Ceramic Substrates with Silicone Gel or Liquids: Dielectric properties

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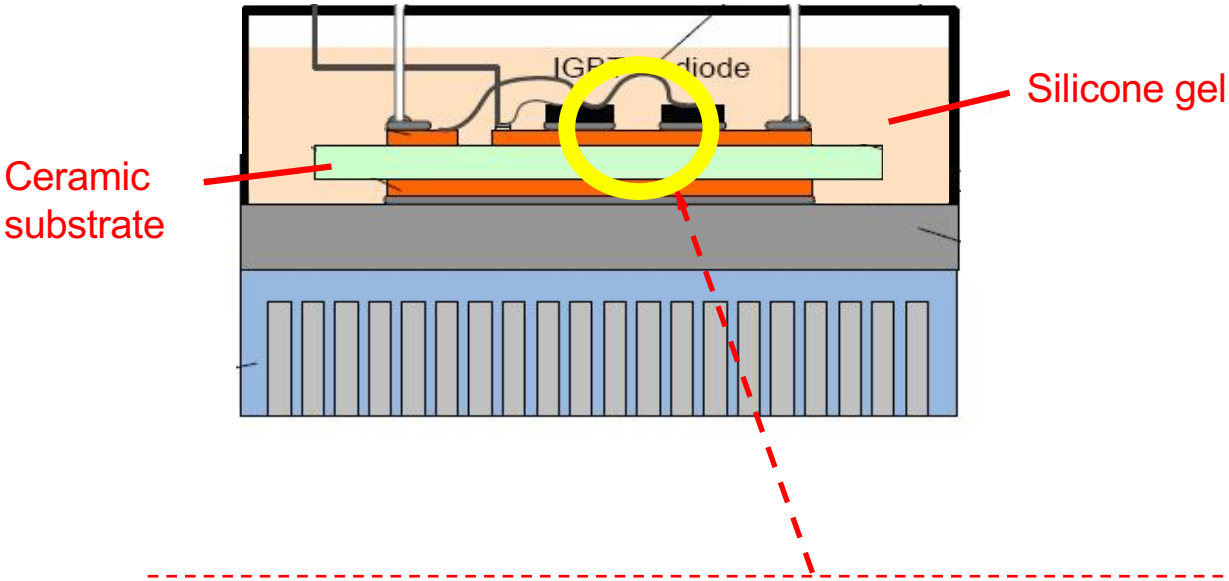
Outline

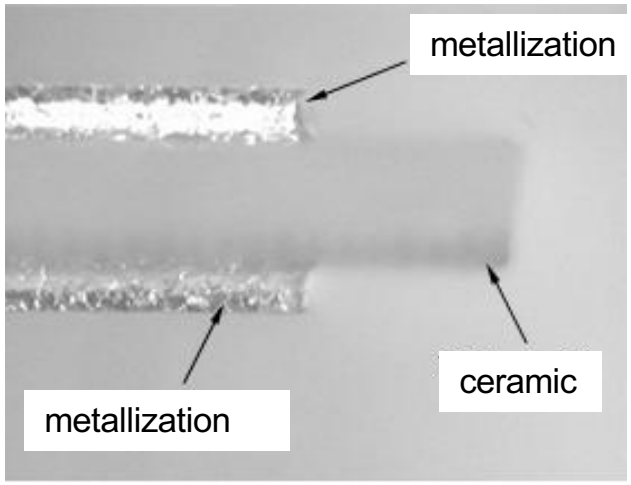
IGBT module

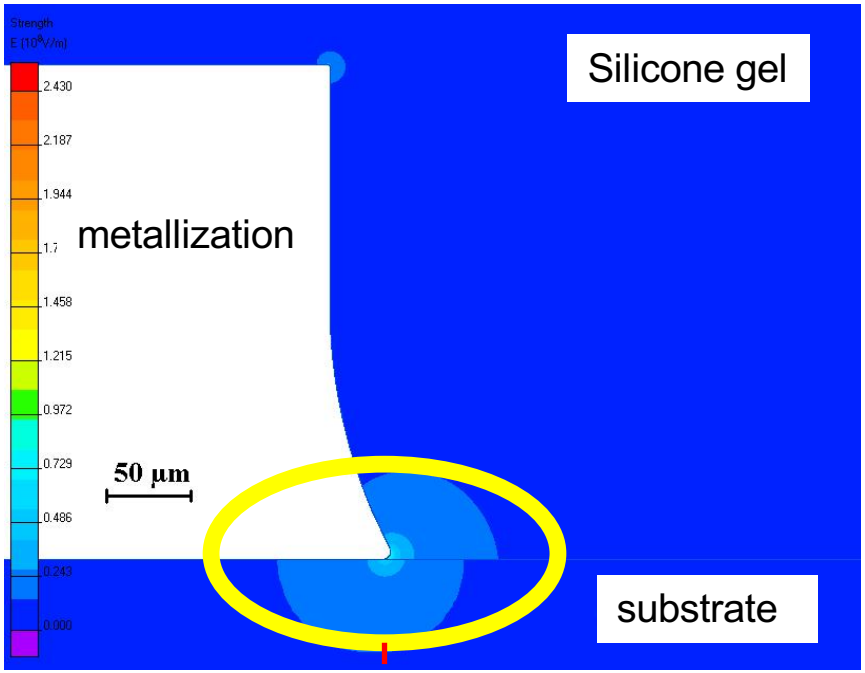


High field region: triple points

- ✓ **partial discharges ? origin ?**
- ✓ **Optical PD measurements with fast dV/dt ?**
- ✓ **Performance of liquids for high temperature insulation ?**

High field region





E_{max}~100kV/mm → Partial discharges (PD's = localized dielectric breakdown)

- <u>origin, location</u> ?

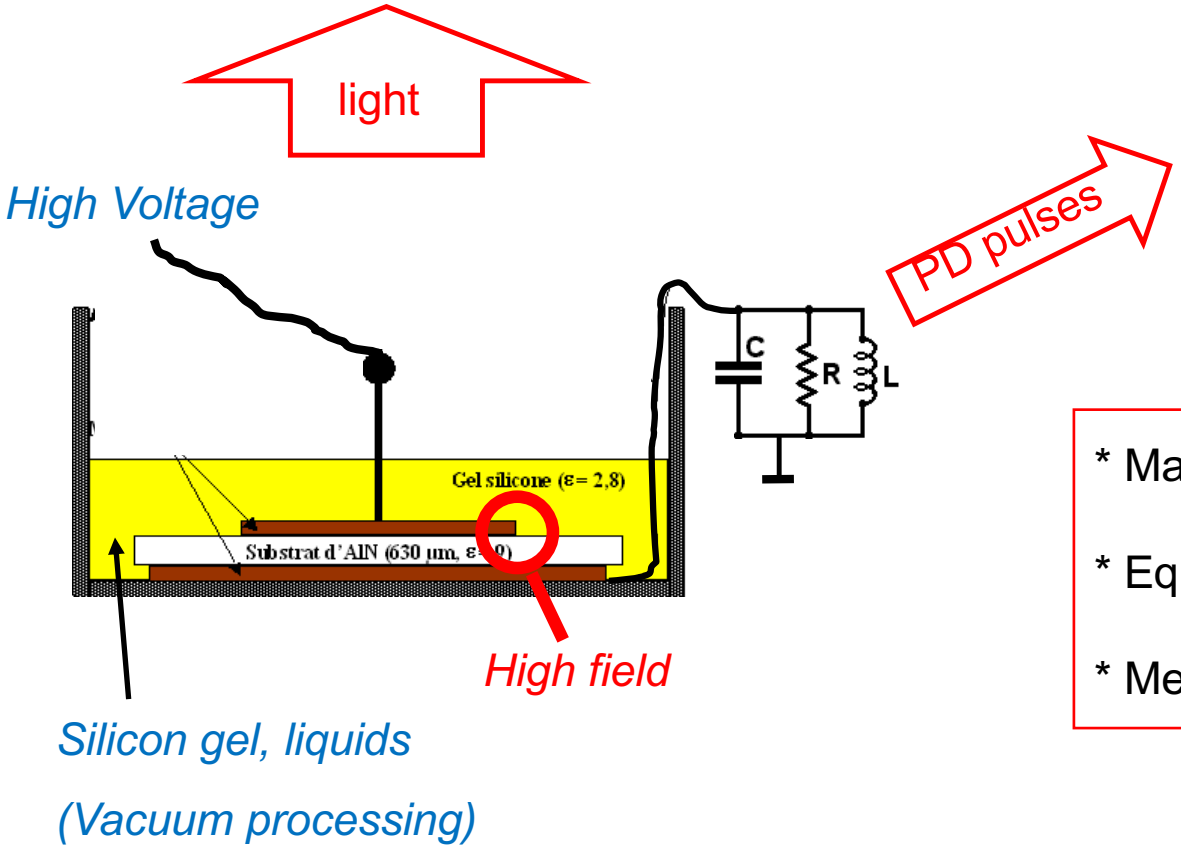
  ⇒ PD measurements, light emission, visualization

- <u>Influence of encapsulant nature, temperature</u> ?

