PhD in Materials and Engineering Science

Processing of Smart Porous Electro-Ceramic Transducers (ProSPECT)

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, $\varepsilon_{33}^{T} > 1000$, with low permittivity air ($\varepsilon_r = 1$) 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, $g_h = (d_{33} + 2d_{31})/\varepsilon_{33}^{T}$, 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.

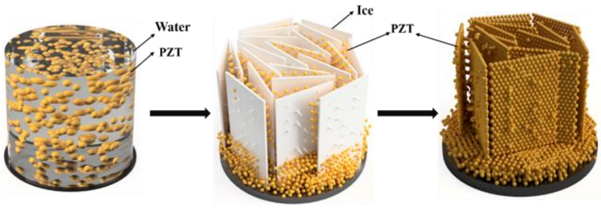

Fig 1. The freeze casting process **[1]**

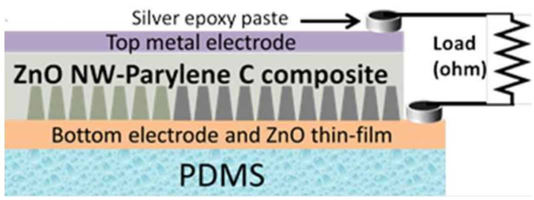

Fig 2. ZnO nanowire based nanogenerator **[5]**

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, Fig. 1 **[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]** (Fig. 2), 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.

PhD Studentships

Fully funded PhD studentship will cover UK/EU tuition fees and a tax-free maintenance allowance at the UKRI Doctoral Stipend rate (£15,285 in 2020/21). This PhD programme is jointly managed by the French MOD's Defence Innovation Agency (AID) and the UK MOD's Defence Science and Technology Laboratory (Dstl).

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.

Application Process

Starting date of the PhD project : before January 2021.

We are inviting applications for a 3 year fully funded studentship, for students with a background in **relevant disciplines of Science and Engineering**, including Acoustics, Mechanical Engineering, Chemistry, Chemical Engineering, Physics and other related disciplines. Applications are welcomed from UK/France students with, or expecting to obtain, a first class or upper second class honours degree, or equivalent, in the relevant disciplines.
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:

- Approximately 250 words on your motivation
- A two-page CV which includes your academic and work experience
- Scans of your academic transcript(s)

All applications will be reviewed rapidly and promising applicants will be invited to an interview at Bath or via Skype.

Research Institutes

UNIVERSITY OF BATH

University of Bath: The Materials and Structures (MAST) Centre is a multidisciplinary centre whose goal is to develop and design innovative materials with unique properties, whilst targeting the structural and manufacturing applications. MAST has an emphasis on strong industrial collaboration in materials processing, characterisation, sensing, structural health monitoring, and transport. The proposed PhD will benefit from MAST equipments for ferroelectric characterisation and processing, such as sintering furnaces, poling rigs, piezo-meters, polarisation-field testing, impedance spectroscopy, XRD/CT and mechanical testing. The Materials and Chemical Characterisation (MC2) Facility at Bath also provides cutting-edge facilities for microstructural/chemical analysis of materials fabricated within the PhD.

GREMAN: GREMAN is a research laboratory on materials, microelectronics, acoustics and nanotechnology of the University of Tours, CNRS and INSA Centre Val de Loire, located in Tours and Blois, France. Its expertise is aligned to the goals of the PhD since covers materials science, devices (components, sensors, transducers) and their integration. GREMAN's activities rely on technical platforms which can support the manufacture of the composites and their characterisation. At CERTeM, a R&D center for microelectronics (including a 400m^2 class 100 clean room), state-of-the-art equipments are available to develop innovative processes, manufacture and characterise components. Of particular relevance of the PhD are four probes measurement for resistivity testing, laser Doppler vibrometers, probe station measurements (I(V), C(V), impedancemetry), and energy harvesting test bench.

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).