Piezoelectric Composite oriented via Dielectrophoresis for **F**ractional **F**low **R**eserve pressure sensors

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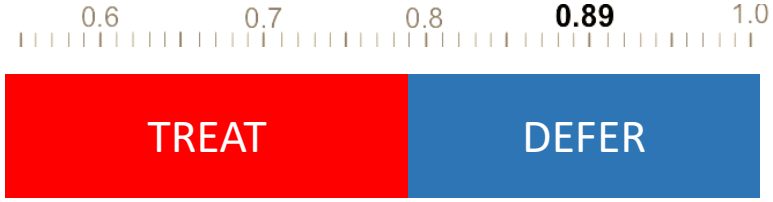
OUTLINE

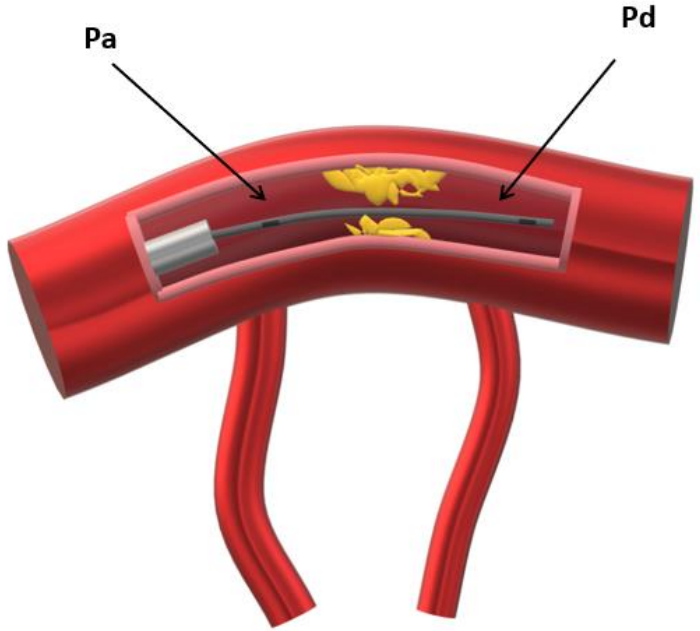
1. Fractional Flow Reserve (**FFR**)
2. FFR sensors- *state of art*
3. Piezoelectricity
4. Piezoelectric composites
5. 0-3 or 1-3 connectivity?
6. Dielectrophoresis
7. Piezoelectric properties
8. Temperature stability
9. Process optimization
10. Proofs of concept
11. Conclusions

1. FRACTIONAL FLOW RESERVE (FFR)

Technique developed to evaluate the **significance** of **coronary stenosis**

$$\mathbf{FFR} = \frac{\mathbf{distal\ coronary\ pressure\ (Pd)}}{\mathbf{proximal\ coronary\ pressure\ (Pa)}}$$

