



Nanostrain

Providing highly accurate measurement of strain in nanoscale systems to drive innovation

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# Welcome

Welcome to the second edition of the quarterly EMRP Nanostrain project newsletter. Over the next three years this newsletter will provide you with everything you need to know on the latest project developments, as well as interviews with global industry leaders and a summary of upcoming global events and academic conferences on the exciting technological area of nanoscale piezoelectrics.

## Project news

### *Interferometer commissioning underway*

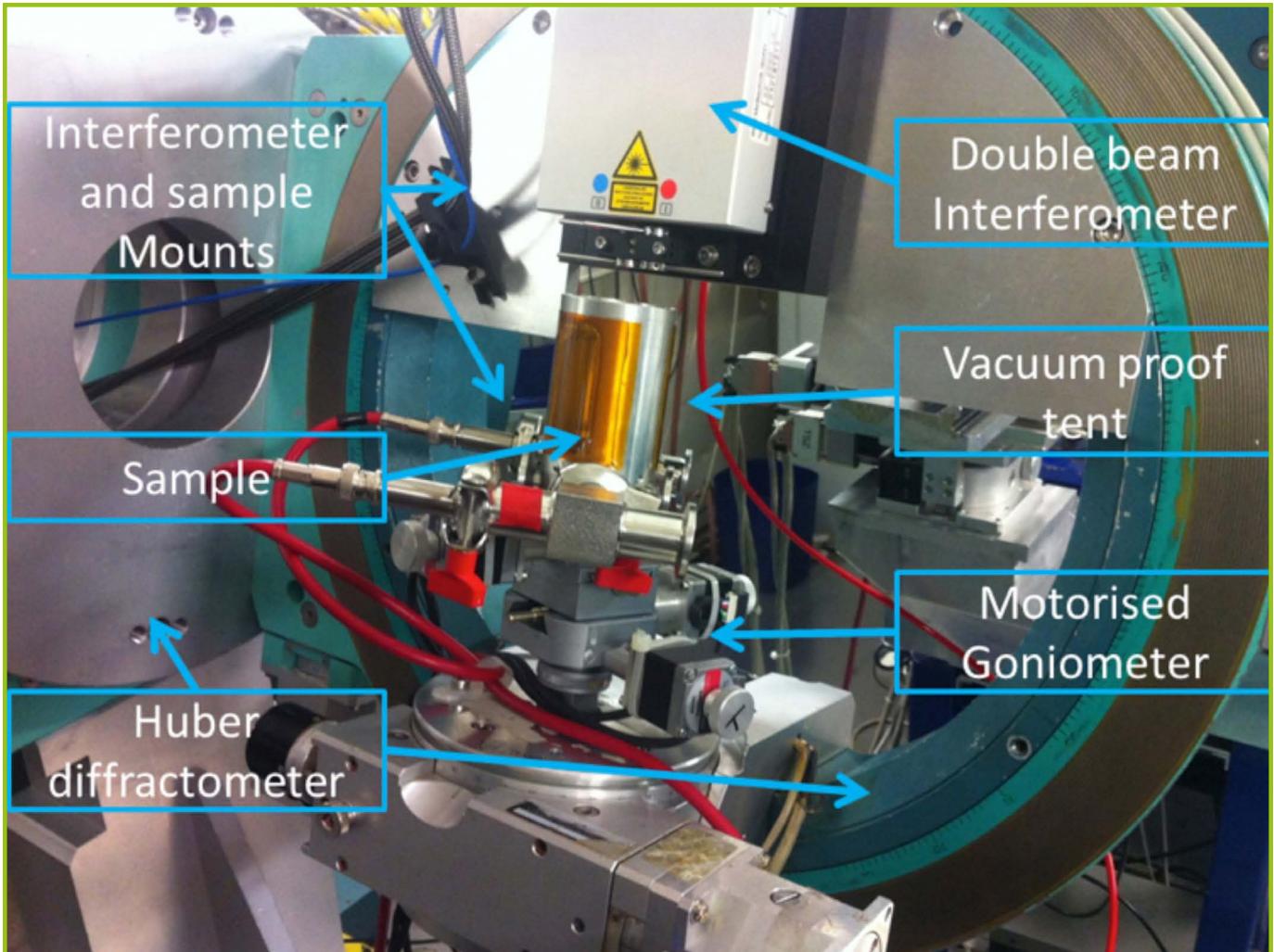
Work package 1 aims to develop a new metrology tool combining x-ray diffraction with laser interferometry to measure displacements in piezoelectric materials. Synchrotron x-rays are often used in atomic scale structural studies, and optical interferometry is used to measure displacements at the micro and nanoscale. By combining the two techniques, scientists working on the EMRP project Nanostrain hope to establish a direct comparison between the intrinsic atomic displacement (changes of the unit cell size, ionic movements, pm range) and macroscopic changes which are typically the combined effect of both intrinsic and extrinsic (domain wall motion, etc.) phenomena occurring in the sample of interest.

