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Relaxor/ferroelectric composites for high strain applications

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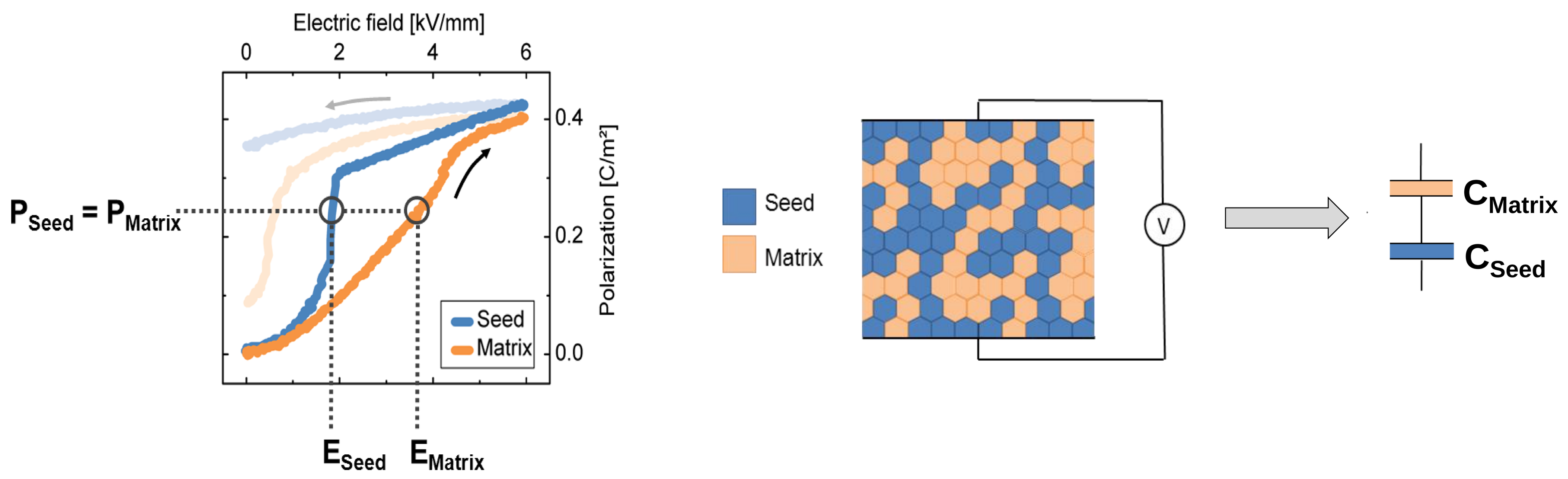
Motivation

- Bi-based piezoceramics are one of the most promising lead-free alternatives for actuator applications
- giant strains are generated by a reversible electric-field-induced phase transformation from ergodic relaxor to ferroelectric phase
- one of the major drawbacks is the requirement of relatively high electric fields (~ 6 kV/mm) to induce this phase transformation and therefore to obtain the giant strain

Composite approach

- the field level required to trigger the relaxor-to-ferroelectric transition (E_{pol}) is reduced by making composites comprised of such giant strain ergodic relaxors (matrix) and nonergodic relaxors or ferroelectric materials (seed)
- the composite approach can be rationalized by the coupling of strain and polarization of the constituent phases

