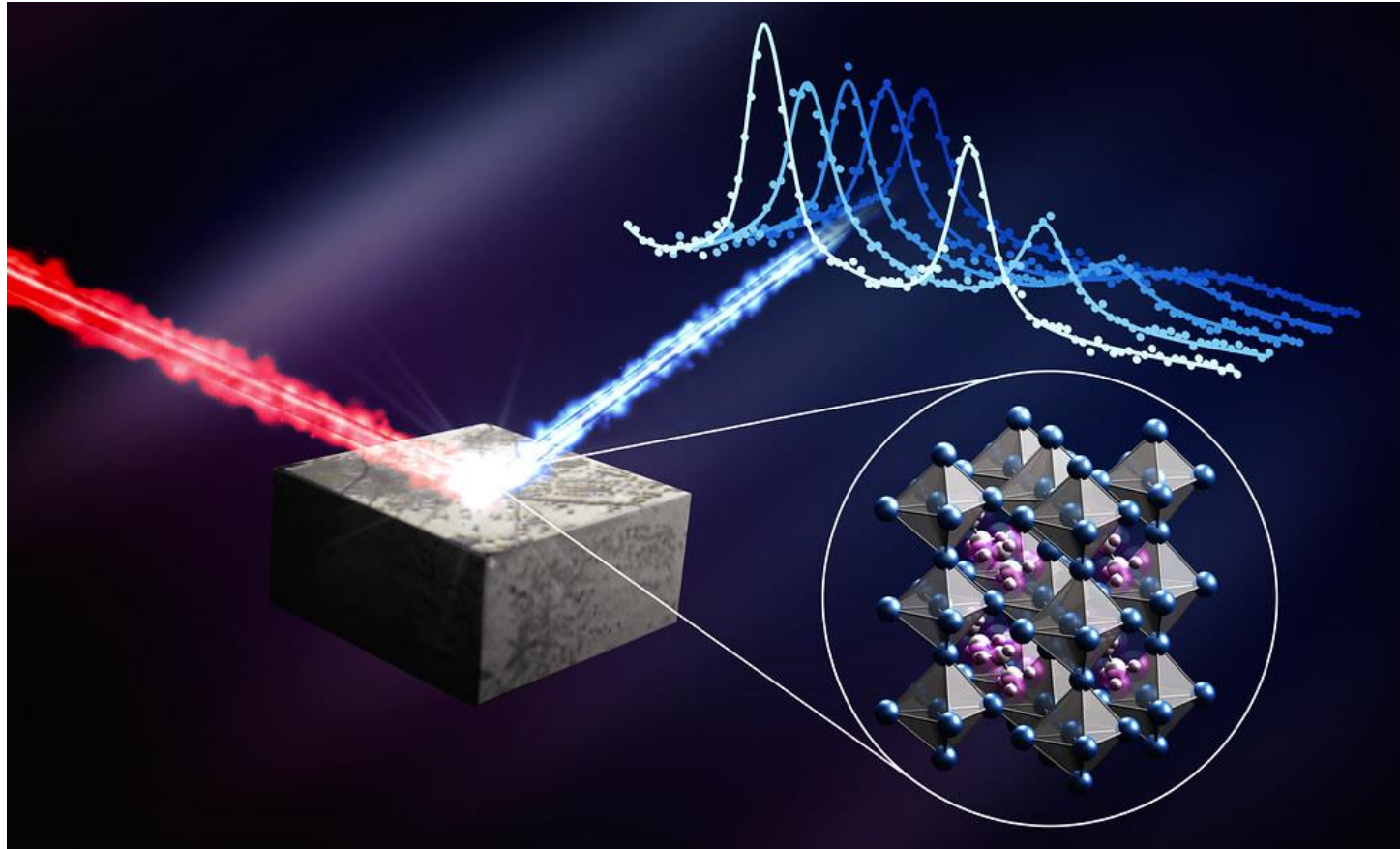


Road Towards Flexible Smart Materials



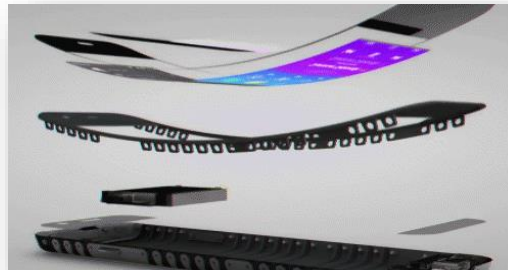
Jibran Khaliq

**Department of Mechanical and Construction Engineering, Northumbria University
at Newcastle, Newcastle Upon Tyne, United Kingdom.**

Smart Materials



Darkens in Sunlight



Smart materials

Everywhere.....

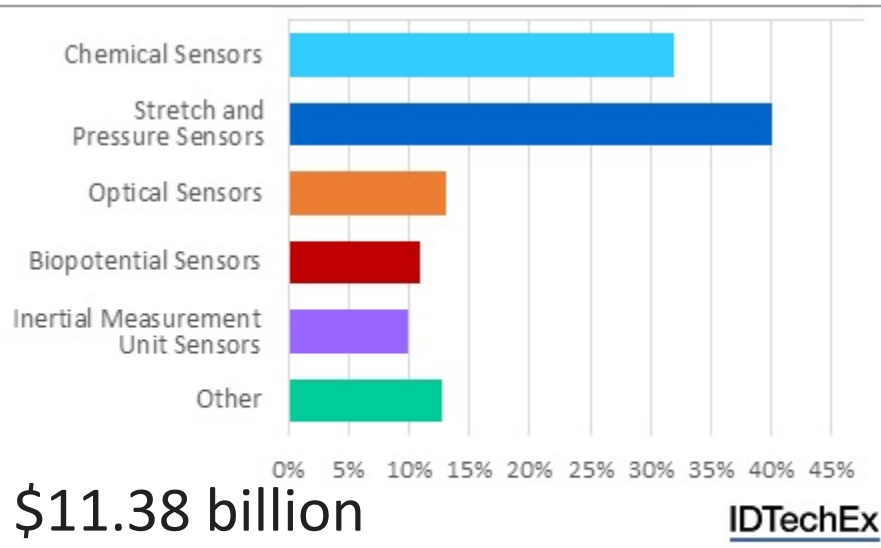


Fig 1. CAGR by sensor type 2015-2025. Source: IDTechEx Research report "Wearable Sensors 2015-2025: Market Forecasts, Technologies, Players"

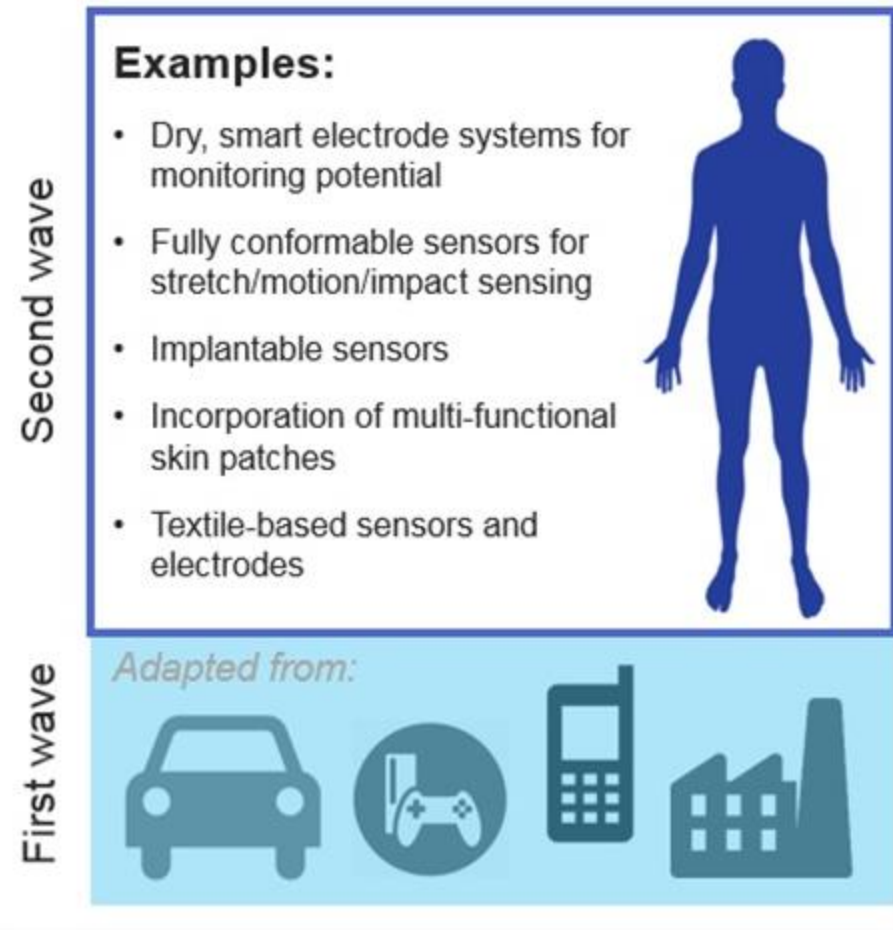
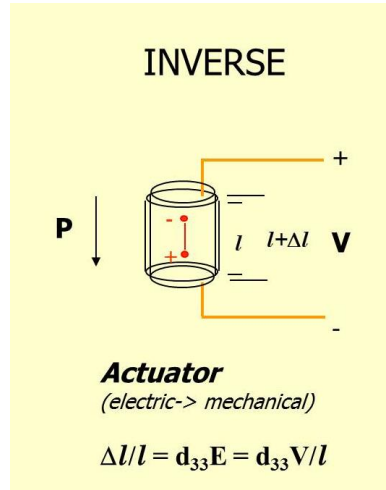
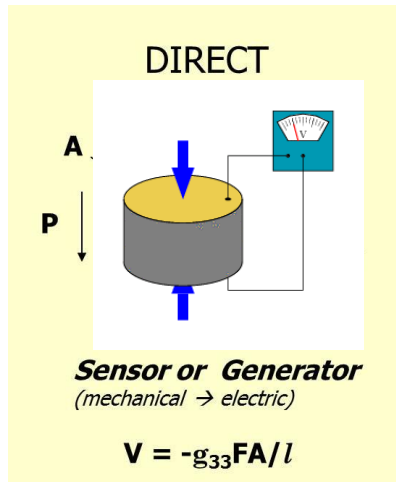