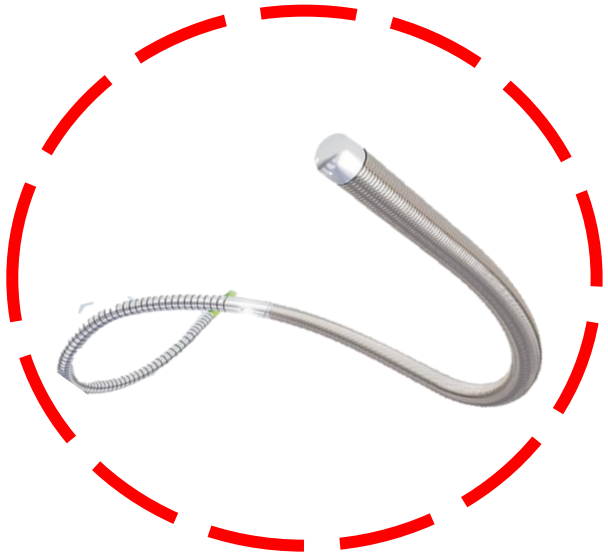




Need of **direct monitoring** of blood pressure

2. FFR SENSORS

Stiffness



Optical waveguide sensors

Large temperature dependence

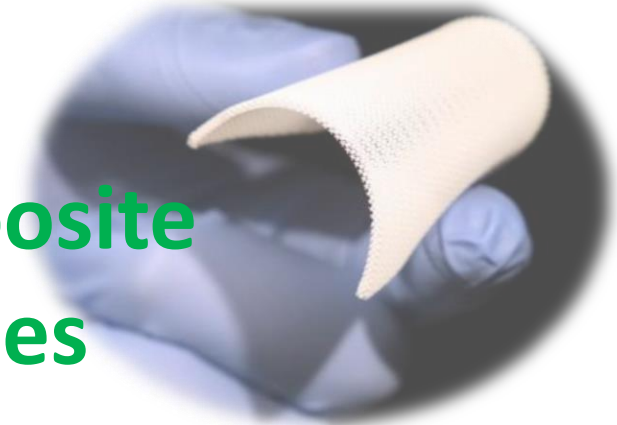
Stiffness

High-power requirement

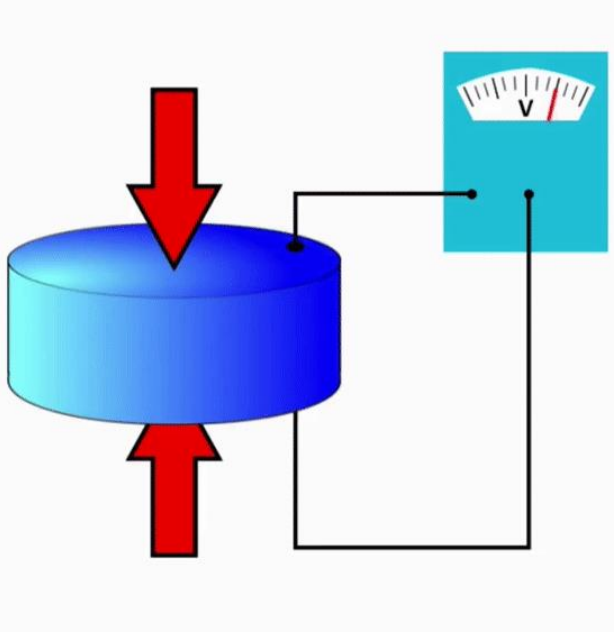
Piezoresistive sensors

OUR PROPOSAL :

Flexible piezoelectric composite with enhanced properties



3. PIEZOELECTRICITY



DIRECT EFFECT

EXTERNAL STRESS ***T***

ELECTRIC DISPLACEMENT ***D***

$$D_i = d_{iJ} T_J$$

REVERSE EFFECT

EXTERNAL ELECTRIC FIELD ***E***

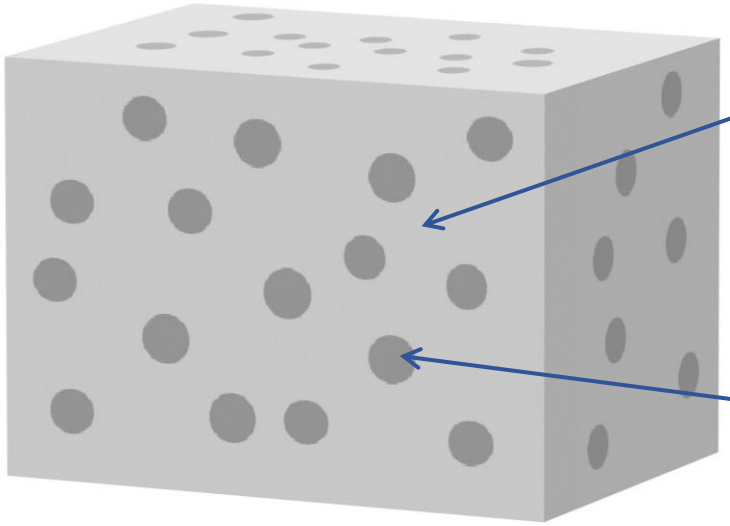
STRAIN ***S***

$$S_I = d_{Ij} E_i$$

Piezoelectric charge coefficient $d_{iJ} = d_{Ij}$

Piezoelectric voltage coefficient $g_{iJ} = \dfrac{d_{iJ}}{\varepsilon_0 \, \varepsilon_r}$

4. PIEZOELECTRIC COMPOSITES



- **HIGH PIEZOELECTRIC** properties of the particles
- **GOOD MECHANICAL PROPERTIES** of the matrix
- **LOW POLING ELECTRIC FIELD**
- **HIGH THERMAL STABILITY**

Key factor: CONNECTIVITY

=

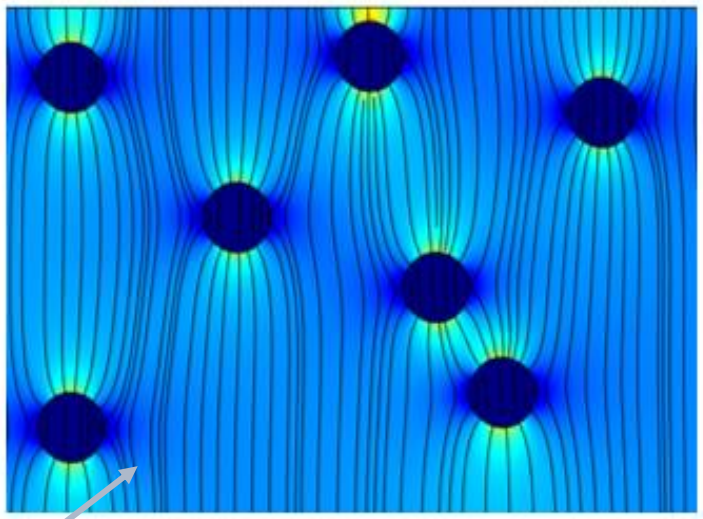
Disposition of the phases within the composite

