Memristors get the hues

Syed Ghazi Sarwat[1] and Harish Bhaskaran[2]

[1]IBM Research– Zurich, 8803 Ruschlikon, Switzerland
[2]Department of Materials, University of Oxford, Oxford OX1 3PH, United Kingdom

The memristor, in which an external electric field controls the formation and annihilation of conductive channels has been described both as a missing electronic element and a memory and computational element. This paper describes their utility as building blocks for promising reflective and energy-efficient colour technology.

Most of the hues that we experience in life are the result of light scattered by objects, unless of course you are staring at the commercially successful emissive electronic displays on mobile phones and computer screens. The latter emit light using a backlit light source; there is now emerging evidence around the disruptive effects of emissive displays,[1] renewing an interest in reflective display technologies. Such technologies reflect ambient light at selective wavelengths similar to how we largely perceive the natural world. In this edition of *Nature Nanotechnology*, Yan et al.[2] report the use of "memristive" technologies for applications that use dynamic colour changes in the reflective mode, such as displays. Their device technology has the potential to span the visible colour spectrum, whilst being non-volatile, i.e. the colours are retained after power is turned off. Similar to its memory-based predecessors, this technology can be scaled to very small length scales (tens of nanometers) to enable ultra-high resolution.

The use of thin-film interference to create vivid reflected colours relies on modulating the optical path length in ultra-thin films. This in turn "picks" the colours to be reflected when white light is shone on the films, similar to how colours are produced in soap bubbles. While most of these applications used "transparent" materials, the use of absorptive materials to manipulate reflected colours in ultra-thin films was described by Kats et al.[3] Subsequently, Hosseini et al, achieved dynamic switching between reflected and transmitted colours to create ultra-high resolution images using changes in the refractive index of phase change materials, which can be switched electrically.[4] Phase change materials are also widely used as data storage devices both in the optical domain as rewritable optical discs as well as in the electronic domain as phase change memories, and therefore are also non-volatile, a term used to describe the property of the material to retain its current state until energetically nudged to change. Now, Yan et al describe the use of another class of memory materials - the memristor[5] - to achieve dynamic colour changes in thin films. Memristors had not yet shown such an optoelectronic property and thus, the present work presents an intriguing result.

The authors refer to their films as floating solid-state thin film (FSTF). These comprise of a stack of electrically conductive top and bottom electrodes, sandwiching the functional layers of amorphous iron oxide (which acts as a matrix) and high-mobility silver (which functions as the "floating" thin film) (see Figure 1). This stack is an absorptive optical cavity, where the thin-film interference is modulated by the moving ions of silver. When an electrical bias is applied to FSTF device, the silver atoms (ions) move position under the action of the electric field. When the top electrode is negatively biased, the silver ions move through the insulating iron oxide film and segregate at the interface with the top electrode. When the bias is turned off, these silver ions are "fixed" at this interface. Once the bias polarity is reversed, the process reverses itself. Using atomic-scale imaging and spectroscopy, the authors also observe the physical volume (thickness) of the iron oxide film to expand from silver dissolution, and the extent of silver migration in either bias polarity to change from amplitude and duration modulation of the bias. The result of this physical reconfiguration of the film is that the optical cavity length changes, leading to dynamic coloration. Such a solid electrolyte effect has previously been observed to have opto-structural coupling[6], but this work presents the first instance of a reversible effect due to the physical movement of the silver ions.

As with any new science, numerous issues need to be addressed before the proposed concept can become a technology. A key issue that needs further investigation is the underlying mechanism that produces dynamic coloring in such thin films. At this point, on the available evidence, the cause is likely a result of many inter-related effects such as changing film thicknesses due to diffusion as well as the moving ions, both contributing to changing the optical cavity; these mechanisms are not yet very clear and the relative contribution of each needs to be understood. From an application standpoint, many display applications require high speed to deliver full-motion video content. The switching speeds in the reported devices are much too low (tens of seconds); they are not yet on par with modern electronic readers. Further, the intermediate colours in the reported experiments are temporary (i.e. volatile), a behavior likely determined by the diffusion kinetics of silver. In addition to this, device cyclability, and pixel uniformity require more investigation. Finally, to enable high-contrast and realistic images the colour gamut must extend to give a fully black or fully white colour, in addition to providing a large span of grey scales. As the science in this paper progresses towards a technology, its manufacturing will require fabrication compatibility with thin-film-transistor technology. This, in the existing context of displays also necessitate compatibility with flexible substrates, another property that requires further investigation.

In spite of the challenges (or indeed because of them), Yan, and co-workers' optical memristive device is a surprising finding, which promises exciting new applications for the "missing" memristor.

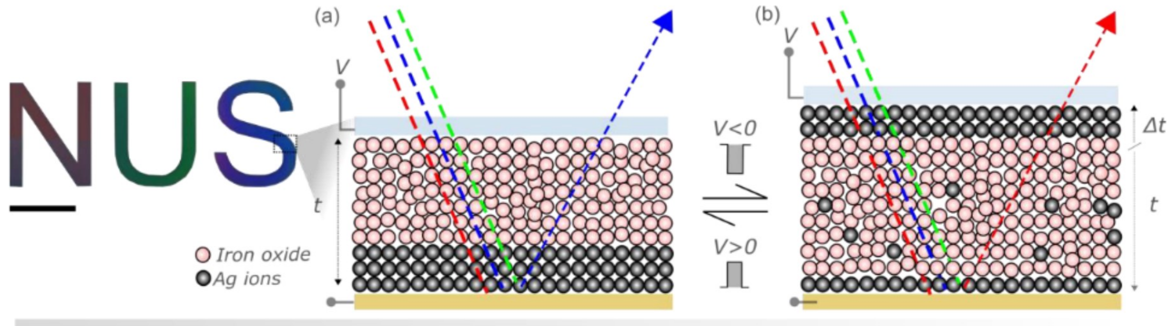

Figure 1. Memristive colour technology. Yan and co-workers render the letters "NUS" in three colours. The memristor thin film forms an optical cavity, where the thin-film interference is modulated electrically by the motion of silver ions (black spheres), through the amorphous solid-state electrolyte (pink spheres). When the top electrode (blue) is negatively biased ($V < 0$), the silver ions move from the bottom electrode (yellow), towards the top electrode. When the bias is reversed ($V > 0$), the process reverses itself. Silver migration induces a non-volatile physical thickness (t) change (Δt), as well as, possibly ion-position based reflection changes, which conspire to modulate the optical path length, thus creating the different colours.

References

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