Fig 2. First and second wave wearable sensors. Source: IDTechEx Research report "Wearable Sensors 2015-2025: Market Forecasts, Technologies, Players" www.IDTechEx.com/wtsensors.

Piezoelectricity and Materials



$$g_{33} = \frac{d_{33}}{\epsilon_0 \epsilon_r}$$

Ceramic based:

Expensive, difficult to produce, Fragile
low shock resistance - flexibility
Difficult to integrate in product

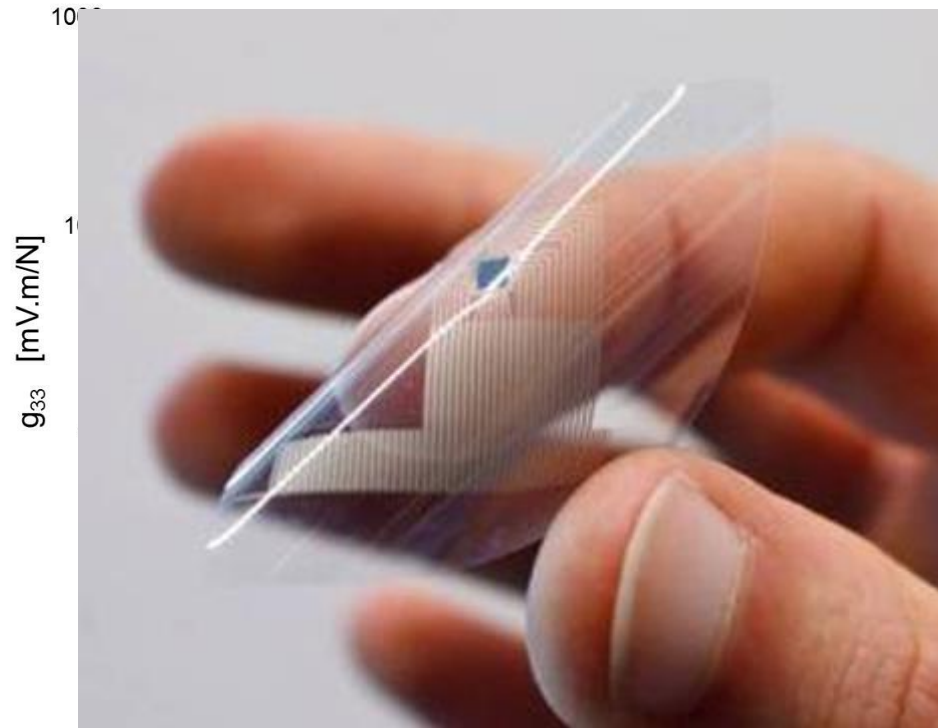
Polymer based:

PVDF family (processing – T range)

Semiconductor based:

Limited functionality / temperature range
Complex / fragile, Limited flexibility

Need for flexible sensors $\rightarrow$ functional electroceramic material composites

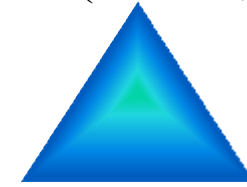


Sensor Development

1. Make them more sensitive
2. Reduce cost
3. Lead free
4. Can be manufactured at a large scale

Structure (random, aligned)

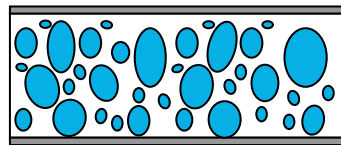
Polymer matrix



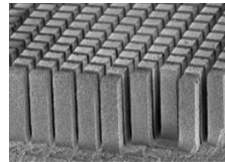
Filler (powder)

Composite

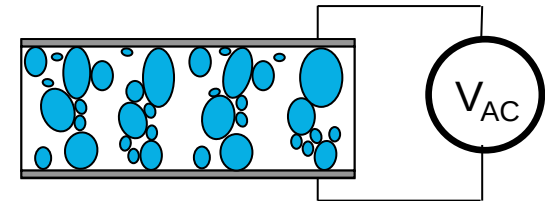
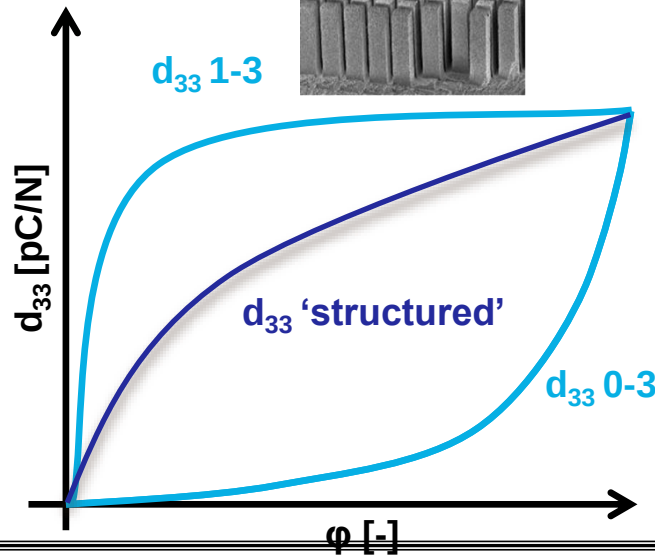
Properties improved by 100%
Estimated cost reduced by 50%



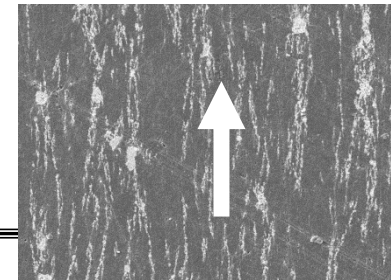
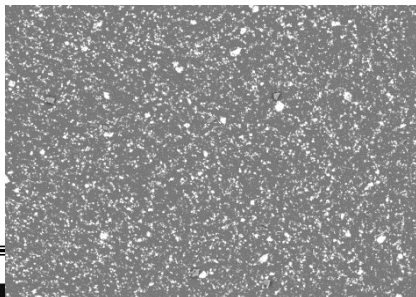
Random,
Sensors

