Bistable liquid-crystals reduce power consumption for high-efficiency smart glazing

Damian Gardiner, Stephen Morris, and Harry Coles

A novel class of liquid-crystal materials demonstrates a route towards simpler and power efficient multi-stable electro-optic devices.

Current commercial liquid-crystal (LC) based technologies, such as those used in laptop screens and high-definition televisions (TVs), are based on nematic liquid crystals. Other applications include electronic ‘smart’ glazing, and smart glass, used in recent architectural designs. In electronic smart glazing, a film laminated between glass sheets can be electronically switched between clear and opaque states. One of the key drawbacks of this nematic-liquid-crystal technology is its monostability, which requires a continuous source of power to maintain a device state. In addition, for most applications, the liquid crystal is sandwiched between crossed polarizers, which results in poor light efficiency (<10% throughput) due to absorption and color filters.

For applications such as information storage displays and smart glazing, it is desirable to reduce power consumption. This can be achieved with a technology that eliminates polarizers (such as in LCD TVs) and is bistable, which means power is only required when charging the device. Additional advantages of bistable operation include the use of simple passive-matrix addressing schemes rather than the active-matrix approach used in modern displays. Passive-matrix technology uses a simple row and column method rather than thin-film-transistor technology.

In nematic liquid crystals, the rod-shaped liquid-crystal molecules share a common orientation of their long axes (known as the director). However, other liquid-crystal phases exist in which the common orientational order is supplemented by positional correlation. We focus on the development of liquid-crystal materials that possess intrinsic bistability and do not need polarizers, specifically the smectic-A phase of liquid crystals in which the constituent molecules self-assemble into a bi-layered arrangement (see Figure 1). The layer formation in this phase confers unusual properties. The most useful is that smectic-A materials possess larger ionic conductivity along the layers rather than across them. This results in ionic electrohydrodynamic effects when we apply a low-frequency electric field, where the chaotic motion of the liquid-crystal material scatters light and the device appears opaque. Increasing frequency suppresses the ionic motion, and the liquid-crystal molecules align with the field through dielectric reorientation, resulting in a clear state (see Figure 2). Due to the high viscosity of the smectic-A phase, both these modes can be stored indefinitely.

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Although the bistable smectic-A device has existed for some time, a new class of materials — organosiloxane liquid crystals — offers considerable promise in this area. In these materials, the molecules consist of three distinct parts: the aromatic core, alkyl (paraffin-like) chain, and siloxane groups. Previously, smectic materials used in these devices only comprised the aromatic core and alkyl chain. The addition of siloxane to these materials profoundly affects their properties. For example, only smectic phases are observed (where the analogous materials were nematic), and they operate across a wide temperature range. Most importantly, we show that these materials possess highly anisotropic ionic conductivities. For example, the ratio of the conductivities parallel and perpendicular to the director can be as low as 0.005. Non-siloxane-based materials, such as 4-octyl-4’-cyanobiphenyl, possess conductivity ratios closer to 1. The high degree of conductivity anisotropy allows considerably lower driving voltages for the scattering (electrohydrodynamic) mode.

Based on our work, it is possible to design materials that possess customized conductivity and dielectric properties. Furthermore, we can achieve a suitable mixture formulation because of the inherently wide temperature ranges of these materials. One of the key practical benefits of this increased flexibility is in devices that ease electronic design. For example, by proper choice of the material properties, both single-frequency (variable voltage) or single-voltage (variable frequency) driving are possible (see Figure 3) in addition to the normal bistable modes at low (100Hz) and high (1kHz) frequencies. Thus, in the case of electronic glazing applications, the device could be driven directly from residential voltage, reducing cost and simplifying construction significantly.

In addition, since material properties determine the shape of the switching curve, it is possible to easily generate multi-stable gray-scale devices since the intermediate modes can also be stored indefinitely. In the case of a smart window in the clear state for one hour, our calculations suggest that the power consumption of the bistable device (during the switch from one state to another) is 8% that of the nematic LC equivalent. In other applications, such as large area signage, we anticipate significant power savings. Future work includes scaling up the technology and further reduction of the driving voltages.

We have developed a novel class of liquid crystal materials that possess unusual but beneficial properties. These materials are well suited for applications where power efficiency is critical, including electronic smart glazing.

Figure 3. Possible driving schemes of the organosiloxane-based device: voltage and frequency (left), frequency (middle) and voltage (right).

Author Information

Damian Gardiner, Stephen Morris, and Harry Coles
CMMPE, Electrical Engineering Division,
Department of Engineering
University of Cambridge
Cambridge, Cambridgeshire, United Kingdom
http://www-g.eng.cam.ac.uk/CMMPE/

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