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Simulation of thermal breakdown in a multi-layered stack of dielectric elastomers

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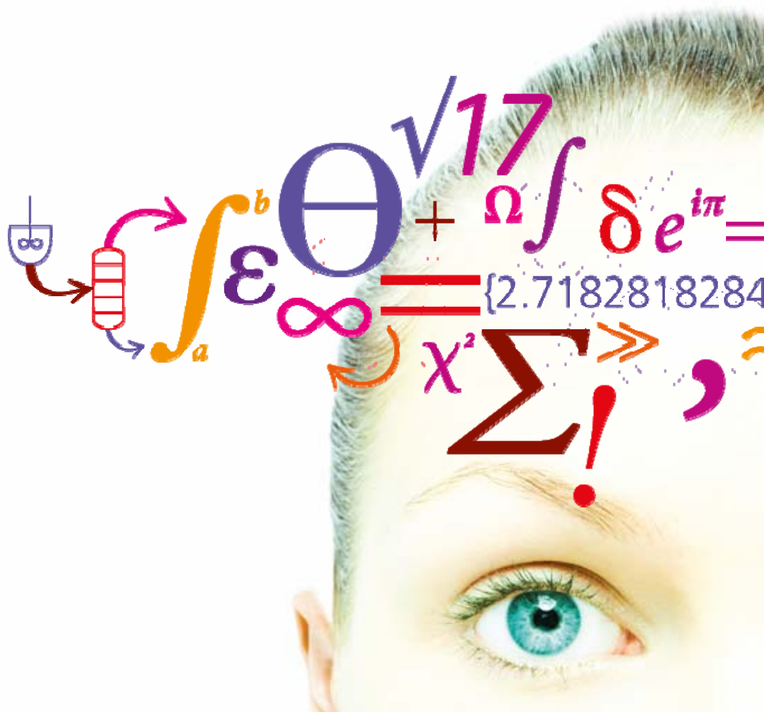
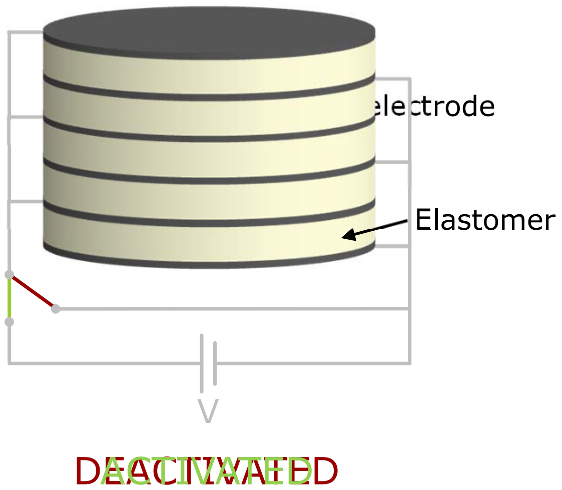


DTU Chemical Engineering
Department of Chemical and Biochemical Engineering

Background - What is dielectric elastomers?

