ISPA 2007

Downscaling of Finger Electrodes in 3-3 Fiber Composite Transducers

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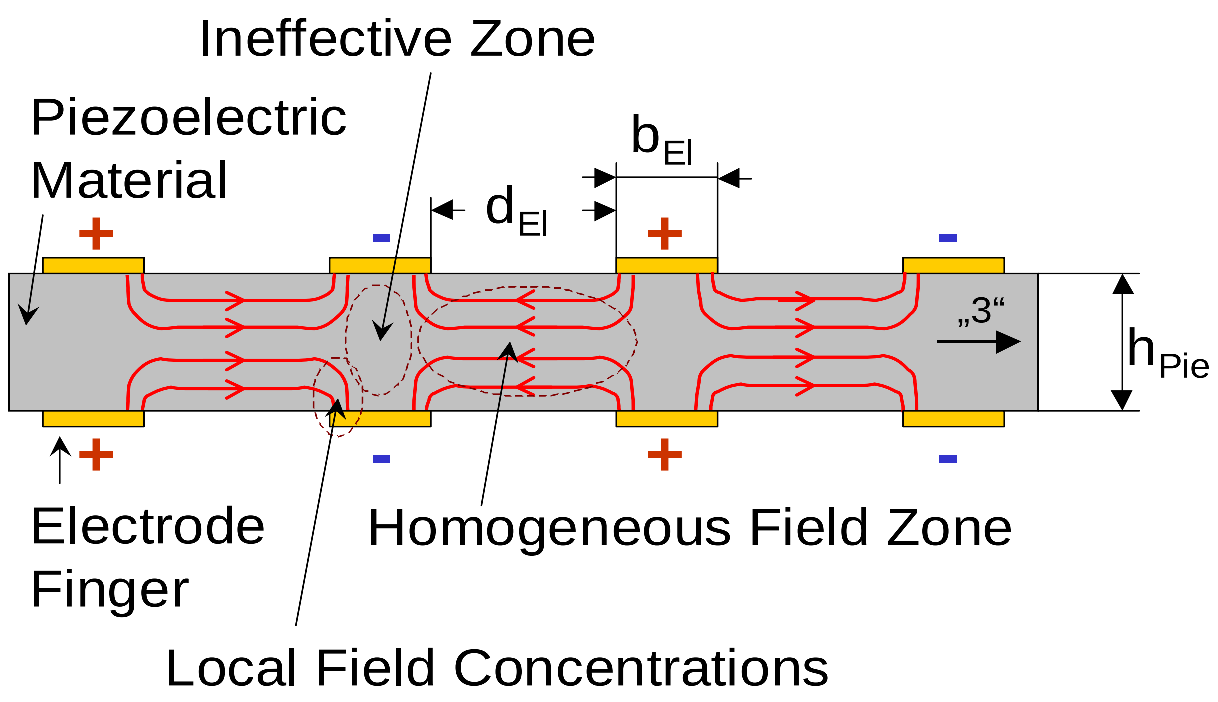
Outline

- Introduction
- Modeling
- Experimental results
- Conclusions

The problem

The IDE geometry,

- finger distance d_{el} = 0,5mm .. 1mm
- driving voltages 1kV – 2 kV.
- limits industrial application due to systems incompatibility and cost

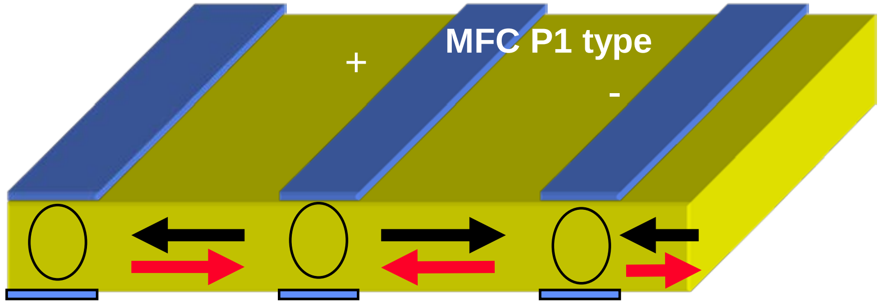


The issue

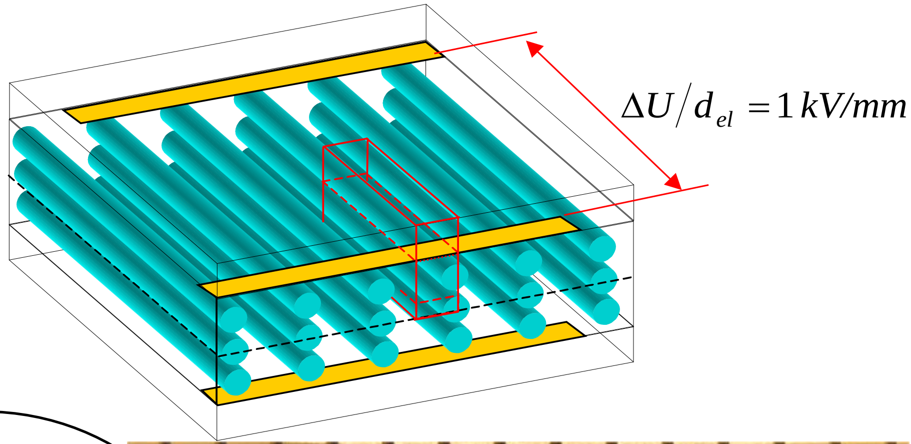
Can the driving voltage be reduced by down scaling the finger IDE geometry, still providing high efficiency and reliability of the device ?