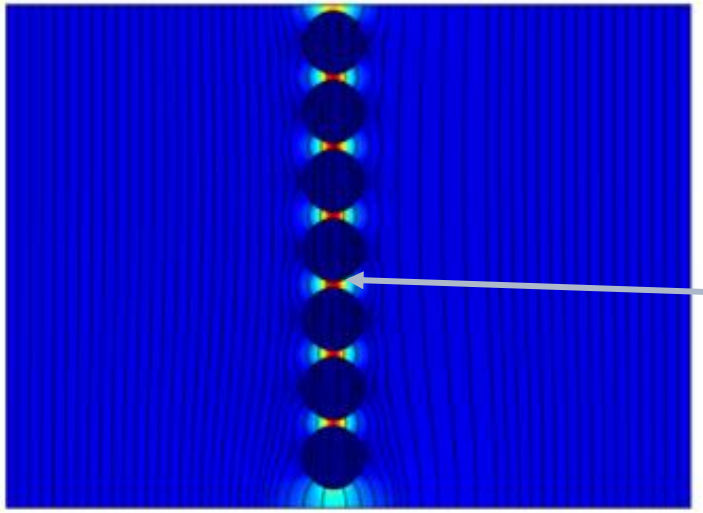
5. 0-3 OR 1-3 CONNECTIVITY?

0-3 Connectivity

1-3 Connectivity

Stronger matrix shielding effect





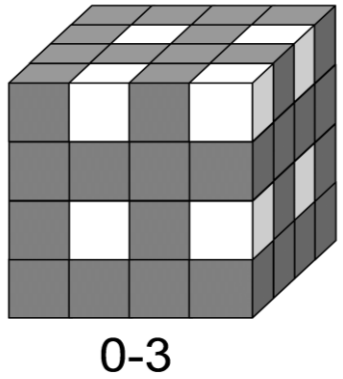
Less shielding effect of the matrix

Electric field lines

1-3 Anisotropic material

Enhanced piezoelectric properties along the column direction

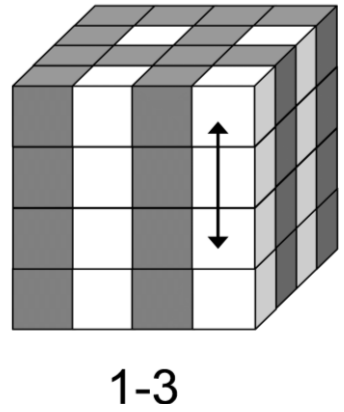
5. 0-3 OR 1-3 CONNECTIVITY?



