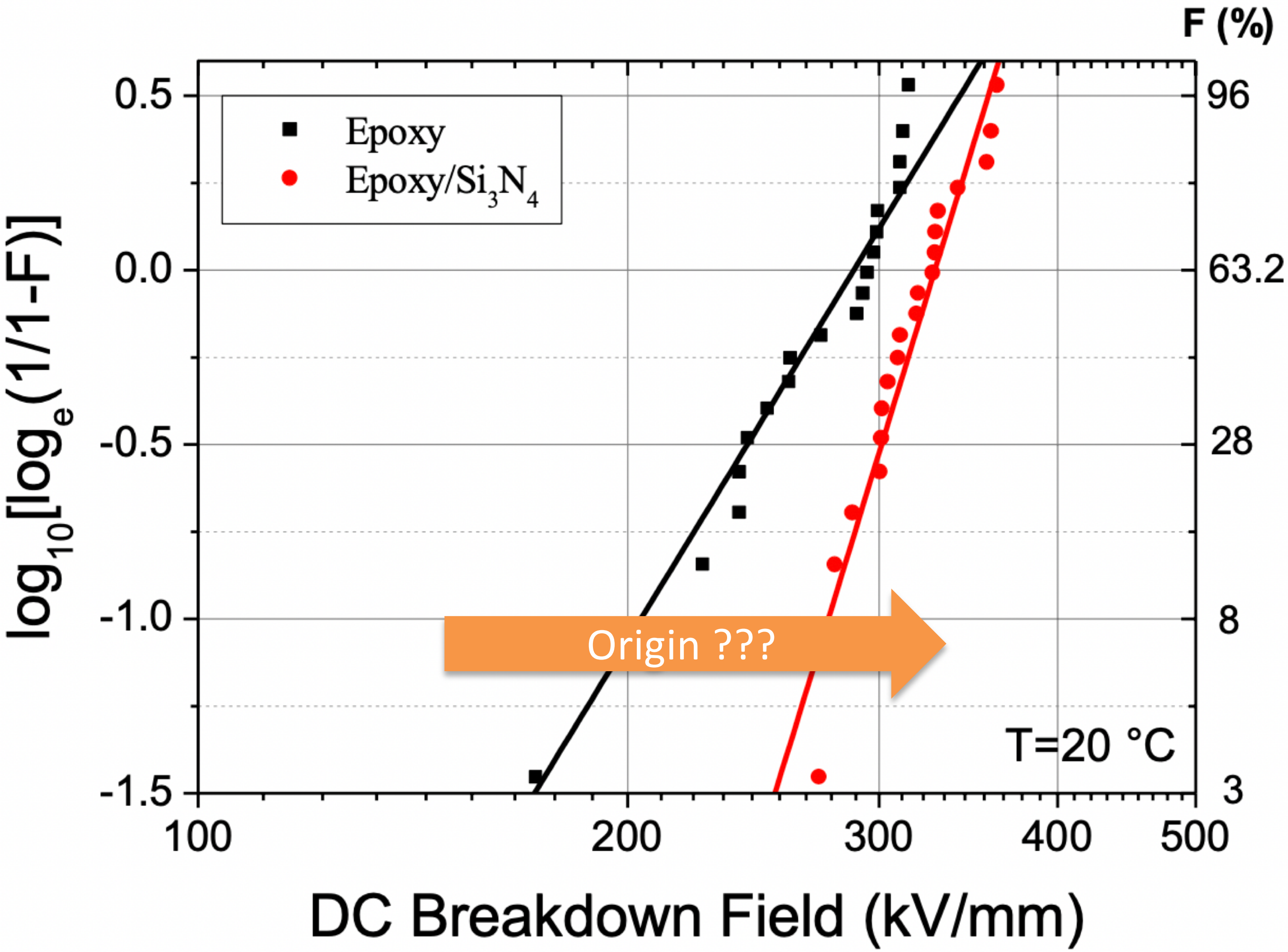


Breakdown field improvement with decreasing conductivity

Epoxy nanocomposites

Albani, Master thesis, Laplace, 2018.

