

RIA-RSE Cost share grant report

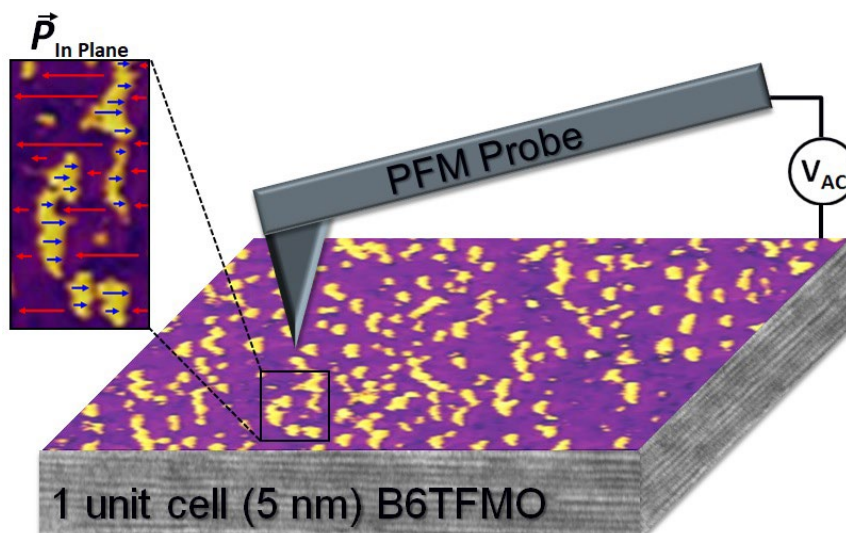
Recipient name:	Dr Lynette Keeney
Amount and year awarded:	€14,785 in 2019
Title of project:	Linking the magneto-electric properties of novel multiferroic materials at the micro- and nano- scale for beyond CMOS data storage technology.

Summary of findings:

During the reporting years, we reported the development of industrially realisable synthetic growth methods to fabricate $\text{Bi}_6\text{TixFeyMnzO}_{18}$ (B6TFMO) samples of ultra-low thickness (sub-7nm). Thin films of 5nm thickness have now been enabled and analysed by XRD and PFM (piezoresponse force microscopy), which equates to one unit-cell of the structure.

Demonstration of switchable polarisation in ultra-thin films can be a challenge for techniques such as polarisation versus electric field measurements, due to leakage currents associated with sub-20nm thicknesses. We have avoided this by probing at nano-scale using piezoresponse force microscopy (PFM) and have demonstrated that stable ferroelectric domains persist in my samples at unit-cell level (5nm thickness) both at room temperature and at elevated temperatures of 120C. In addition, by applying direct current voltages to the PFM tip, we can switch the orientation of the ferroelectric polarization and write arrays that demonstrate anti-parallel data storage states. As expected by crystal symmetry, we observe higher responses in the lateral direction compared to the vertical direction. This result is significant from a fundamental point of view as well as for practical applications in miniaturised electronics.

This work demonstrates the recent progress in the optimisation of B6TFMO materials for potential data storage applications, in particular devices based on in-plane tunnel junctions, which would not be hindered by competing depolarisation fields upon scaling down to ultra-thin dimensions.





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Travel undertaken and institutions visited:

Unfortunately travel was not possible during this project due to the restrictions pertaining to the global COVID-19 pandemic.

Outline the research activities undertaken:

Research samples were exchanged between University of Liverpool and Tyndall National Institute. Tyndall performed local ferroelectric measurements of B6TFMO thin films and KBMN $(\text{K}_{1/2}\text{Bi}_{1/2})(\text{Mg}_{1/3}\text{Nb}_{2/3})\text{O}_3$ -KBT $((\text{K}_{1/2}\text{Bi}_{1/2})\text{TiO}_3)$ ceramic samples by PFM. University of Liverpool performed XRD analysis of B6TFMO thin films. Researchers in Liverpool were able to provide on-line training and expert guidance to Tyndall PhD students so that they could practice on the XRD tool here in Tyndall. Training was conducted through Team Viewer. Students learned how to operate the XRD software Smart Lab Studio to run reactivity, rocking curve and general Omega/2Theta scans on Tyndall samples. Preliminary training on reciprocal space mapping measurements was also performed in addition to learning how to analyse and process the data. Advice was given on how to utilise DIFFaX software for computing diffraction patterns from layered materials.