0-3 Connectivity

VS

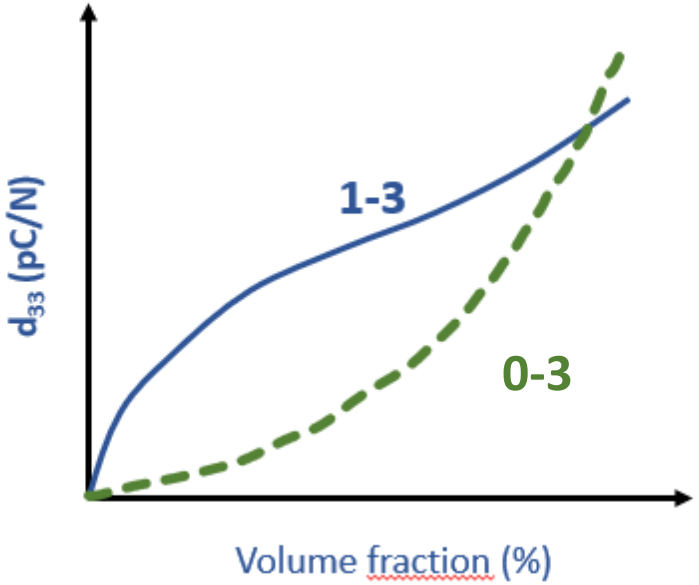
1-3 Connectivity



1-3

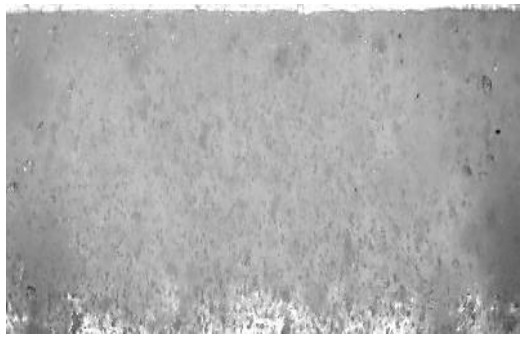
improved piezoelectric properties

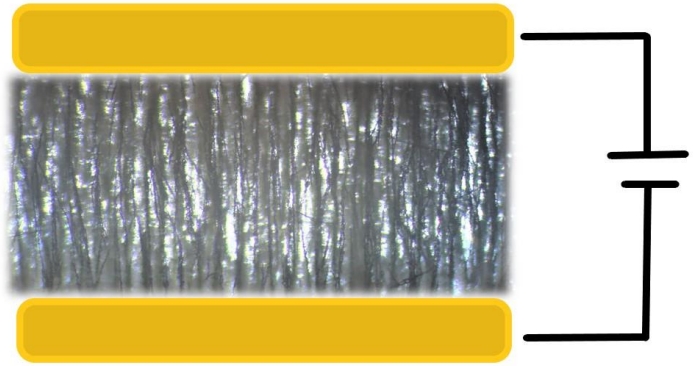
d_{33}



6. DIELECTROPHORESIS

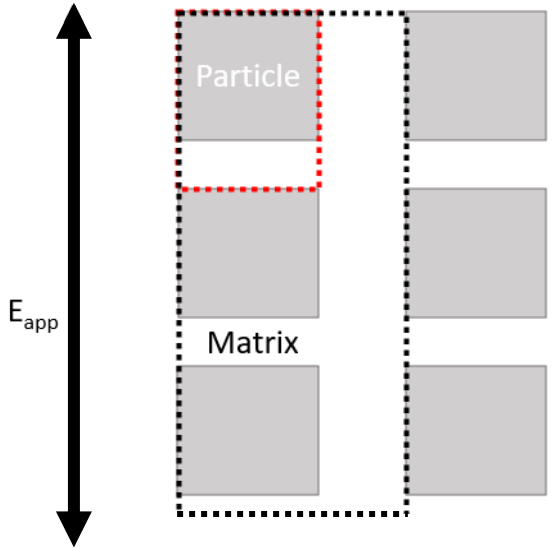
Dielectrophoresis is an easy technique to produce 1-3 oriented composites