Concept of polarization coupling



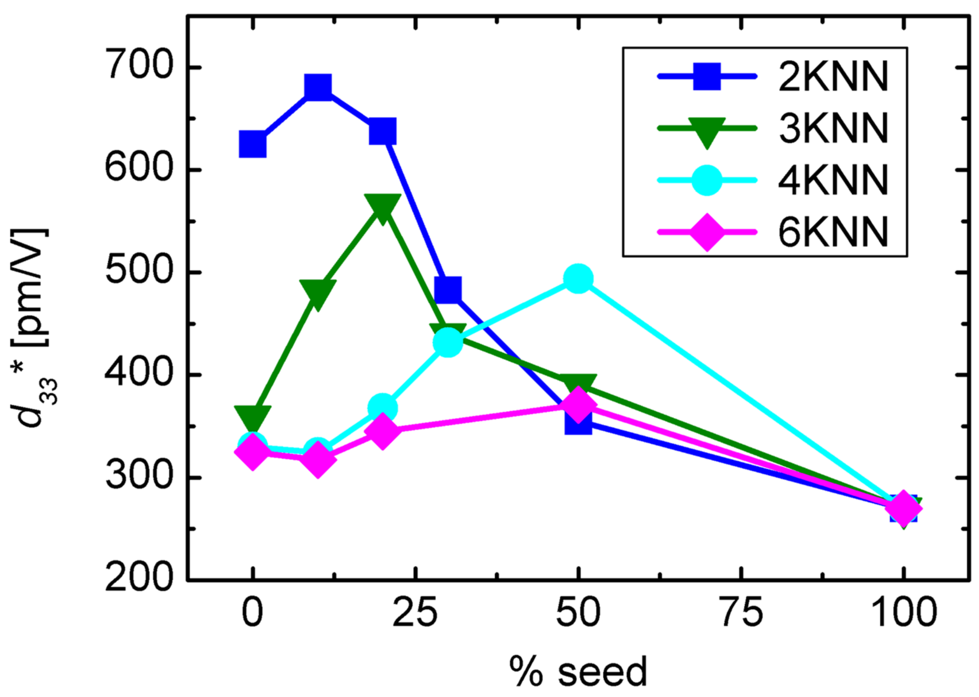
Materials used in this work

- nonergodic relaxor seed
  $0.93\ Bi_{0.5}Na_{0.5}TiO_3 - 0.07\ BaTiO_3$
- ergodic relaxor matrices
  $0.94\text{-}x\ Bi_{0.5}Na_{0.5}TiO_3 - 0.06\ BaTiO_3 - x\ K_{0.5}Na_{0.5}NbO_3$
  (referred as to 100xKNN) with x = 0.02, 0.03, 0.04 and 0.06

Results at E_{max}= 4 kV/mm

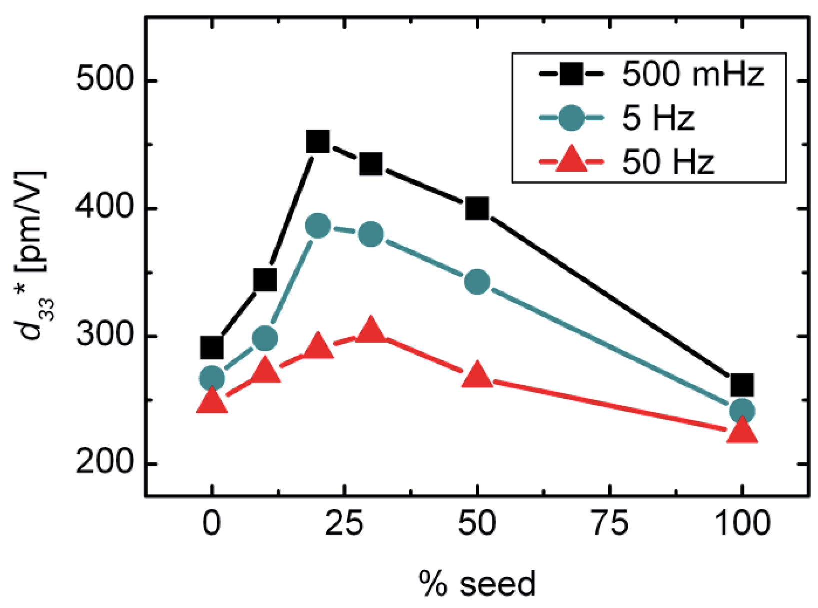
Normalized strain d_{33}* (i.e. S_{max}/E_{max})

- d_{33}* of the pure matrix is significantly enhanced by inserting seed phase
- this „composite effect" is present in all investigated matrices, irrespective on their KNN-content
  → demonstrates universality of the composite effect
- the KNN-content of the matrix has a considerable influence on the maximum d_{33}* available and the amount of seed required to reach the optimum d_{33}*
- the highest d_{33}* at RT: 2KNN – matrix with 10% seed



