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Elaboration of BaTiO₃ piezoceramics by Direct Ink Writing for acoustic applications

THALES

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON LGEF

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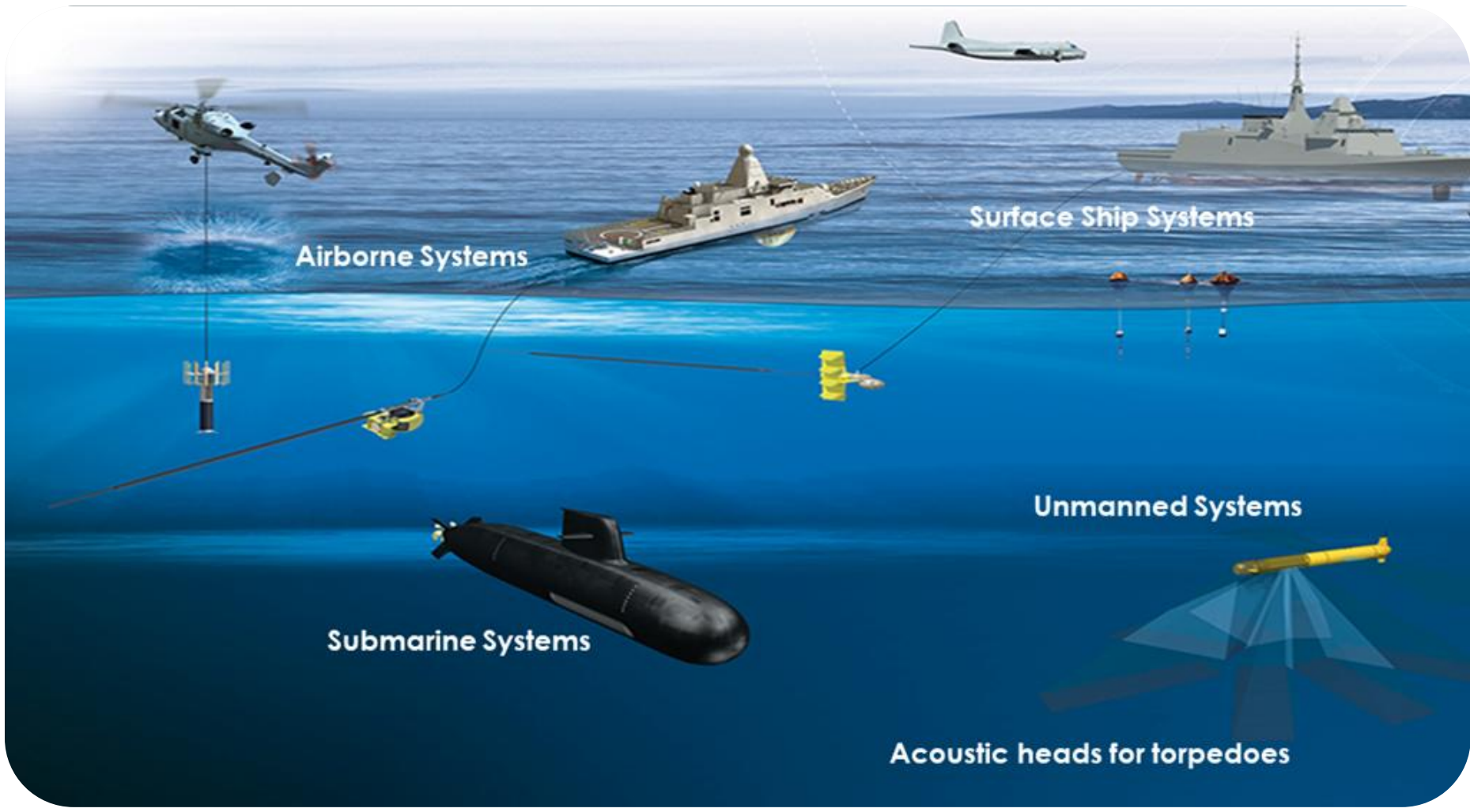
⁴ Thales Research and Technology, 91120 Palaiseau, France

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Introduction

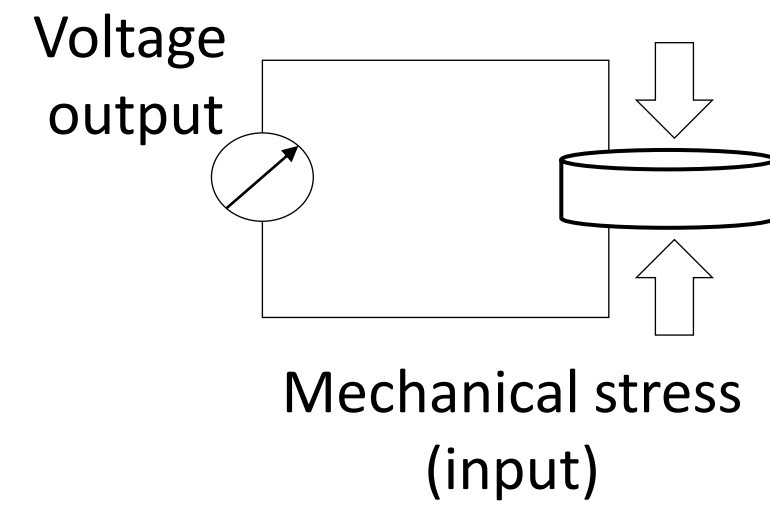
Application of piezoelectric materials in sonars