Interferometry is very sensitive to external vibrations, whilst synchrotron X-ray measurements are typically performed in very noisy environments that can lead to vibrations that can greatly affect the interferometry results. Since the project started last year, the work package 1 team have been working on developing a full metrology kit including an interferometer mount to create a rigid/stable sample-interferometer-diffractometer system to reduce the effect of vibrations.

In February 2014, after the holders had been manufactured, a team of NPL scientists travelled to the XMAs beam-line in France to assemble the newly

developed kit on the beam-line diffractometer, to ensure that all the different components fitted together and that the system was stable enough within the specification needed. The scientists mounted one sample on the new sample holder and managed to simultaneously align the lasers, the sample, the reference mirror and the centre of rotation of the diffractometer with good accuracy. This was an important milestone - it is crucial to both obtain a good initial alignment and to keep the sample and the interferometer perfectly aligned during the duration of the experiment.

The instrument was calibrated using a commercially available piezoelectric actuator and the team measured the lowest DC displacement of less than 1 nanometre - well within the desired range. Pre-commissioning measurements of the vibrations in and around the diffractometer before, during and after axis movements had previously been recorded. During this commissioning run, the team were able to identify several new sources of electrical and mechanical noise and isolate them. The dual beam (differential) configuration of the interferometer significantly reduced the noise pick up on the sample measurement side, though certain mechanical vibrations couldn't be completely removed during this commissioning run and the scientists are currently evaluating hardware as well as software solutions to reduce or correct for them.



*Fig. 1 Interferometer and sample holder fitted on the XM<sub>a</sub>S Huber diffractometer during the first commissioning run in February 2014. Image courtesy of NPL and XM<sub>a</sub>S.*

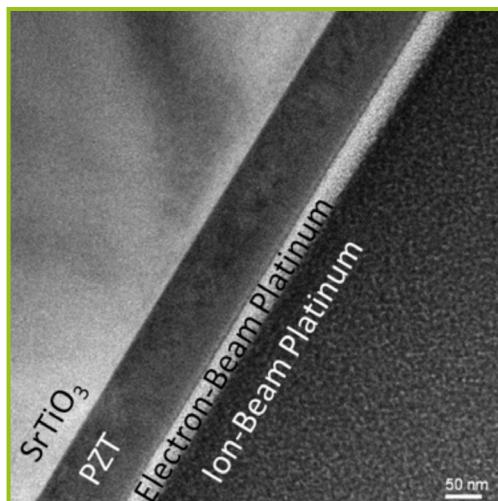
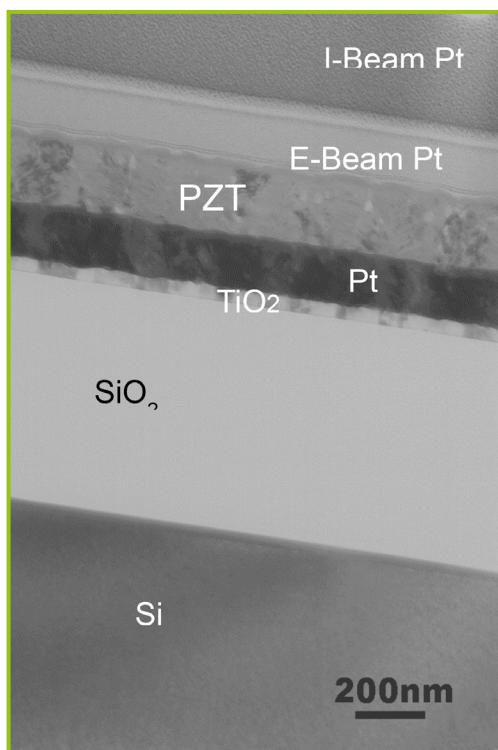
The team have been working on the beam-line software as well as hardware to develop a reliable control system and to determine and incorporate best measurement practices into the data acquisition code. They are currently conducting the commissioning of the equipment, with synchrotron X-rays, with the hope of taking their next set of specification measurements in May 2014.