Published work and publication plans:

'Persistence of Ferroelectricity Close to Unit-Cell Thickness in Structurally Disordered Aurivillius Phases', L. Keeney, Z. Saghi, M. O'Sullivan, J. Alaria, M. Schmidt, L. Colfer, Chem. Mater., 32, 24, 10511-10523 (2020). [Cited by 2]. We established the persistence of stable ferroelectricity close to unit-cell thickness (5 nm) in B6TFMO, in both in-plane and out-of-plane directions, initiating possibilities for miniaturising novel MF-based devices for future neuromorphic computing.

Dissemination and plans for future dissemination:

Invited Talk: "Memories are made of this: My journey into the development of new multiferroic materials", ISAF 2021, Virtual Conference / Sydney, May 2021. Contributed Talk: "Perseverance of Ferroelectricity Close to Unit-Cell Thickness in Chemical Vapour Deposited Aurivillius Phase Thin Films", ISAF 2021, Virtual Conference / Sydney, May 2021.

Contributed Talk: "Persistence of ferroelectricity close to unit-cell thickness in structurally disordered Aurivillius phases", ISAF 2020, Virtual Conference / Colorado, July 2020.

Poster presentation at Microscopy Society of Ireland Symposium, Trinity College Dublin, 8-10 January 2020, "Persistence of ferroelectricity close to unit-cell thickness in structurally disordered Aurivillius phases".

Collaborations and planned collaborations:

France:

CEA-Leti, MINATEC Campus, Grenoble: Dr Zineb Saghi. Dr Saghi has recently performed aberration-corrected scanning transmission electron microscopy on my ultra-thin films.

USA:



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CEMAS, Ohio State University: Prof David McComb and Dr Nuria Bagues Salgeuro, who are performing atomic resolution electron microscopy and energy electron loss spectroscopy on my samples.

India:

Dr Tuhin Maity: Indian Institute of Science Education and Research Thiruvananthapuram: performing magnetic characterisation of our samples.

UK:

Dr Michele Conroy, Imperial College London: performing differential phase contrast electron microscopy on my samples.

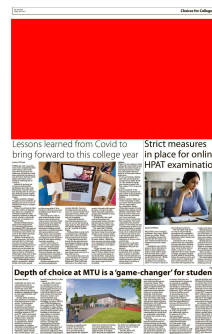
Outreach and engagement activities:

I actively contribute to public engagement/outreach activities, e.g. I conducted in-person (pre-COVID; March 2020 at Scoil Chliodhna Community National School) and virtual primary school visits (for Science Week, Nov 2020) (Making Fun Paper Circuits, An Introduction to Electronics), was a judge for Engineer's Week at Scoil Chliodhna Community National School 2021, and was a host for Transition Year students via the HighTechElec transition Year Work Experience Programme where students got hands on experience in the materials science lab (Feb and March 2020).

My children and I (July-Aug 2020) contributed to a "Tyndall Science at Home" video (<https://www.tyndall.ie/tyndall-science-at-home>) to celebrate John Tyndall's Bicentenary and to show families simple home experiments that can be done during lock-down.

I was invited to interview (Dec 2020 - Jan 2021) as part of a careers supplement for the Irish Examiner newspaper (<https://www.pressreader.com/ireland/irishexaminer/20210115/282604560491177>) for the Sligo Champion newspaper (<https://www.independent.ie/regionals/sligochampion/lifestyle/dr-keeney-flies-the-ag-for-women-in-stem-39888561.html>) (Dec 2020) and for Irish Tech Central (<https://www.techcentral.ie/focus-on-research-dr-lynette-keeney-tyndall-national-institute/>) (Dec 2020). I gave social media interviews for International Women's Day and Mother's Day (March 2020). I also contributed to press releases highlighting my successes e.g.: (<https://www.tyndall.ie/news/tyndall-receives-funding-from-sfi-frontiers-for-the-future-programme-valued-at--53-million/>)

My focus is to encourage people to think actively about science and technology to appreciate the challenges that researchers face, to realise the importance of innovation, the opportunities it can bring and to understand the relevance of research to their daily lives. Positive interactions between researchers and the public are important to how the public views scientific research and enable the public to realise our skills and value, thereby generating support for science and technology research activities.