Weibull statistics of breakdown:



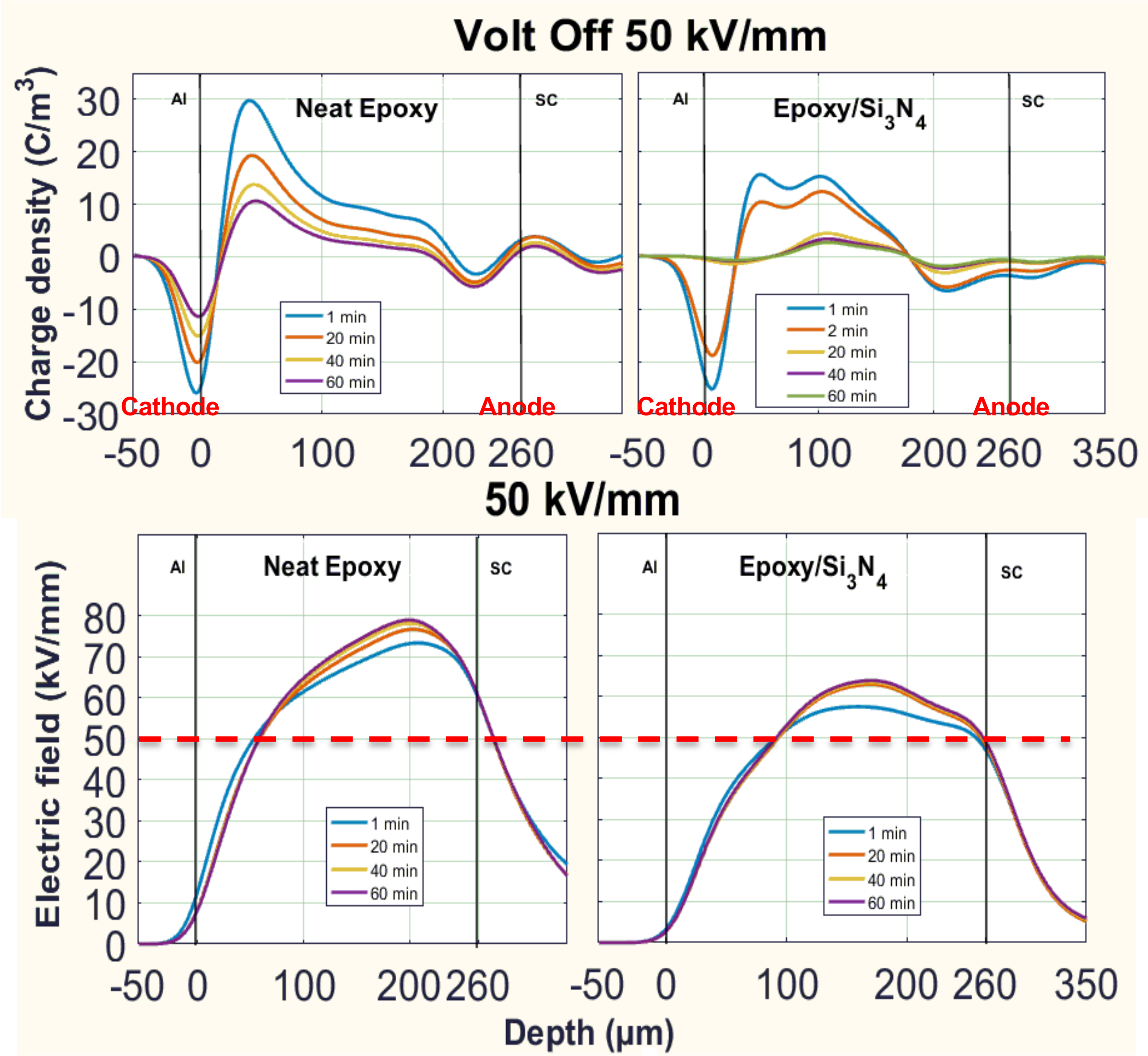
Significant improvement of the dielectric strength with NPs

Epoxy nanocomposites

Albani, Master thesis, Laplace, 2018.