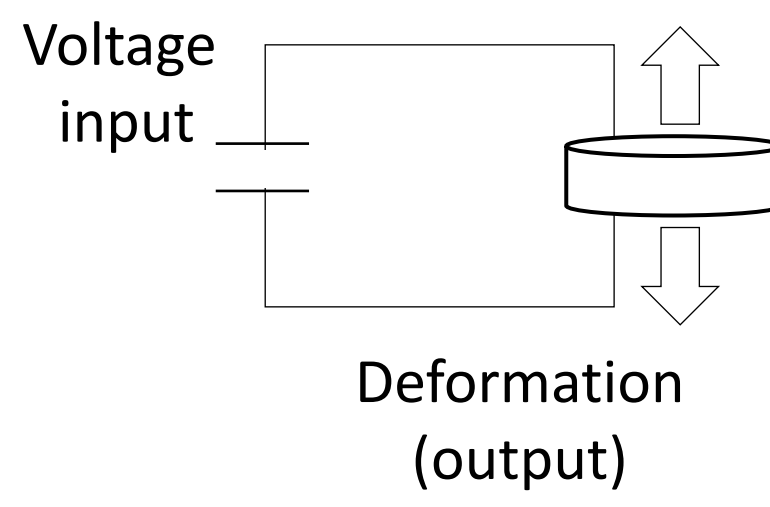
Manufacturing of sonars for detection and underwater 3D imaging devices

Piezoelectric effects

(1) **direct piezoelectric effect** :



(2) **inverse piezoelectric effect** :



Widely used ceramics
Pb(Zr_{1-x}Ti_x)O₃ (PZT)

European Union restricts the use of lead

⇒ RoHS (2006)
⇒ REACH (2012)



Development new lead-free piezoceramics

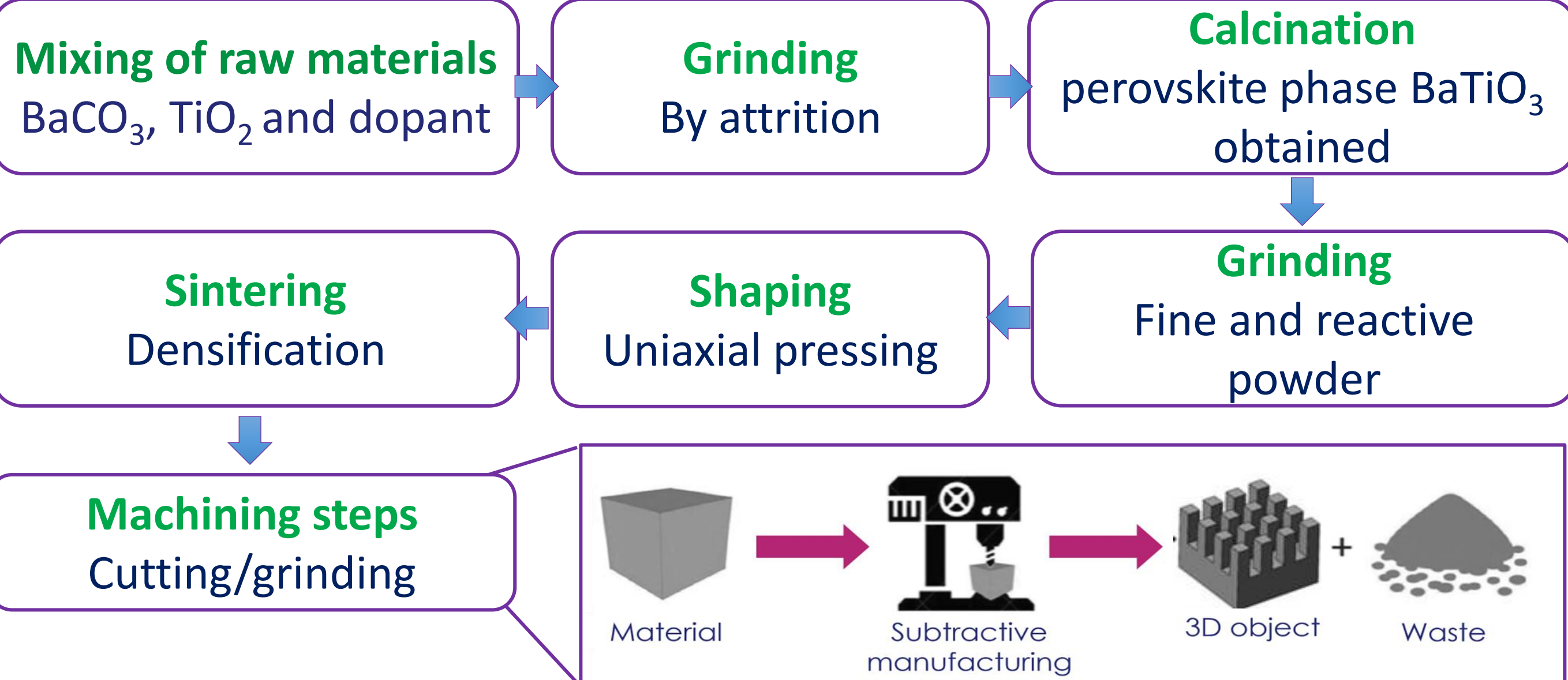
- Improve sonars' transducers responses by use of complex structures
- Use of new technologies to obtain more complex structures and reduce the fabrication wastes