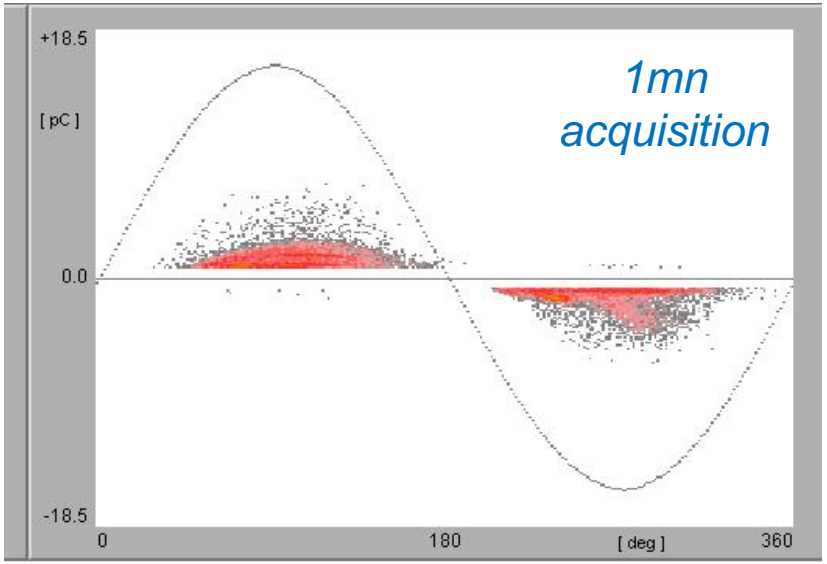
  ⇒ Silicone gel, liquids

Experimental investigations

* Intensity (photomultiplier) → I_{PM}
* High sensitivity visualization
  (≈ photon counting)

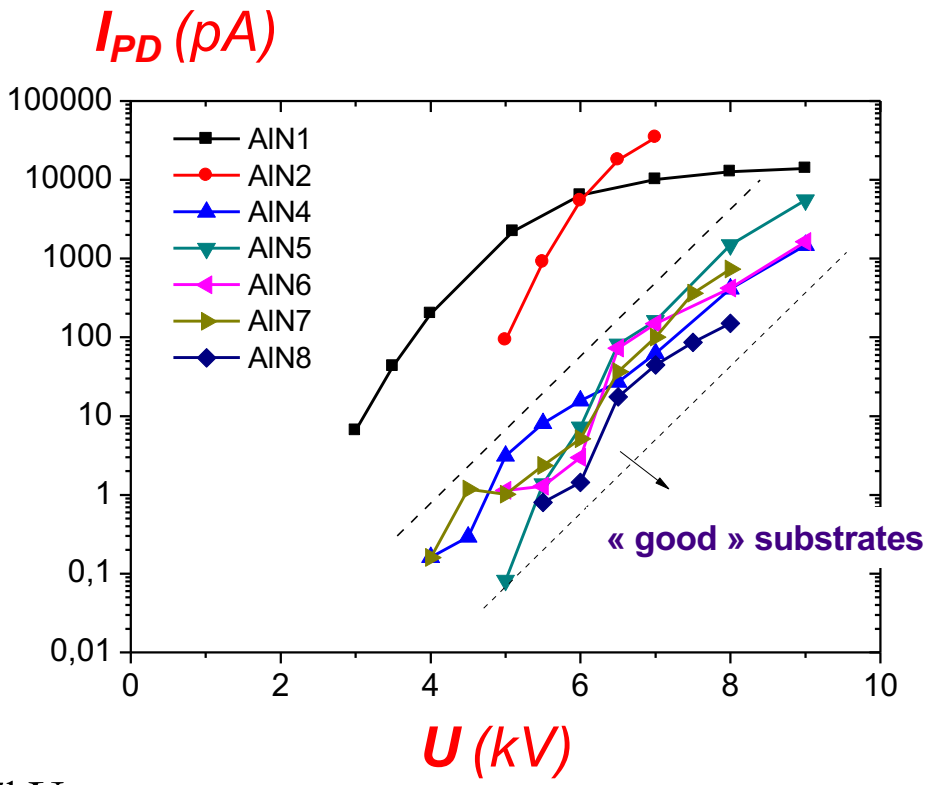


PD pulses

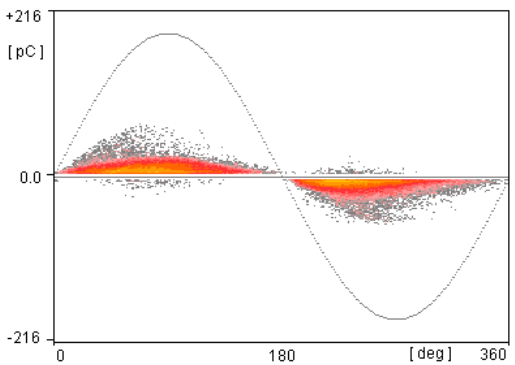


* Magnitude, number, phase distribution
* Equivalent PD current $I_{PD} = \frac{\sum |charge|}{time}$
* Measurements mostly with ac !

« good » and « bad » substrates (AlN)



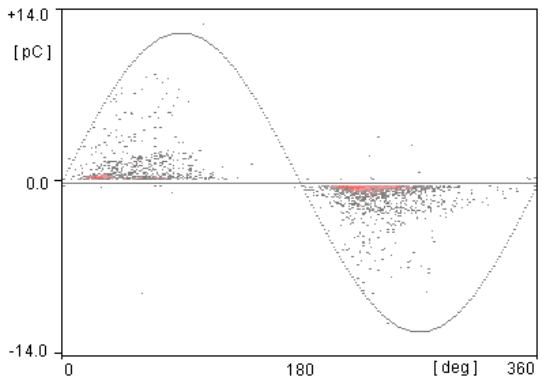
« bad » substrate



$7kV_{eff}$

- ✓Low PDIV <4kV
- ✓PD's >> 10pC
- ✓large I_{DP} → 10 nA à 6kV
- ✓ internal cracks ?

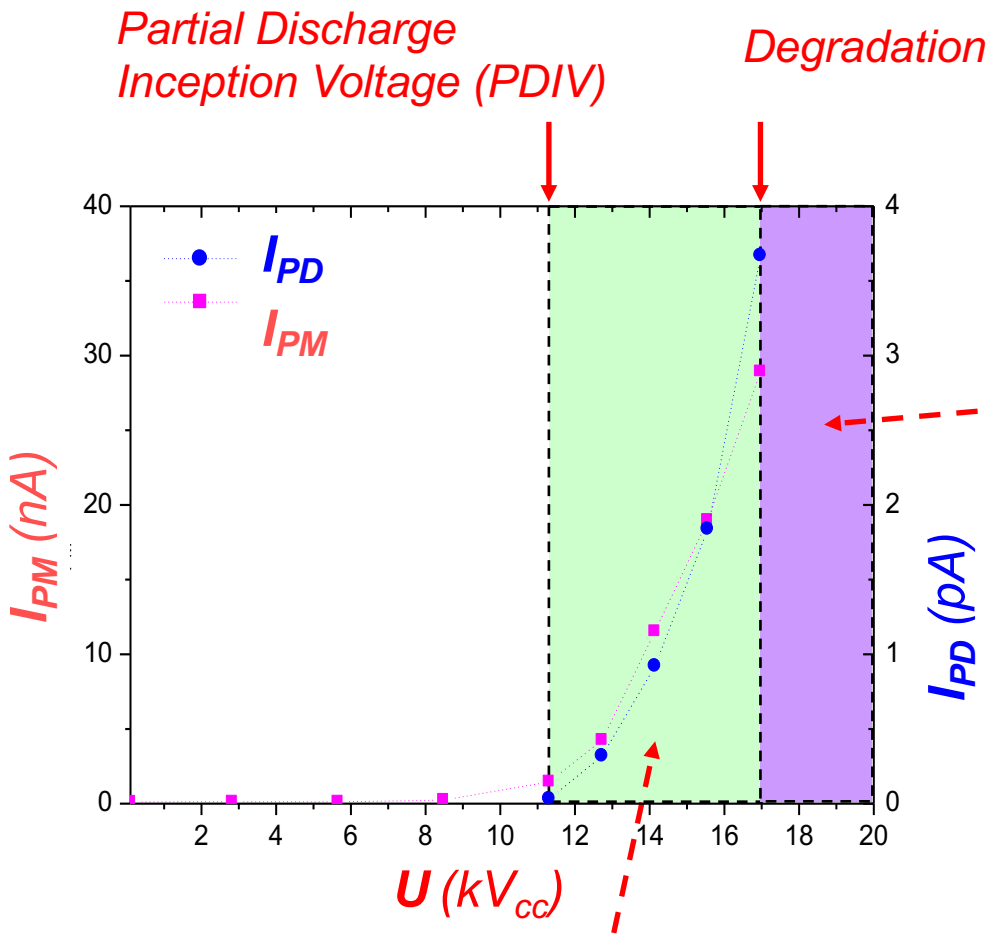
« good » substrate



$7kV_{eff}$

- ✓high PDIV (4-5 kV)
- ✓small PD's < 10 pC
- ✓ low I_{DP} < 100pA @ 6kV

Different PD regimes (AlN & Silicone gel)



