Ceramic Substrates with Silicone Gel or Liquids: Dielectric properties

Olivier LESAINTE

Grenoble Electrical Engineering lab. - G2Elab
CNRS & Grenoble University - France

Dielectric Materials & Electrostatics team (MDE)
High field region: triple points

✓ partial discharges? origin?

✓ Optical PD measurements with fast dV/dt?

✓ Performance of liquids for high temperature insulation?
E_{max} \sim 100 \text{kV/mm} \rightarrow \text{Partial discharges (PD's = localized dielectric breakdown)}

- origin, location?
  \Rightarrow \text{PD measurements, light emission, visualization}

- Influence of encapsulant nature, temperature?
  \Rightarrow \text{Silicone gel, liquids}
Experimental investigations

* Intensity (photomultiplier) \( I_{PM} \)
* High sensitivity visualization
  \((\approx \text{photon counting})\)

* High Voltage
  * Silicon gel, liquids
  * High field

1mn acquisition

* Magnitude, number, phase distribution
* Equivalent PD current \( I_{PD} = \sum |\text{charge}| \over \text{time} \)
* Measurements mostly with ac
« good » and « bad » substrates (AlN)

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

✓ high PDIV (4-5 kV)
✓ small PD’s < 10 pC
✓ low $I_{DP}$ < 100pA @ 6kV
Different PD regimes (AlN & Silicone gel)

« reversible » PD’s
- Low amplitude (≤ 10 pC)
- High stability (days)
- long term degradation?

Partial Discharge Inception Voltage (PDIV)

Degradation Threshold

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

Partial Discharge (PD)

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Irreversible degradation (AlN & silicone oil)

Reversible small PD’s

Permanent substrate degradation

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**

- 11kV
- 18kV

**Jarylec, DBT**

- No PD
- 11kV
- 18kV

<table>
<thead>
<tr>
<th>PDIV (kV)</th>
<th>Silicon oil</th>
<th>ester</th>
<th>Transf. oil</th>
<th>Jarylec</th>
<th>Ugilec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8</td>
<td>11</td>
<td>9</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
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⇒ PDIV & PD patterns considerably depend on liquid nature
Silicone gel

Transformer oil

Jarylec

8kV

⇒ reversible PD’s occur within the ceramic
    (sintered material with pores)

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

⇒ dégradation threshold = PD’s in the encapsulant

no influence of encapsulant nature on PD’s!
Light emission for PD detection?

**Electro-luminescence (EL)**
- very low light emission, no PD

  AIN electroluminescence
  +
  Liquid electroluminescence

→ not observed with Al$_2$O$_3$, epoxy, silicone gel, silicone oil, esters, ...

![Graph showing PD light and EL emissions](Image)

**PD light + EL**

- AIN + Silicone oil
- AIN + Jarylec

**PD light only**

- Al$_2$O$_3$ + Silicone oil
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 (Al₂O₃ + silicone oil)

I_PM

Bruit de fond du PM

I_PM(t) à 7kV_eff

AC

Square (7µs rise & fall time)

PDs occur during dV/dt
Optical PD detection ($\text{Al}_2\text{O}_3 + \text{silicone oil}$)

$\rightarrow$ Larger PD activity with impulses!

⚠️ Standard ac measurements underestimate PD activity

$\text{PDIV}_{\text{AC}} \approx 7 \text{ kV}, \text{PDIV}_{\text{impulse}} \approx 4 - 5 \text{ kV}$

$\rightarrow$ 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
- \( \Delta P = +0.15 \) 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 (N₂)
- PD and breakdown measurements
DBT at high temperature: breakdown

DC Breakdown, uniform field

- 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** $\text{Al}_2\text{O}_3$
- **PDIV remains > 4 kV at high temperature**

→ **PD’s are substrate dependent, not liquid dependent**
DBT: breakdown with substrates at high temperature

- **0.5 mm**
- **HV**
- **DC**
- **10 µs impulses (100 Hz)**

Alumina & epoxy substrates

- Breakdown occurs in the liquid (can be repeated, self-healing)
- Breakdown occurs in the substrate (destroyed after 1st shot)

![Graph showing mean breakdown field vs. temperature]

- DC Epoxy-DBT
- IM Epoxy-DBT
- DC Al2O3-DBT
- IM Al2O3-DBT
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 within the substrate, not in the encapsulant

  → 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 ?
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