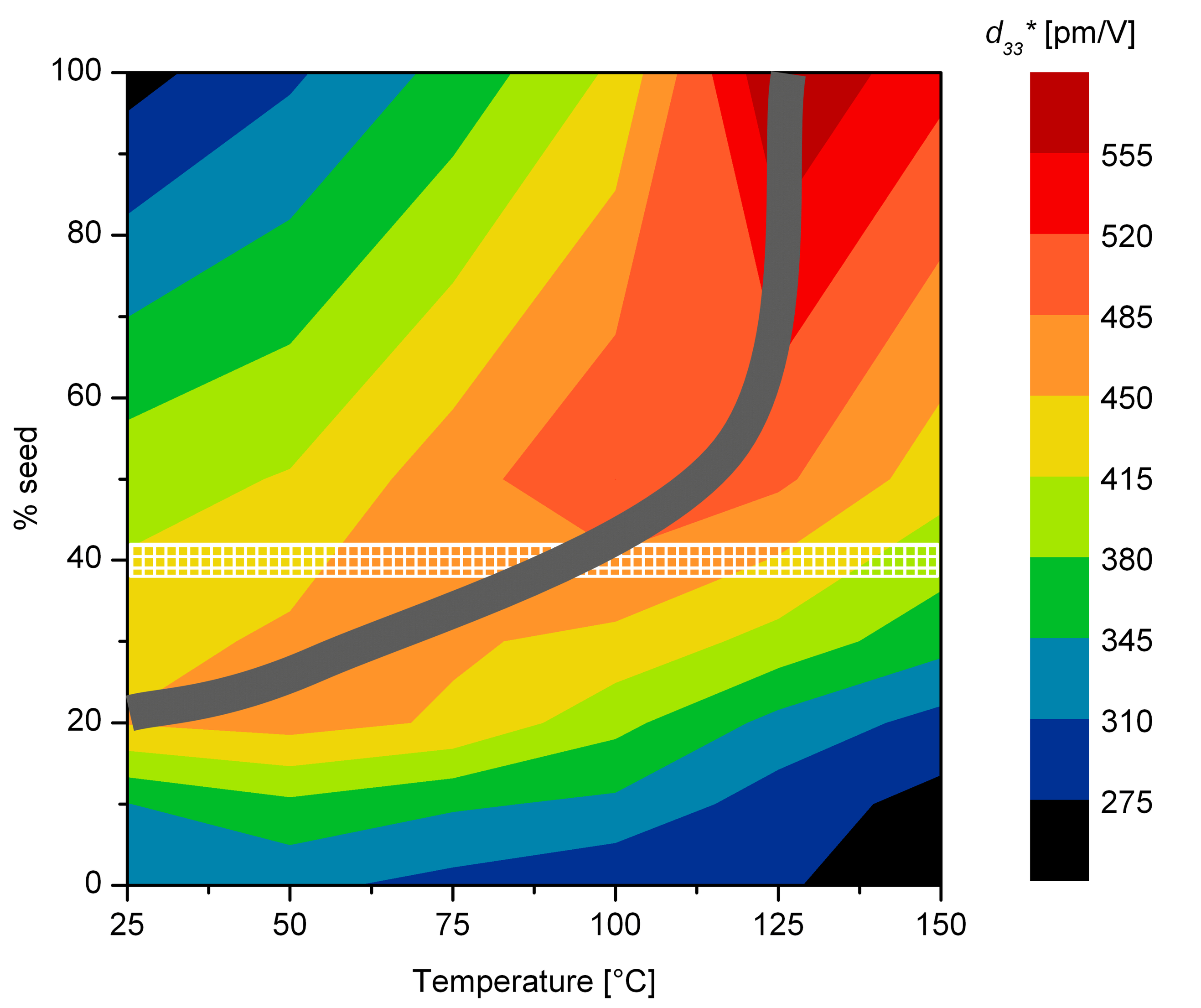
Frequency dependence of 3KNN-composites

- optimum in d_{33}* shifts to higher seed contents with increasing frequency
- can be rationalized by an increase in E_{pol} due to the kinetic limitation of the electric-field-induced phase transformation, which is compensated by additional seed phase
- pronounced frequency dependence of composites due to vicinity of E_{max} to E_{pol}
- this is inherent to giant strain mechanism
  → adjust E_{max} to meet frequency range of specific application



Temperature dependence of 3KNN-composites

- highest d_{33}* at room temperature (RT): 20% seed
- this optimum seed content shifts to higher seed contents with increasing temperature (compare grey line in the figure below)
- the best temperature stability is expected for a composite with about 40% seed (white shaded area in the figure below)
  → in order to improve the temperature-stability of the composites over the entire temperature range of 25 to 150°C a sacrifice of strain at RT has to be made



Conclusions

- composite approach successfully implemented: by inserting seed phase the giant strain inherent to the matrix material is already induced at low electric fields → this means in turn: higher strains available at lower electric fields
- the composite approach can be used to tailor the properties of giant strain materials regarding the specific operational requirements such as temperature-stability

References: Groh et al., Adv. Funct. Mater., 24:356, 2014. Groh et al., J. Am. Ceram. Soc., 97(5):1465, 2014. Groh et al., J. Appl. Phys., 115(23):234107, 2014.