Space charge/internal field:

Heterocharge formation



Lower internal field in nanocomposites compared to neat epoxy

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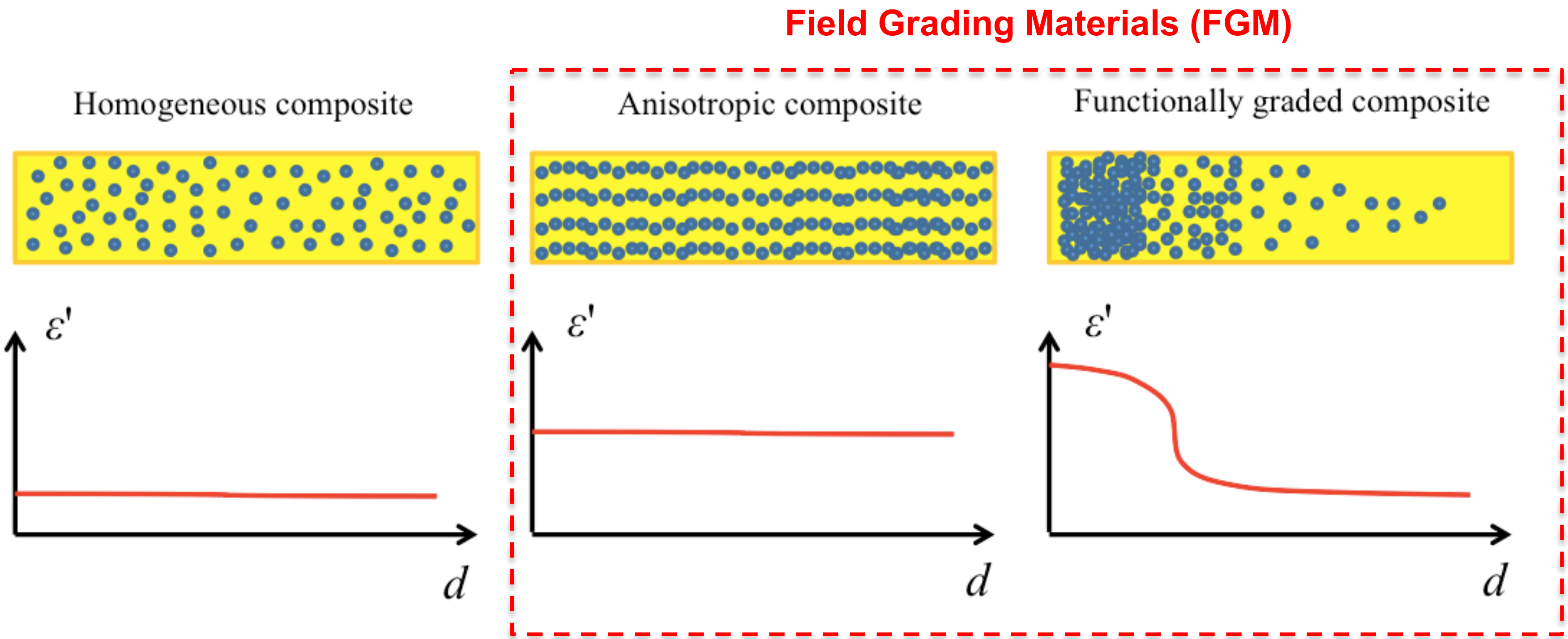
New field grading material concepts

