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EDITORIAL

High performance under pressure

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The accumulation of charge in certain materials in response to an applied mechanical stress was first discovered in 1880 by Pierre Curie and his brother Paul-Jacques. The effect, piezoelectricity, forms the basis of today's microphones, quartz watches, and electronic components and constitutes an awesome scientific legacy. Research continues to develop further applications in a range of fields including imaging [1, 2], sensing [3] and, as reported in this issue of *Nanotechnology*, energy harvesting [4].

Piezoelectricity in biological tissue was first reported in 1941 [5]. More recently Majid Minary-Jolandan and Min-Feng Yu at the University of Illinois at Urbana-Champaign in the USA have studied the piezoelectric properties of collagen I [1]. Their observations support the nanoscale origin of piezoelectricity in bone and tendons and also imply the potential importance of the shear load transfer mechanism in mechanoelectric transduction in bone. Shear load transfer has been the principle basis of the nanoscale mechanics model of collagen.

The piezoelectric effect in quartz causes a shift in the resonant frequency in response to a force gradient. This has been exploited for sensing forces in scanning probe microscopes that do not need optical readout. Recently researchers in Spain explored the dynamics of a double-pronged quartz tuning fork [2]. They observed thermal noise spectra in agreement with a coupled-oscillators model, providing important insights into the system's behaviour.

Nano-electromechanical systems are increasingly exploiting piezoresistivity for motion detection. Observations of the change in a material's resistance in response to the applied stress pre-date the discovery of piezoelectric effect and were first reported in 1856 by Lord Kelvin. Researchers at Caltech recently demonstrated that a bridge configuration of piezoresistive nanowires can be used to detect in-plane CMOS-based and fully compatible with future very-large scale integration of nanoelectromechanical systems.

Researchers in China exploit the coupling between piezoelectric and semiconducting properties of ZnO in an optimised diode device design [6]. They used a Schottky rather than an ohmic contact to depress the off current. In addition they used ZnO nanobelts that have dominantly polar surfaces instead of [0001] ZnO nanowires to enhance the on current under the small applied forces obtained by using an atomic force microscopy tip. The nanobelts have potential for use in random access memory devices.

Much of the success in applying piezoresistivity in device applications stems from a deepening understanding of the mechanisms behind the process. A collaboration of researchers in the USA and China have proposed a new criterion for identifying the carrier type of individual ZnO nanowires based on the piezoelectric output of a nanowire when it is mechanically deformed by a conductive atomic force microscopy tip in contact mode [7]. The p-type/n-type shell/core nanowires give positive piezoelectric outputs, while the n-type nanowires produce negative piezoelectric outputs.

In this issue Zhong Lin Wang and colleagues in Italy and the US report theoretical investigations into the piezoresistive behaviour of ZnO nanowires for energy harvesting. The work develops previous research on the ability of vertically aligned ZnO nanowires under uniaxial compression to power a nanodevice, in particular a pH sensor [8]. Now the authors have used finite element simulations to study the system. Among their conclusions they find that, for typical geometries and donor concentrations, the length of the nanowire does not significantly influence the maximum output piezopotential because the potential mainly drops across the tip. This has important implications for low-cost, CMOS- and microelectromechanical-systems-compatible fabrication of nanogenerators. The simulations also reveal the influence of the dielectric surrounding the nanowire on the output piezopotential, especially for low donor concentrations.

Back in 19th Century France, observations of the reverse piezoresistive effect inspired Pierre Curie to investigate similar symmetry in other physical processes. These endeavours led to significant progress in the theories of magnetism, such as the discovery of the Curie point at which temperature the magnetic properties of materials change. As an avid scientist, he is remembered as happiest in the lab, where he spent most of his time with his wife with whom he shares the 1903 Nobel Prize for physics [9]. As he once said to his wife, "[In science] we can aspire to accomplish something...every discovery, however small, is a permanent gain" [10]. His life was cut short in a traffic accident in 1906 but the truth in his words are evident as his work continues to inspire research and progress in the understanding and application of the piezoelectric effect and other physical phenomena.

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