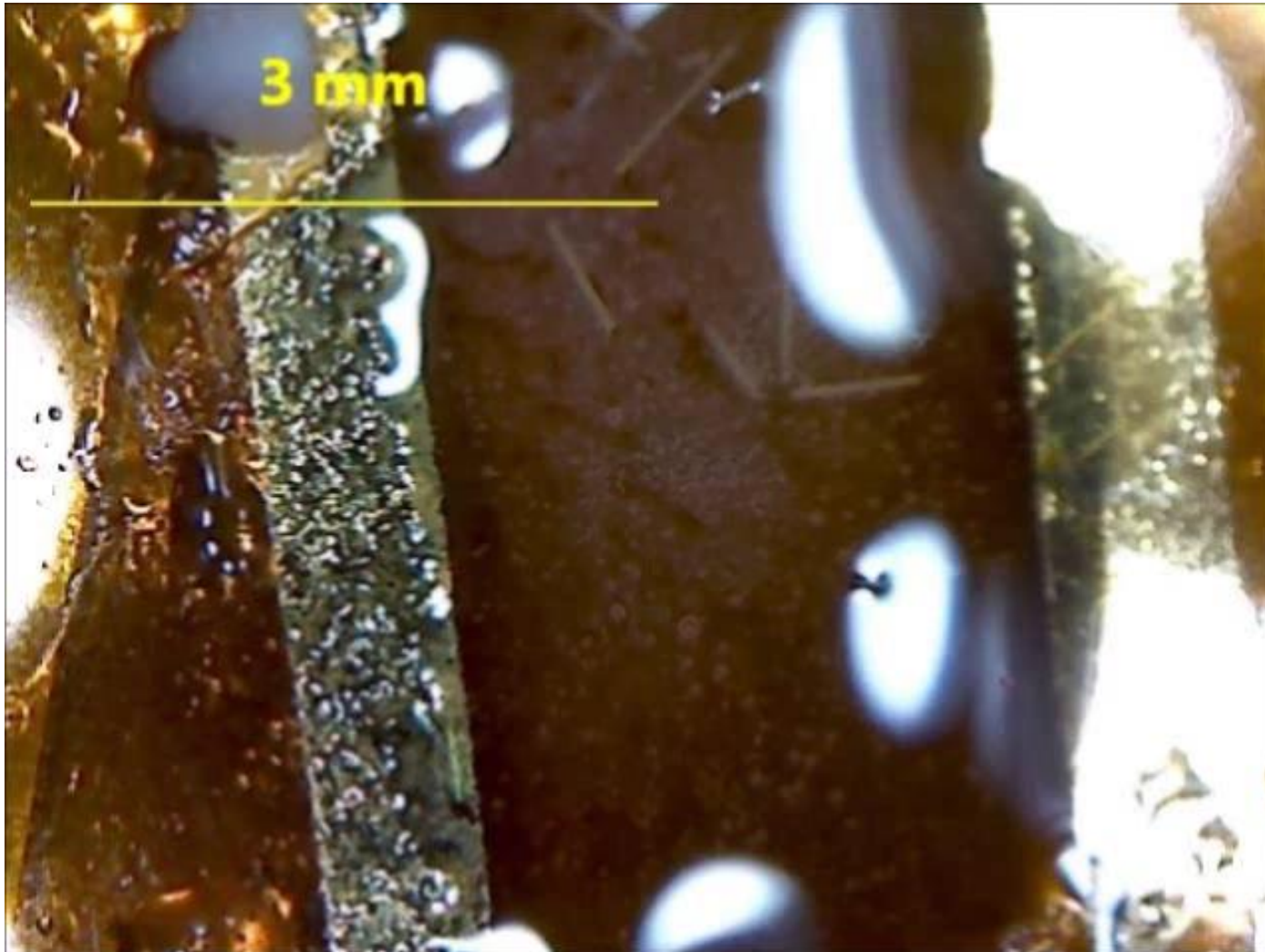


d_{33} 1-3



Structured
Sensors





Processing Technique

Calcined PZT
(Hard or Soft)



+



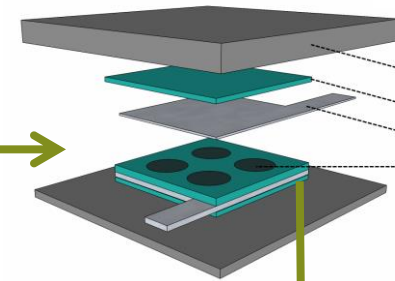
Mixing



Degassing



Molding



Steel plates
Teflon spacers
Aluminum electrodes
PZTmples

Random

Structured

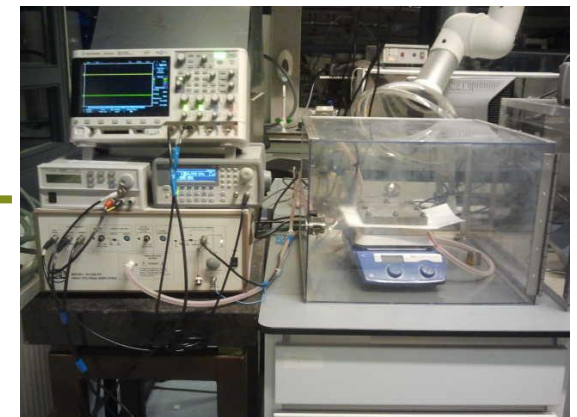
Post-curing



Electroding

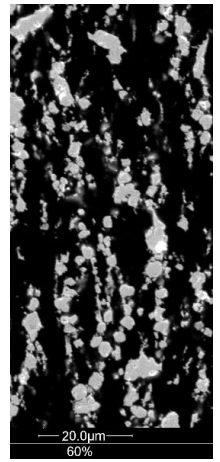
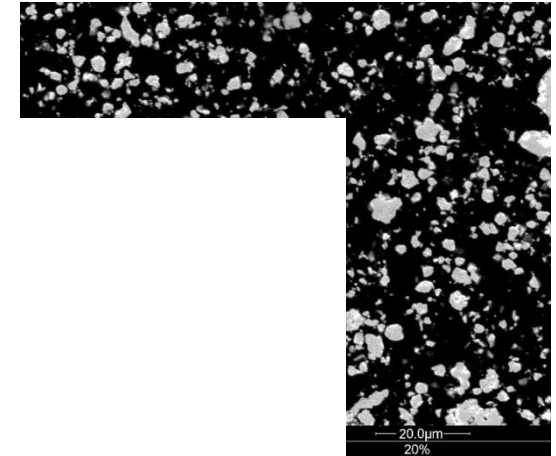
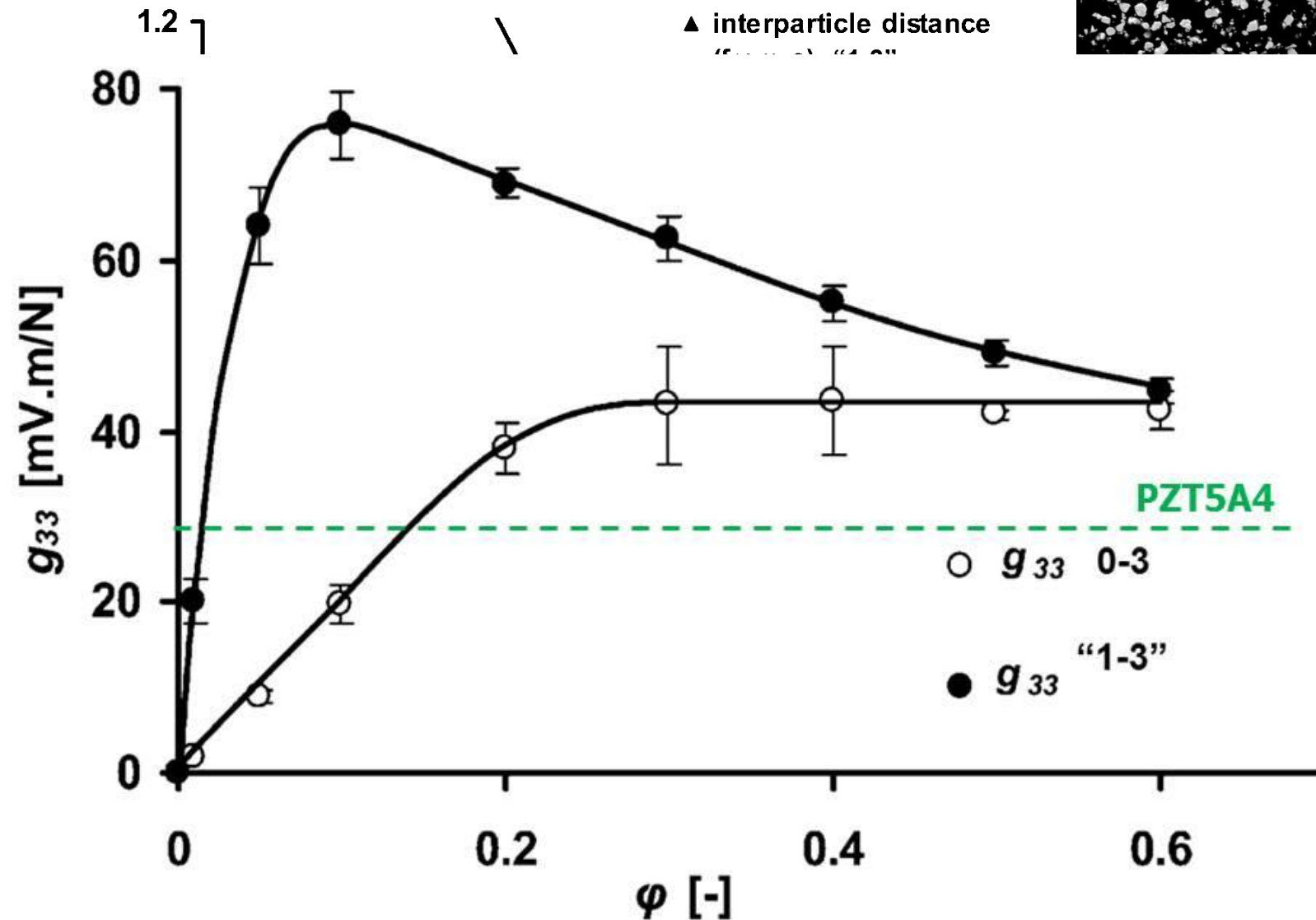