SCOPE: 3D printing of a lead-free piezoelectric ceramic by Direct Ink Writing

Ceramic manufacturing process

Conventional shaping methods

Subtractive manufacturing for complex geometries



→ Ceramic brittleness
→ Wastages near 80% for underwater devices

Lead-free piezoelectric ceramics

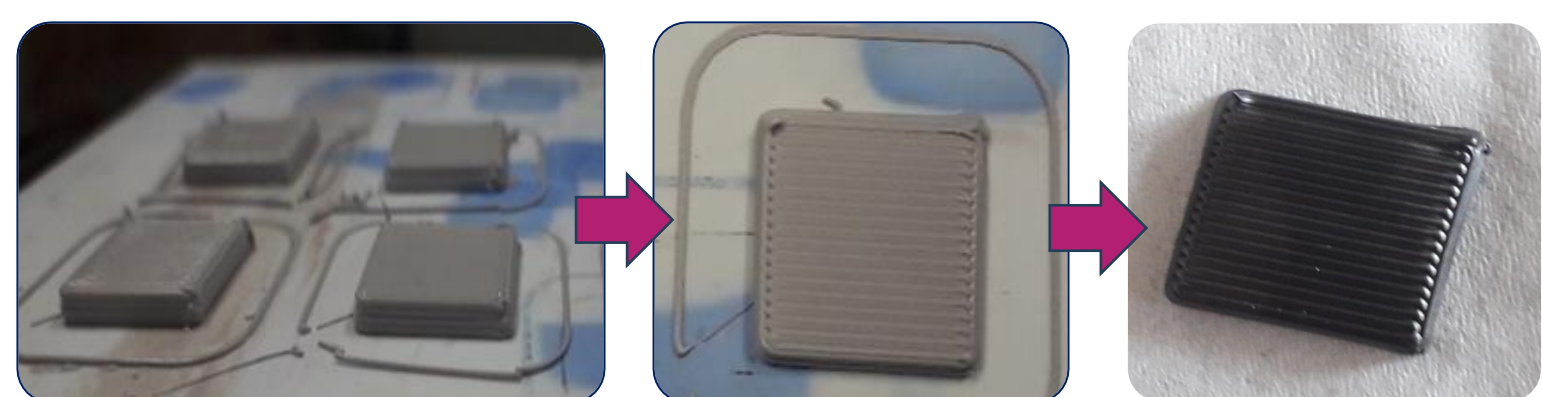
Use of a doped (Nb, Co, Ca) BaTiO₃ developed by Thales R&T

Comparison of the dielectric and piezoelectric properties for an undoped and doped pressed BaTiO₃ [1]

	BaTiO ₃	Doped-BT
Dielectric losses (%)	2,8	0,3
Piezoelectric constant d ₃₃ (pC/N)	145	255
Relative permittivity	2415	1862
Curie temperature (°C)	~ 126	~ 110°C