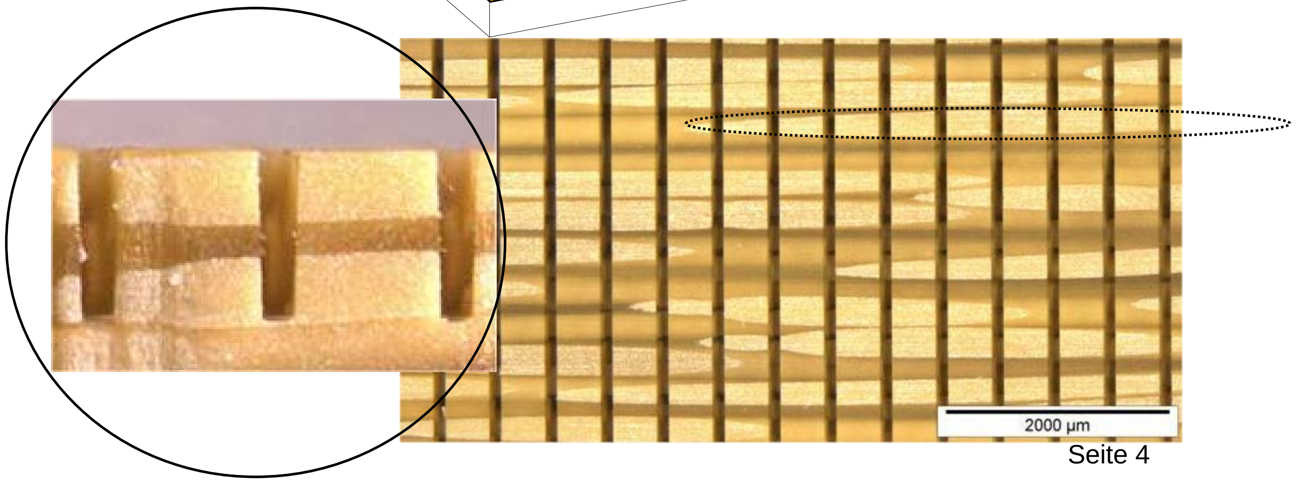
Considered Devices

Macro Fiber Composite (P1)



Smart Fiber Composite





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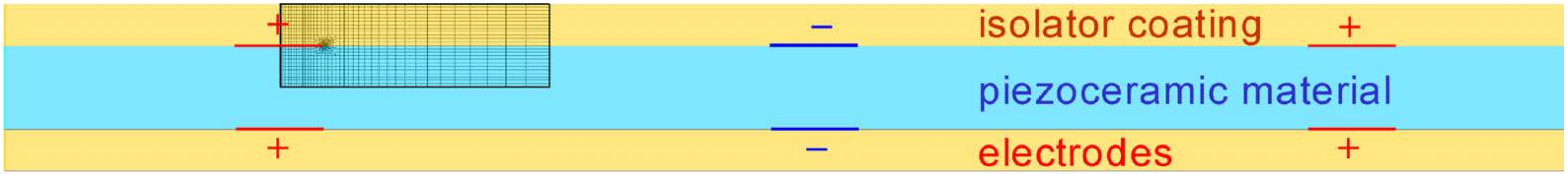
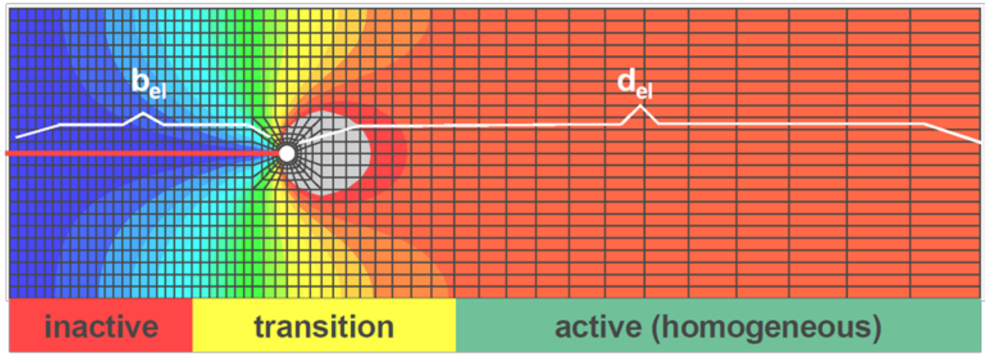
Finite Element Model – Direct Metalization of PZT Fiber