Poling

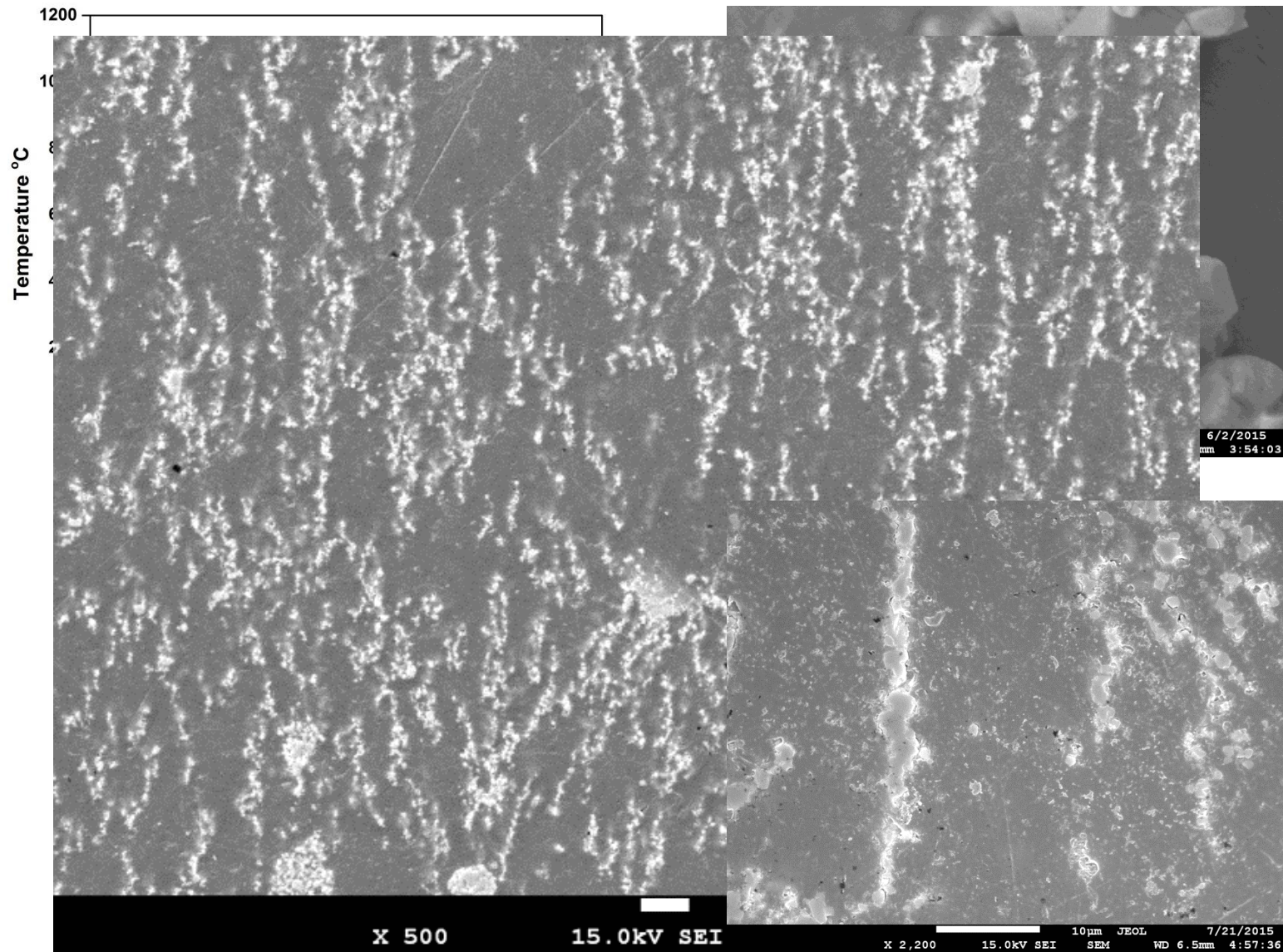


Results, Modelling interparticle distance

10% PZT

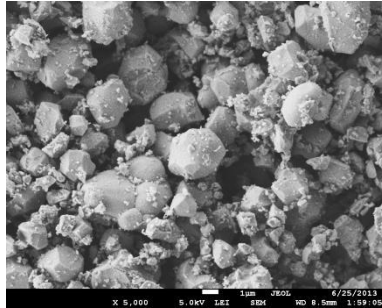


Lead Free composites (Epoxy-(K_{0.5}Na_{0.5})_(1-x)Li_(x)NbO₃)

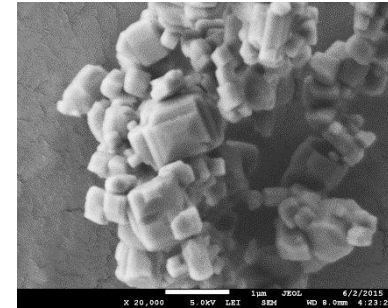


Lead Free composites

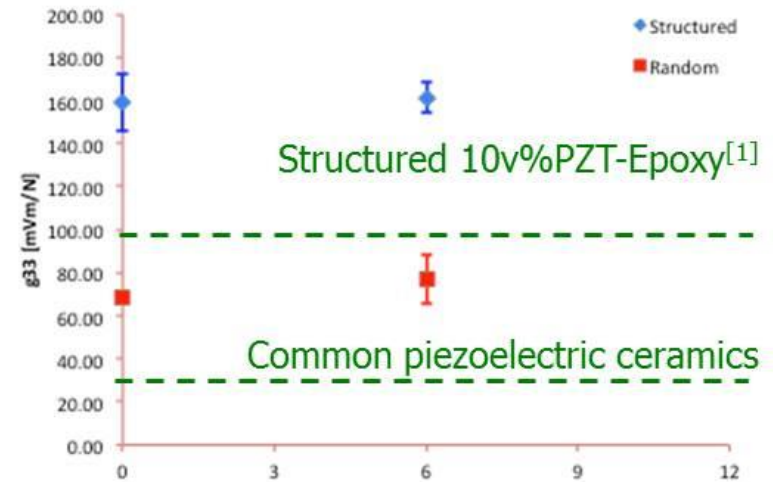
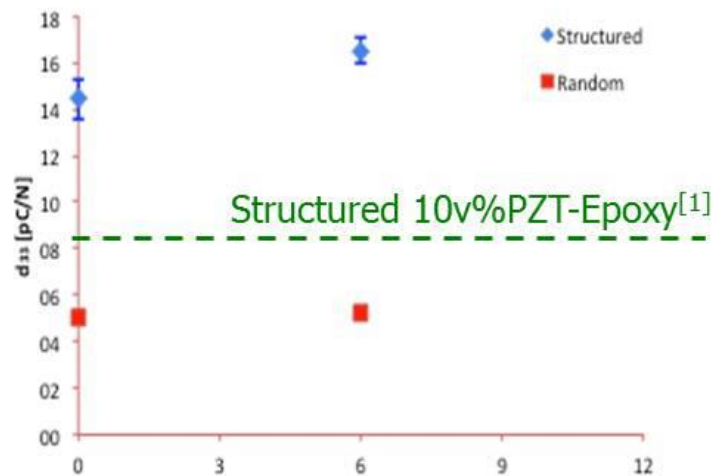
PZT
'spherical' particles



KNN
'cubic' particles
lead free



Lead free structured and random composites, with filler: $(K_{0.5}Na_{0.5})_{(1-x)}Li_{(x)}NbO_3$

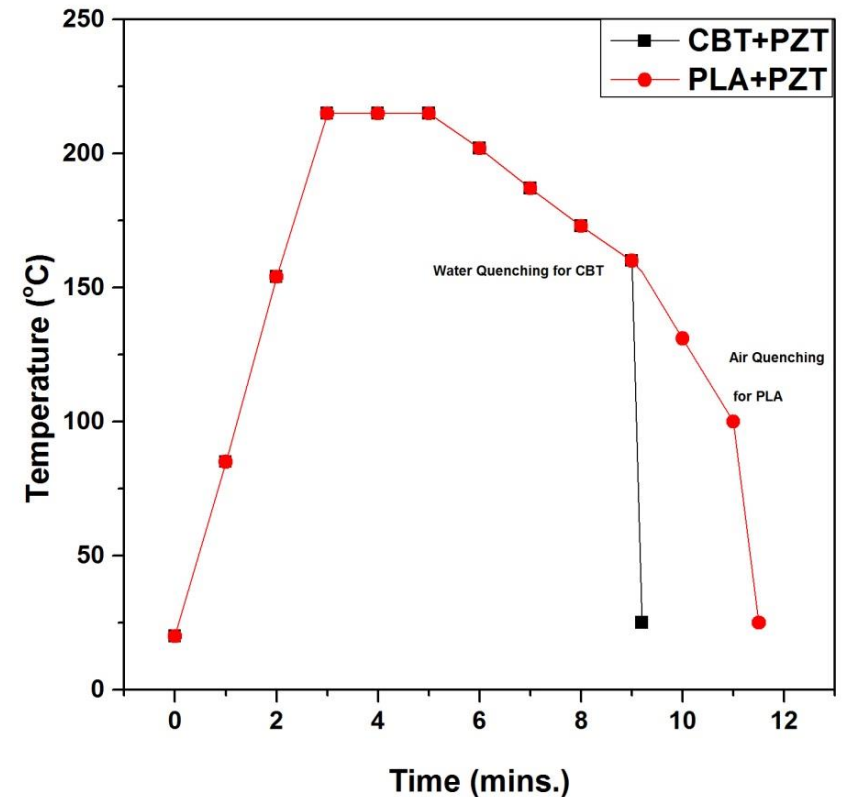
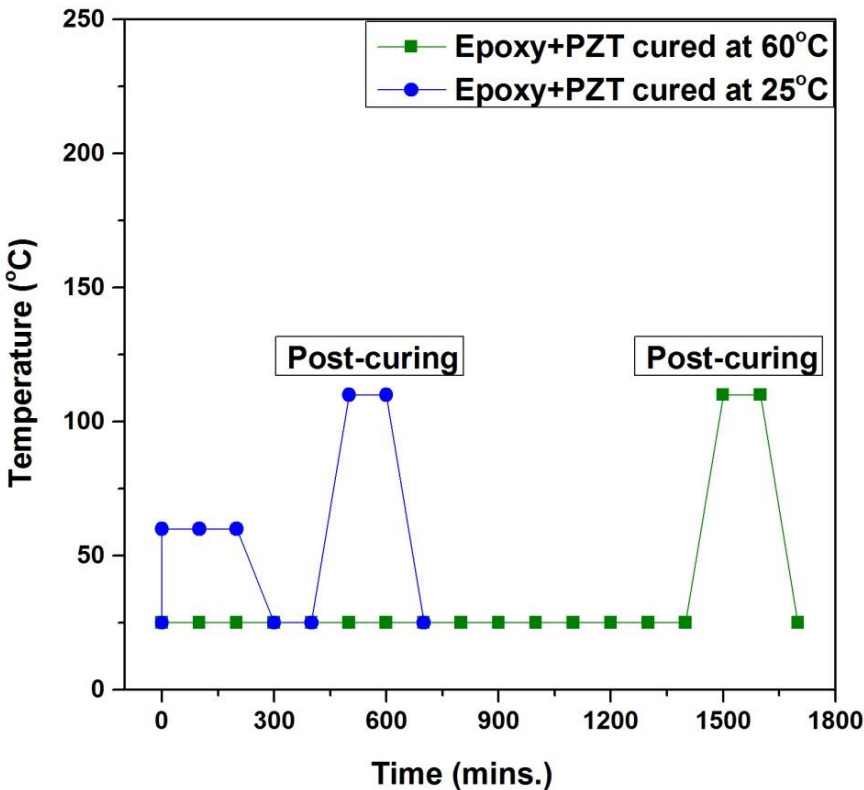