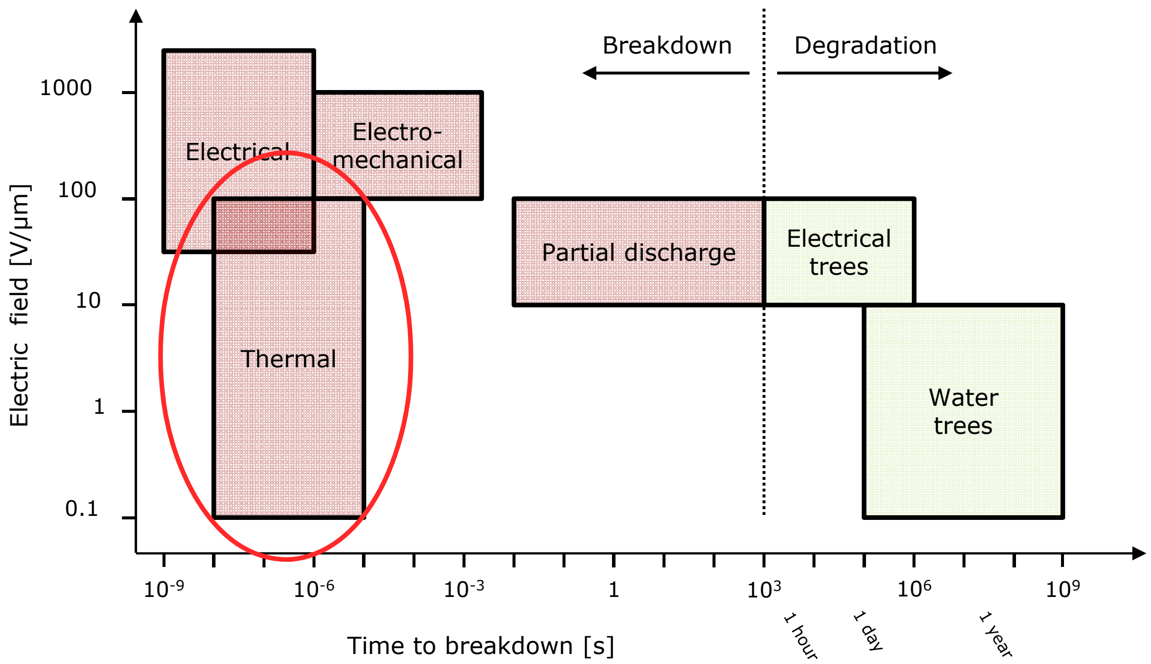


Actuator

Generator

Sensor

Background - Electric breakdowns



Thermal breakdown occurs due to a thermal runaway.

Temperature is increased due to Joule heating, as stated by Joules law:

$$Q = \frac{V^2}{R} = E^2 \sigma \, N \, d \, A$$

Q = Generated heat

V = Applied voltage

R = Resistance

E = Electrical field

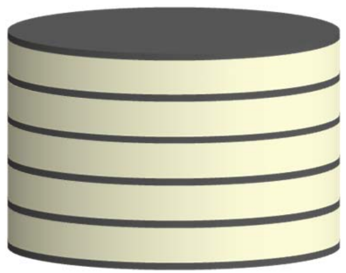
σ = Electrical conductivity

N = # of layer in DE

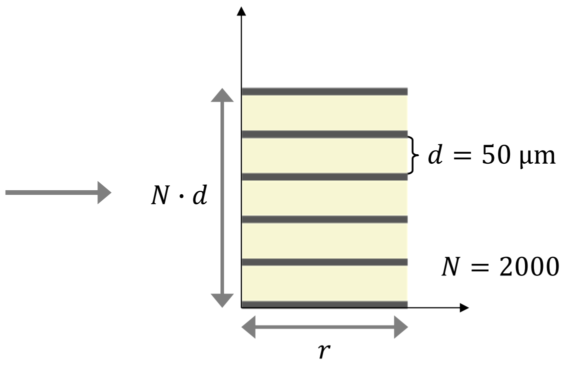
d = height of single layer

A = Cross-sectional area

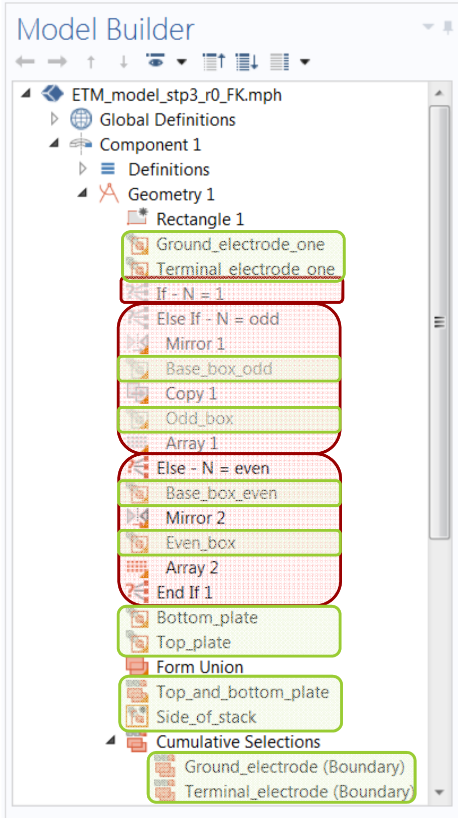
Setup - Geometry



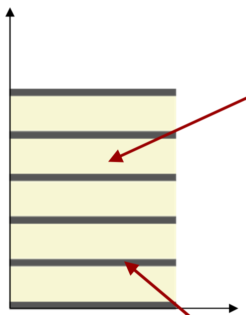
3D



2D axisymmetry



Setup – Materials



Elastomer:

- PDMS elastomer (Elastosil RT625)
- Constant relative permittivity: $\epsilon_{r,\mathrm{PDMS}} = 2.8$
- Constant thermal conductivity: $k_{\mathrm{PDMS}} = 0.15\,\frac{\mathrm{W}}{\mathrm{mK}}$
- Electrical conductivity: $\sigma_{\mathrm{Arr}}(T) = \sigma_{0,\mathrm{Arr}} \exp(-\beta_{\mathrm{Arr}}/T)$
- Yeoh material model for stress-strain behaviour[1]

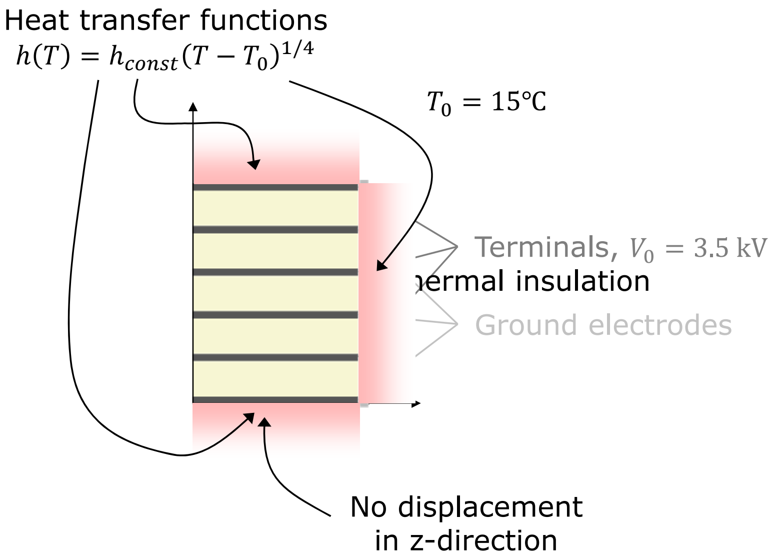
Electrode:

- Neglected

$$d_{\mathrm{electrode}} \ll d_{\mathrm{PDMS}}$$

[1] Kuhring et al. *Finite Element Analysis of Multilayer DEAP Stack-Actuators*, Proc. SPIE, 9430 (2015)