Microstructure

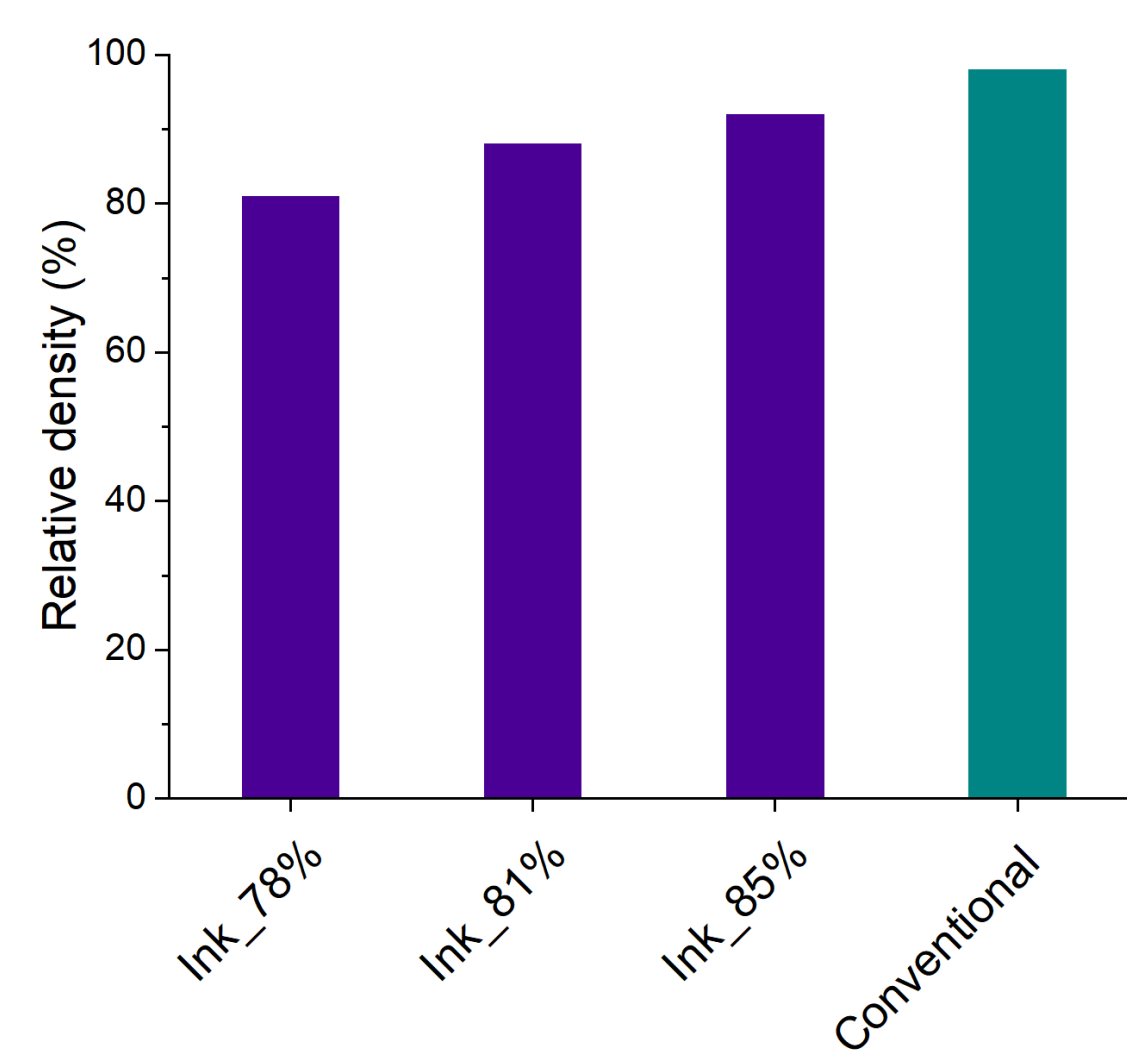
Thermal treatments and parts densities



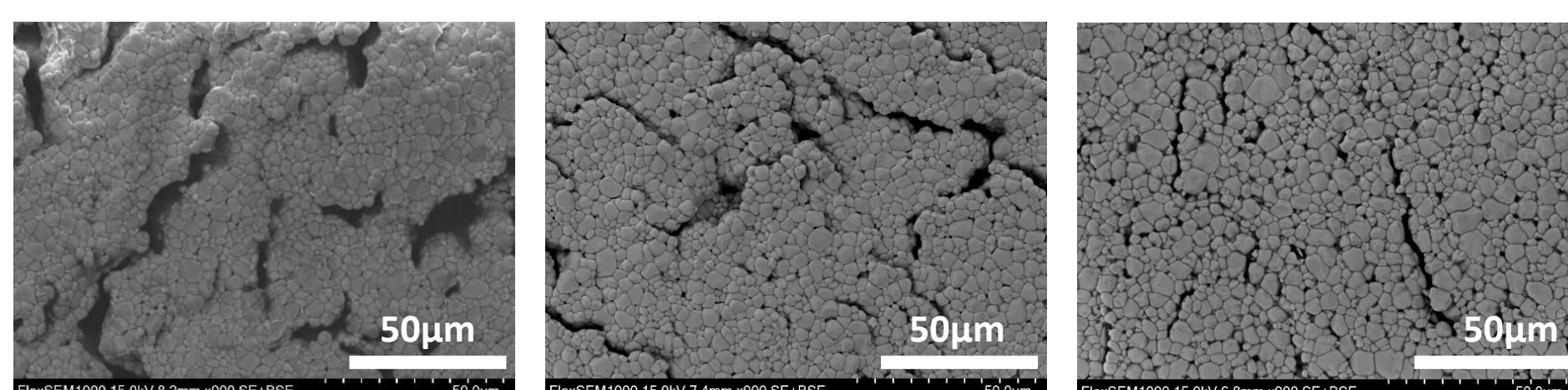
Drying :
40°C - 15h
1°C/mn

Debinding :
600°C - 4h
1°C/mn

Sintering :
1100°C - 4h
3°C/mn



SEM images of the printed parts