Under an external electric field the particles become polarized and attract each other

Dielectrophoresis leads to a **chain-like structure**



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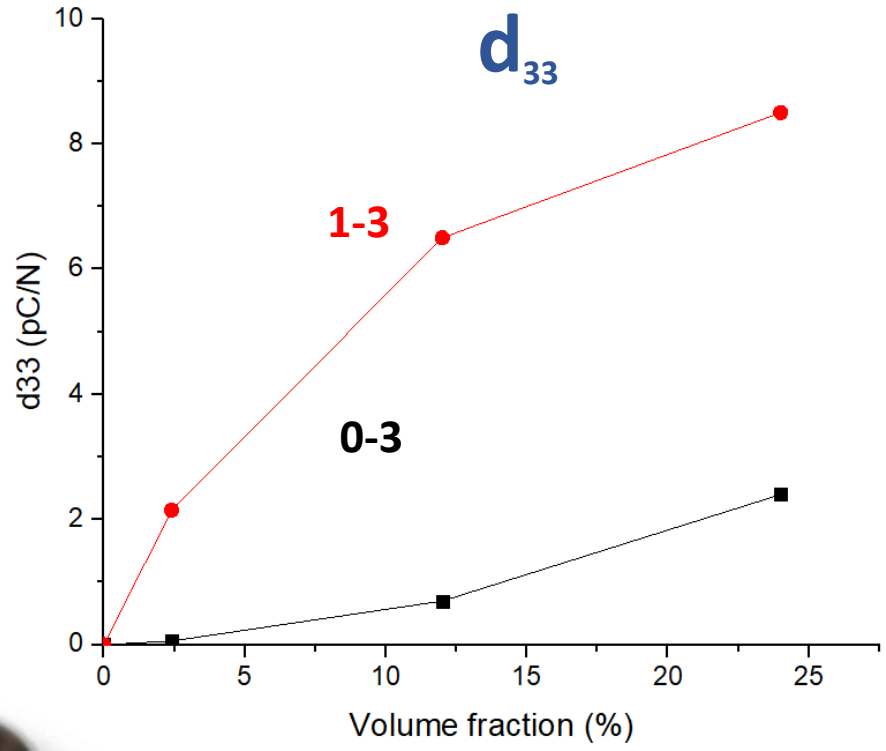
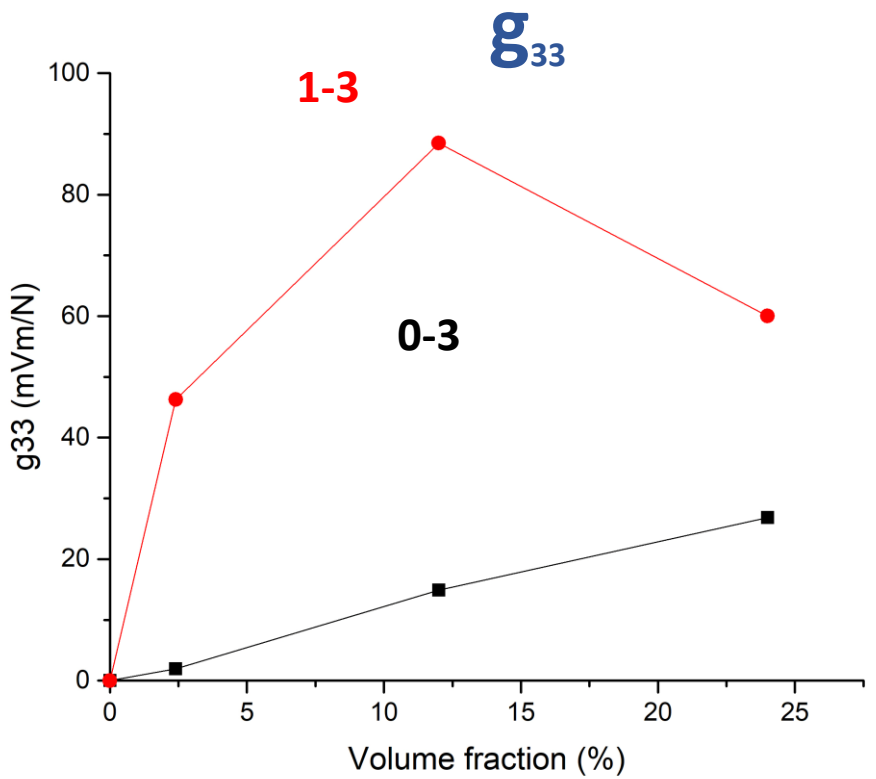
7. PIEZOELECTRIC PROPERTIES