Setup – Physics



Joule heating

Electric Currents

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Electromagnetic Heating

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Heat Transfer in Solids

Electromechanics

Electrostatics

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Electromechanical Forces

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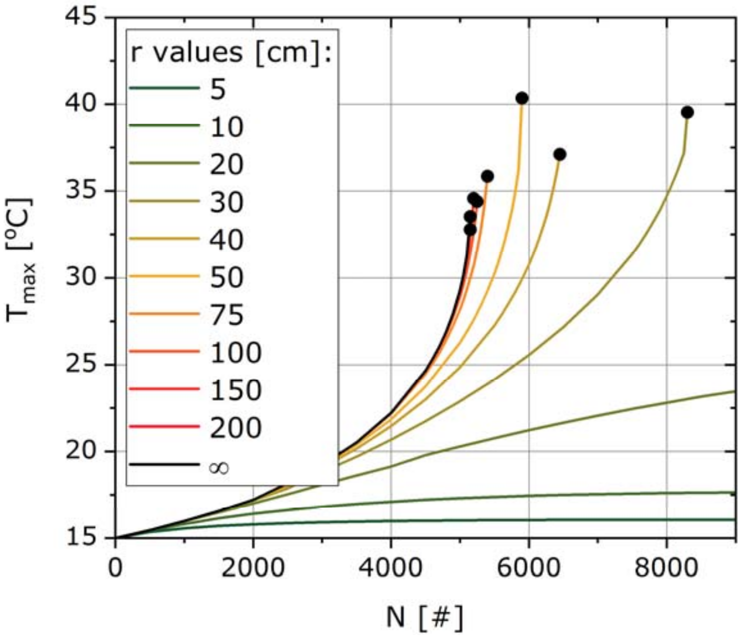
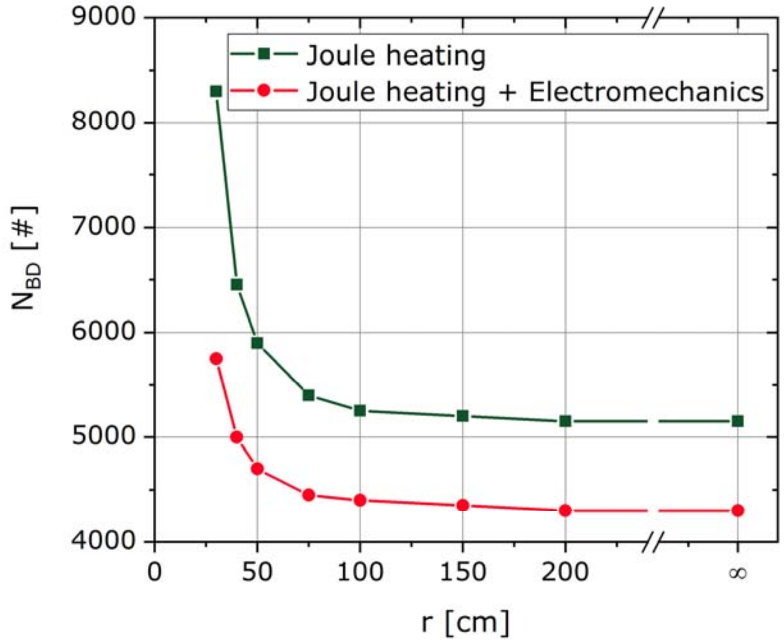
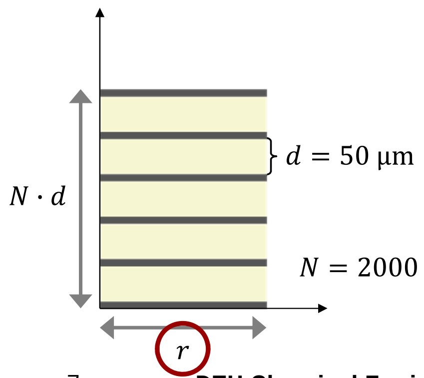
Solid Mechanics

