SQUEEZING CRYSTALS AND MAKING WAVES: PAVING THE WAY TO SELF-POWERED ELECTRONICS

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Imagine a world where smartphones can recharge themselves and portable devices are transparent and unbreakable. Research in electronic materials holds the key to smarter, more efficient and more reliable devices. My research breakthroughs in two fields – piezoelectric energy harvesting and flexible electronics – are discussed here.

Techniques and materials for alternative energy generation are of extreme relevance to current society. One of my research activities in this context utilises piezoelectric materials. Piezoelectric materials convert mechanical energy to electrical energy and vice versa. The aim was to synthesise high-performance energy harvesting piezoelectrics in thin film form, to realise micro- and nano-scale energy harvesters.

I have attained the highest response piezoelectric thin films to date, reporting increases of up to 300% in piezoelectric response (Sriram et al. 2010a; Sriram et al. 2010b; Bhaskaran et al. 2011a). The choice of the material was made by careful design, but with a starting point using the highest response piezoelectric material (lead zirconate titanate, PZT) at that time. The choice was to use strontium (Sr) to replace a very small amount (1.6%) of the lead in the PZT composition. This choice was based on its significantly smaller atomic size compared with lead to enhance asymmetry; as predicted, this resulted in 300% enhancement in piezoelectric response of PZT.

I have presented the use of nanoindentation to characterise *in situ* the voltage and current generation of piezoelectric thin films (Bhaskaran et al. 2011b; Nili et al. 2013). These findings provide fundamental insight into thin film properties and geometries which determine their efficiency for energy generation. This work presents the controlled observation of nanoscale piezoelectric voltage (~40 mV) and current generation (~200 pA), allowing accurate quantification and mapping of force function variations.

The implications of these findings include the potential to generate power by application of pressure, enabling possibilities of charging portable devices by typing or pressing touchscreen interfaces. Longer term implications include the possibility to harness pressure from biorhythms such as blood flow and respiration to power implantable sensors and devices (such as cardiac pacemakers).

Flexible electronic devices are used in a wide variety of applications, including electronics, energy and healthcare. These are lightweight, low-cost, conformal devices which allow for the creation of new applications in combination with functional materials. Applications such as light-emitting diodes, sensor networks, energy harvesters and displays represent the building blocks of future flexible and transparent device technology incorporating complex circuitry and functionality. In integrating all the applications together to realise a powerful and practical technology that is fully transparent, flexible and functional, two scientific bottlenecks need to be overcome. First, the flexible substrate should ideally be transparent and colourless. Second, functional oxide materials that offer tailored properties need to be integrated. Almost all high performance functional oxides need to be crystalline and are deposited at high temperatures (ranging from 400–700°C), ruling out direct deposition on to the polymeric flexible substrates.

I have recently demonstrated a universal technique (Gutruf et al. 2013) for the incorporation of high-temperature-processed functional oxides with a flexible, elastomeric substrate. It uses standard microfabrication and materials processing techniques, enabling features of large area fabrication and scalability. The substrate material chosen for this work is polydimethylsiloxane (PDMS), which is widely used in flexible electronics and microfluidics. The technique is demonstrated with indium tin oxide (ITO), the extensively adopted transparent conductive oxide, as the functional layer, allowing us to realise and demonstrate electronics that are transparent, flexible and stretchable. This acid-free and scalable transfer process presented for integration of high-temperature-processed functional materials onto flexible substrates will enable a plethora of applications.

Acknowledgements

The author acknowledges funding from the Australian Research Council (ARC) *via* projects DP1092717 and DP140100170. The author also acknowledges an ARC Australian Postdoctoral Fellowship (DP1092717).

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