Barium Titanate (BTO) nanoparticles in PDMS

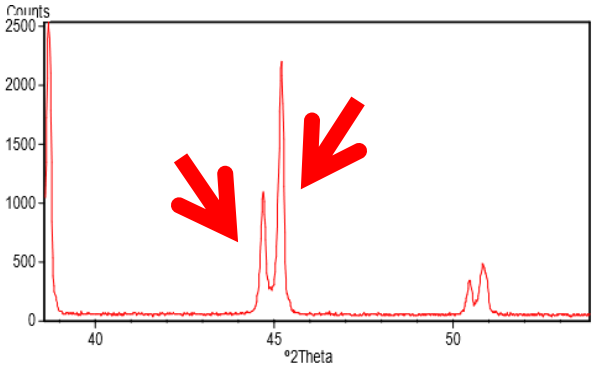


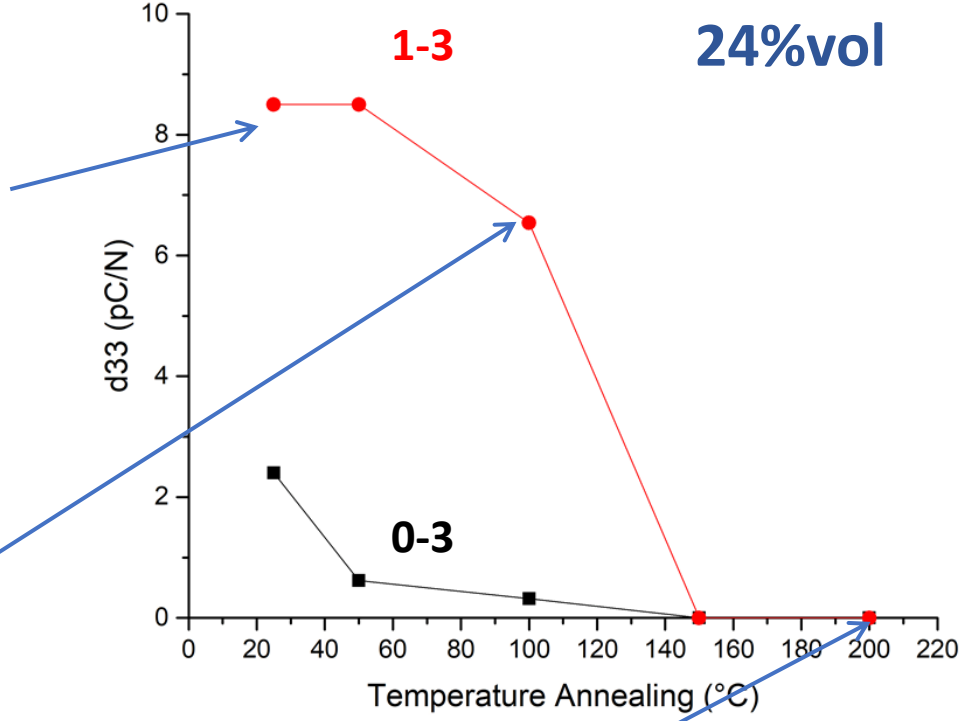


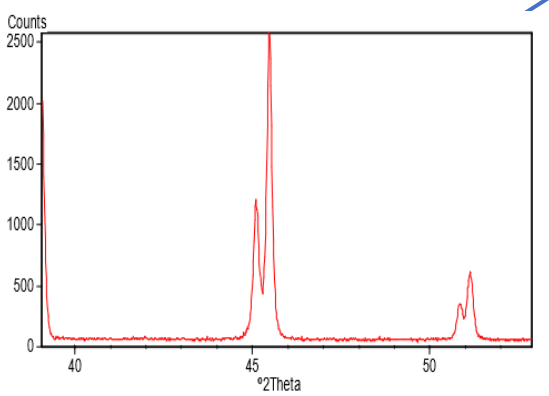
Dielectrophoretic alignment improves BTO_{np}/PDMS piezoelectricity

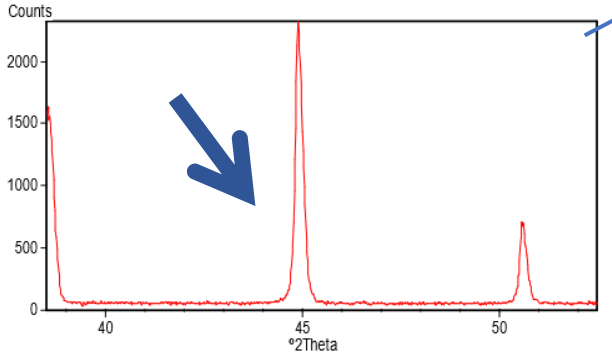
8. PIEZOELECTRIC STABILITY IN TEMPERATURE