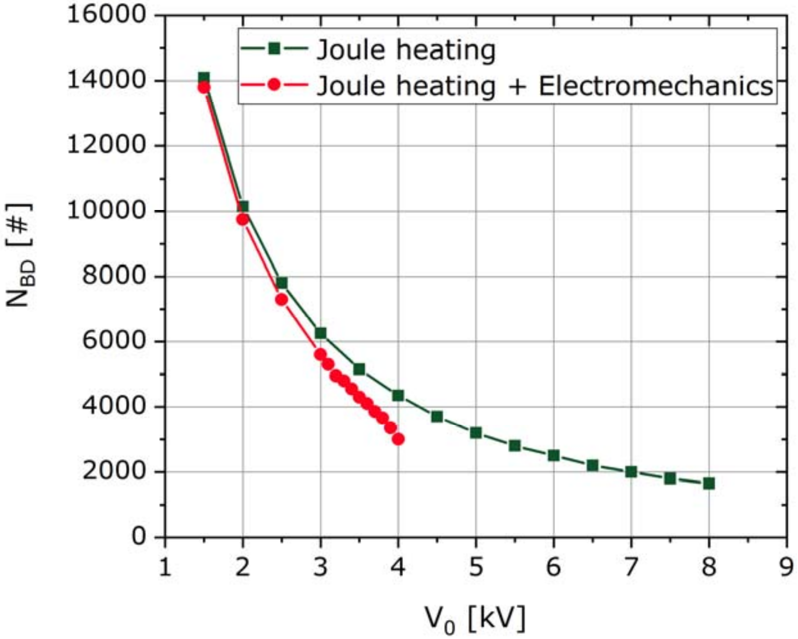
Parameter study – Radius

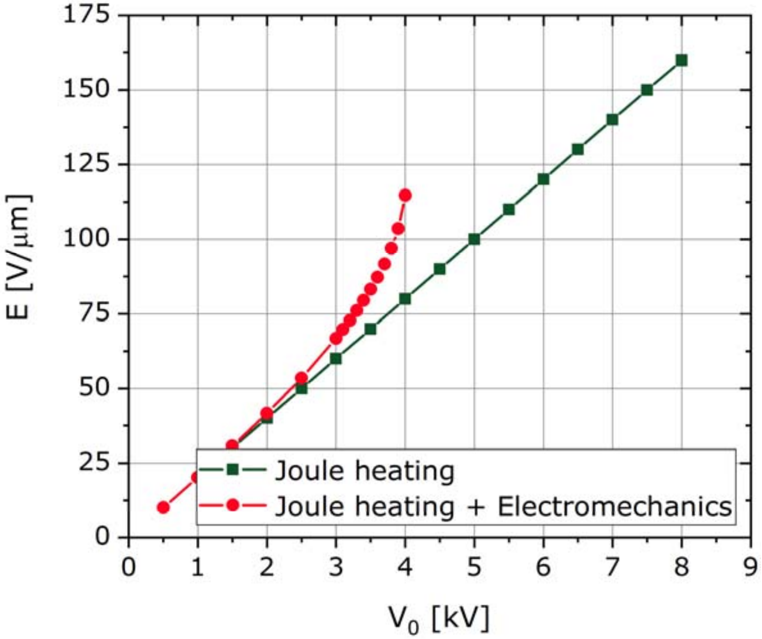


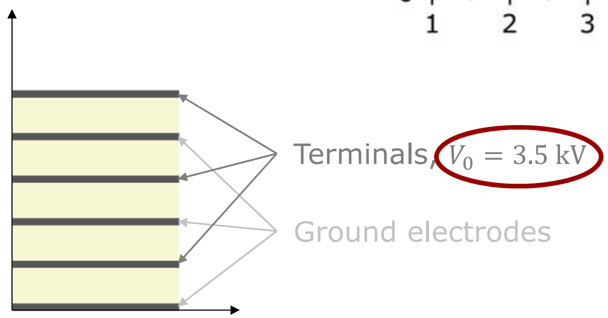




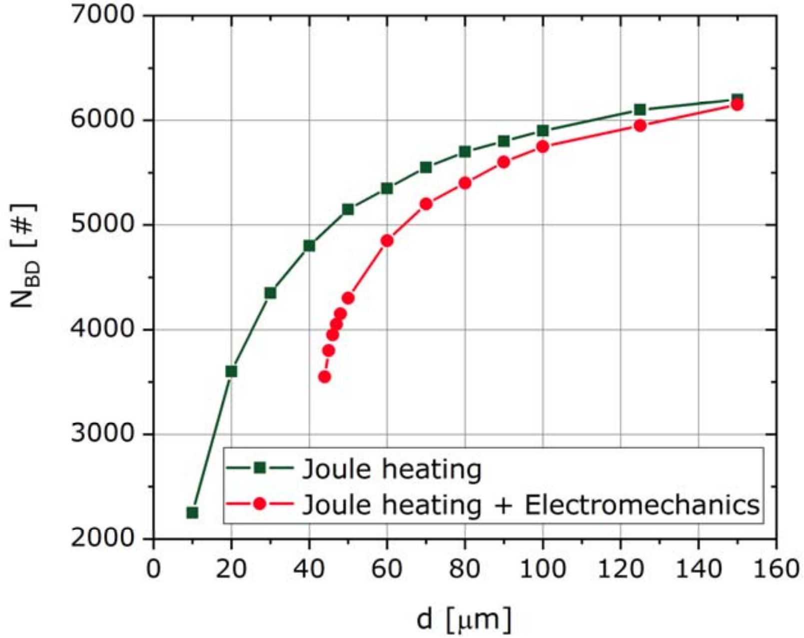
Parameter study – Applied voltage

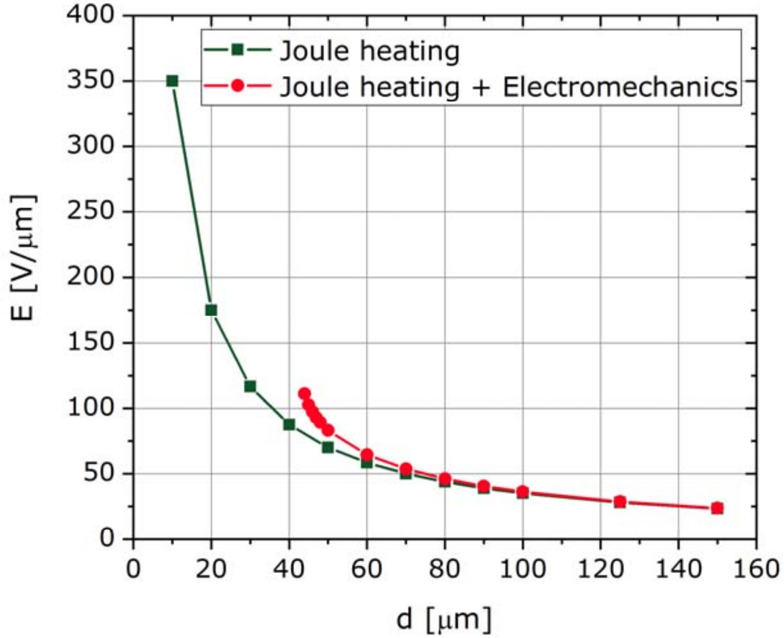


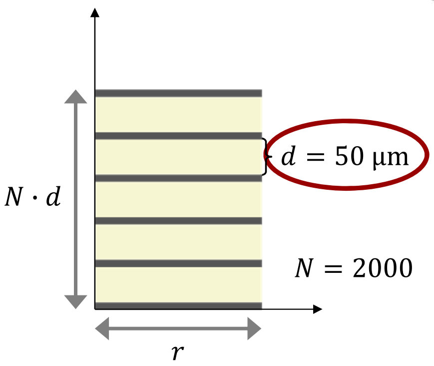




Parameter study - Thickness



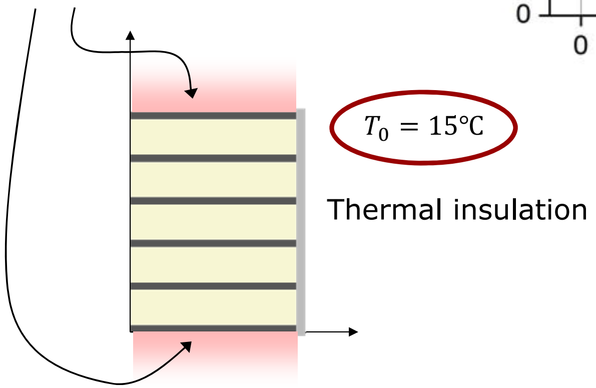


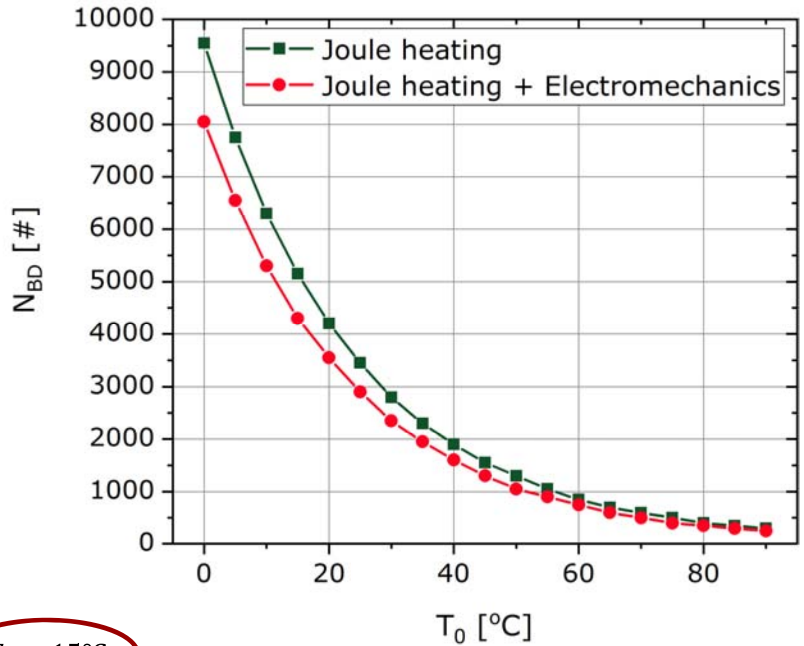


Joule heating:
$Q = \boldsymbol{E}^2 \sigma\, N\, \boldsymbol{d}\, A$

Parameter study – Temperature of surroundings

Heat transfer functions