[1] Van den Ende, D. A. (2012). Structured piezoelectric composites: Materials and applications. Delft University of Technology.
 Redha Bella, Mahmoud M. Almadhoun, Jesus Alfonso Caraveo Frescas, Ibrahim Al-Howais, N. K. James, S. van der Zwaag, J. Khaliq and W.A. Groen,
 "Method for making high piezoelectric voltage coefficient Lead free piezoelectric composites."
 Novel Aerospace Materials Group, Faculty of Aerospace Engineering,
 Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands
 Nicola Tresca Masciole, Nicola Masciole, Dr Jibran Khaliq
 Email: Jibran.khaliq@northumbria.ac.uk

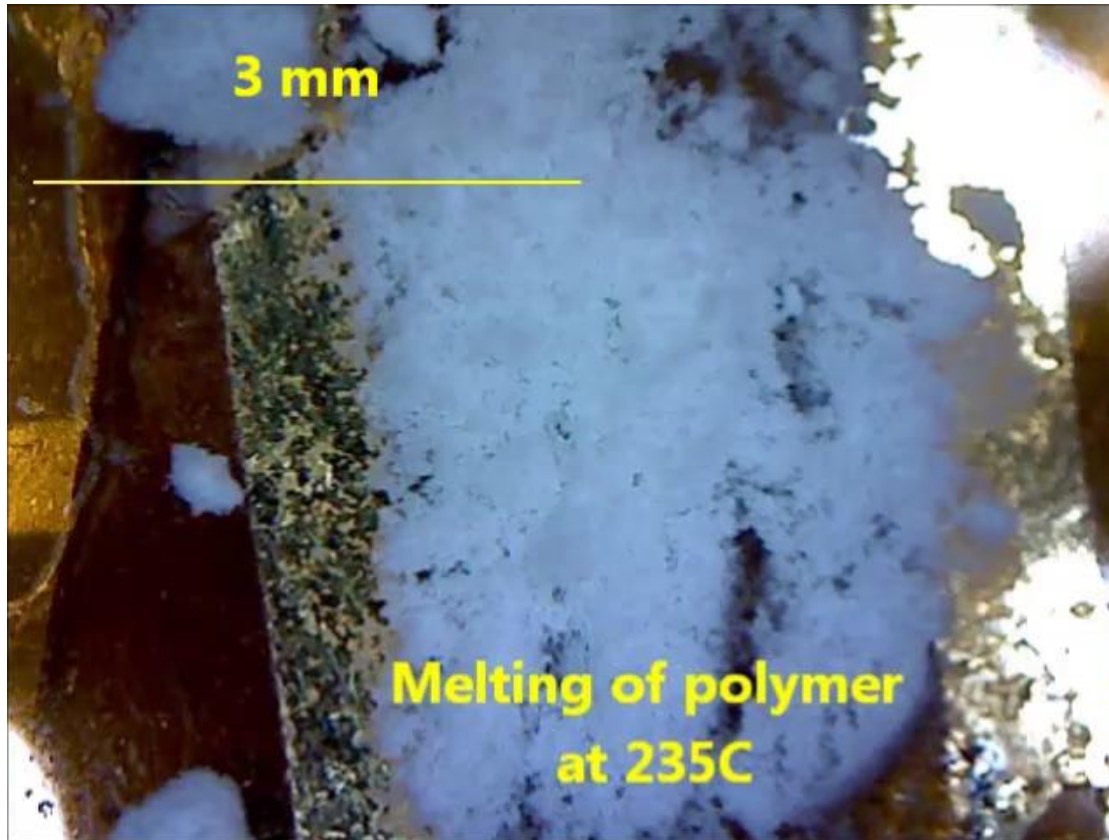
Manufacturing/Upscaling

Average preparation time for thermoset based composites = 1800 minutes

For the **very first time**, making aligned composites using thermoplastic polymer matrix

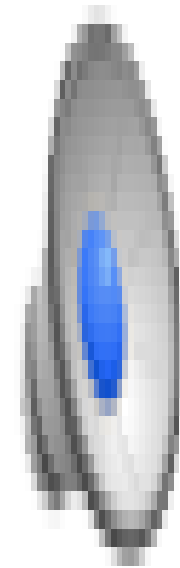
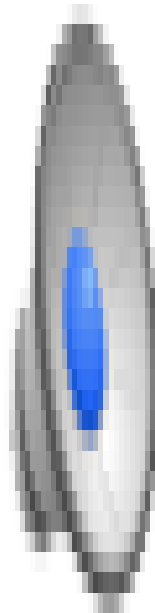
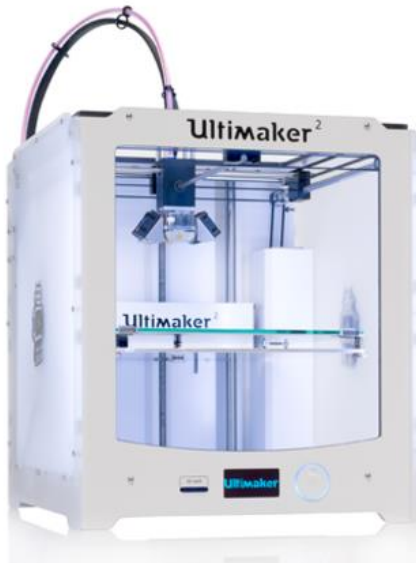