The actual experiments, on real samples will be carried out in July, 2014. By then, the software will be fully developed and the hardware fully calibrated. There's still a lot to do but progress so far has been good and initial work has been very positive.

## Preparing piezoelectric samples

BAM, the German Federal Institute for Materials Research and Testing, is tasked with preparing thin lamellae from the piezoelectric materials for the Nanostrain project.

A focused ion beam (FIB) technique is used to produce these lamellae. Since October 2013 two thin film piezoelectric structures have been investigated as potential samples. The first one (system 1) is a standard 20/80 lead zirconate titanate (PZT) thin film on platinized silicon wafer, and the second one (system 2) is a 100 nm thick epitaxially grown PZT film on doped strontium titanate substrate. As revealed by the overview TEM micrographs Figs.1 and 2, the two systems differ considerably.



Whereas system 1 is a polycrystalline film on silicon wafer with various interlayers including a rather thick, presumably thermally grown amorphous SiO<sub>2</sub> layer, system 2 was identified as monocrystalline PZT grown epitaxially on strontium titanate wafer.

FIB is a destructive method. System 1 was used to study systematically the impact of Ga<sup>+</sup> ion beam irradiation on near surface superficial layer structures of PZT films. This was done by preparing cross-sectional lamellae from areas exposed to different ion doses, different ion beam energies and different beam inclination angles.

The results of the parameter studies on ion implantation into PZT show that under the most unfavourable conditions – i.e. highest ion dose, beam energy and inclination angle - the depth of the affected zone is 26 nm, which is of the same order of magnitude as results published for silicon. On the other hand, under the most favourable conditions – low ion dose, lowest possible accelerating voltage and a glancing beam incidence of 1° - the thickness of the Ga<sup>+</sup> implanted layer can be reduced to 2 nm (for 5kV, 5nm for 16kV), comparable to as observed for silicon. This is good news, but it also shows that completely defect-free samples cannot be expected after FIB preparation.

Therefore, the next step is to explore whether lamellae prepared either by the standard and/or by the optimised procedure are suitable for nanostrain measurements. Since at the moment only epitaxially grown PZT films on STO seem to be well adapted to this technique it was decided to start with this system. A first lamella (see Fig.2) was already prepared with the standard procedure and a second lamella will be prepared while taking account of the experiences obtained with system 1. A further idea is to correlate the results of implanted layer thickness with electrical measurements.

A one-day workshop was organised in January giving Nanostrain project partners the opportunity to watch most of the necessary preparation steps live in the lab and to discuss needs and expectations towards specimen preparation for future nanostrain measurements with the different techniques available within the consortium.



The Nanostrain project partners

### Nanostrain at ALTECH 2014

From the 26th-30th May, partners of the Nanostrain project will be in Lille, France for the European Materials Research Society (EMRS) Spring Meeting, and its symposium H, ALTECH 2014- Analytical techniques for precise characterization of nanomaterials.

Nanomaterials have the potential to improve modern technology in many areas, in everything from energy storage to biosensors. Accurate characterization of nanoscaled materials is essential for a better understanding of their functional properties and ultimately, the commercialisation of these innovative materials.

ALTECH looks at recent and innovative developments in analytical techniques that can provide precise characterization of materials and devices with dimensions at the nanoscale and/or atomic resolution.

This year the ALTECH event attracted over 150 contributions demonstrating how innovative analytical techniques enable a deep understanding of new materials. Technical contributions and tutorials will be provided by the Nanostrain project (IND54- Novel electronic devices based on control of strain at the nanoscale) as well as three other EMRP projects: Traceable characterisation of nanostructured devices, Metrology for the manufacturing of thin films and Chemical metrology tools for manufacture of advanced biomaterials in the medical device industry.