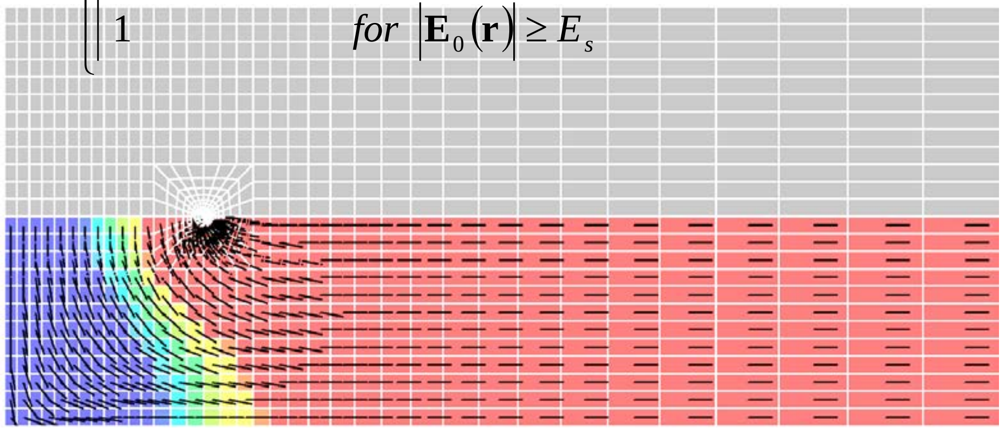


FEM using ANSYS

- three level polarization model
- poling direction $\mathbf{e}^P(\mathbf{r}) = \frac{\mathbf{E}_0(\mathbf{r})}{|\mathbf{E}_0(\mathbf{r})|}$

$$X(\mathbf{r}) = \begin{cases} 0 & for \ |\mathbf{E}_0(\mathbf{r})| < E_c \\ \frac{|\mathbf{E}_0(\mathbf{r})| - E_c}{E_s - E_c} & for \ E_c \le |\mathbf{E}_0(\mathbf{r})| < E_s \\ 1 & for \ |\mathbf{E}_0(\mathbf{r})| \ge E_s \end{cases}$$





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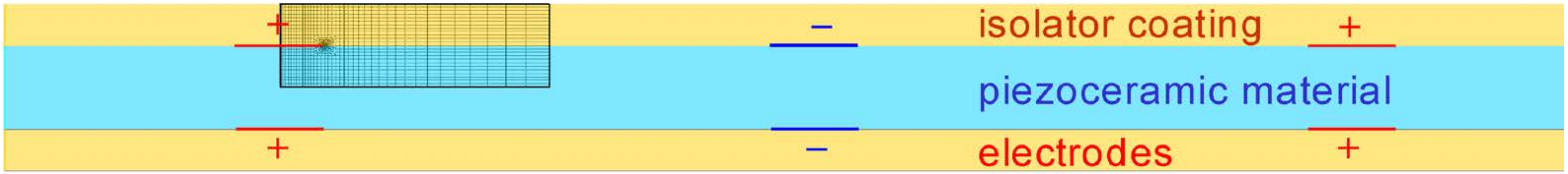
Finite Element Model – Consequences of IDE



Consequences of IDE

- Reduced active zone d_{el} - 2 l_{tr}
- Repeating d_{el} + b_{el} length partly passive
- Scaled piezo module $C{\cdot}d_{33}$ accounting for the deformational constraint by the composite stack arrangement
- potential difference between neighbouring electrode fingers reduced by some voltage drop $\Delta U - 2\,\Delta\phi$

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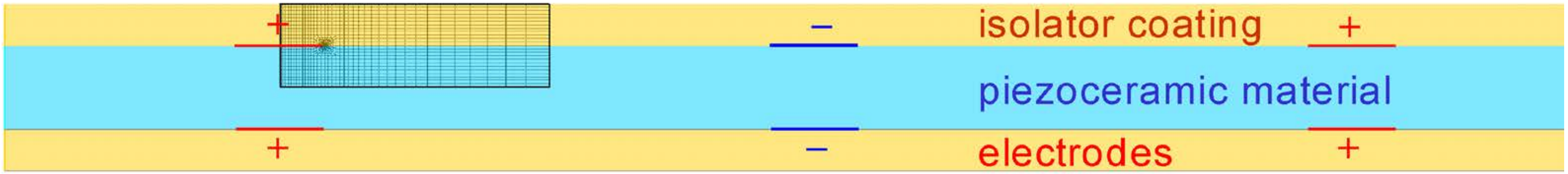
Longitudinal Deformation



The maximum longitudinal deformation available from a layer arrangement with constant longitudinal electric field

$$\gamma_{\max} = C \cdot d_{33} \cdot \frac{\Delta U}{d_{el}}$$

Longitudinal deformation with inhomogeneous electric field due to IDE electrodes

$$\gamma_{eff} = \frac{d_{el} - 2 \cdot l_{tr}}{d_{el} + b_{el}} \cdot C \cdot d_{33} \cdot \left(\frac{\Delta U - 2 \cdot \Delta\phi}{d_{el}} \right)$$