Laurie O'Flynn meets two researchers who urge young women to consider science, technology, engineering and mathematics (STEM) careers



My STEM Career Journey

Dr Lynette Keeney,
Tyndall National Institute.

DR Lynette Keeney is based at the **Tyndall National Institute** and is working on developing a new material incorporating electrical and magnetic properties capable of storing a lot more digital data than existing technologies, at a faster speed and using less power.

She describes her research as 'basic oriented' which looks at fundamental problems in order to improve people's lives. Dr Keeney recently received a three-year Royal Society-SFI University Research Fellowship on foot of a five-year one just completed. Besides materials science research, Dr Keeney also teaches materials chemistry at UCC.

"This Fellowship is unique as it promotes intellectual freedom and independence in early career researchers, and it facilitates the work science-life balance that women often have to juggle."

"In secondary school I liked Science. I chose Chemistry and Biology but not Physics, even though I know that the nuns at the school would have organised the timetable

"Over time, you develop independence as a researcher. It doesn't happen overnight"

if I had wanted to do all three. Even though I didn't do it in the Leaving Cert, I use Physics a lot now. It just shows that even if you don't make the big decisions at school, there are still options open down the road.

"I did a Science degree course in UCG (NUIG) with Physics, Chemistry, Biology and Maths in first year. After that I chose Chemistry. I had enough points to do other courses but I went with what I liked. When I finished my degree, I had to decide whether to go to industry or do a

PHD. I asked lecturers and they said industry may be too narrow a field.

"After the PHD, I spent 2 ½ years in Montreal working in analytical chemistry, assessing new pharmaceuticals as part of pre-clinical trials.

"I then moved to the **Tyndall National Institute** in Cork as a post-doc researcher. In this role you're not a student anymore so you have to come up with your own ideas within the project.

"You need to be creative asking what are the gaps and how can I contribute? Over time, you develop independence as a researcher. It doesn't happen overnight.

Grant proposals are a big part of the job. It is a very competitive area so it really focuses the mind. The proposal system looks for ideas where there is new learning or a benefit to society.

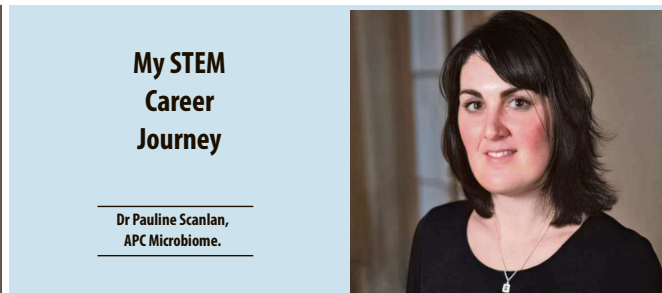
"In 2015, I was awarded the Royal Society-SFI University Research Fellowship, with funding for five years, which has just been extended by a further three years.

"I see myself as a researcher. The main challenges are

the fact that there isn't a secure income for them with families and it can be too expensive to travel to present work when children are very small because at that age, you need to bring them with you. There is a need for practical support like being able to bring a child and carer on the trip until the children are old enough to leave at home. One thing that has changed is the flexibility of being able to work from home.

Advice
"My advice to students is to pick the discipline you have a flair for and that you will continue to love. Some subjects are more recession proof but Science will always be there. It is a good base. There are always jobs in science and engineering in education, research and industry. They are creative careers where you are constantly learning."

"A Science degree is a well-rounded education, but don't be afraid to deviate from what you did in college or secondary school. It's ok to be open minded. We don't know what's coming down the road."