$h(T) = h_{const}(T - T_0)^{1/4}$





Heat transfer:
$$h(T) = h_{const}(T - \boldsymbol{T_0})^{1/4}$$

Conclusion

- The thermal breakdown of a multi-layered stack of dielectric elastomers has successfully been simulated using:
  - The **joule heating** multiphysics module
  - The **electromechanical** multiphysics module
- It has been found that when including **electromechanical** deformation to the Joule heating simulations, the N_{BD} is **decreased in all cases**
- A parameter study has been performed
  - Increasing **r** leads to a **decrease** in N_{BD}, approaching the value obtained with thermal insulation
  - Increasing $\mathbf{V_0}$ leads to a **decrease** in N_{BD}. The effect of varies material models will be examined.
  - Increasing $\mathbf{d_0}$ leads to a **increase** in N_{BD}, because the decrease in E has bigger impact than the increase in d.
  - Increasing $\mathbf{T_0}$ leads to an **decrease** in N_{BD}, due to limitation in the driving force for heat transfer.

Acknowledgements

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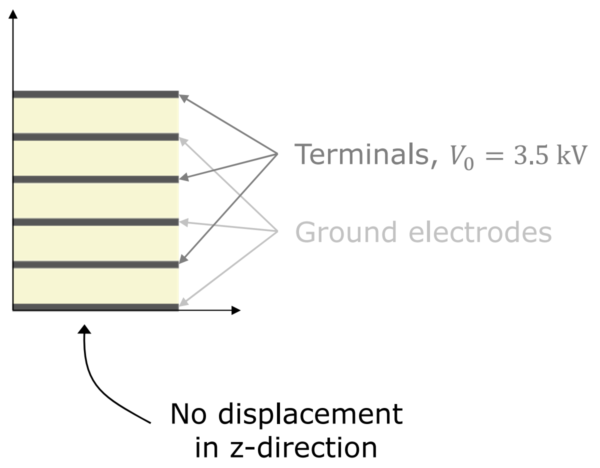
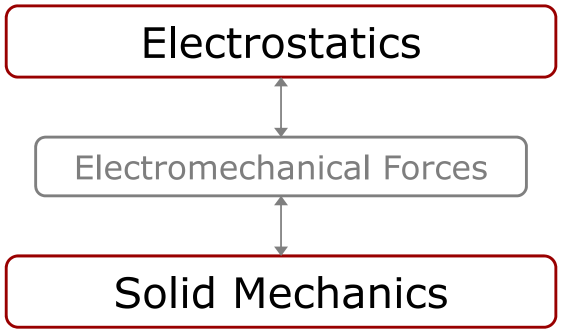
Aage og Johanne Louis-Hansens Fond