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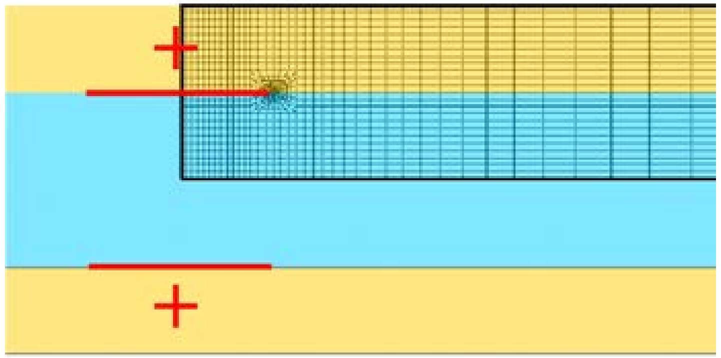
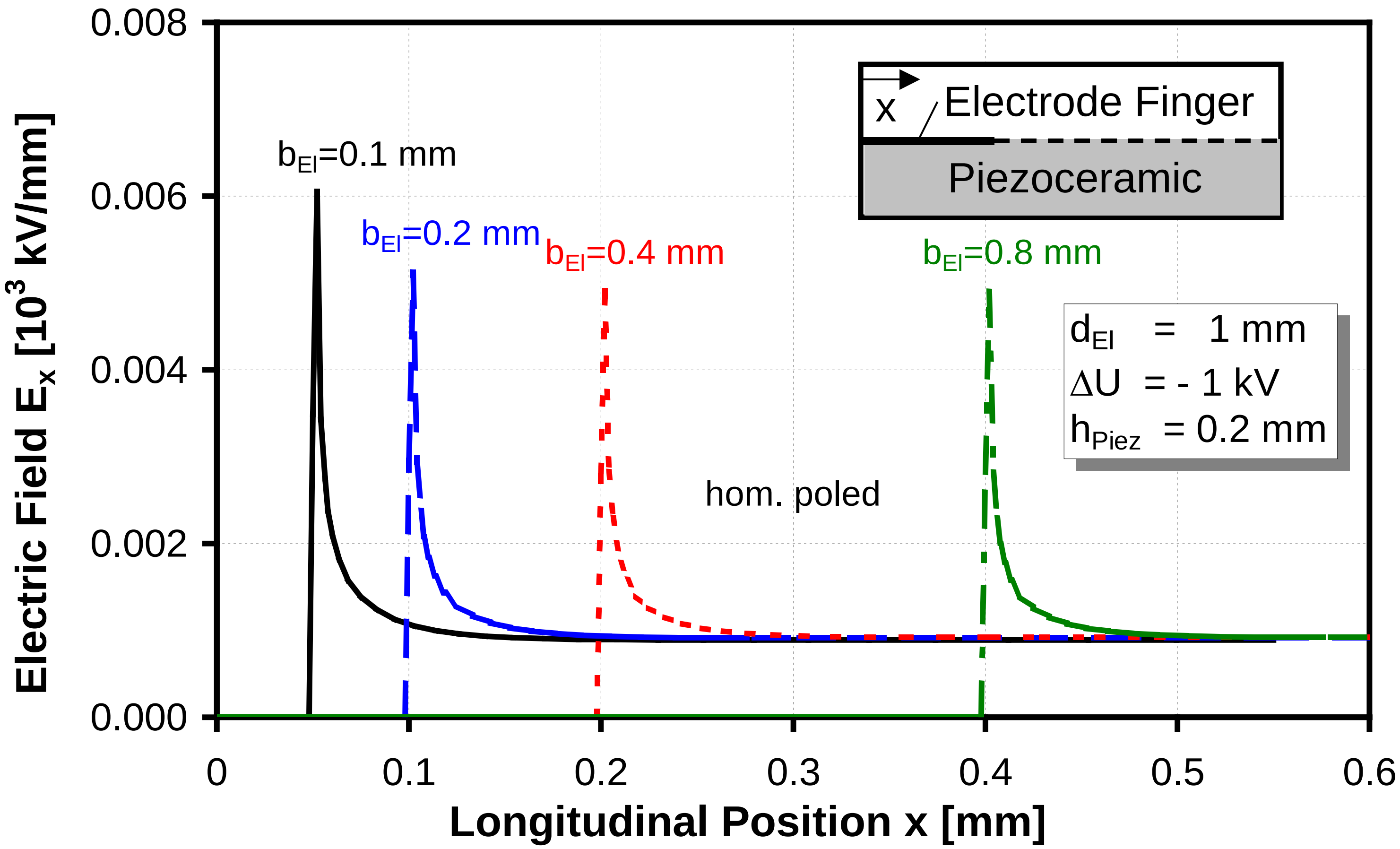
Local E- field concentrations, effect of finger width