My STEM Career Journey

Dr Pauline Scanlan,
APC Microbiome.

DR Pauline Scanlan, APC Microbiome, has recently received the Royal Society-SFI University Research Fellowship for the second time to continue her early career success researching the origins of microbial diversity in the human gut.

She is a researcher, teacher, student supervisor and mentor.

The prestigious awards amount to eight years of financial support allowing Dr Scanlan to carry out her research independently.

Dr Scanlan believes everyone should be encouraged to engage with Science and STEM subjects for the greater good of society.

"It's important that young people are encouraged to go to science. We need a science literate society so that people are able to separate the nonsense from the truth."

"At school I wasn't very hard working. To learn I just had to listen in class. I loved languages, art and the sciences. I put a lot of courses on the CAO application but I accepted

"We need more fellowships like this that allow women transition to the highest levels"

a general science degree in Cork. I studied microbial and plant biotechnology for my degree and then I was offered a PHD studying diseases of the digestive tract.

"I worked with Fergus Shanahan examining how the microbiota in the gut of a healthy human are different from those in an unhealthy person. We were looking for patterns."

"After the PHD I didn't feel satisfied. I knew that there was so much more to learn so I went to the



University of Oxford for four years to work on how viruses and bacteria interact and co-evolve. It was a steep learning curve. I was in a famous lab with very high standards.

"My research studies how viruses affect diversity in the gut, how they integrate with the bacteria and how that affects human health."

"I was pregnant when I applied for this fellowship. Some people would put having a family on hold, but not me. This fellowship is advantageous to family life. I'm independent, and I have the flexibility to drop the kids off and then go into the office."

"Also, if I am having any difficulty, SFI is willing to petition my host university. Having a family while working hasn't compromised my research. People have been hugely supportive. Having an academic career and raising a family can be done if you have flexible working hours and childcare support."

"We need more fellowships like this that

allow women transition to the highest levels so that there are women's voices at the highest levels. For example today we see the lack of a woman's voice in the Dail where there is no provision for maternity leave for our Justice Minister."

Advice

"If you are interested in Science, a general Science degree lets you try all the subjects in the first two years. Then you can decide which stream you'd like to go into."

"I could never have predicted my career. I'm very easy-going and I would just do the next most interesting thing. I did know that I wanted to work for myself and pursue my own ideas, but I don't think too far ahead."

"If you can work where your interest lies, then it will bring you to a good place. Do the next best thing and it will constantly bring you forward. You just need to avoid overwhelm and keep perspective."

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DR KEENEY FLYS THE FLAG FOR WOMEN IN STEM

SLIGO RESEARCHER
AWARDED SECOND
PRESTIGIOUS FELLOWSHIP

By **CIARA GALVIN**

DR Lynette Keeney says being a mother and having a full time career is a balancing act.

The Cairns Hill native is a researcher at Tyndall National Institute in Cork and has recently been awarded a prestigious Royal Society-SFI University Research Fellowship for the second time for her outstanding

early career success in the area of deep-tech data storage.

Described as an ambassador for careers in STEM, Dr Keeney wants to make a difference and does so by nurturing people's curiosity. She has previously hosted transition year and other students in labs, virtual primary school visits and gives career talks, even providing guidance for BT Young Scientist & Technology Exhibition projects.

So where did Dr Keeney's education journey begin?

"I went to school in Carraroe before going to The Mercy. I went to NUI Galway in 1997 and studied Science. I did a general degree and ended up with a Chemistry degree."

The daughter of Maria and Kieran, Dr Keeney went on to complete her PHD in Chemistry and combined travel with work



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going to Montreal for two years.

In Canada Lynette was involved in analytical chemistry for pre clinical trials.

Returning home in 2008, Dr Keeney moved to Cork and began working at the Tyndall National Institute.

The RS-SFI University Research Fellowship scheme that Dr Keeney was awarded for a second time gives early career researchers a generous time frame to develop their own research field and build their careers at a time when many are often also starting their families.

