ELECTROCHROMIC MATERIALS

Out of a niche

Electrochromic materials have been around for more than 30 years and have found some applications in niche areas. Now, thanks to new electrochromic materials and manufacturing procedures, electrochromism may become a household word.

CLAES-GÖRAN GRANQVIST
is at the Ångström Laboratory, Uppsala University, SE-75121 Uppsala, Sweden.
e-mail: claes-goran.granqvist@angstrom.uu.se

Architects have long dreamt of buildings with windows and glass façades that can let in controlled amounts of light and heat[1]. The materials that could allow this are often referred to as 'chromogenic'[2]. The optical change can be induced by different stimuli in different materials, leading to photochromic, thermochromic, gasochromic and electrochromic (EC) materials, amongst others. EC materials are easy for the user to control through an electrical voltage and therefore have the widest range of applications[3]. They can be used not only for 'smart windows' in buildings, but also in cars and trucks, information displays, ski goggles and motorcycle helmet visors, to name just a few applications. The 2005 Fall Meeting of the Materials Research Society (MRS), which took place in Boston, 28 November to 2 December, gave broad coverage to the current and future scientific and technical status of electrochromism.

Figure 1 shows a prototype five-layer EC device structure on a transparent substrate or between two transparent substrates[3]. In the centre is an electrolyte, usually a polymer layer or a thin film of a hydrous oxide. To the right of this layer is a thin film of an EC material, typically an oxide (WO_3 is widely used) or a suitable organic film. On the opposite side of the electrolyte is a thin film that provides ion storage, with or without electrochromism. Again one can use an oxide (NiO or IrO_2 are two candidates with good combinations of optical and electrochemical properties) or an organic film. Thin films of a transparent and electrically conducting material (such as indium tin oxide, ITO) act as electrodes on the two sides of the central three-layer stack. Applying a voltage of only 1–2 V d.c. across the ITO films moves charge into or out of the EC film, changing its optical absorption. If everything else in the device is transparent, or if the ion storage material darkens at the same time as the EC film, then the transparency of the whole device changes. The device has open circuit memory, that is, the voltage only needs to be applied to alter the optical absorption, and the device retains its properties until another voltage is applied. The change takes place, typically, over a few seconds in a device of square centimetre size and over minutes for square metre size.

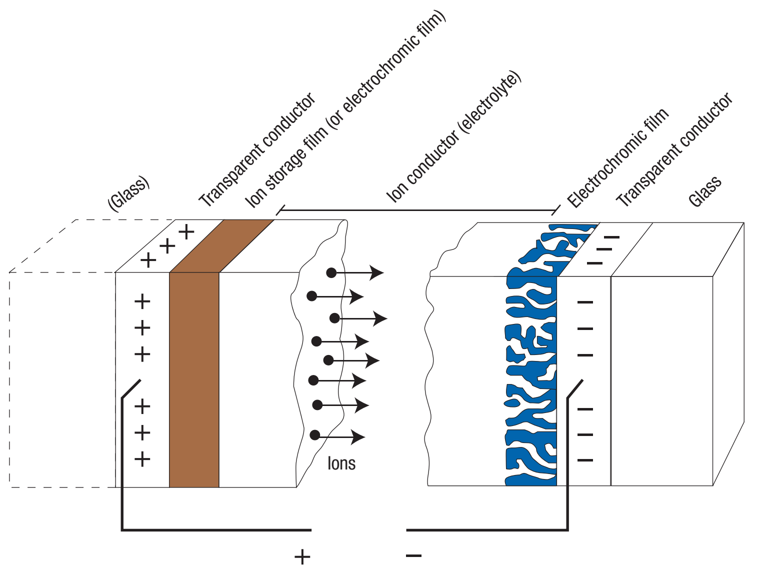

Figure 1 Electrochromic device design, showing the movement of ions under an externally applied electric field.