Local field concentration E_x

- at finger edge .. 6 kV/mm
- field concentration zone 50 µm
- U -> U- 2 ϕ

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* Beckert W, Kreher WS
Computational Materials
Science 26 (2003) 36–45

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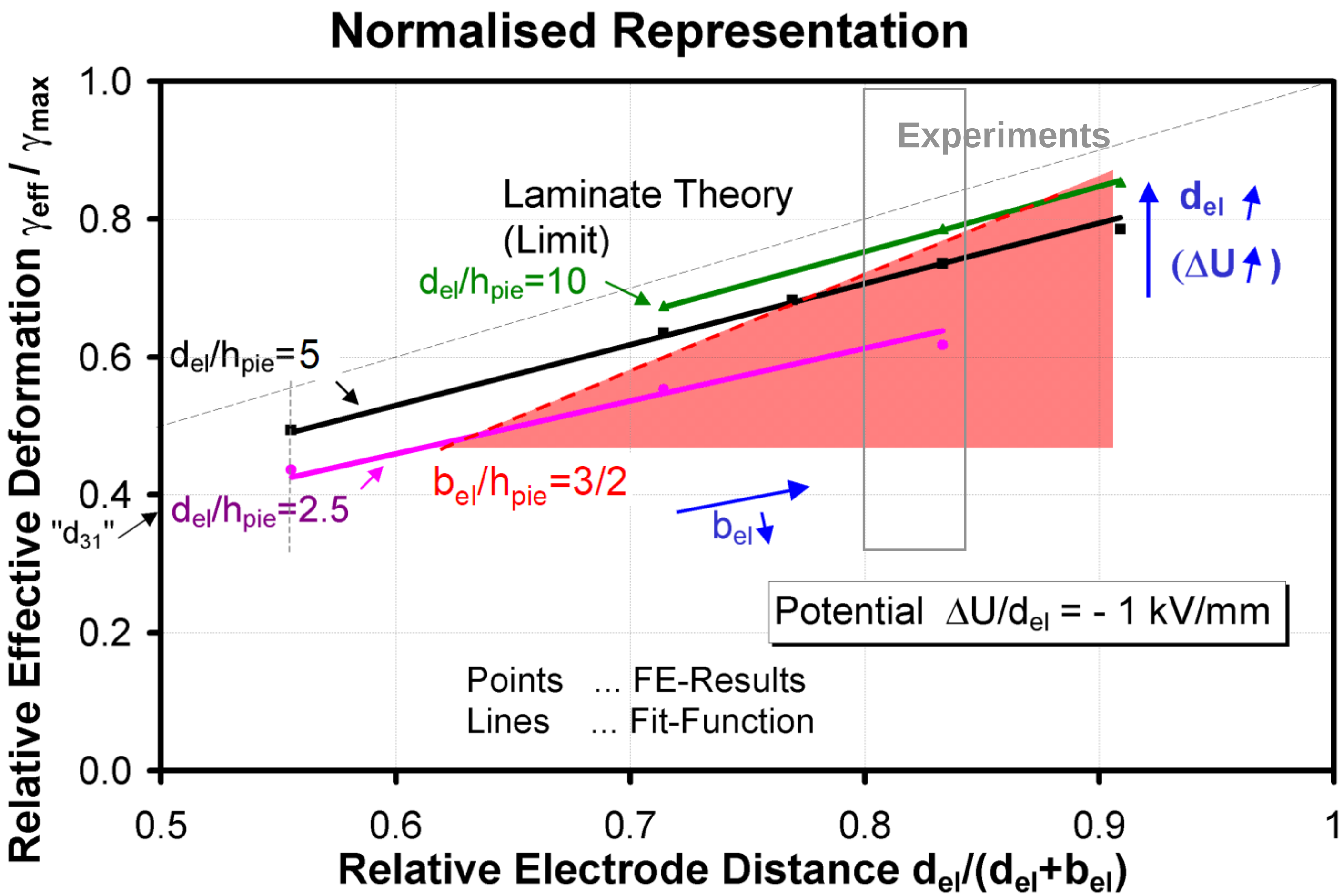
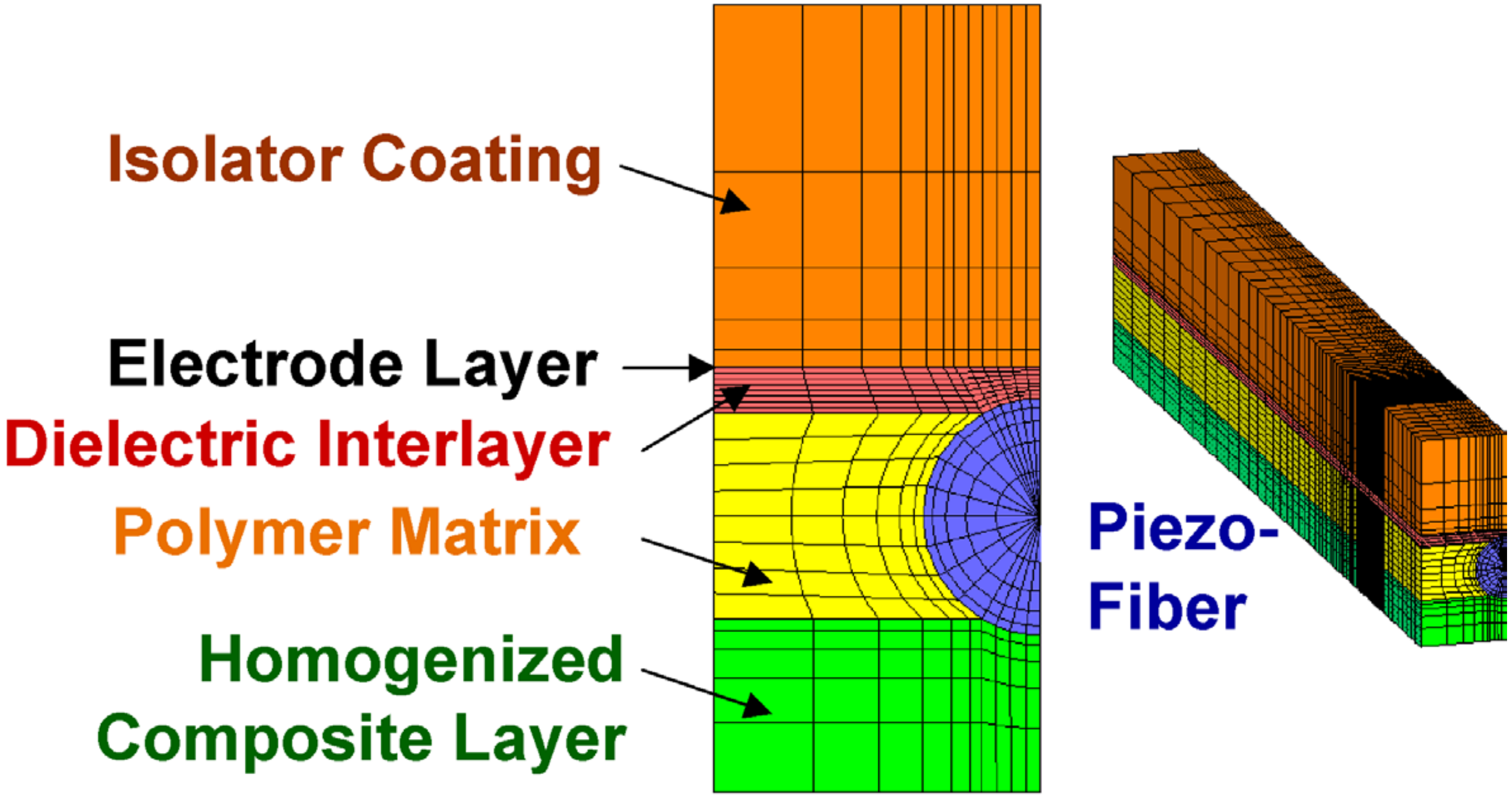
Longitudinal Strain Performance