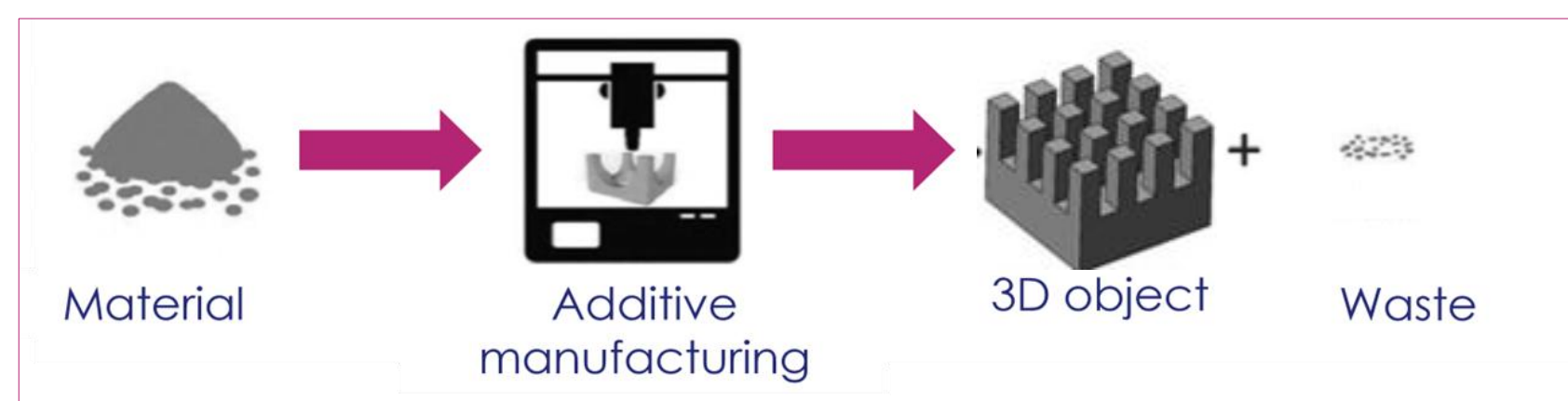
78% 81% 85%

Ceramic filling rate in ink formulation

Grain size ranging from 1 to 12µm

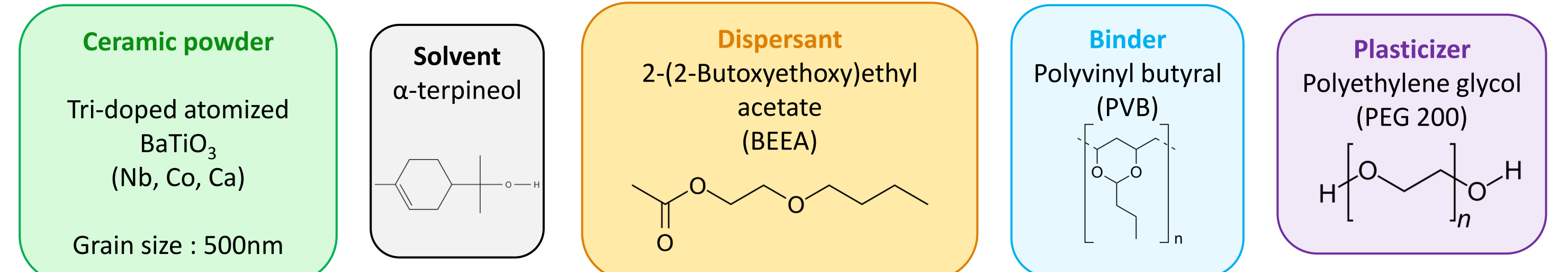
Enhancement of the densification with the increase of ceramic filling rate

