Institute for High Voltage Technology

RWTH AACHEN UNIVERSITY

Partial Discharge and Breakdown Behavior of Syntactic Foams at 77 K

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Motivation

State of the art

- Typical electrical insulation systems for superconducting components are based on liquid nitrogen (LN_2)

Disadvantages of liquid nitrogen based insulation systems

- Bubbling of LN_2 due to losses → field displacement → could initiate breakdown
- LN_2: area/volume effect: Dielectric strength not proportional to gap distance

Advantages of solid insulation systems

- Significant higher dielectric strength compared to liquids or gases

But: Fillers needed to reduce thermal contraction. This generates an inhomogeneous material, which boundaries can cause partial discharges (PD) and thus lead to premature breakdown

Aims: Determine influence of temperature on partial discharge initiation and identify effects of modifications to increase PD inception and breakdown field strength

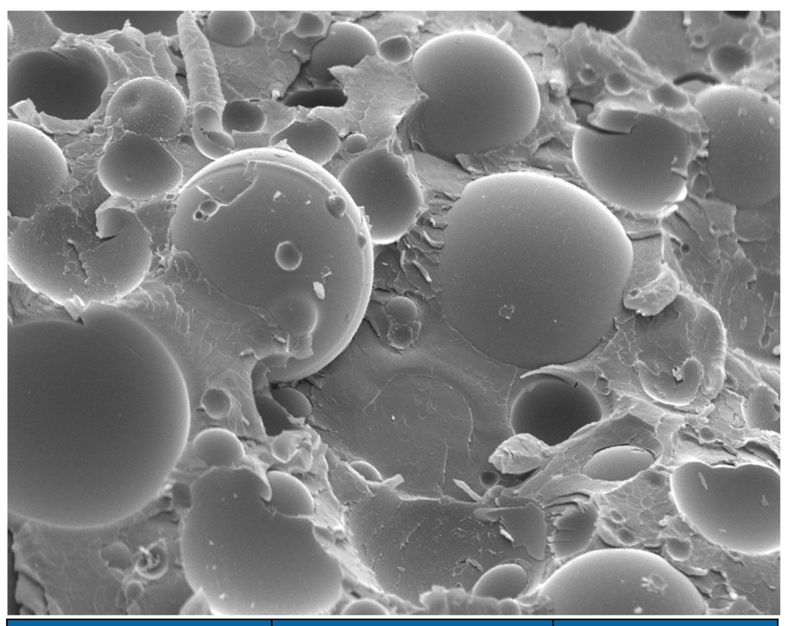
Syntactic foam

Generally

- Composite material consisting of hollow microspheres (HMS) embedded in a polymeric matrix
- Average diameter of HMS: several 10 µm, wall thickness of about 1 µm

In this investigation

- Epoxy resin as matrix materials
- Gas-filled glass hollow micro-spheres (GHMS) as filler
- Silanization used to provide better adhesion between the organic matrix materials and the inorganic glass
- Two different filling degrees