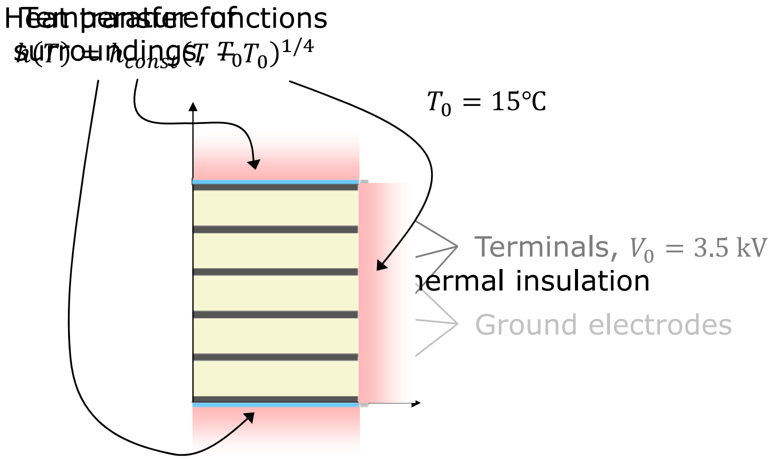
Thank you for your attention

Setup - Electromechanics





Setup – Joule heating



Electric Currents

Electromagnetic Heating

Heat Transfer in Solids

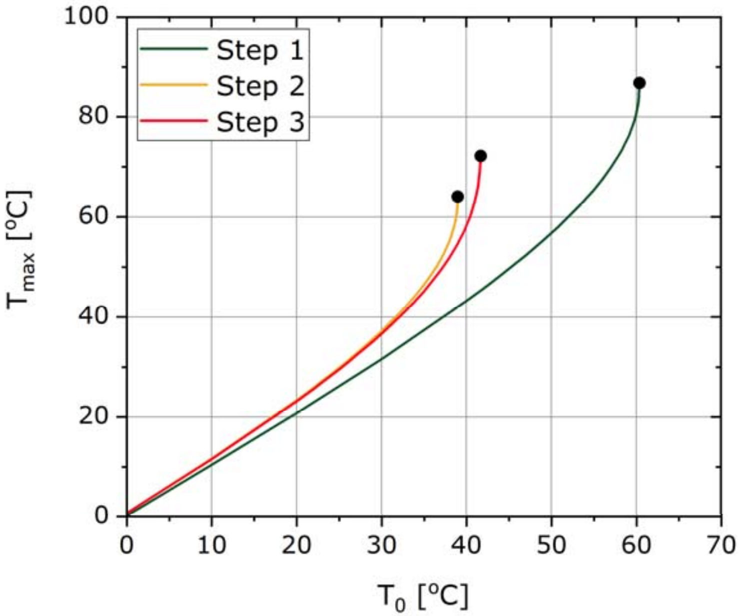
Step 1: Constant temperature on top and bottom, Thermal insulation on the cylindrical surface

Step 2: Heat transfer functions on top and bottom, Thermal insulation on the cylindrical surface

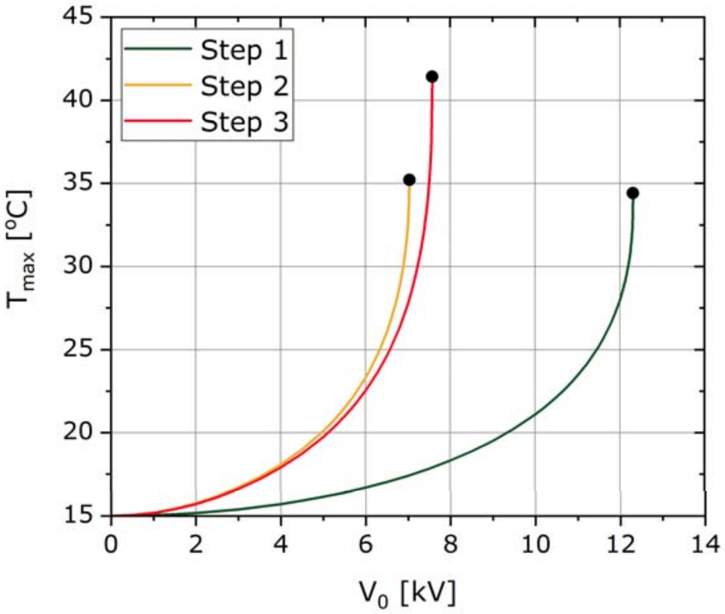
Step 3: Heat transfer functions on all surfaces

Effect of heat transfer – Joule heating

Varying T_0



Varying V_0



Varying N