Manufacturing/Upscaling

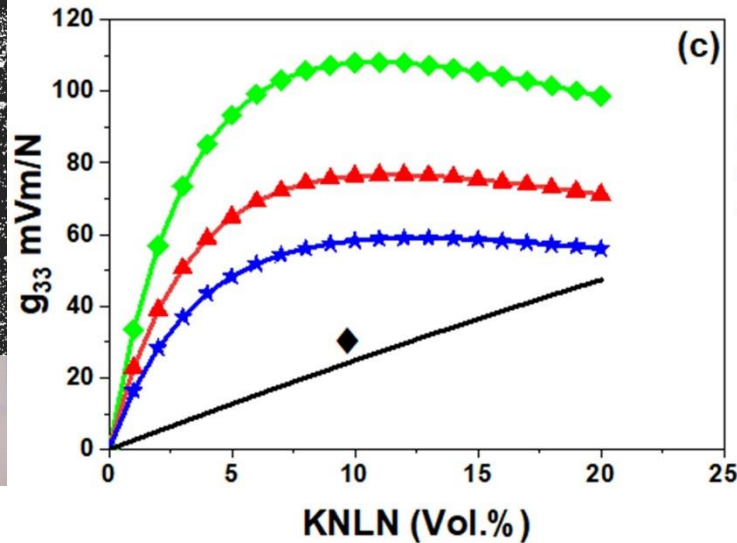
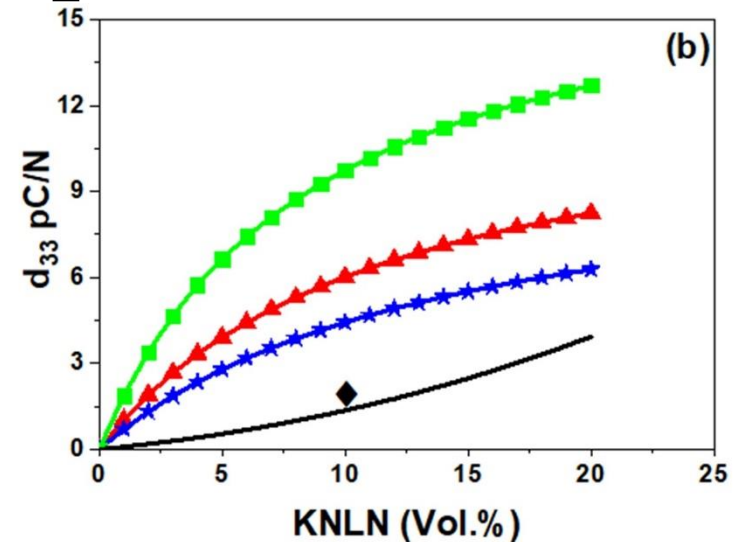
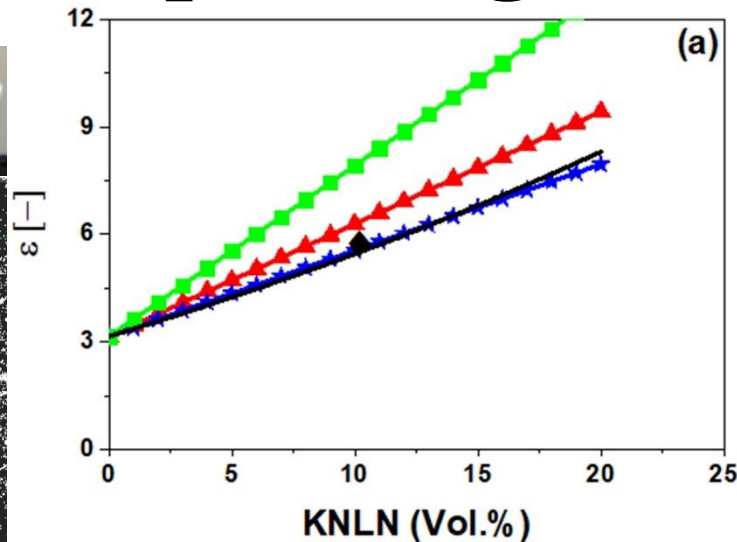
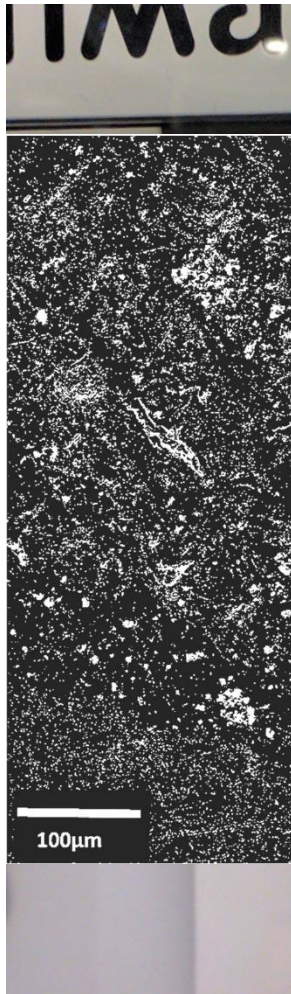


3D Printing

Fused Deposition Modeling

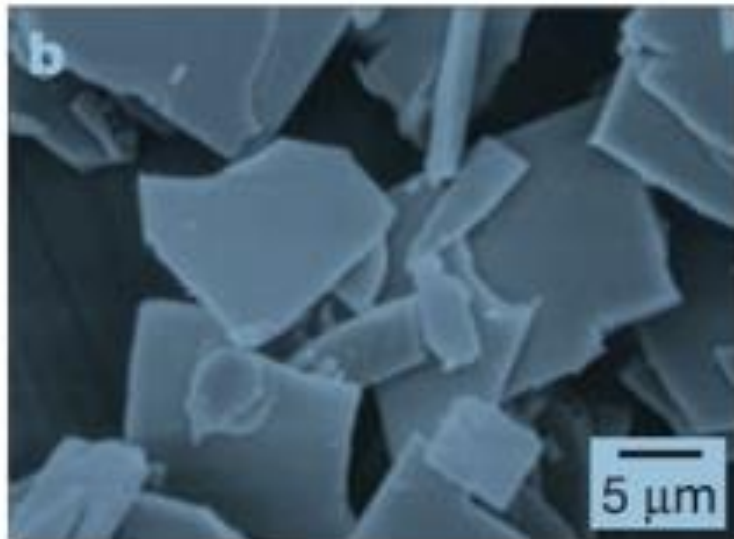
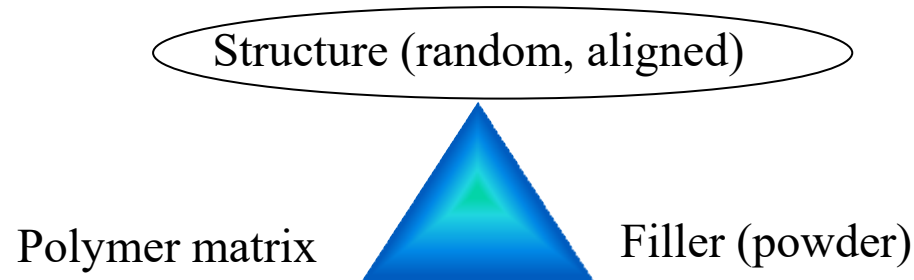


In – situ printing/DEP process

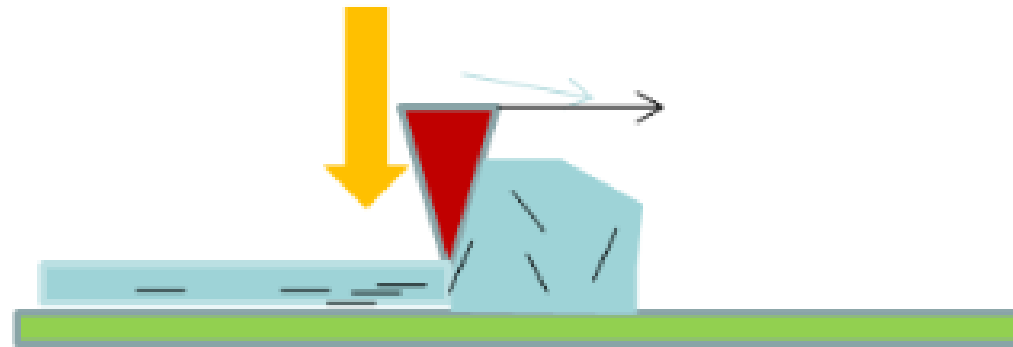


- *— van Den Ende Model with interparticle distance of 0.4 μm
- ▲— van Den Ende Model with interparticle distance of 0.3 μm
- van Den Ende Model with interparticle distance of 0.2 μm
- Yamada Model
- ◆ Experimental Value

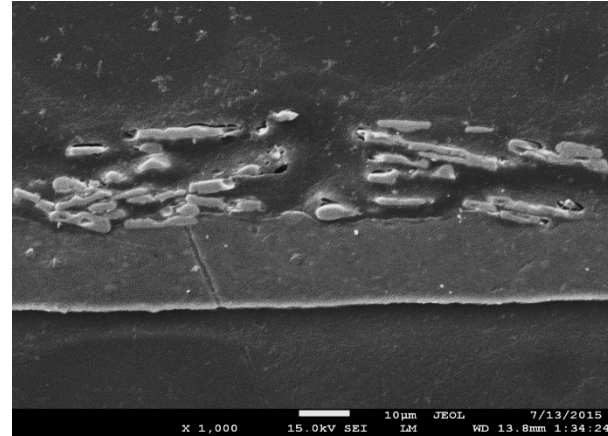
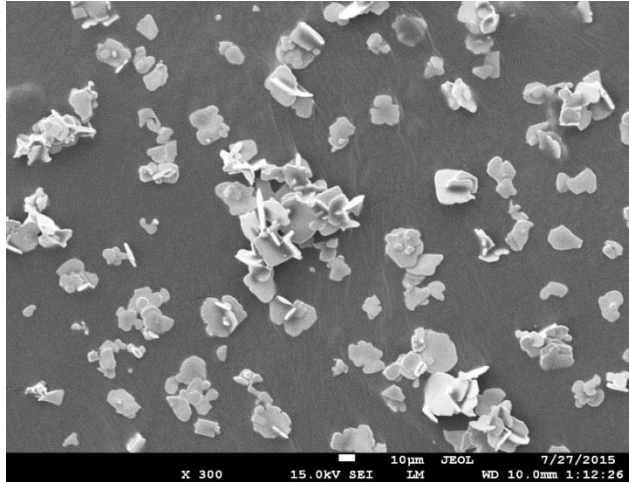
Alignment without Electric Field



Bismuth Sodium Niobate (BNT)