Irreversible degradation

- PD up to 100 pC
- gel & ceramic rapidly destroyed
- Bright luminous spots
- close to substrate breakdown

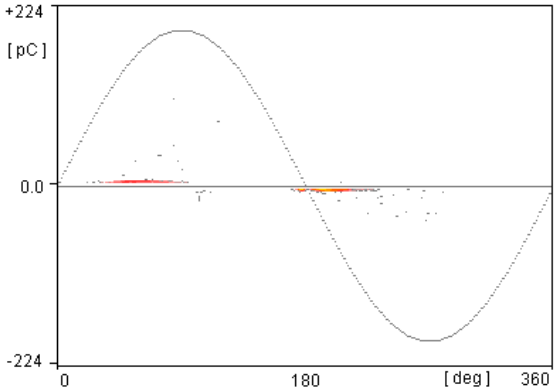
« reversible » PD's

-Low amplitude (≤ 10 pC)

-High stability (days)

- long term degradation ?

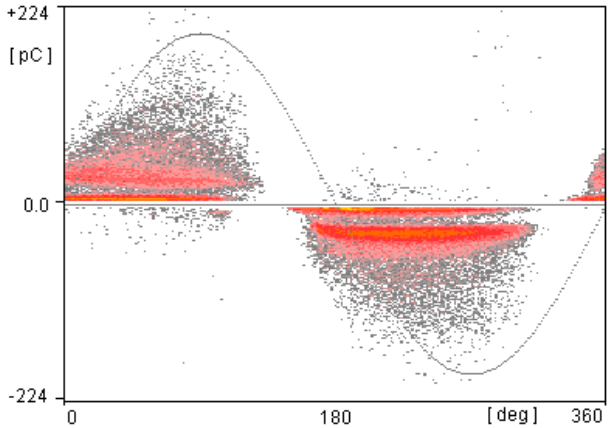
Irreversible degradation (AlN & silicone oil)