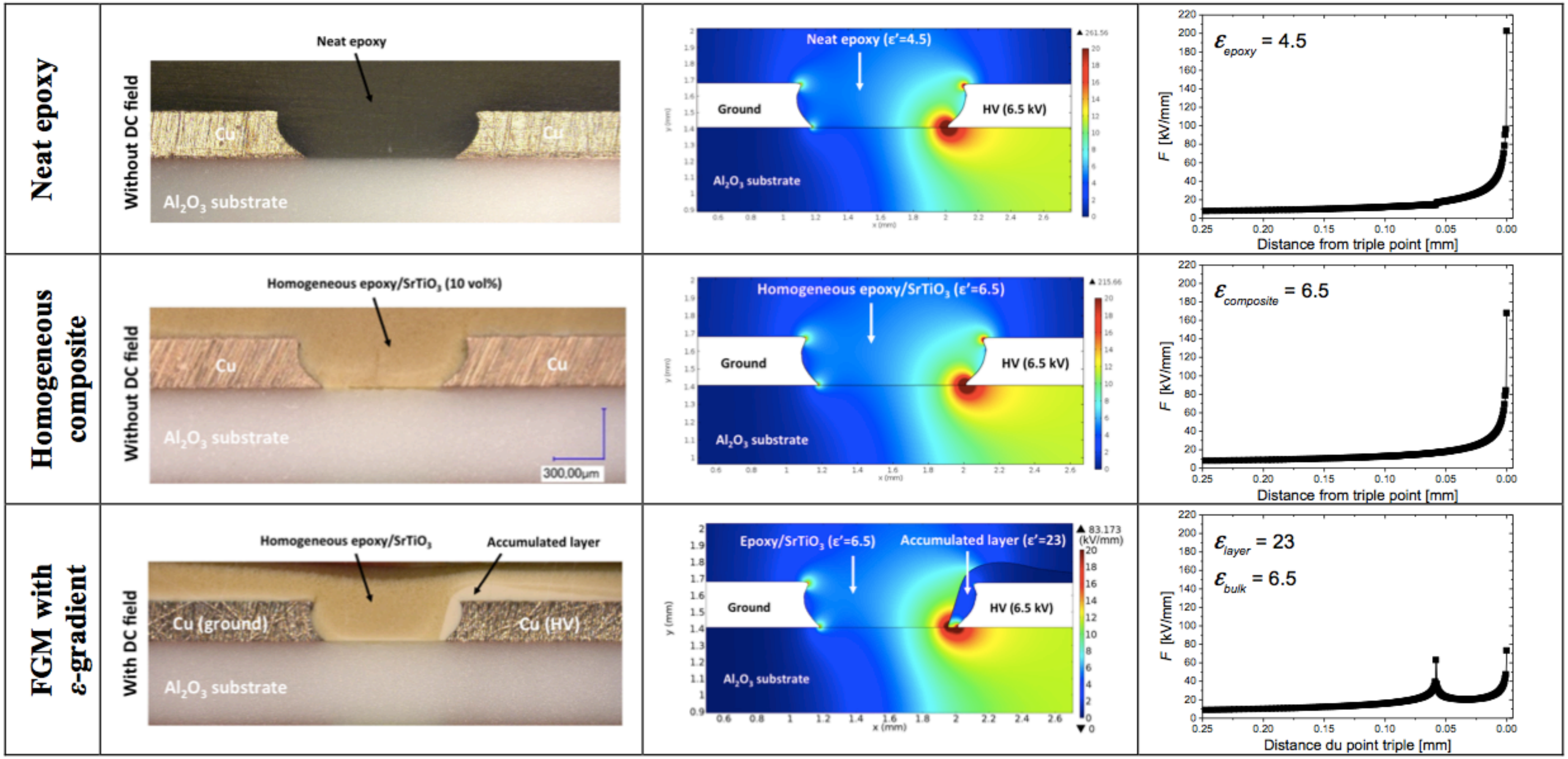
(Di)electrophoresis composite tailoring:



Application to field grading in power modules

Diaham et al, Proc. ICD, 2018.