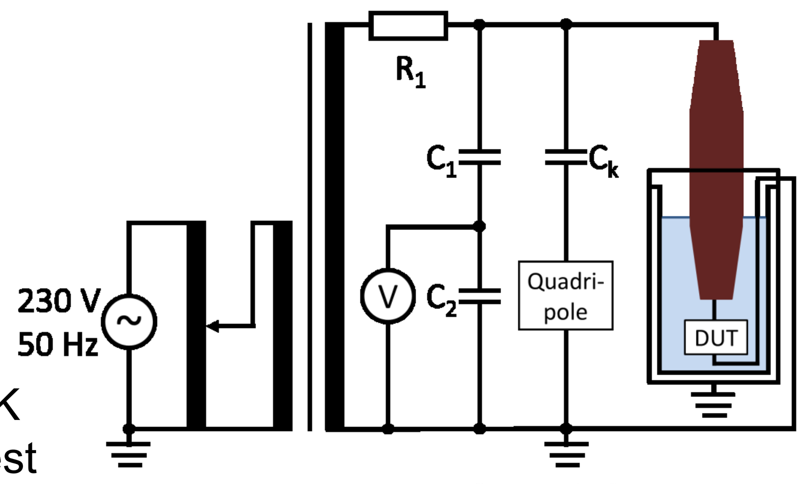


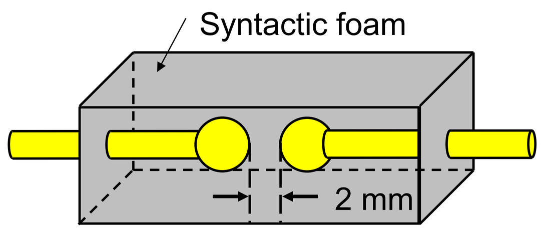
Matrix material	Hollow microspheres (Ø=45µm)	Filling degrees
Epoxy resin (ER)	Untreated glass (GHMS)	30 vol. %
	Silanized glass (SGHMS)	50 vol. %

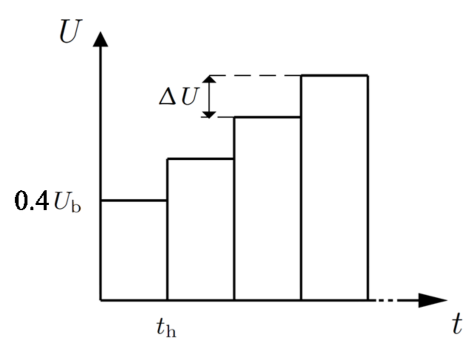
Experiments

Measurement setup

- Determination of PD inception and PD amplitude until breakdown at room temperature (RT, 293 K) and liquid nitrogen temperature (LNT, 77 K)
  - Oil vessel for investigations at 293 K
  - Cryostat filled with LN_2 serves as test vessel at 77 K
- Electrodes in sphere-sphere arrangement
  ➡ Quasi-homogeneous electrical field (η = 0.9)
- Test parameters of voltage step function
  - Starting voltage $U_s = 0.4\ U_b$
  - Step holding time t_h = 20 s
  - Step height ΔU depends on U_s according to IEC 60243-2