Increased Performance
- Increase the d / h ratio
- decrease the electrode finger width
- increase the electrode finger distance.

Restrictions
- Calculated field distributions show a saturation behaviour at
  b ≥ 1,5 h
  d ≥ 4 h
- Increasing the electrode distance d requires increase of the control voltage



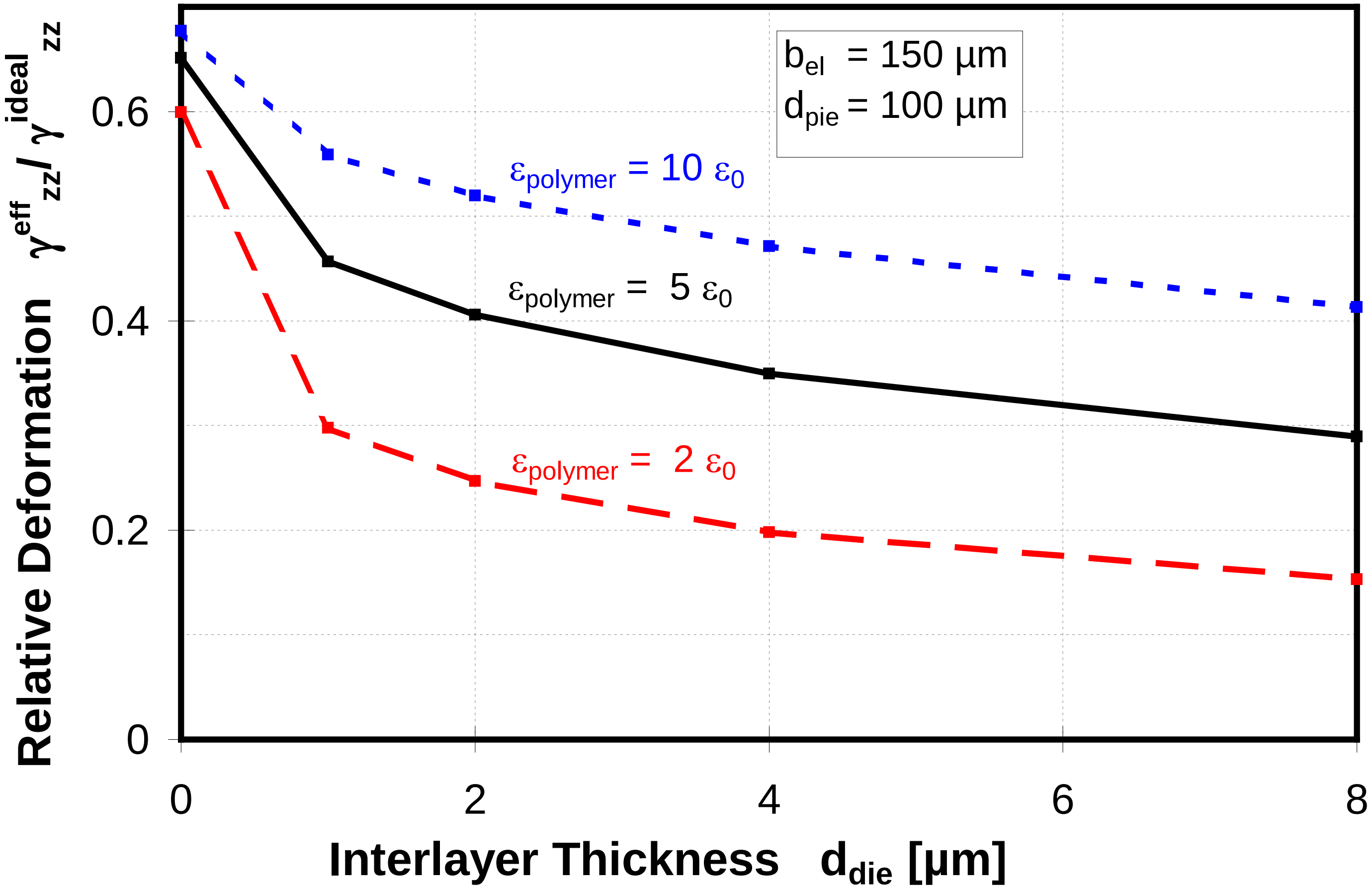
Finite Element Model – Effect of Dielectric Interlayer



Longitudinal Strain Performance – Effect of Dielectric Interlayer

Local strain performance

- Reduced by dielectric interlayer
- Improved by the increase of permittivity of the dielectric interlayer



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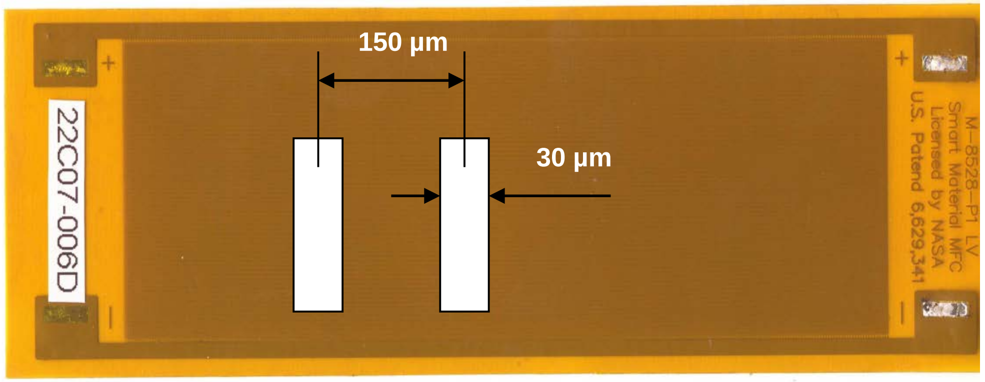
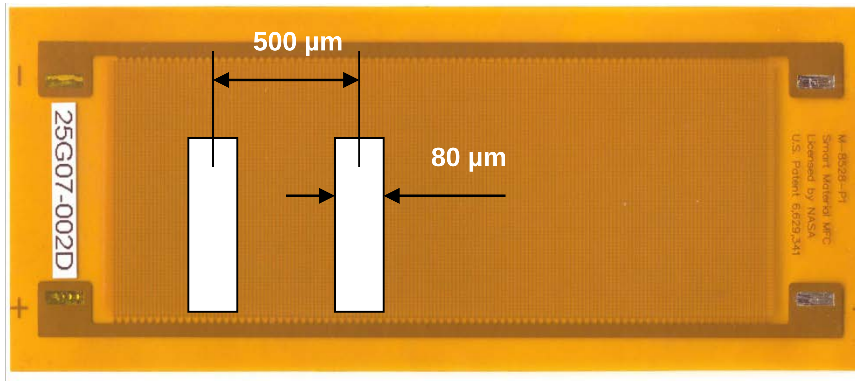
Test Samples