Above 130°C
the crystalline structure
changes from
tetragonal to **cubic**



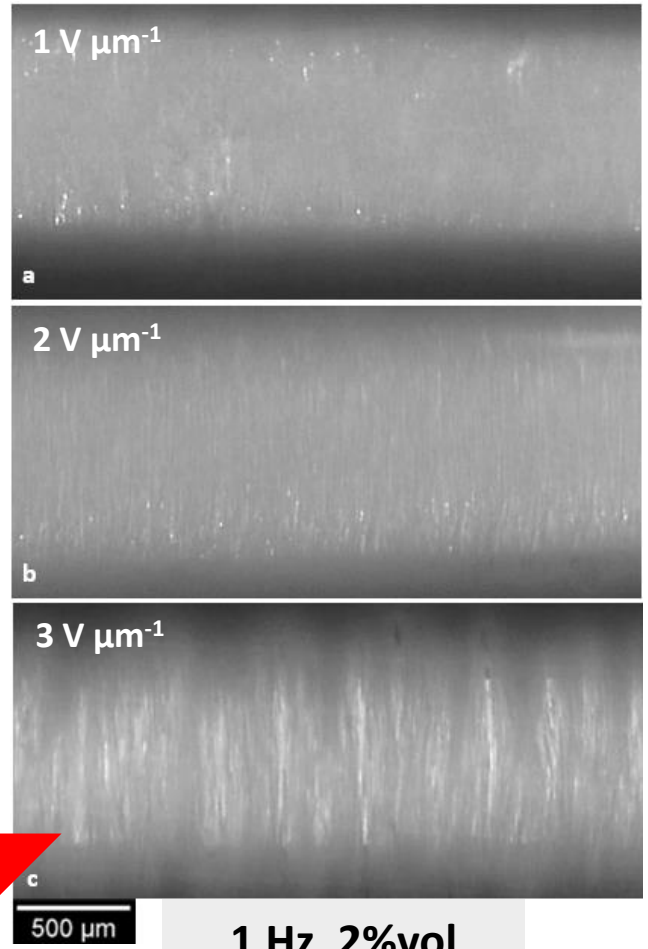




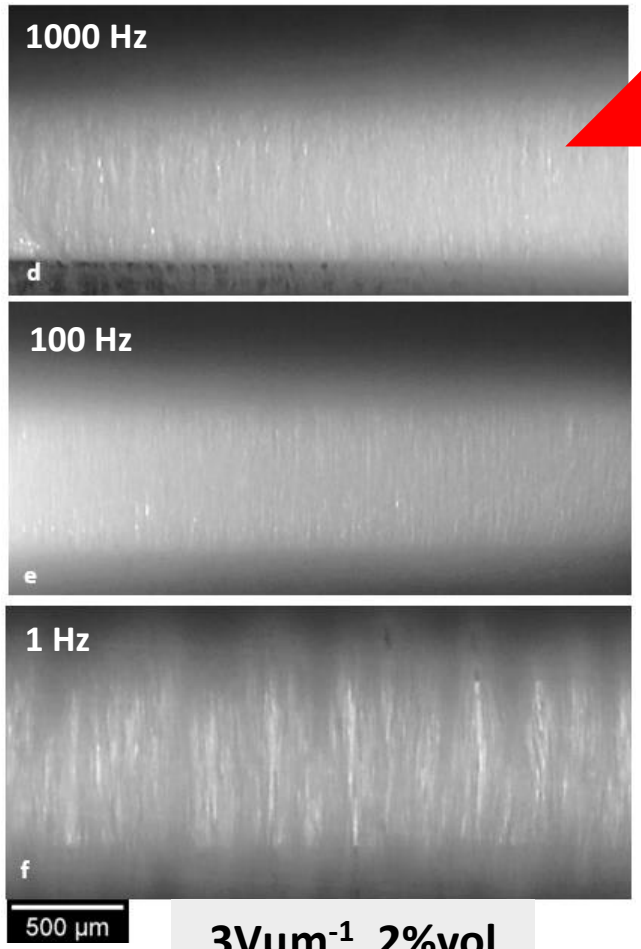


9. PROCESS OPTIMIZATION

AMPLITUDE



1 Hz, 2%vol

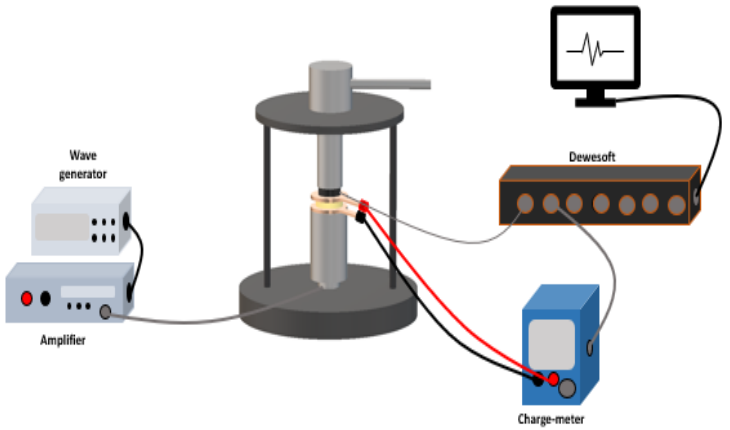


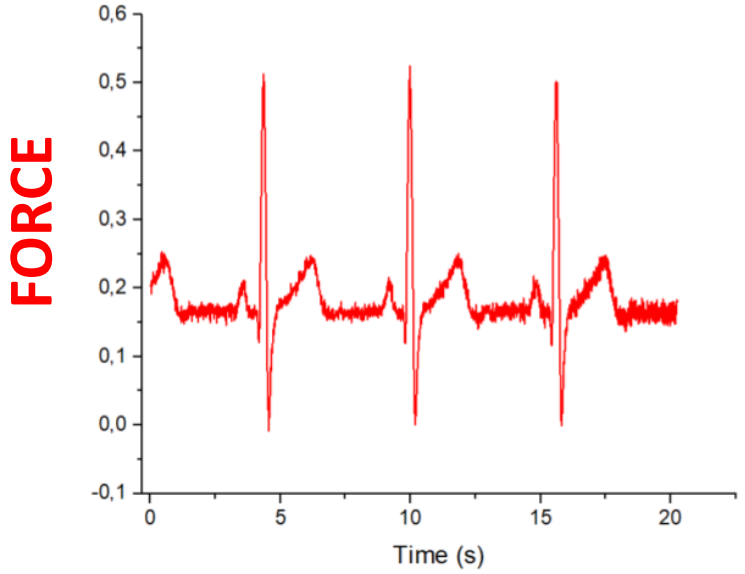
3Vµm^{-1}, 2%vol

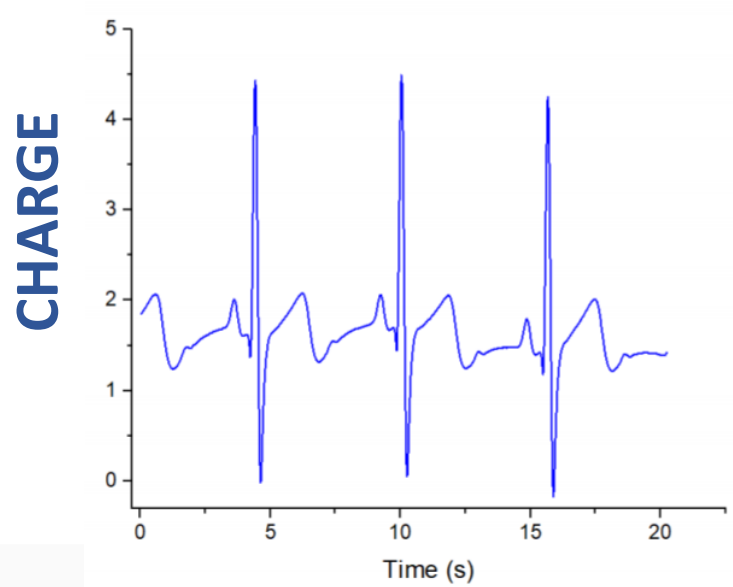
FREQUENCY

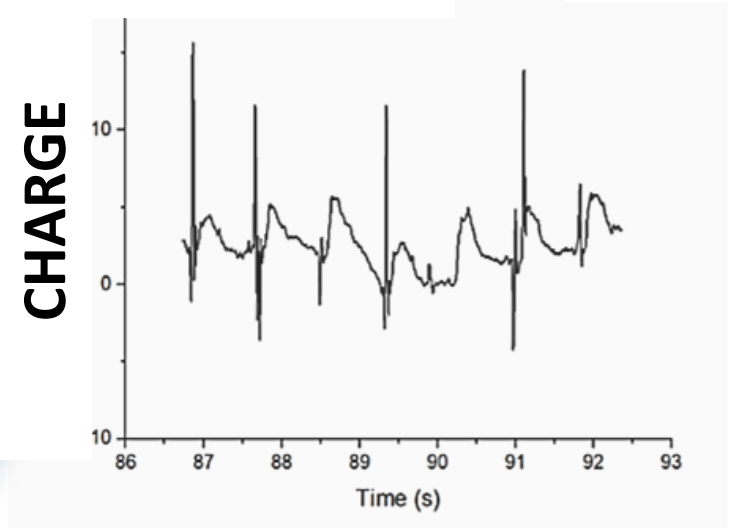
10. PROOFS OF CONCEPT

Sensor response to heart rhythm









11. CONCLUSIONS

ACHIEVEMENTS

- ✓ Flexible film with enhanced piezoelectric response developed via dielecrophoresis
- ✓ Good thermal stability