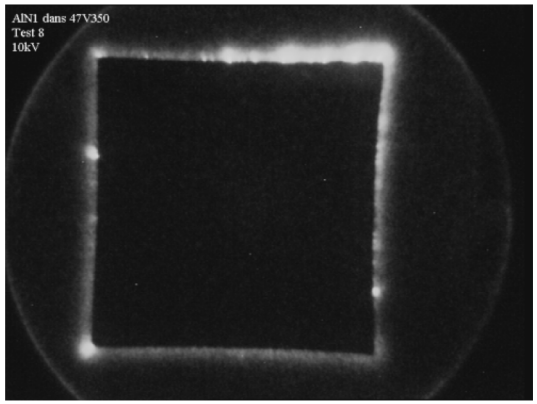


10kV

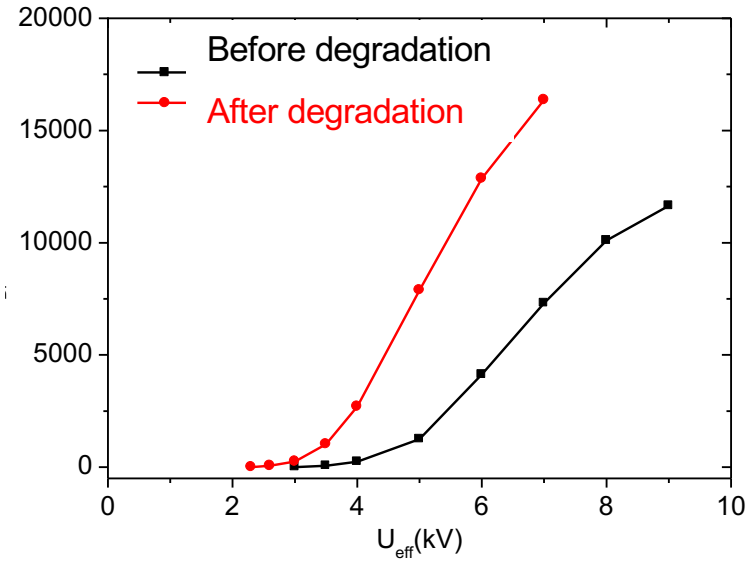
Permanent substrate degradation

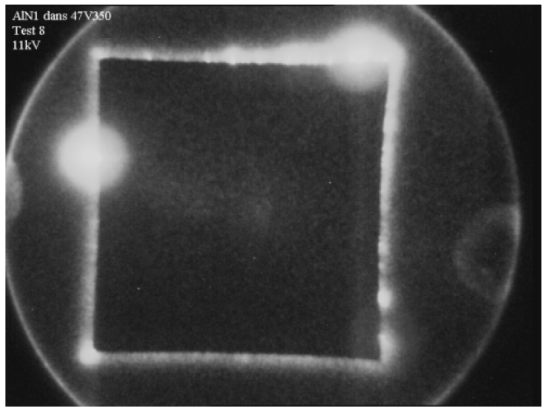
11kV





Reversible small PD's

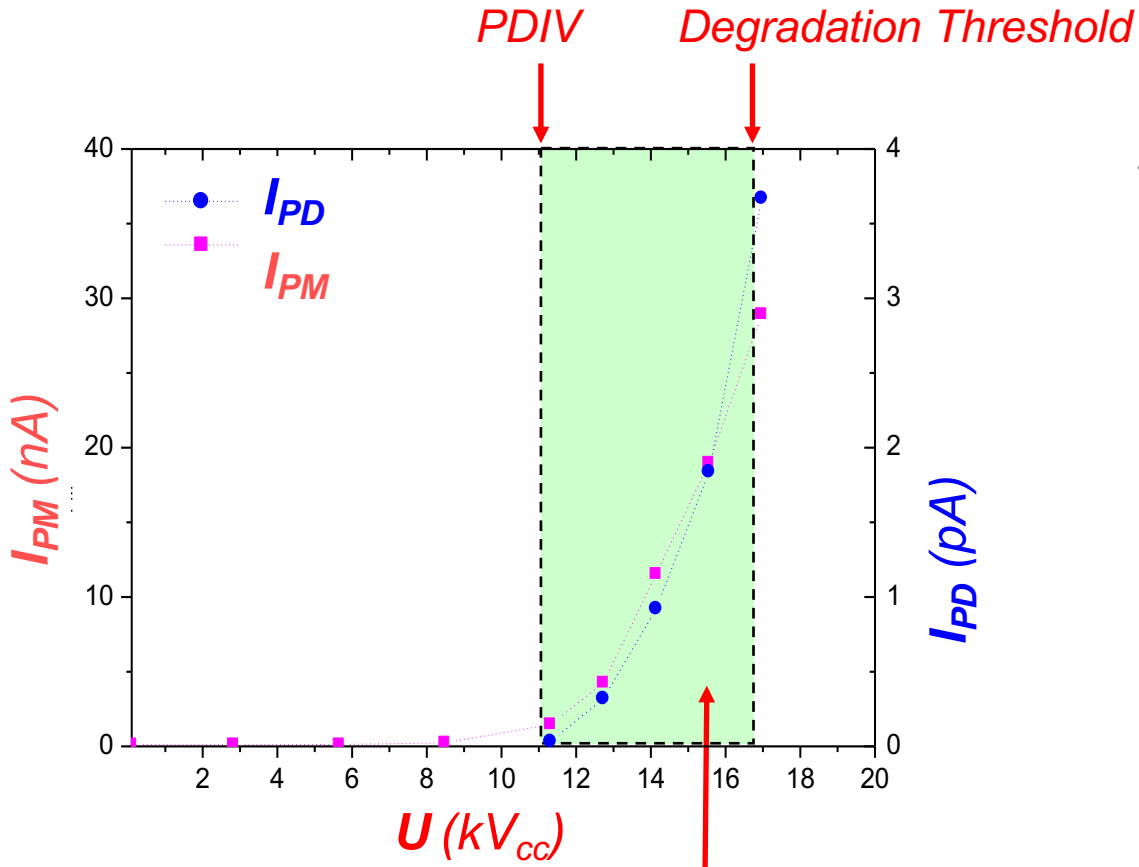


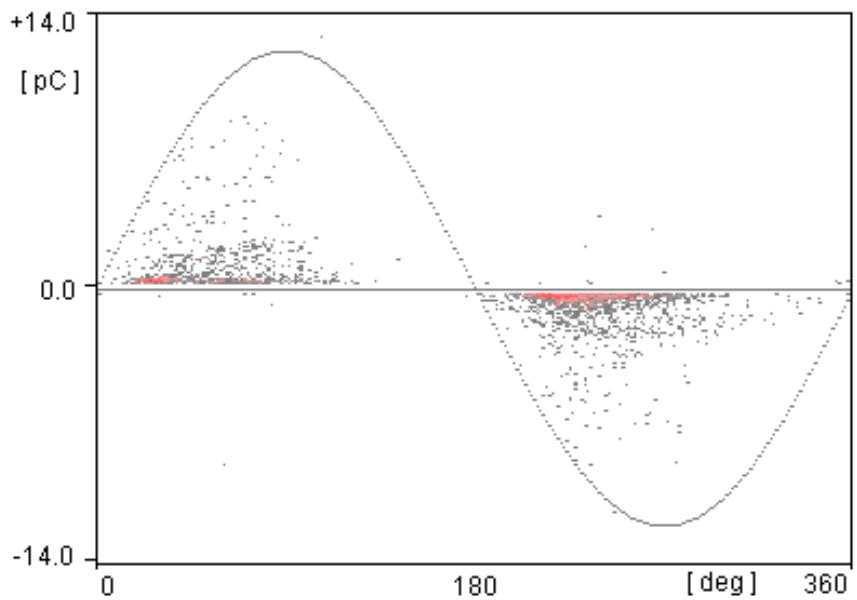


Irreversible defects

(gel and/or ceramic)

Origin of « reversible » PD's ?





→ Symmetrical (+/-) PD patterns

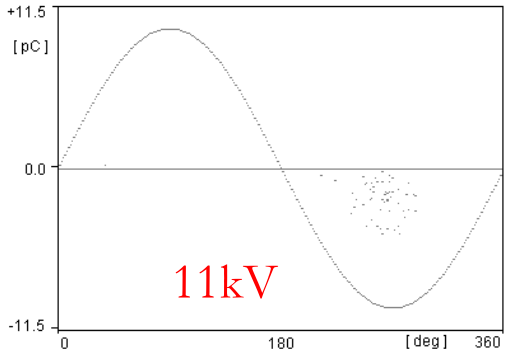
→ High stability (hours), no degradation ⇒ unusual PD behaviour !! (silicone gel not self healing)

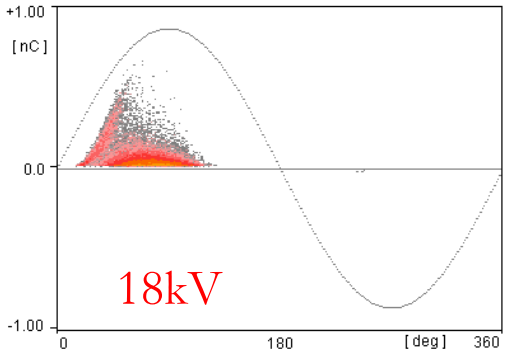
* Origin of PDs ?? Silicon gel ? Ceramic substrate ?

⇒ measurements with different encapsulants (liquids)

Different liquids = different PD properties (point-plane gap geometry)

Silicon oil

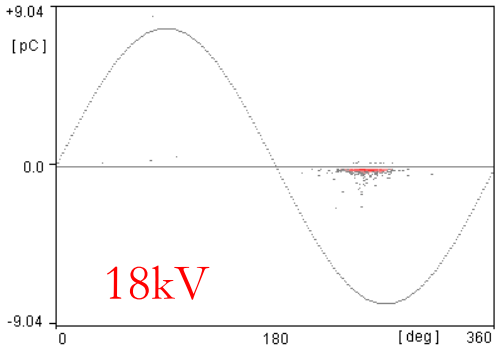




Jarylec, DBT

No PD

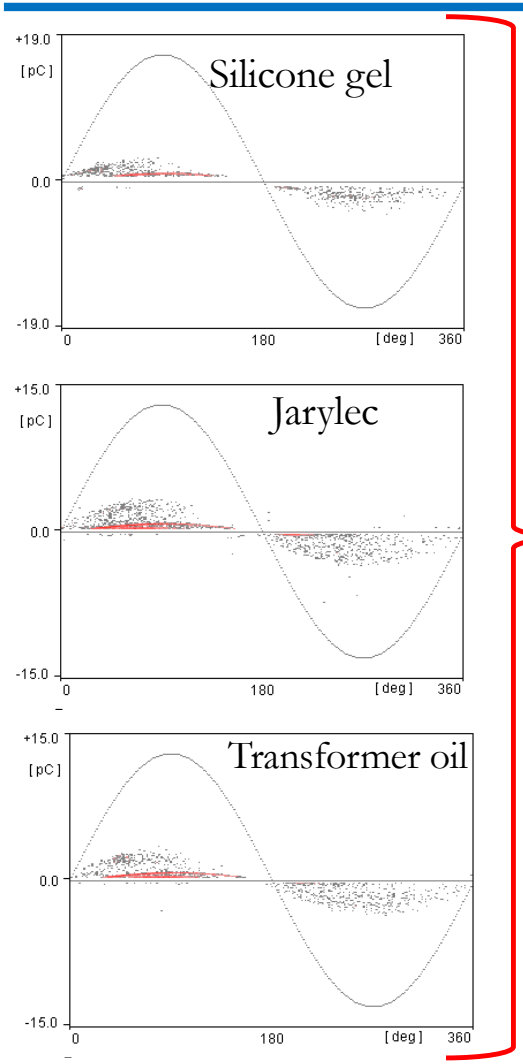
11kV



	PDIV (kV)
Silicon oil	8
ester	11
Transf. oil	9
Jarylec	11
Ugilec	12

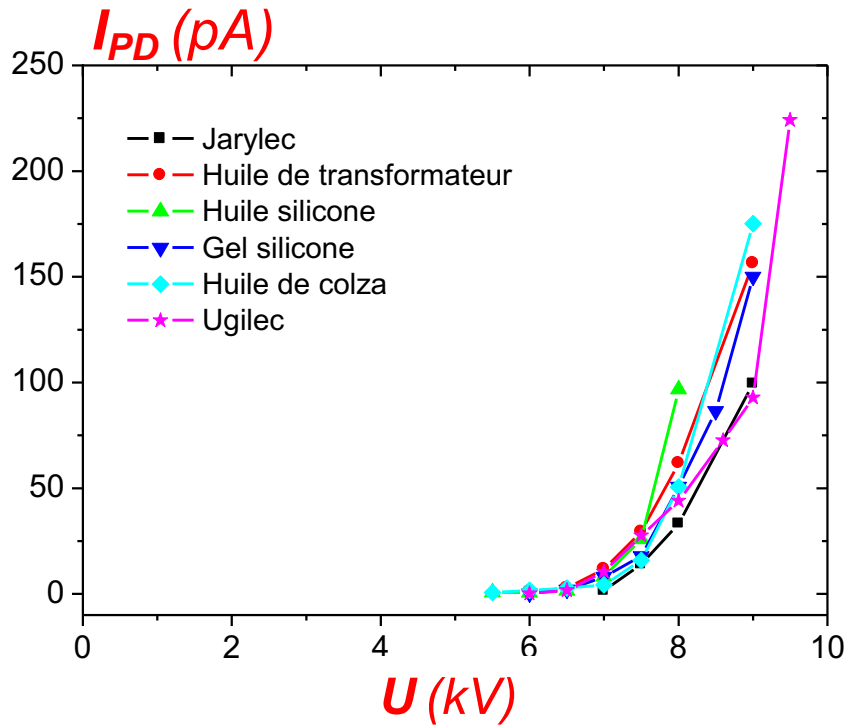
⇒ PDIV & PD patterns considerably depend on liquid nature

AlN substrate with different liquids



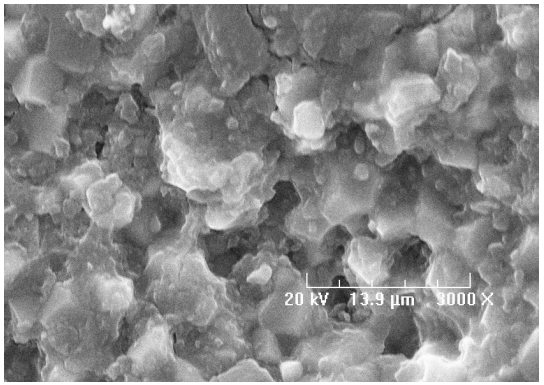
8kV

no influence of encapsulant nature on PD's !