Additive manufacturing



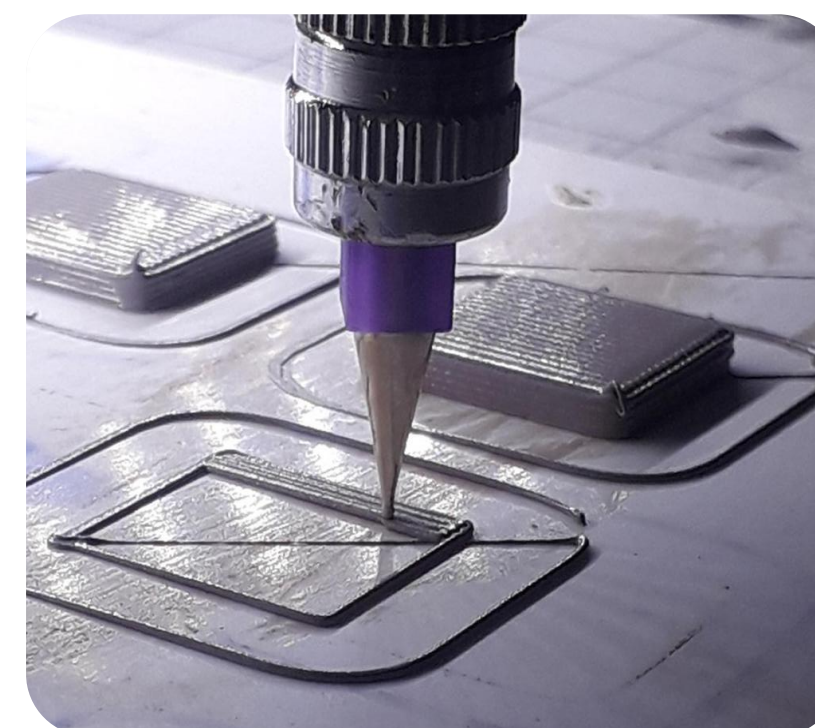
→ Design freedom and flexibility
→ Less material wastages