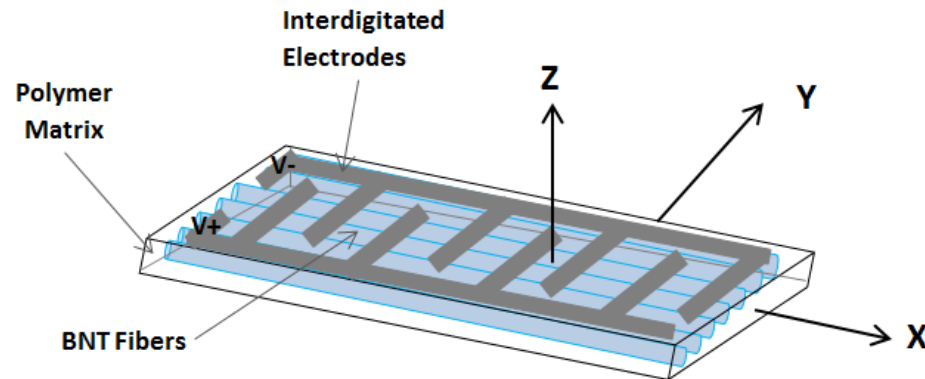
Alignment without Electric Field



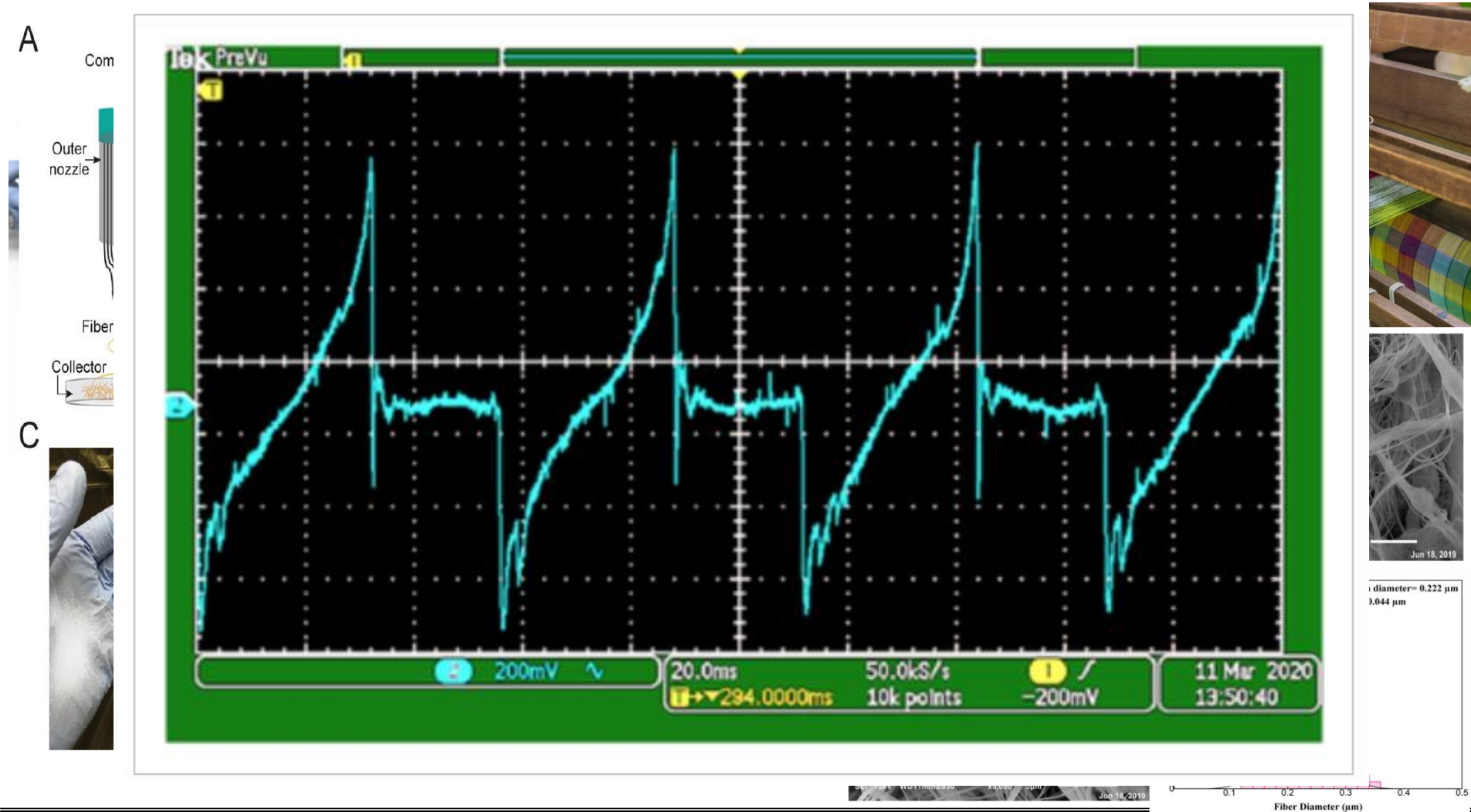
BNT/epoxy composite

Aluminium foil

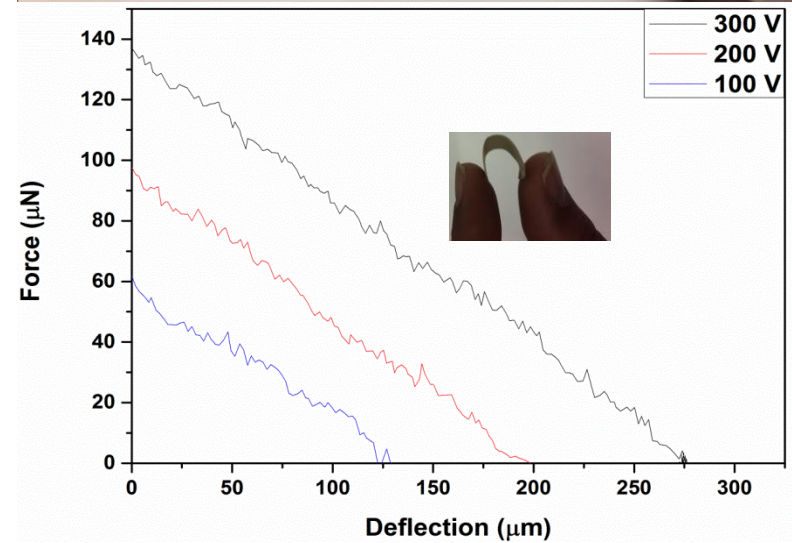
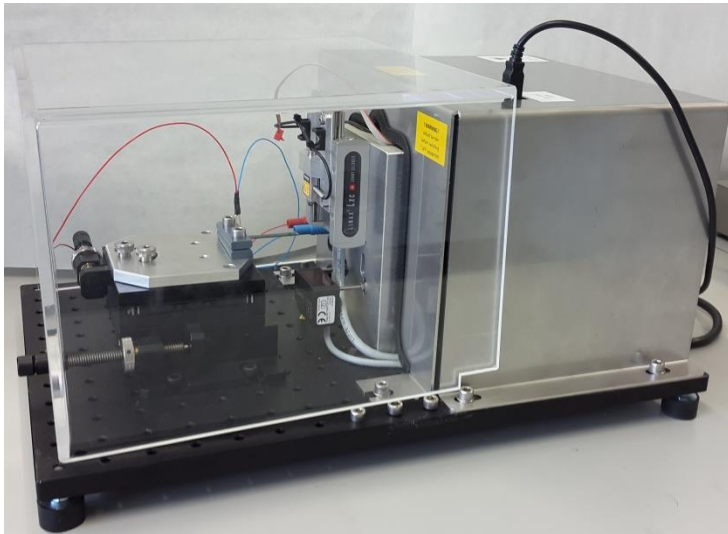
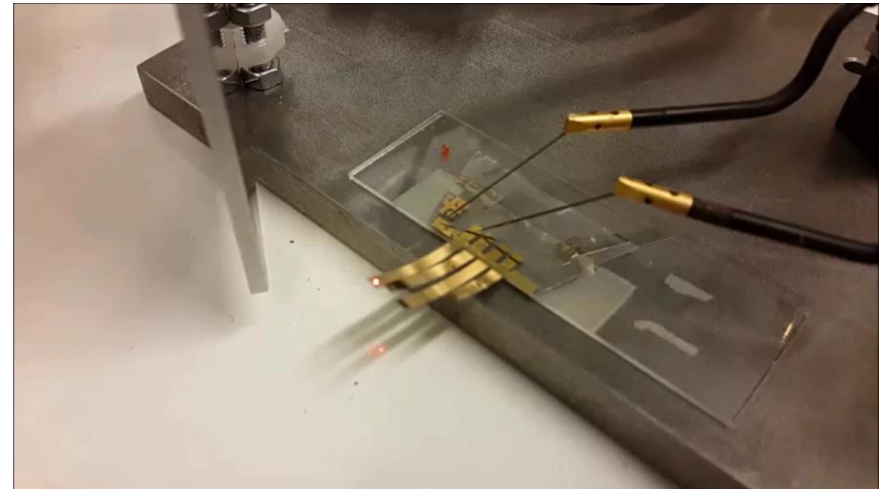
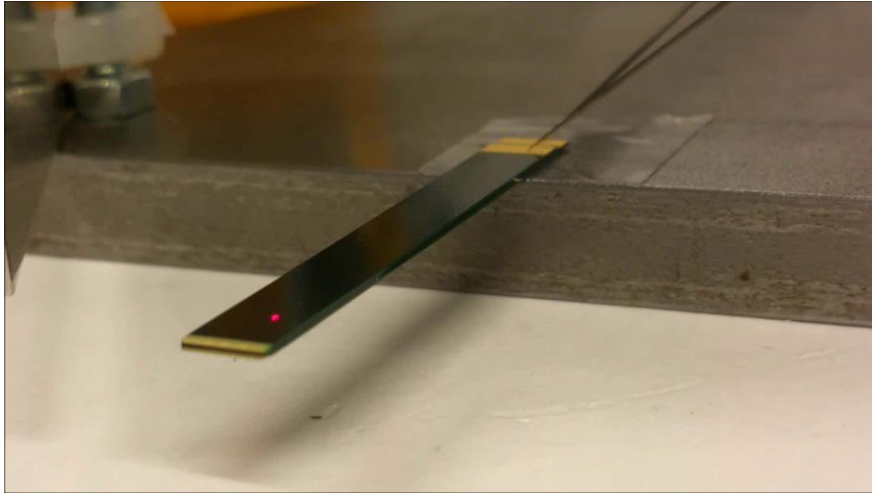
30 volume % of
ceramic in composite