Papers presented at the MRS conference showed many recent advances in EC multicolour displays based on organic materials[4,5], such as PEDOT-PSS [poly(3,4-ethylene-dioxythiophene)–poly(styrene sulphonate)]. John Reynolds and co-workers (University of Florida in Gainesville, and Loughborough University) reported new organic polymers that enable a wide range of colours to be achieved. Combining these advances with developments in transparent electrical conductors[6] and in matrix addressing[7], it seems that full-colour EC displays on flexible substrates may not be far off.

Organic EC devices have limited lifespans under ultraviolet exposure outdoors, but for improved durability under such conditions one can use inorganic oxide-based EC materials. David Pender (Saint Gobain Sekurit in Herzogenrath) presented EC coatings deposited on large, strongly curved glass substrates, which has resulted in EC car roofs that are now available on a limited commercial scale on the new Ferrari Super America, a model limited to

Figure 2 Motorcycle helmet with visor based on electrochromic foil, in dark and transparent state.

550 cars. With these roofs it is possible to combine the feeling of space afforded by a glass roof with the protection from overheating in bright sunlight. The cost of the present roof may be prohibitive for all but a small group of wealthy enthusiasts, but new EC materials and manufacturing techniques may well turn EC car roofs into common products within the 15 years it normally takes to go from the extreme high end of the automotive sector to standard cars.

Cheap production of EC devices is certainly a must if the technology will be used beyond narrow niche markets. As I reported at the MRS meeting, my colleagues and I (at Uppsala University and also at ChromoGenics Sweden) have developed EC technology making it possible to produce devices on flexible polymer substrates so that continuous roll-to-roll manufacturing becomes feasible, particularly as there is now the possibility to insert and extract charge in the EC material and in the ion storage layer using facile gas treatments[8]. A pilot plant for polyester-based EC foil is being set up by ChromoGenics. The foil uses the design in Fig. 1 with WO_3 as the EC film and a NiO-based film[9] for ion storage. The centrally positioned electrolyte also serves as lamination material. Using a polymer-based foil, rather than glass, opens new applications for EC devices. One of them is illustrated in Fig. 2 — a visor with variable transmittance that gives a biker the comfort provided by a dark visor in sunlight and the safety provided by a clear visor in the dark[10]. The colour change takes place in a few seconds. The clear-state transmittance was deliberately set to 50%, although new EC materials[9] can give more than 80% transmittance.

So electrochromism seems to be advancing into fields such as displays, visors and goggles, and car roofs. But what has happened to 'smart windows' for buildings? So far they have been rather elusive — available on a 'semi-commercial' scale for limited periods of time. But Sage Electrochromics (in Faribault, Minnesota) is now introducing EC roof windows. Most people in the EC field believe that this is only a small beginning. Roll-to-roll coating of EC window foil, as mentioned above, may truly open new vistas.

REFERENCES

1. Wigginton, M. *Glass in Architecture* (Phaidon, London, 1996).
2. Lampert, C. M. & Granqvist, C. G. (eds) *Large-Area Chromogenics: Materials and Devices for Transmittance Control*, Vol. IS4 (SPIE Optical Engineering Press, Bellingham, 1990).
3. Granqvist, C. G. *Handbook of Inorganic Electrochromic Materials* (Elsevier, Amsterdam, 1995).
4. Sonmez, G., Sonmez, H. B., Shen, C. K. F. & Wudl, F. *Adv. Mater*. **16,** 1905–1908 (2004).
5. Argun, A. A. *et al. Chem. Mater*. **16,** 4401–4412 (2004).
6. Wu, Z.-C. *et al. Science* **305,** 1273–1276 (2004).
7. Andersson, P. *et al. Adv. Mater*. **14,** 1460–1464 (2002).
8. Azens, A. *et al. Mater. Sci. Eng*. B **119,** 214–223 (2005).
9. Avendaño, E., Azens, A., Niklasson, G. A. & Granqvist, C. G. *Solar Energy Mater. Solar Cells* **84,** 337–350 (2004).
10. Buyan, M. *et al. Int. J. Ind. Ergonomics* published online 18 August 2005 (doi:10.1016/j.ergon.2005.06.005).