Low voltage 500 V
h = 180 µm, 100 µm

High voltage 1500 – 1800 V
h = 180 µm





b/h = 0,17 & 0,30
d/h = 0,67 & 1,20

b/h = 0,44 --> > 1,5
d/h = 2,33 --> > 4

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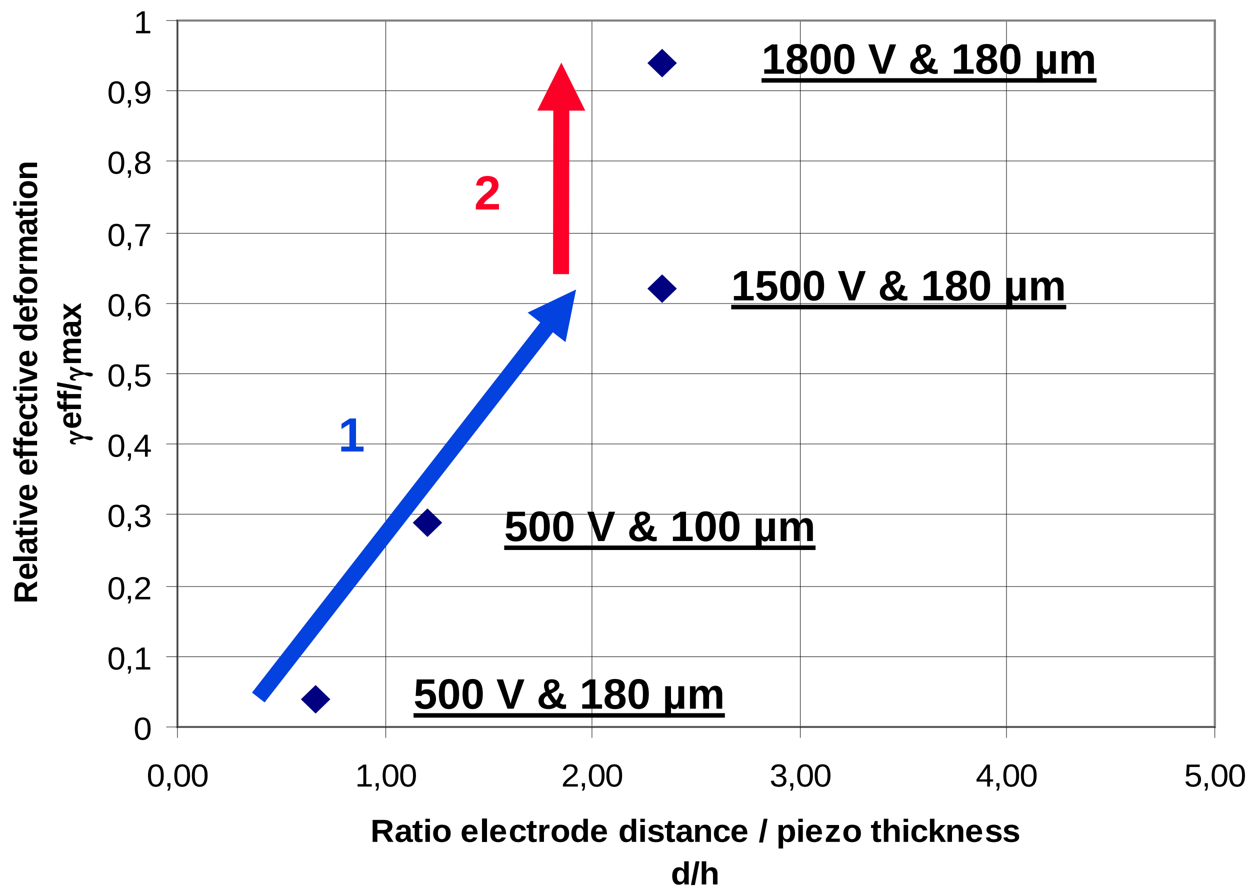
Performance

Increase of relative effective deformation by

1
homogenization of the electric field between the electrode edges

2
Increase of the electric field strength within the ceramic by compensation of the field drop at finger edges



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Conclusions

- According to FEM modeling, high performance MFC require electrode distance d and finger width b related to PZT thickness h by the relations d > 4 h and d > 1,5 h. This is due to electric field homogenization between the finger edges.
- E.g., Low driving voltages require downscaling of finger width b, finger distance d and ceramic thickness h, as well. Accordingly, the expected block force is reduced.
- A 500 V - MFC was prepared with b=30µm / d=120µm showing acceptable performance if the IDE was applied on 100µm PZT – fibers.
- Electric field drops at the finger edges and dielectric interlayers, which are found in MFC and SFC devices. This may be compensated by raised operation field strength > 2 kV/mm.
- The calculated electric field gradient at the IDE edges approaches a few kV/mm. Devices should be investigated in this area in view of degradation and failure modes.

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