⇒ reversible PD's occur <u>within</u> the ceramic
(sintered material with pores)

⇒ explains long term stability
(ceramic = PD resistant material)



⇒ dégradation threshold = PD's in the encapsulant

Light emission for PD detection ?

Electro-luminescence (EL)

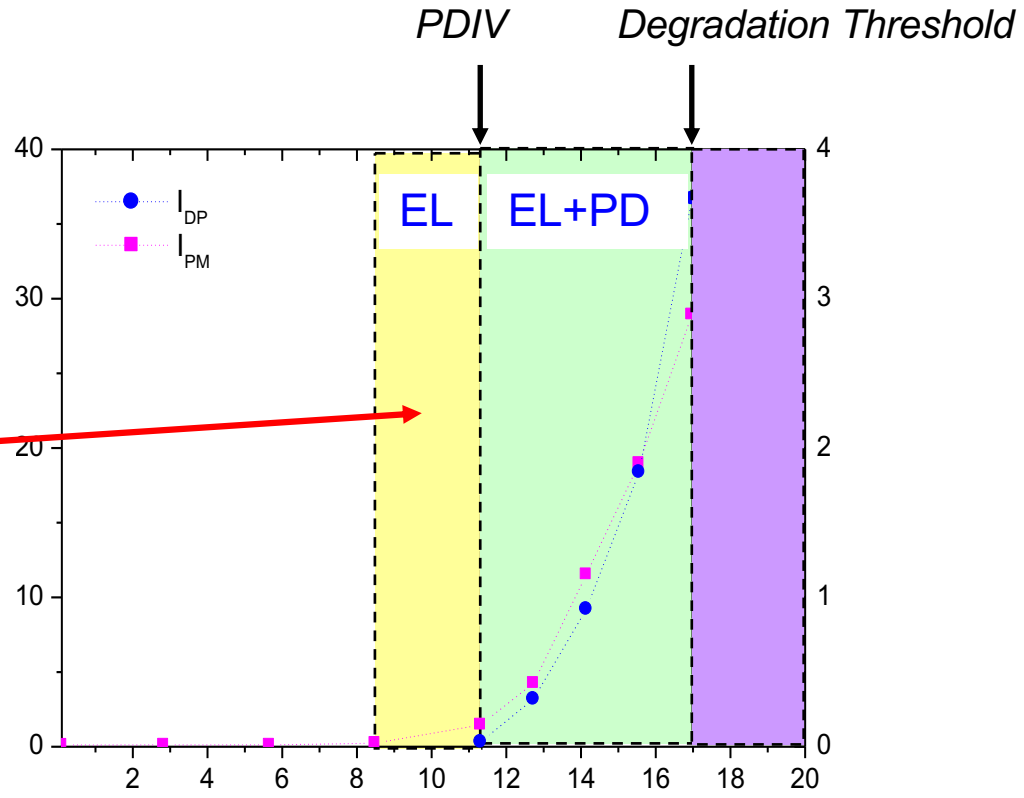
- very low light emission, no PD

AlN electroluminescence

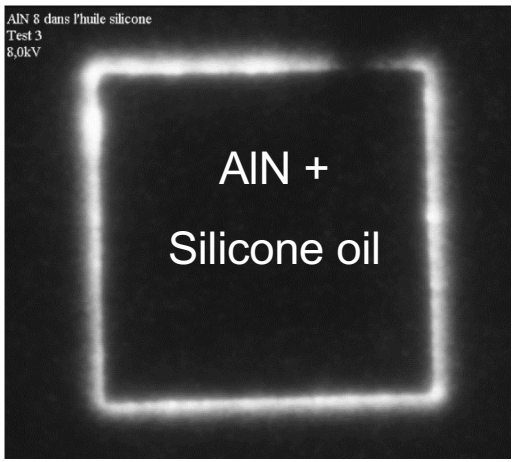
+

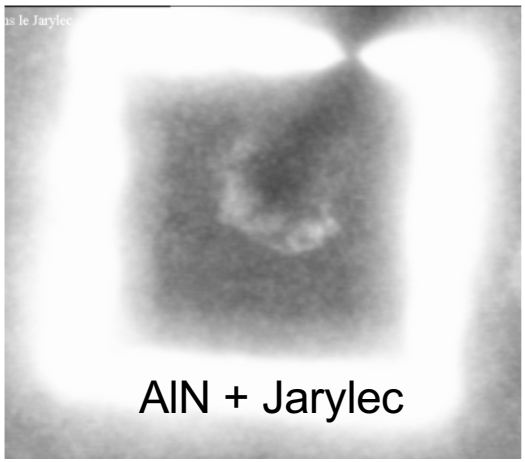
Liquid electroluminescence

→ not observed with Al_2O_3, epoxy, silicone gel, silicone oil, esters, …

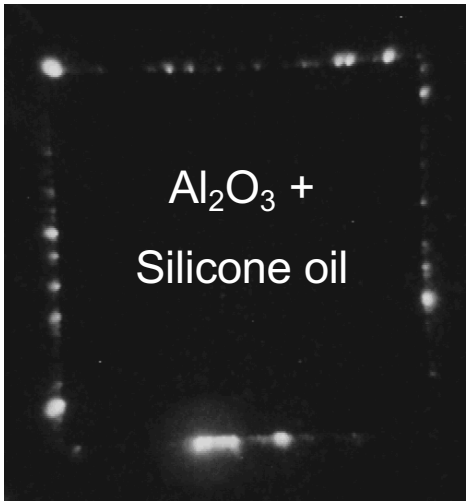


PD light + EL

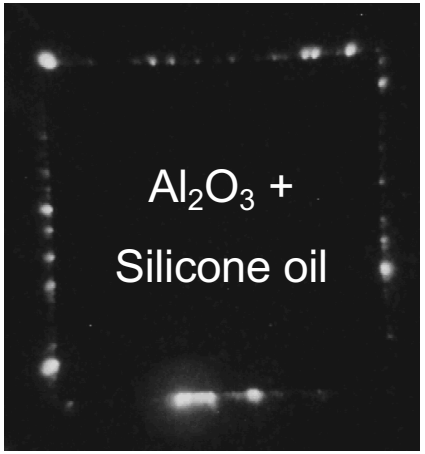


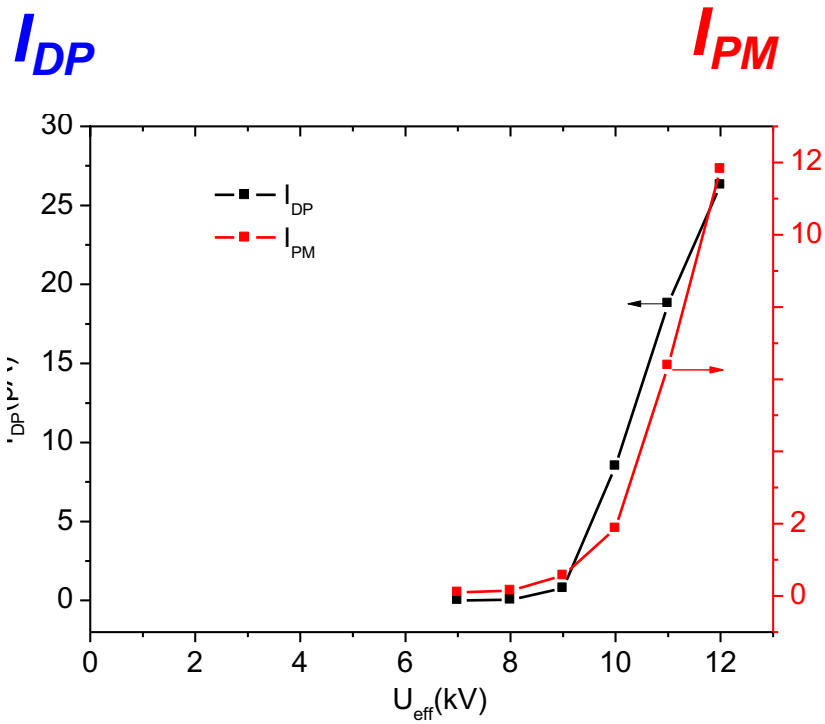


PD light only



PD detection from light emission





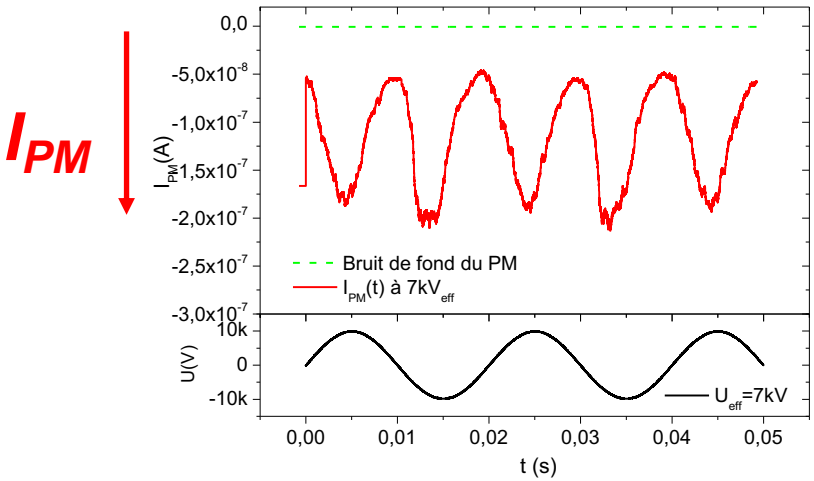
➔ without EL, light emission correlated to PD activity