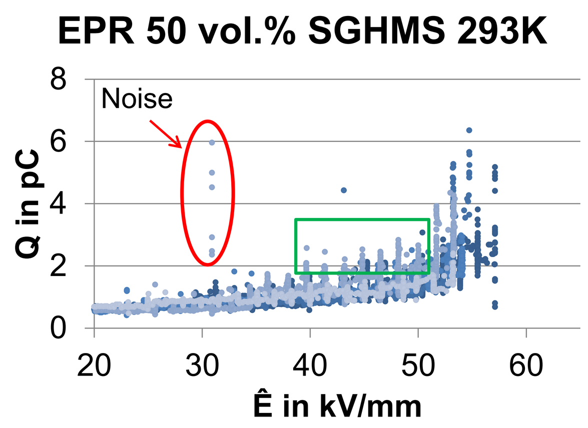


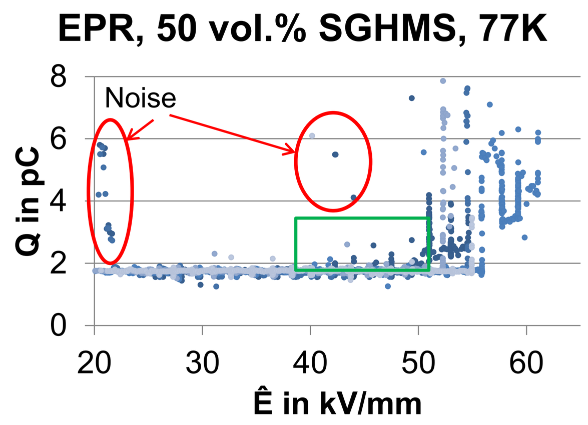


Results

PD inception at 293 K and 77 K

- At RT, for EPR-based foams with 50 vol.% SGHMS, an increase of PD amplitude can be observed over a wide range of the applied electrical field
  ➡ At 293 K, field displacements lead to PD in gas of HMS
- At 77 K, PD exceeding the background noise of 2 pC occurs at ~50 kV/mm. This is approx. 10 kV/mm above the 2 pC PD threshold at RT
  ➡ Due to cryogenic temperatures, filling gas sublimates. Thus, inside HMS at 77 K is vacuum, which can withstand higher field stress and therefore higher PD inception field stress is reached

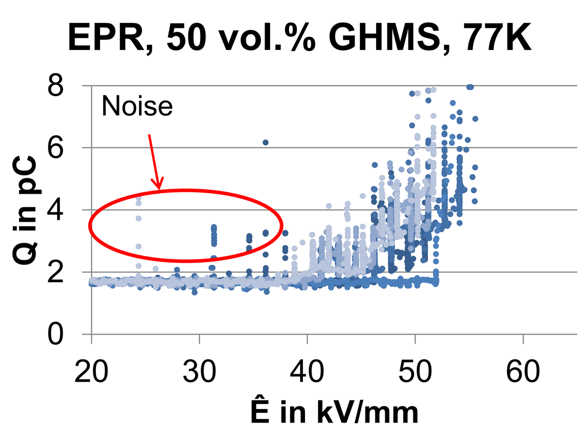


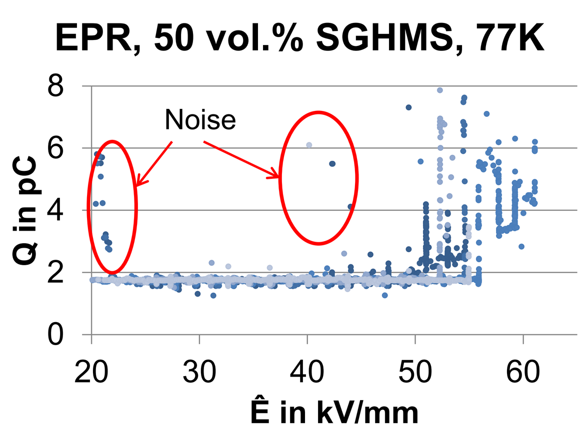


Results

Effect of silanization on ER-based foams at LNT

- For untreated microspheres, ER-based foam shows an increase in PD activity in the range of 40-50 kV/mm at 77 K
  ➡ Possible sources of this activity could be cracked HMS walls (field emissions), or a vacuum breakdown inside HMS or in gaps between HMS and matrix
- Samples investigated with silanized hollow microspheres (SGHMS) show a higher PD inception field stress of at least 50 kV/mm and a higher breakdown field stress
  ➡ Better bonding of spheres could reduce thermal cracking of microspheres, which can be considered as potential weak spot for initiation of PD and breakdown





Discussion

- In syntactic foams, possible weak spots for the occurrence of PD are micro-gaps between matrix and filler, the void inside of the microspheres as well as micro cracks of broken HMS
- At 293 K, due to $\varepsilon_{Resin} > \varepsilon_{Gas}$, the electric field will be displaced into the gas inside the microspheres or into gaps and generate PD even at low field stress
  ➡ At 77 K, the field will be displaced into a vacuum inside the HMS. This leads to PD inception at higher field stress compared to 293 K
- Due to thermal stress during cooldown, some microspheres crack. At cracks, field emissions heat and resublimate gas, which is ionized and creates PD
  ➡ By applying a silanization, the bonding between matrix and filler is enhanced which reduces thermal cracks as well as micro-gaps. PD inception field stress is higher compared to untreated HMS at LNT

Conclusion: In syntactic foams at 77 K, PD leading to fast ageing is detected at higher field stress compared to 293 K, especially when using silanized HMS. Possible effects on long-term stability will be part of further investigations

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