This is especially pertinent for female researchers. According to a US study, more than 40% of women with full-time jobs in science leave the sector or choose part time work after having their first child. Only 23% of fathers make similar changes.

For Lynette she said she was lucky in that she receives great support from her

husband, Jonathan Molony.

"If I have to travel for work my husband will take a week off work".

So how does she juggle her research with raising Jacob (5) and Sophia (3)?

"It was harder at the start. Any mum or dad would say that. In the early days you may not sleep, you may be breastfeeding, and you can't be around them all the time."

She goes on to explain, "In research it was hard, big moments in research are when you get results you want to communicate it, and you have to travel to conferences to present results and that can be hard when children are small."

Dr Keeney says there is obviously costs with deciding to bring your children with

and sometimes it can be the decision to bring them, or to not take opportunities.

"I would say any working parent has to juggle. There are some benefits in research. If you are doing practical work in the lab, you can do paperwork at home and if the kids are sick you can rearrange your work day."

Dr Keeney says supports are very important in order to encourage more women to enter STEM.

"I had my first baby when I was at interview stage for the original award and the Royal Society accommodated online interviews rather than having me travel to London. I had my

second baby during the course of the project, when I was allowed pause during maternity leave. Not all funders are as accommodating as this."

Dr Keeney studies multiferoic materials for nanoscale data storage, working towards a paradigm shift in memory technologies.

And in layman's terms?

"When solids get very small, we call them materials. Components in computers tend to be made from silicone."

The researcher explains that when you save something like a Word document it is either saved on electric charge storage or on a hard disc drive which is made of magnets.

Dr Keeney's main area of research is to combine electric storage with magnetic storage. Which she explains is tricky, as the two things to different things, but would be hugely beneficial for data storage if

achieved.

Going back to the issue of women undertaking research, Dr Keeney is asked if it is a problem she still sees in her field?

"It's a real recognised problem. In some disciplines, like physics, there may be not as many women. In chemistry it seems to be quiet equal."

But gaps can begin to appear.

In a university setting it might be a 50/50 split in gender, but as soon as careers progress, from PHD to Post Doc, it might drop to 30 percent women and can drop to 16 percent women in research.

It's 84% male in my grade, we definitely have a problem that needs to be addressed."

Like a lot of women returning to work, Dr Keeney admits she felt guilty returning from maternity leave.

"Now I see I'm giving back more to my kids, I'm not saying it's easy. You still have all the housework to do," she laughs, but adds that her career is important to who she is.

"I absolutely love being a mother, but I also love work. I feel like I'm more than just

a mother. I have a lot more to give. There's a sense of satisfaction and you're giving back to other people that aren't your family.

In a way you are a role model, by being a working parent. I was in my son's school the week before lockdown doing experiments and now they know Jacob's Mom is a scientist!"

Asked what can be done to help women, Dr Keeney is candid.

"I don't have all the solutions, I wish I did," she laughs.

But the Cairns Hill native cites practical support as being a good place to start.

"You're doing well at work, and you're starting a young family, you need to travel and be recognised internationally. Extra funding maybe, for a partner or carer to come with you and your young children would help.

"She continues, "It wouldn't be for a long period of time, that would really really help. It could help females in deciding to go to a higher grade."

Athena SWAN an equality charter started in the UK is now in Ireland to build data on the gap and then find out why the gaps are happening.

"The last part of that is how we can correct it. There are programmes that are working," Dr Keeney says with an air of hope.

In the year that was, Dr Keeney said she was quite lucky in that a lot of her research continued.

"A lot of work would be in the lab and I have a lot of PHD students, we were busy in Jan February and March and the first few weeks was great to put research together, but then there's only so much writing and reading students can do."

Still based in Cork, Dr Keeney admits she does miss getting back to Sligo to see her parents and many friends from home.

"My parents love to see the grandchildren. We were back in August before Jacob went back to school, and we're hoping to get back before the New



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Year. My parents are brilliant for coming down. Sligo is a big part of me.”



Dr Lynette Keeney.



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Dr Keeney has been recognised for her early career success in deep tech data storage.