EDITORIAL

Non-volatile memory based on nanostructures

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Non-volatile memory refers to the crucial ability of computers to store information once the power source has been removed. Traditionally this has been achieved through flash, magnetic computer storage and optical discs, and in the case of very early computers paper tape and punched cards. While computers have advanced considerably from paper and punched card memory devices, there are still limits to current non-volatile memory devices that restrict them to use as secondary storage from which data must be loaded and carefully saved when power is shut off. Denser, faster, low-energy non-volatile memory is highly desired and nanostructures are the critical enabler. This special issue on non-volatile memory based on nanostructures describes some of the new physics and technology that may revolutionise future computers.

Phase change random access memory, which exploits the reversible phase change between crystalline and amorphous states, also holds potential for future memory devices. The chalcogenide Ge$_2$Sb$_2$Te$_5$ (GST) is a promising material in this field because it combines a high activation energy for crystallization and a relatively low crystallization temperature, as well as a low melting temperature and low conductivity, which accommodates localized heating. Doping is often used to lower the current required to activate the phase change or ‘reset’ GST but this often aggravates other problems. Now researchers in Korea report in-depth studies of SiO$_2$-doped GST and identify ways of optimising the material’s properties for phase-change random access memory [1].

Resistance switching is an area that has attracted a particularly high level of interest for non-volatile memory technology, and a great deal of research has focused on the potential of TiO$_2$ as a model system in this respect. Researchers at HP labs in the US have made notable progress in this field, and among the work reported in this special issue they describe means to control the switch resistance and show that limiting the current during electroforming leads to the coexistence of two resistance switching modes in TiO$_2$ memristive devices [2]. They also present spectromicroscopic observations and modelling results for the Joule heating during switching, providing insights into the ON/OFF switching process [3]. Researchers in Korea have examined in detail the mechanism of electronic bipolar resistance switching in the Pt/TiO$_2$/Pt structure and show that degradation in switching performance of this system can be explained by the modified distribution of trap densities [4]. The issue also includes studies of TiO$_2$ that demonstrate analog memory, synaptic plasticity, and spike-timing-dependent plasticity functions, work that contributes to the development of neuromorphic devices that have high efficiency and low power consumption [5].

In addition to enabling a wide range of data storage and logic applications, electroresistive non-volatile memories invite us to re-evaluate the long-held paradigms in the condensed matter physics of oxides. In the past three years, much attention has been attracted to polarization-mediated electronic transport [6, 7] and domain wall conduction [8] as the key to the next generation of electronic and spintronic devices based on ferroelectric tunnelling barriers. Typically local probe experiments are performed on an ambient scanning probe microscope platform under conditions of high voltage stresses, conditions highly conducive to electrochemical reactions. Recent experiments [9–13] suggest that ionic motion can heavily contribute to the measured responses and compete with purely...
physical mechanisms. Electrochemical effects can also be expected in non-ferroelectric materials such as manganites and cobaltites, as well as for thick ferroelectrics under high-field conditions, as in capacitors and tunnelling junctions where the ionic motion could be a major contributor to electric field-induced strain. Such strain, in turn, can affect the effective barrier width in tunnelling experiments, resulting in memristive ionic switching. These phenomena must be differentiated from intrinsic physical polarization switching effects. Similar analysis of solid-state electrochemistry versus physical mechanisms is also important for future research in all areas of oxide materials.

In an age where miniaturised computer components can enable GPS tracking, internet access and even the remote operation of machinery from a mobile phone, there is an endearing quaintness associated with images of the large rooms rammed with wires and boxes that comprised early computers. Yet there was a time when these cumbersome devices were state of the art. When the electronic numerical integrator and computer (ENIAC) was developed it achieved speeds one thousand times faster than previous electromechanical machines, a leap in processing power that has not been achieved since. It is easy to imagine future generations looking back on the slow start up and shut down times and high energy consumption of today’s computers with a similar wry smile. The articles in this special issue on non-volatile memory based on nanostructures present the very latest research into the next generation’s device technology, which may eventually consign today’s cutting edge electronics to the history books.

References

[5] Seo K et al 2011 Nanotechnology 22 254023