👍 can be used to detect PD's, high sensitivity

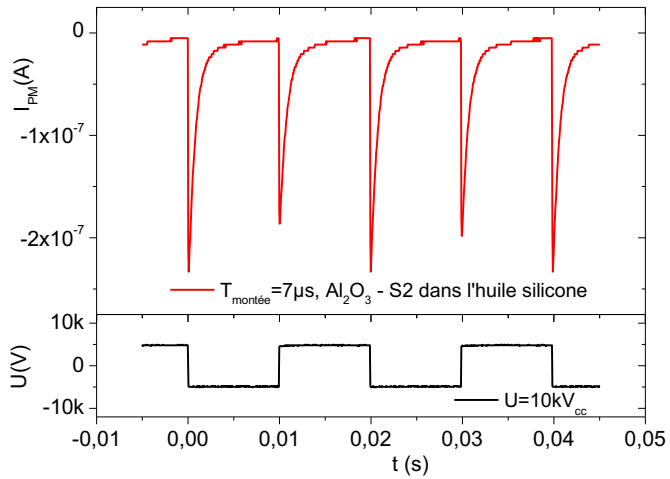
👍 with any voltage waveform (AC, fast impulses …)

👎 only with transparent, non EL encapsulating material

Optical PD detection (Al_2O_3 + silicone oil)



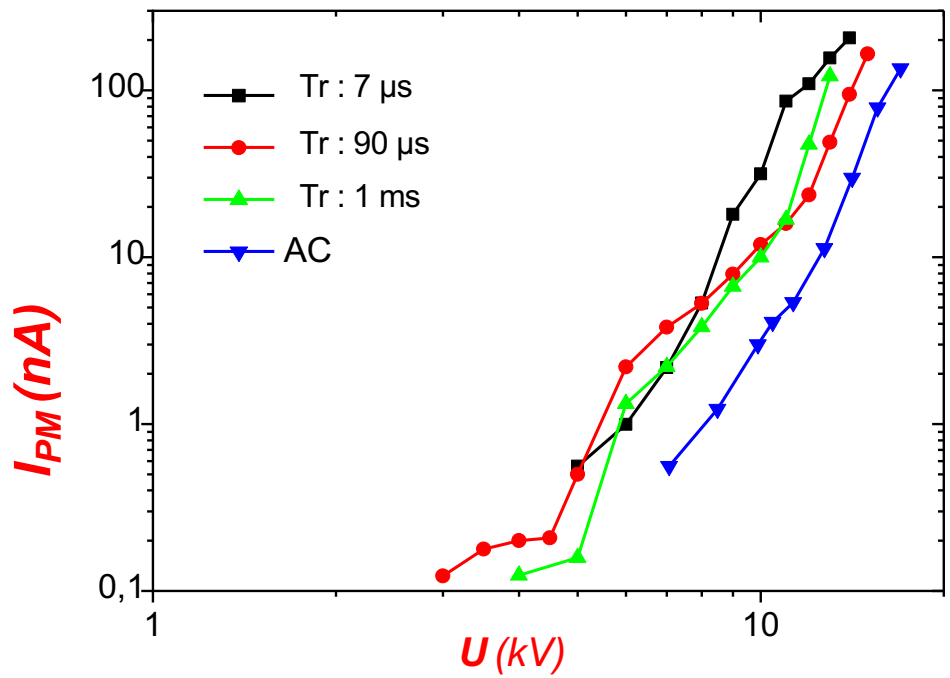
AC



Square (7µs rise & fall time)

➔ PDs occur during dV/dt

Optical PD detection (Al_2O_3 + silicone oil)



→Larger PD activity with impulses !

👎 standard ac measurements underestimate PD activity

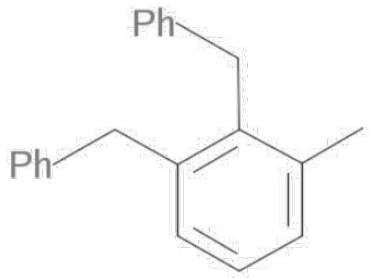
$PDIV_{AC} \approx 7$ kV, $PDIV_{impulse} \approx 4 - 5$ kV

→ low influence of pulse risetime

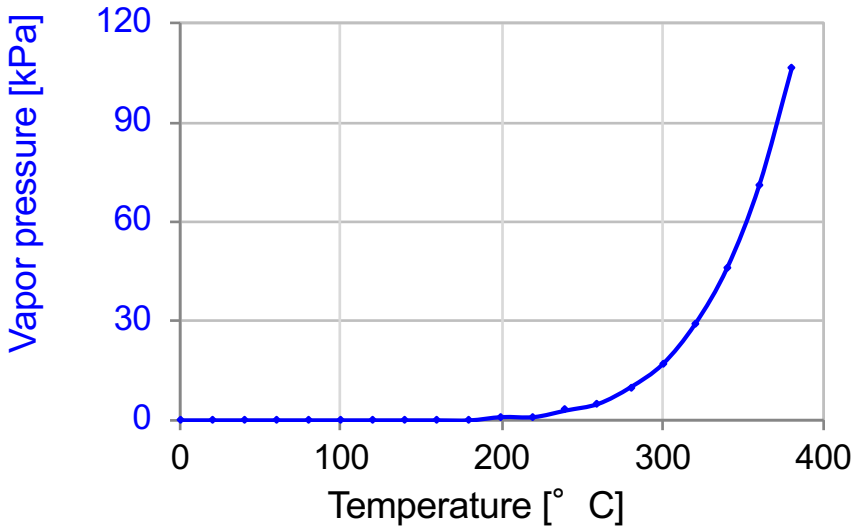
Liquids for high temperature / high voltage insulation ?

Objective: suitable environment for HV & HT testing ?

(laboratory scale, Diamond HVDC project)



- High temperature non-polar insulating liquids exist: Jarytherm® DBT
- Used in industry for heat transfer up to 380°C
- Boiling temperature: 390 ° C
- ΔP = +0.15 Bar @ 300 ° C
- Dielectric properties ?