FEM modelling of field grading efficiency

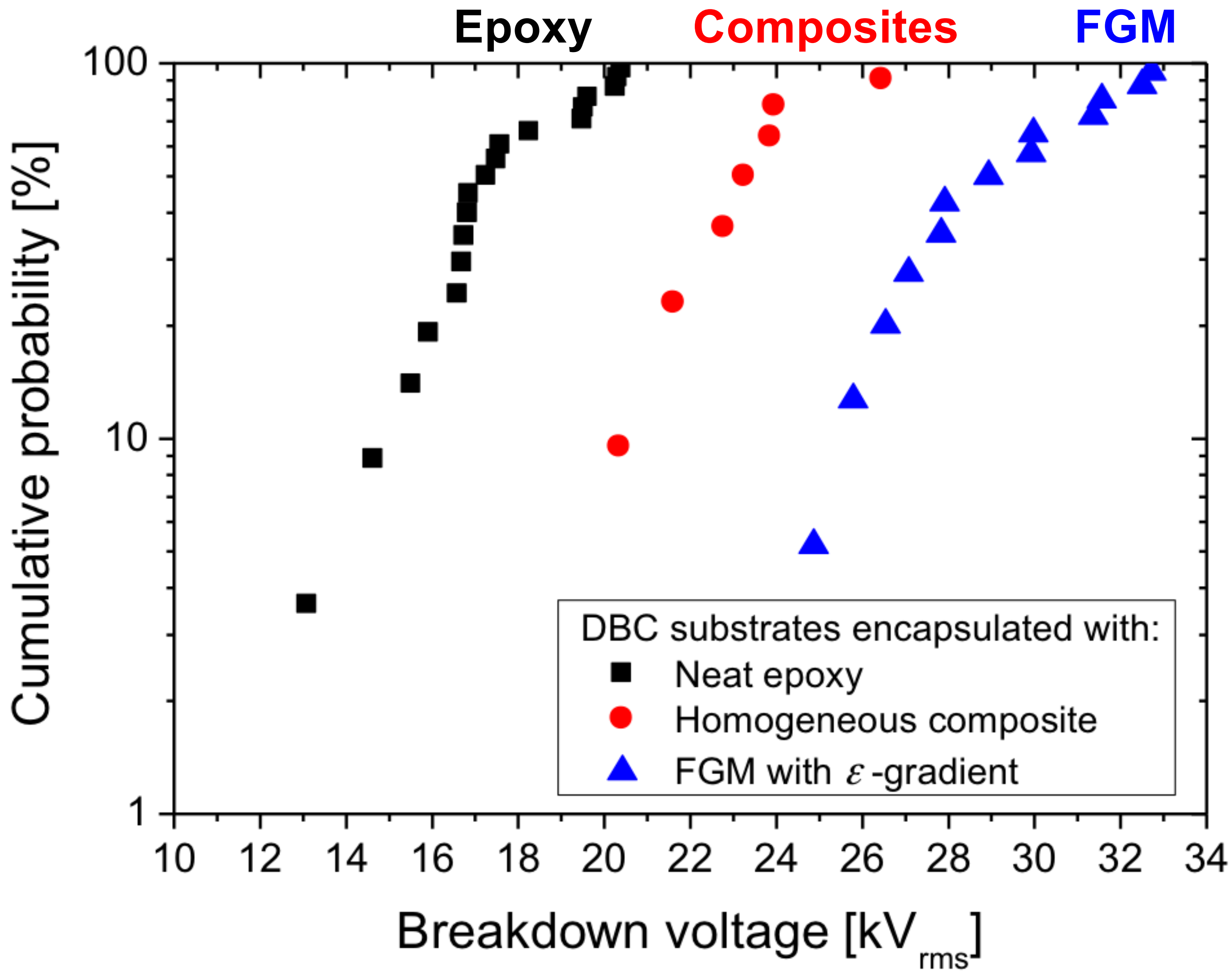


Up to 60% of attenuation of the maximum field for FGM

Application to field grading in power modules

Diaham et al, Proc. ICD, 2018.

AC breakdown voltage



Breakdown voltage is twice higher for FGM compared to neat epoxy

However no bulk BD of the FGM → Validation of field grading efficiency

Conclusion

- **New applications in PE → Trend towards higher working voltage**
- **Thermosetting polymers interesting … but some electrical limitations**
- **Charge injection and space charge formation → Field distortion / Degradation**
- **Polymer-based nanocomposites → Way to improve the dielectric properties**
- **Innovative FGM composite concepts tailored by electrophoresis**

  → In-situ tailoring of FGM with auto-adaptative ε'-gradient

  → FGM efficiency paves the way of a new field grading approach
- **Such material improvements will afford better HV system performances and reliability**

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Cong-Duc Pham, Post-Doc (2010-2013)
Louis Lévêque, PhD Thesis (2013-2016)
Guillaume Belijar, PhD and Master Thesis (2013-2016)
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