### Nanostrain partners will present the following at Altech 2014:

- Werner Österle, Nicole Wollschläger (BAM Federal Institute for Materials Research and Testing, Berlin, Germany): *Focused Ion Beam Machining for Site-specific Nanocharacterization - Advances and Drawbacks (training tutorial)*
- Thomas Hase (University of Warwick, UK): *Advanced XRD methodologies (training tutorial)*

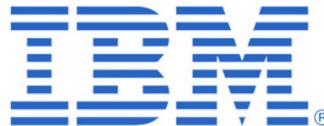
- Peter Hermann, Arne Hoehl, Bernd Kaestner, Gerhard Ulm and Burkhard Beckhoff (Physikalisch-Technische Bundesanstalt, Berlin, Germany): *Characterization of Si-based Nanostructures by Near-Field Imaging and Nano-FTIR Spectroscopy (training tutorial)*
- Mark Stewart, Serban Lepadatu and Markys Cain (National Physical Laboratory, UK): *A Geometry Independent Approach to the Measurement of the Piezoelectric Coefficient of Thin Films*
- Alex Bogdanov (A.P. Vinogradov Institute of Geochemistry SB RAS, Irkutsk, Russia; and Irkutsk State Technical University, Irkutsk, Russia), Anna V. Kimmel (National Physical Laboratory, UK): *The effect of mutual order of B-cations on electronic and optical properties of strained Pb(ZrxTi1-x)O3 (talk)*
- Anna V. Kimmel, Markys G. Cain (National Physical Laboratory, UK): *Properties of Pt/Pb(Zr0.5Ti0.5)O3 interfaces (talk)*
- J. Wooldridge, M. Stewart, C. Vecchini, M. G. Cain, M. Gutmann, M. Reece (National Physical Laboratory, UK): *Temperature and Frequency Dependence of Electric Field Induced Phase Transitions in PMN-xPT (talk)*
- Anna V. Kimmel, Carlo Vecchini, Markys Cain (National Physical Laboratory, UK): *Structural properties of Pb(ZrxTi1-x)O3 (poster)*

Read more about ALTECH 2014 [here](#)

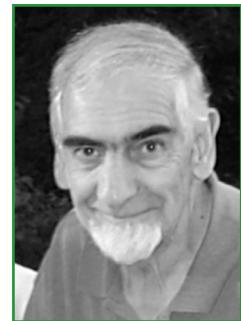
The programme of ALTECH is available [here](#)

# Big Interview:

Glenn J. Martyna and Dennis M. Newns



Glenn J. Martyna



Dennis M. Newns

*IBM, an unfunded partner of the Nanostrain project, is working to develop a novel PiezoElectronic computer switch that could reduce power consumption by 50 to 100 times in comparison to current technology, enabled by DARPA (Defence Advanced Research Projects Agency) support.*

## What is the technology you are developing?

A nanoscale piezoelectric-based computer switch with a very low power requirement yet that operates at high speed.

## Why are you developing it?

Currently almost all computing devices use a silicon based technology called CMOS (complementary metal oxide semiconductor). As the technology has developed, functionality has increased to enable vastly increased processing capabilities. However, if you look at your laptop or mobile device, the chips in them aren't getting any faster. As CMOS devices have become smaller and smaller over the years, in accordance with Moore's Law, the reduced scale has led to improved capabilities, but they have now reached their performance limit. The amount of energy required to switch the devices can no longer be lowered because the operating voltage has remained the same (around 1V) for a decade. So, if you want higher performance, you need to increase power - but most devices are already power limited, so performance improvement is effectively frozen. We have the technology to do much more with our phones and mobile devices but we are limited by human factors – the amount power we choose to spend. No one wants to carry around a cooling system in a backpack or charge their phone every 3 hours. Clearly, if we want functionality of electronics to continue to improve without making other sacrifices, then we need to change something.

## Why now?

The physics underlying CMOS devices was working fine until 2003, when they reached their power limit. It took everyone a while to realise that there was a problem, and then a few more years for people to do something about it. So, here we are in 2014 on the cutting edge of research into the area.