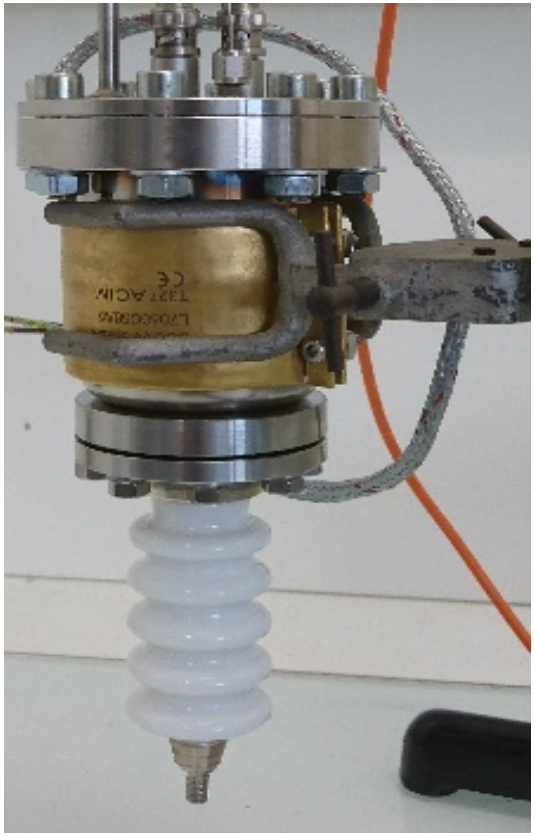


Permittivity: 2.66, Fire point: 230°C, Auto ignition: 500°C

* DBT samples provided by ARKEMA

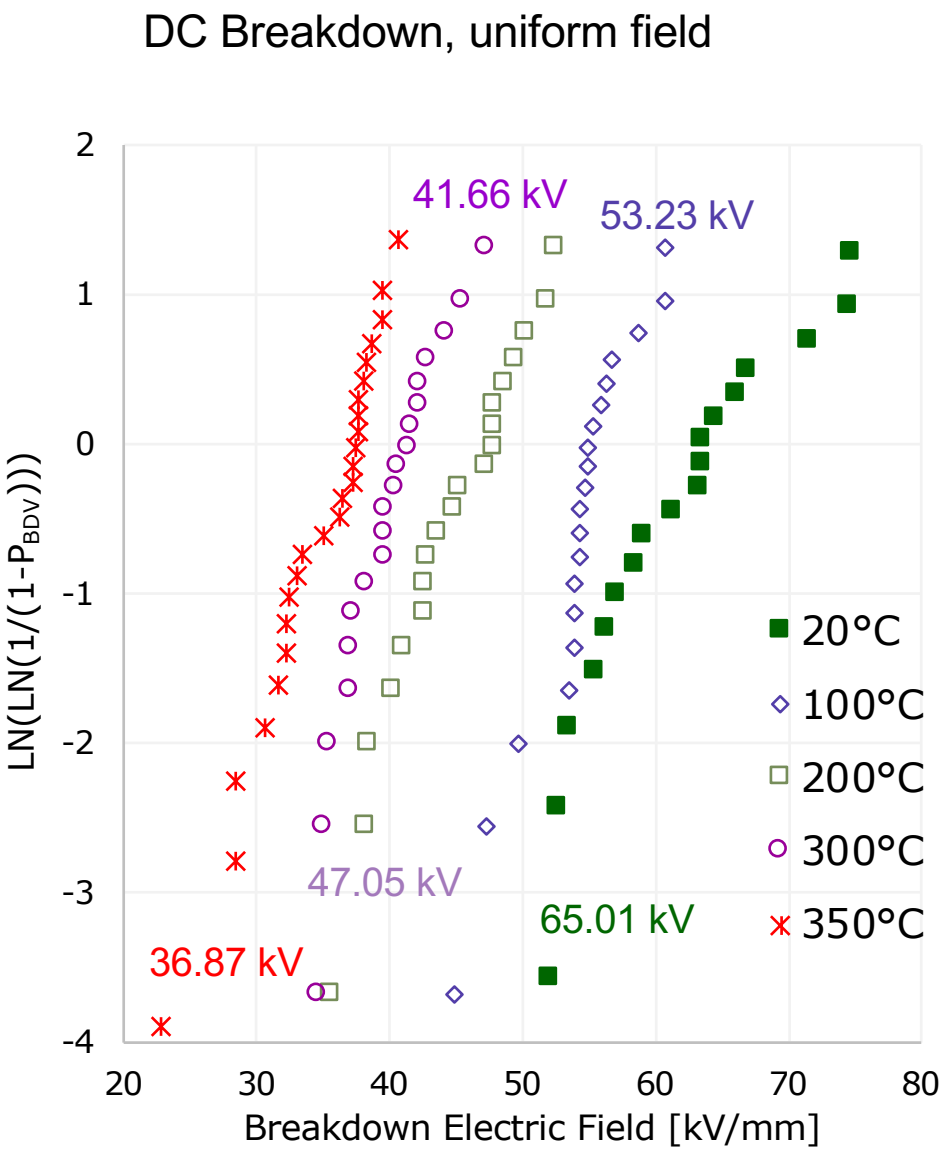
Dielectric measurements at high temperature

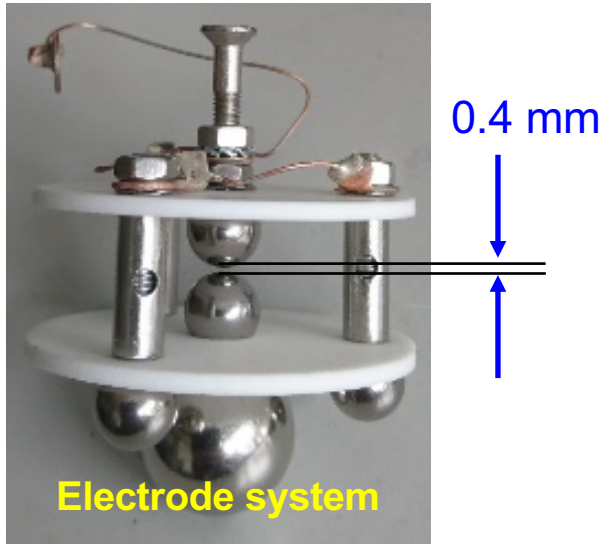
- DBT dielectric properties at high temperature ?
  - ✓ Breakdown
  - ✓ Partial Discharges with substrates
  - ✓ Breakdown with substrates (ongoing study)



- 400°C max., 30 kV
- Inert atmosphere (N_2)
- PD and breakdown measurements

DBT at high temperature: breakdown





- high breakdown field (60 kV/mm), down to 30 kV/mm @ 350°C
- Higher than gel (20 KV/mm) and ceramic

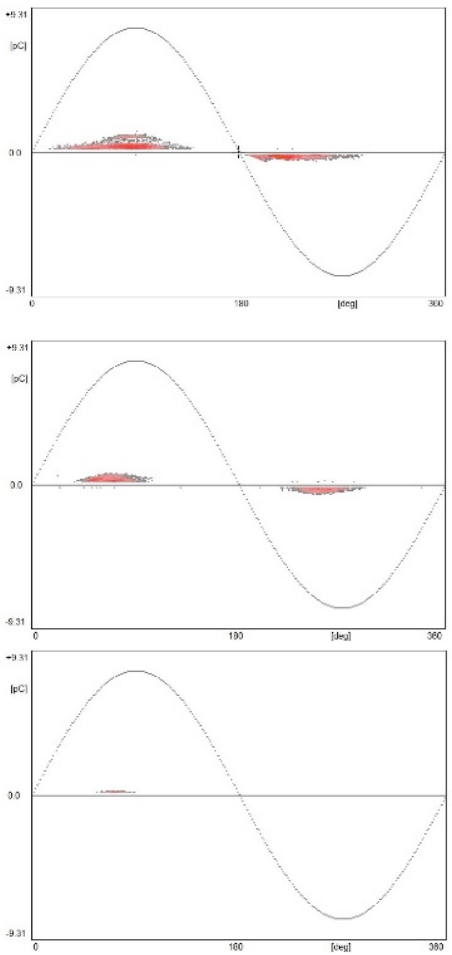
DBT at high temperature: PDs with substrates