Smart Textiles



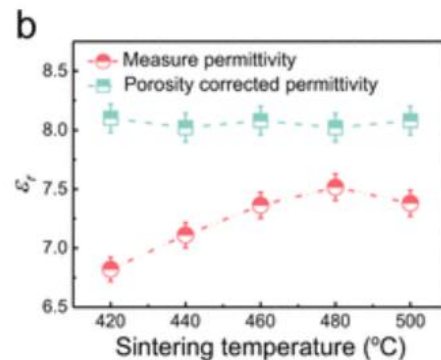
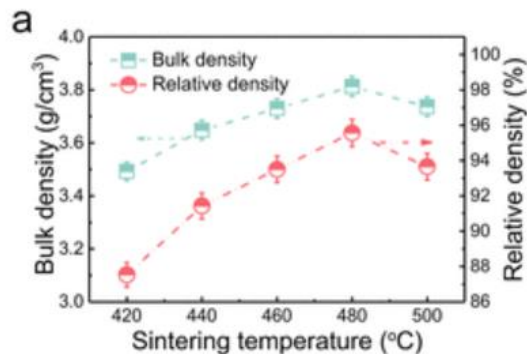
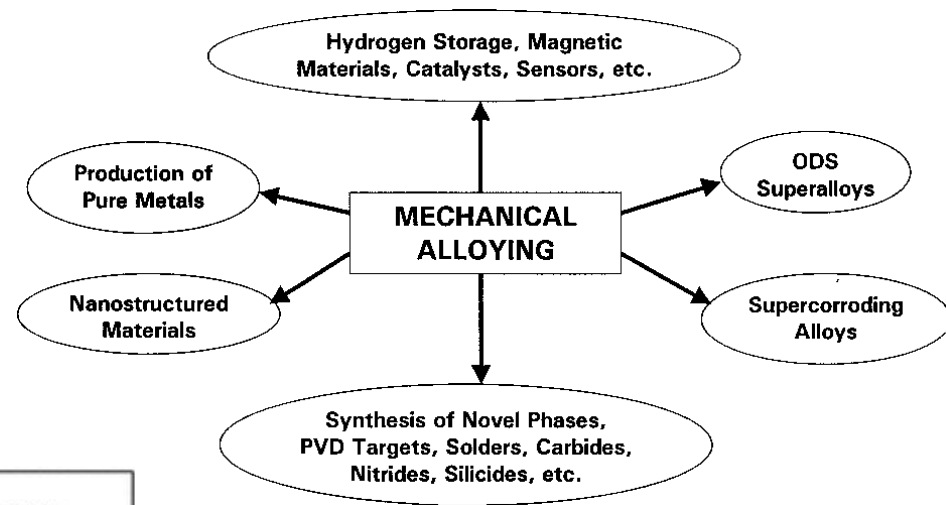
Development of New Measurement Technique



Microwave Dielectric Ceramics using LTCC

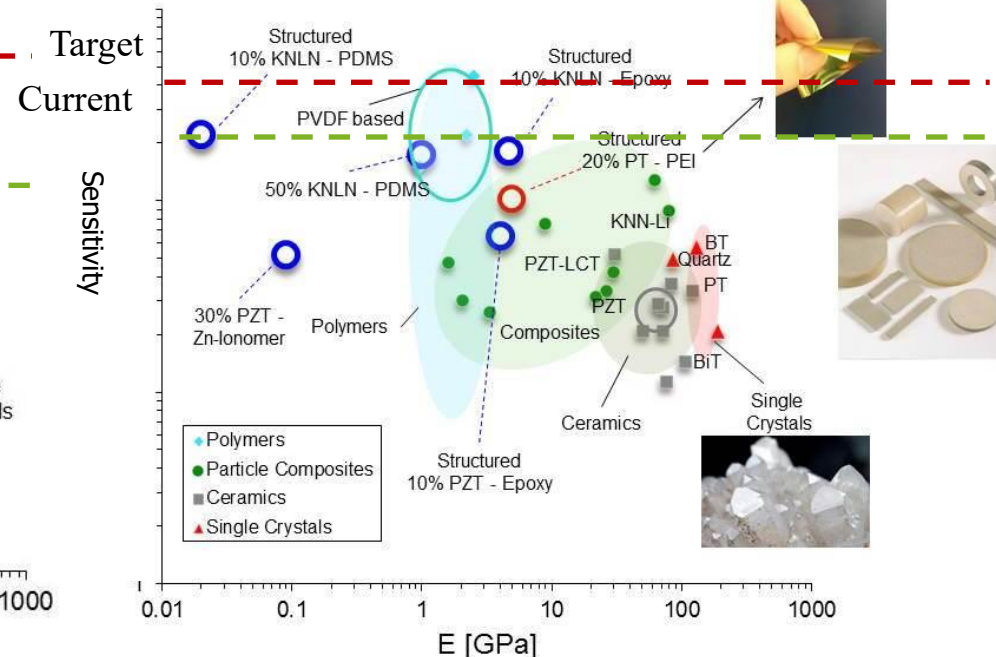
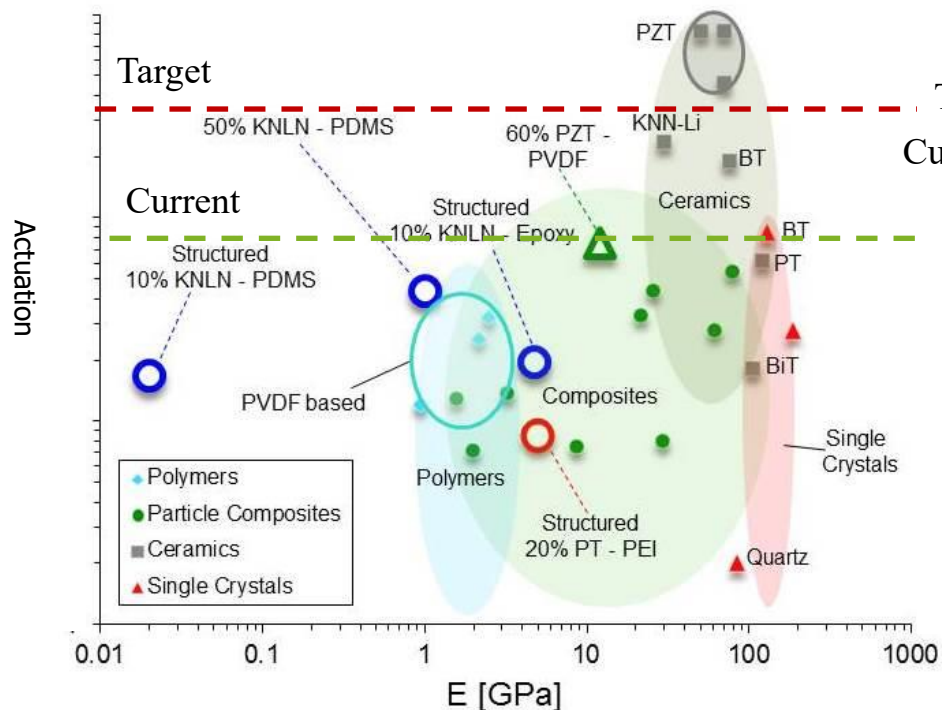
Used communication systems, such as dielectric antenna, oscillators, substrates, and phase shifters.

typical Materials Include $\text{Ag}_2\text{O}-\text{CaO}-\text{V}_2\text{O}_5$ systems, LiBO_2



Current Status and Target

1. Made them more sensitive
2. Reduced cost
3. Made them Lead free
4. Can be produced at large scale



Sponsors and Collaborators