Ceramic paste formulation



3D-printing by Direct Ink Writing

Printing parameters



Printing of ceramic parts with 85% of filling rate

Ceramic filling rate : 78 – 81 – 85 %

Rectilinear filling

Cross hatching angle : 90°

Filaments overlapping : 10%

Printing speed : 3 mm.s⁻¹

Nozzle diameter : 0,5 mm



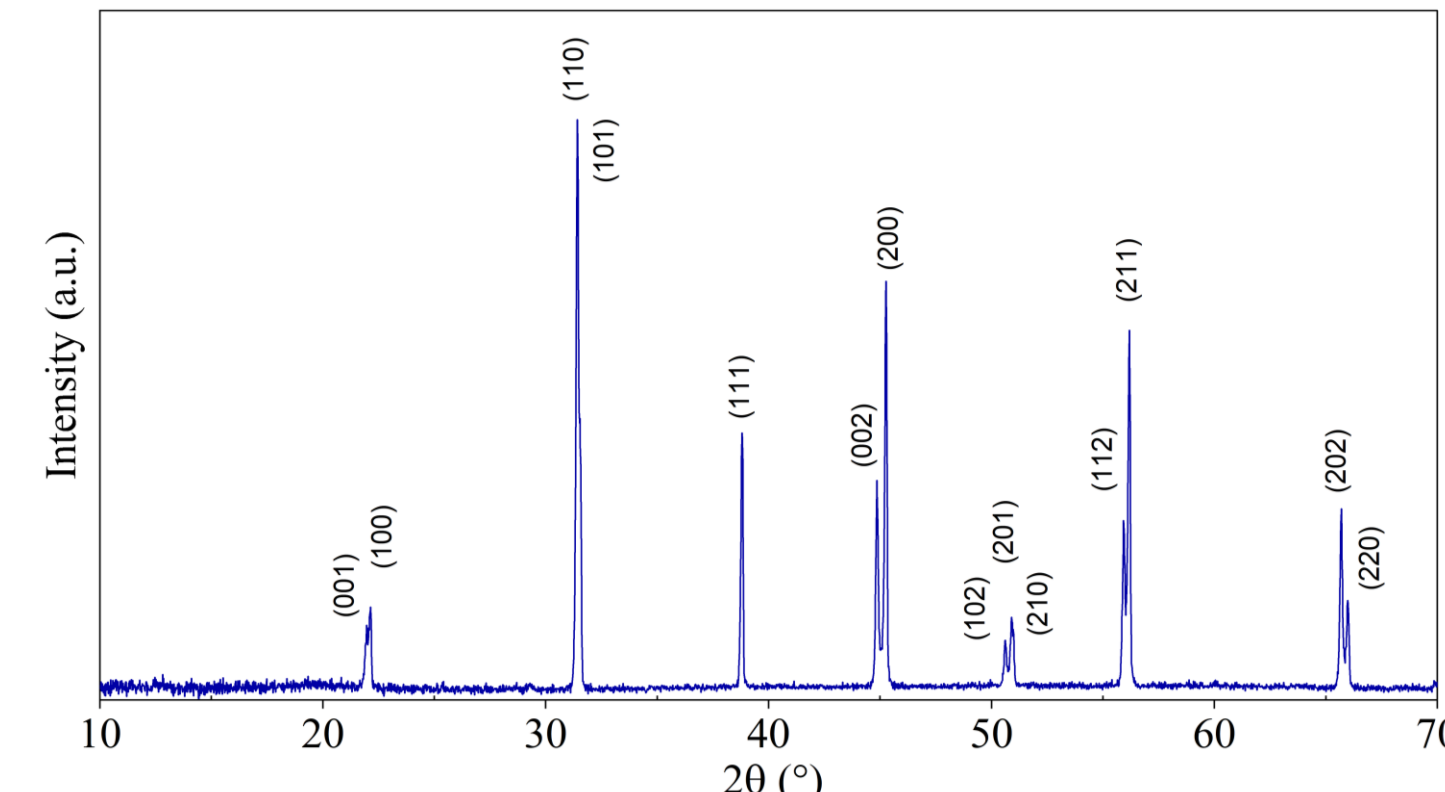
Unoptimized



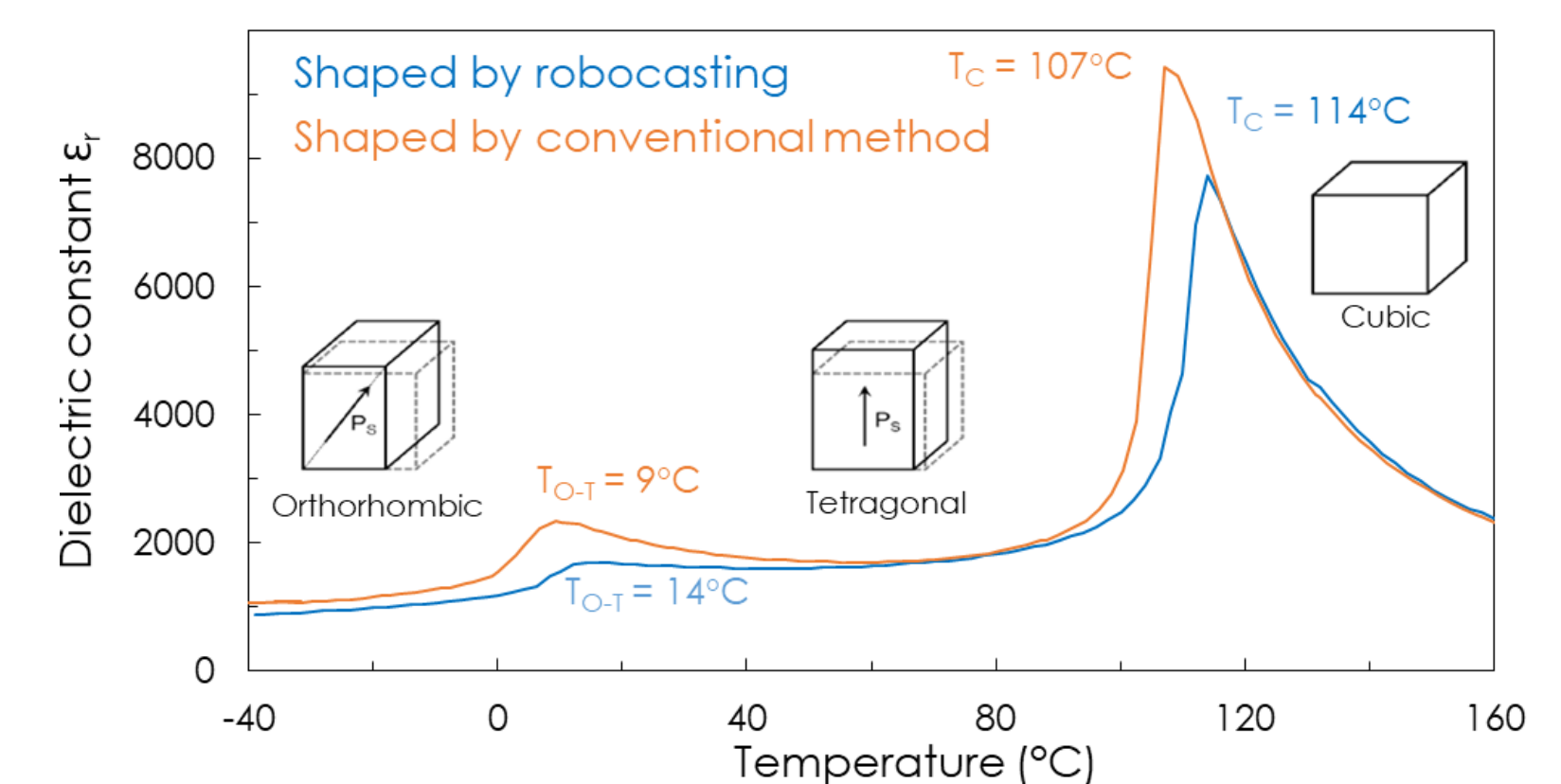
Optimized

Functional properties

Perovskite structure with a tetragonal crystal system



X-ray diffraction pattern of a 3D-printed (Nb, Co, Ca) BaTiO₃

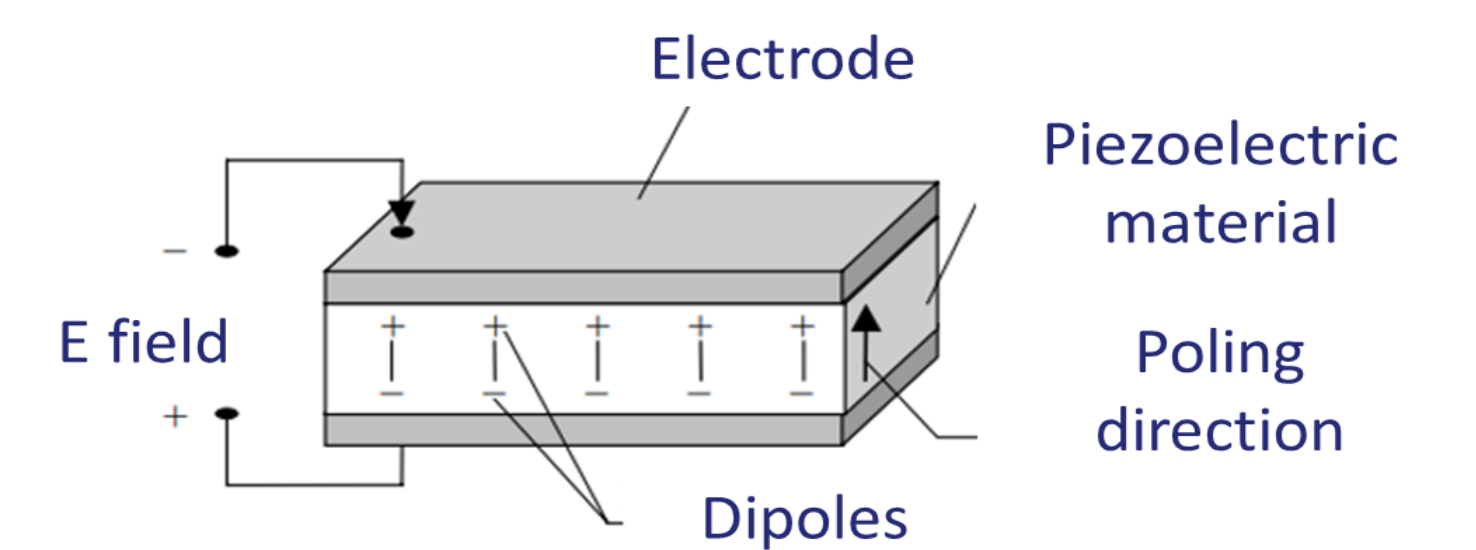


Relative dielectric constant variation under temperature [2]

Poling by field cooling method

Cooling from T^o_{initial} > T_{curie}

Electric field applied : 10 kV.cm⁻¹



Dielectric and piezoelectric properties

	ε _r	tanδ (%)	d ₃₃ (pC.N ⁻¹)	k _t (%)
Ink_78%	1506	1,32	242	20
Ink_81%	1571	0,75	251	18
Ink_85%	1714	0,52	252	22
Conventional ceramic	1862	0,34	255	47
PZT (NAVY I) ^[3]	1275	0,75	290	-

Conclusion and prospects

Successful shaping of simple geometries
Well densified ceramics that provide good piezoelectric properties (A85%)

Work in progress for the printing of complex geometries such as 1-3 piezocomposites
Elaboration of a water-based ink



References

- R. Ul, « Céramiques piézoélectriques : le titanate de baryum dopé pour transducteurs acoustiques », Thèse de doctorat, Bourges, INSA Centre Val de Loire, 2018.
- R. Damamme, L. Seveyrat, B.-B. Ana, V.-C. Nguyen, M.-Q. Le, P.-J. Cottinet, « 3D Printing of Doped Barium-titanate Using Robocasting - Toward New Generation Lead-free Piezoceramic Transducers », Journal of the European Ceramic Society, vol. 43, Febr. 2023, doi: 10.1016/j.jeurceramsoc.2023.02.054
- « Piezoelectric Materials | Piezo Material | APC International ». <https://www.americanpiezo.com/apc-materials/piezoelectric-properties.html>.