## How does the new switch work?

The new piezoelectric switch uses completely different physics from CMOS. Only by doing so can it overcome the limits encountered by CMOS. It works by applying a voltage to a piezoelectric material that expands under voltage. As it expands it compresses another material, a piezoresistor- which under pressure transforms from a non-conductor into a metal. This change causes current to flow (switch on).

## How will it change the electronics market?

If the device is successfully developed, it could reduce computing power requirements by 50 to 100 times. This could mean a number of things. It could mean that mobile devices wouldn't have to be charged nearly as much as they do now. Although it's more likely that manufacturers will keep the same charging requirements but offer significantly more capability- more bang for your buck if you will.

It's not just personal computing that could change. This device could have implications on a much larger scale. Data centres currently have huge problems with power consumption and account for around 6% of total power consumption worldwide. Use of this device could allow for very reasonable power requirements, without sacrificing processing speeds, which in turn has significant environmental and cost benefits.

## What stage are you at now?

We have achieved proof of concept. DARPA gave us the funding to build the technology and together we have developed two prototype devices that have

been modelled and patented. These are reported in a paper that we have just submitted to Nature. We are now currently building a more powerful set of prototypes.

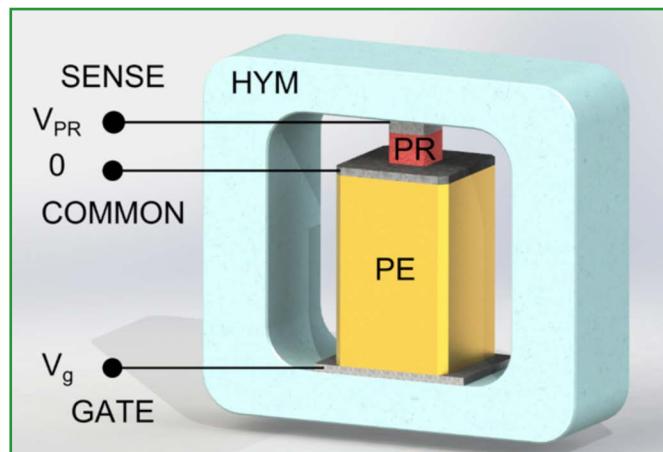
### What are the next steps?

After this next prototype we will be looking for more funding to scale the devices down and make them operate more efficiently, eventually reaching the nanoscale where they can be introduced into the market.

### How has working for with the Nanostrain project helped your work?

We know that piezoelectric materials work beautifully when they're big, but we need to work out how to make them small. All piezoelectric materials produce strain- only visible at the nanoscale. We need to understand how they work on the nanoscale in order to make them more efficient. The Nanostrain project is really pushing the envelope as characterisation of piezoelectric materials has only ever been done on the micron scale, never before on the nanoscale.

Working with the Nanostrain project has already been hugely informative and will play an instrumental role in the next step of our project when we come to scale our devices down.



The PET concept. The transductive stack consists of a piezoresistive (PR) element on top of a piezoelectric (PE) element confined by a high Young's modulus (HYM) yoke. The three metal contacts (grey) are termed Gate, Common and Sense. The PR material undergoes a continuous metal-insulator transition under pressure. The designed PE/PR cross-sectional area ratio is ~25:1 to amplify the stress in the PR.

## Upcoming events

### Nanomaterials for industry 2014- energy, environment, products

San Diego, USA  
7th-9th April 2014

### IEEE ISAF / IWATMD / PFM conference

Penn State University, USA  
12th-16th May 2014

### Altech 2014 – E-MRS Spring Meeting

Lille, France 26th-30th May 2014

### Nanotech 2014

Washington D.C., USA 15th-19th June 2014

### NanoLondon

London, UK 17th-19th June 2014

### EMRP Nanostrain Meeting

CMI Brno, Czech Republic 24th-26th June 2014

### Modeling of Electronic Devices and Materials at the Nanoscale- Workshop

Copenhagen, Denmark 1st-3rd July 2014

### NanoKorea

Seoul , South Korea 2nd-4th July 2014

### PFM 2014

Ekaterinburg, Russian Federation  
14th-17th July 2014

### ICNFA 2014

Prague, Czech Republic 11th- 13th August 2014

### Nanoforum

Rome, Italy 22nd-25th September 2014

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**EMRP**

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