- ✓ Proof of concept

PERSPECTIVES

- 🔍 Developement of stable and compatible electric connections
- 🔍 Miniaturization and integration with the catheter
- 🔍 In-vivo test

Thank you for your attention

THE PRINCIPLE OF DIELECTROPHORESIS

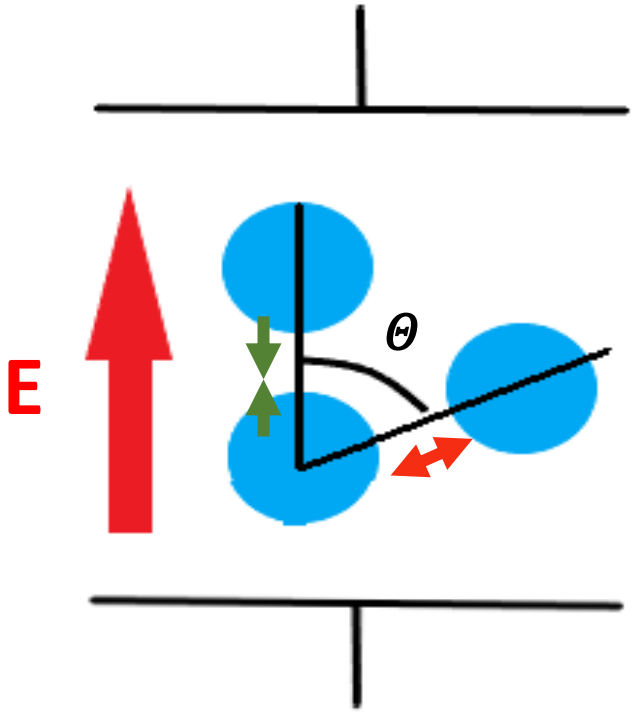
Particles dispersed in a matrix subjected to inhomogeneous electric field become **polarized**

Polarized particles under non uniform electric field undergo to **dielectrophoresis force**

$$F_{dep}(\varepsilon_p, \varepsilon_m, R, E, f)$$

Polarized particles affects the electric field lines

Interaction between particles



θ <55° ATTRACTION
θ >55° REPULSION