Centre for Sustainable & Circular Technologies

UNIVERSITY OF BATH

Centre for Sustainable and Circular Technologies; University of Bath

Project Title:	Processing of Smart Porous Electro-Ceramic Transducers (ProSPECT)
Lead Supervisor and co-supervisors:	Professor Chris Bowen (University of Bath) and Guylaine Poulin-Vittrant (Greman research laboratory, University of Tours)
Industrial Partner:	French MOD's Defence Innovation Agency (AID) and UK MOD's Defence Science and Technology Laboratory (Dstl)

Project Summary

Ferroelectrics are an important class of electro-active materials. Their piezoelectric and pyroelectric properties make them vital materials for SONAR, pressure sensors/ accelerometers, energy harvesting, thermal imaging/sensing, and non-destructive evaluation. Porosity in ferroelectric materials is often viewed as a defect. This PhD will demonstrate that porosity can be used positively to significantly improve the performance of ferroelectric materials. To this aim, the PhD **will develop modelling tools and manufacturing processes** that enable the controlled design and manufacture of porous ferroelectrics.

Porosity in ferroelectrics can be used positively in a number of ways. Introducing porosity can reduce acoustic impedance, $Z= (\rho Y)^{0.5}$, where ρ is material density, and Y is the Young's modulus. This improves impedance matching between the piezo-transducer and fluids, biological media or structural materials for SONAR, medical ultrasound or non-destructive applications. Researchers at Univ. of Bath have shown that replacing the high permittivity ferroelectric,1000, with low permittivity air (ε_r =1) reduces the permittivity and increases performance for piezo-sensing [1], pyro-sensing [2] and energy harvesting [3] since Performance Figures of Merit are inversely proportional to permittivity. Porosity can also decouple the longitudinal (d_{33}) and transverse (d_{31}) piezo-coefficients for improved hydrostatic sensing, which is beneficial for passive SONAR [4]. Research to date has been experimental in nature and models are simplistic, since they do not include the poling process. This PhD **will develop modelling tools** to design porous microstructures that provide reduced permittivity, while achieving a high level of polarisation for a high piezo- and pyro-electric activity.

While porosity provides benefits, there is a need to tailor the porosity for each application. Freeze casting is a route that involves directional freezing of ceramic particles dispersed in a freezing vehicle, such as water, leading to environmental benefits [1]. This PhD **will enhance the freeze casting process** to deliver timely benefits in terms of ease/speed of processing, to tailor the porosity, to form complex shapes by freezing in a mould of the desired geometry, which will help to reduce waste. In collaboration with GREMAN lab, pores will be infiltrated with **compliant polymers** to impart toughness and flexibility/conformability to the transducer devices. A range of polymers will be studied and compared to maximise transducer performance adhesion to the ferroelectric, and ageing. Performance will be compared to other competing piezoelectric composite technologies, such as zinc oxide (ZnO) nanowire based composites [5,6], manufactured at GREMAN lab, to evaluate the relevant **Figures of Merit** for sensing, SONAR and harvesting applications.

This will enable the production of porous lead-free piezoelectric and ferroelectrics materials of the required architecture at low-cost with tuneable mechanical, thermal and electrical properties to be tailored to their

application. This will be demonstrated by the development of flexible transducer devices for SONAR/sensor/harvesting applications to showcase the technology.

References

[1] Y. Zhang, C. R. Bowen et. al., J. Euro. Ceram. Soc. 10.1016/j.jeurceramsoc. 2018.04 .067 (2018).

[2] Y. Zhang, C.R. Bowen et al., J. Am. Ceram. Soc., 98, 2980 (2015).

[3] Y. Zhang, C.R. Bowen et al., J. Mat. Chem. A, 5, 6569 (2017).

[4] C. R. Bowen et al., IEEE Trans. Ultra. Ferro Freq. Cont., 50, 289 (2003).

[5] A. S. Dahiya, G. Poulin-Vittrant et. al, Advanced Materials Technologies 1700249 (2017).

[6] K. Nadaud, G. Poulin-Vittrant et. al, Mechanical Systems and Signal Processing, 133, 106278(2019).

Sustainability issues addressed

The development of porous lead-free piezoelectric and ferroelectrics materials will lead enhance sustainability of a range of devices.

Eligibility criteria and selection process

The nominated Research PhD student will be either a British or French National and will be required to spend a minimum of 6 months in the partner French University.
As part of the award, the student is expected to meet the following requirements:
During year 1, attend a 1-day induction meeting in Paris (this usually takes place in April);
Attend 2-day annual conference, which alternates between UK and France. The 2021 conference will be held in the UK.
Attend 2-day meeting at Dstl each year in winter or spring.

British or French candidates can apply by sending an expression of interest to the supervisors Chris Bowen (c.r.bowen@bath.ac.uk) and Guylaine Poulin-Vittrant (guylaine.poulin-vittrant@univ-tours.fr) to include a CV which includes your academic and work experience. All applications will be reviewed rapidly and promising applicants will be invited to an interview at Bath or via Skype.