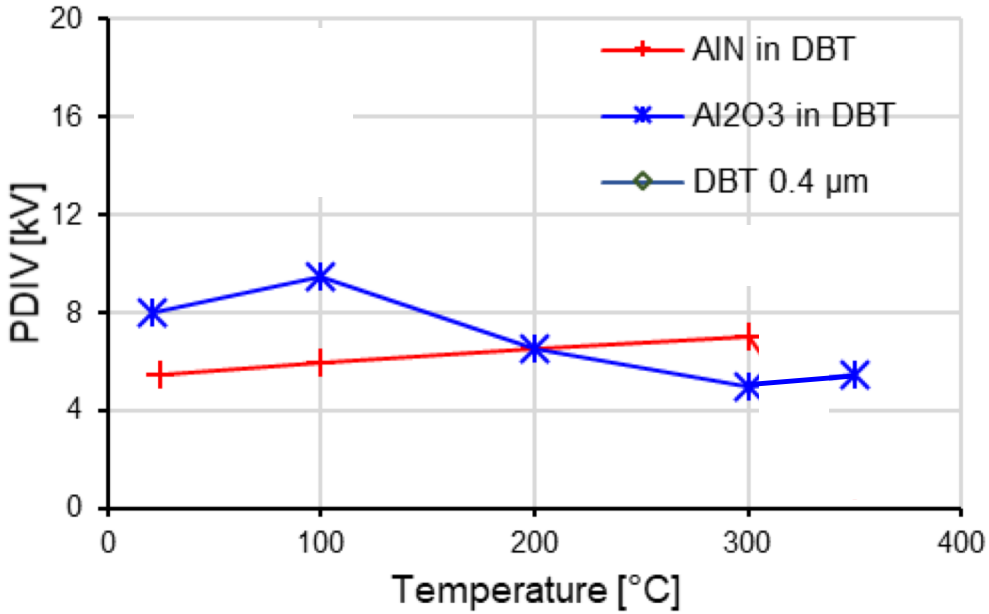
AlN substrate in DBT @7 kV

25 ° C

200 ° C

300 ° C

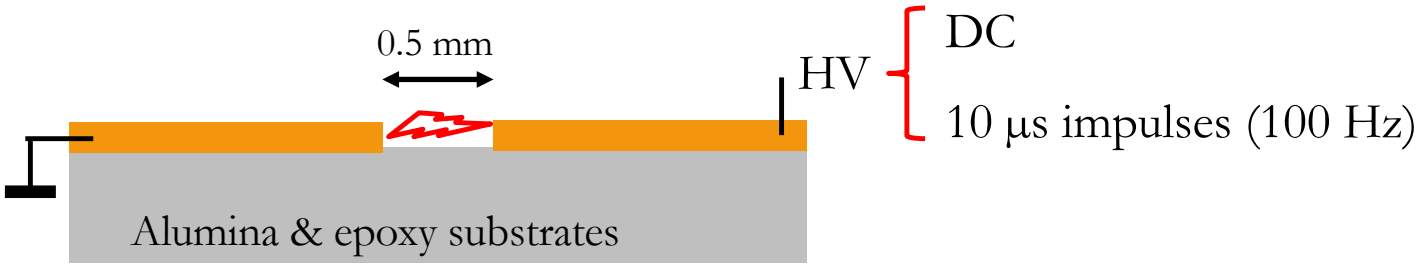


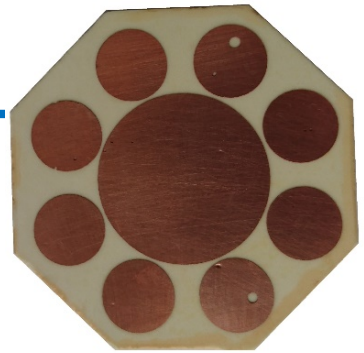


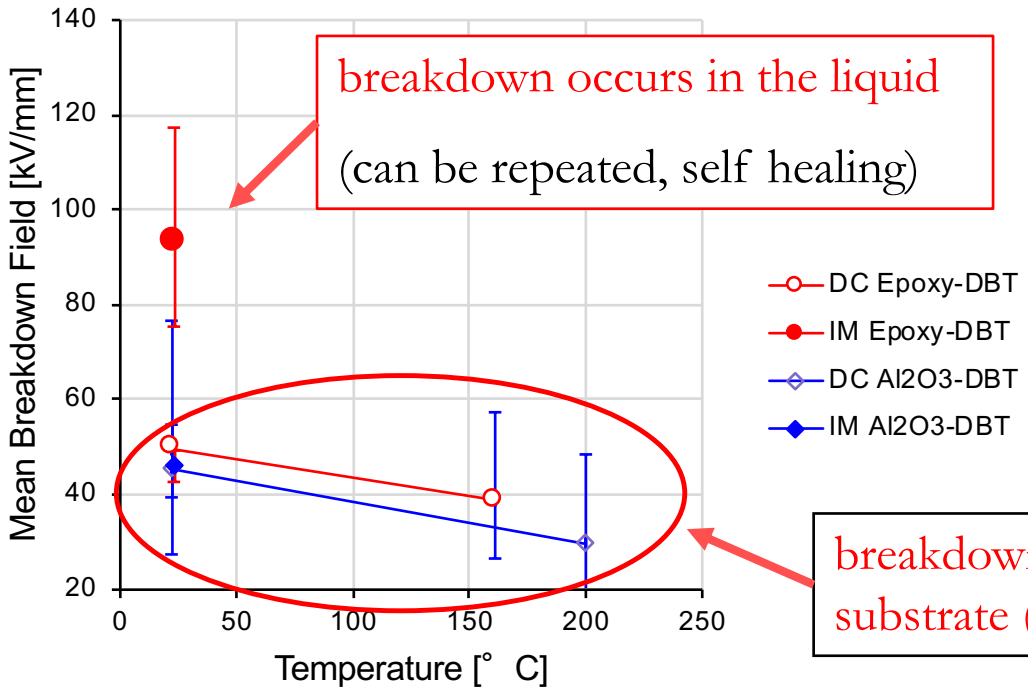
- PD activity decreases vs temperature with AlN
- Opposite trend with Al_2O_3
- PDIV remains > 4 kV at high temperature

→ PD's are substrate dependent, not liquid dependent

DBT : breakdown with substrates at high temperature

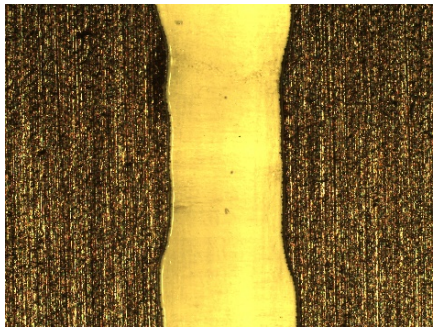




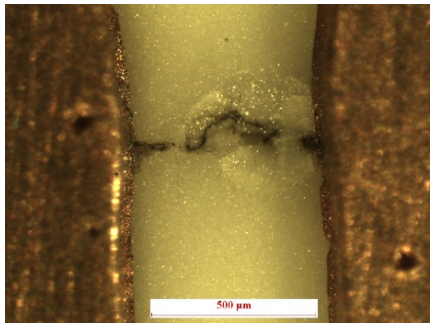


breakdown occurs in the liquid

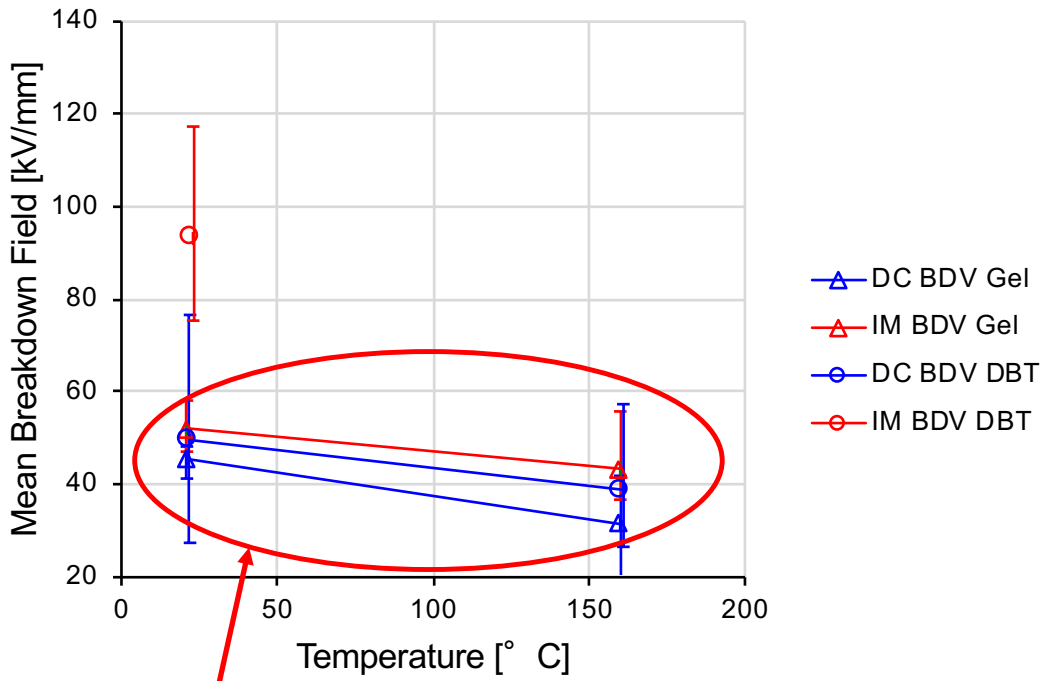
(can be repeated, self healing)



breakdown occurs in the substrate (destroyed after 1st shot)



Breakdown: Comparison with Silicone gel (epoxy)



DBT slightly better than silicone gel

→ Breakdown of the substrate

→ Influence of temperature mostly relevant of substrate ?

→ Further measurements to come …

Some conclusions …

- ✓ ≈ 10 pC PD's on embedded ceramic substrates (processing under vacuum) occur <u>within the substrate, not in the encapsulant</u>

  → nearly independent on encapsulating material

  → consequences for the long term reliability ?

- ✓ Irreversible degradation can be seen only at large overvoltage (≈ 1.5 PDIV)

  → immediate irreversible degradation (gel, substrate)

- ✓ Optical measurements done with selected materials shows that conventionnal ac PD measurements underestimate PD activity

  → more relevant of actual working conditions

- ✓ Liquids may show interesting properties at high temperatures (up to 350° C)

  → Can be used for laboratory testing under HV & HT

  → Applications of liquids in real components ? Cooling ?

Acknowledgements

- ✓ J.L. Augé, R. Hanna (Dielectrics Team)
- ✓ PhD students : N.V. Tuan, V.T. Tho, J. Muslim