Wiping out dirty displays

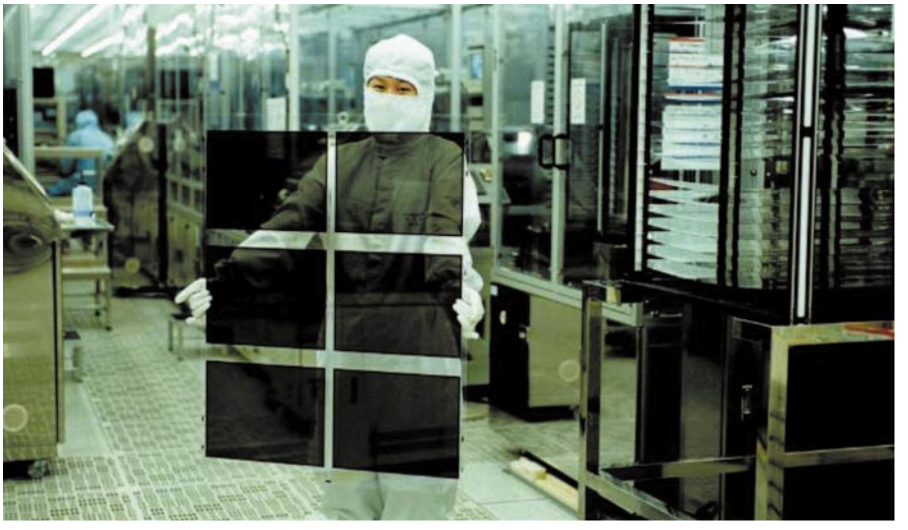
Jos van Haaren

The manufacture of liquid crystal displays still involves a surprisingly low-tech and messy process: rubbing polymer films with a velvet cloth. A twenty-year search for a cleaner alternative may finally be over.

Liquid crystal displays (LCDs) are commonly used in the screens of notebook computers and thin desktop monitors. From humble beginnings in the 1970s, modern LCD screens now have more than one million pixels, and the advent of new mobile and palm-sized devices means the market for applications is still growing. LCDs are manufactured in high-quality clean rooms (Fig. 1), with a large number of robot-driven processes. These high-tech factories require the sort of investment usually reserved for the semiconductor industry.

But deep inside the LCD factories, an old, mysterious and dirty process continues to be used to control the orientation of the liquid crystal molecules, and hence the clarity of the displays. At a crucial point in the production, a velvet cloth wrapped around a roller is rubbed across a surface that in turn aligns the crystals. Alternative alignment processes have been suggested, but none has been successfully transferred to large-scale manufacturing. Now, on page 56 of this issue[1], a team at IBM led by P. Chaudhari proposes to replace the velvet-covered roller with a low-energy beam of ions.

Some basics about LCDs help to paint the full picture. A liquid crystal display consists of two glass substrates with a gap 5 μm wide between them. One of the glass substrates carries an array of thin-film transistors that make it possible to control individual pixels in the display. Each pixel has a small, transparent electrode connected to the output of the transistor. The transistor inputs are connected to a data bus line, which is shared by other pixels in the same column. During operation, external integrated circuits send pulses of information through the data buses to individual transistors. A display using this technology is known as an active matrix LCD. To produce full-colour displays the pixels are grouped into threes and the outer glass substrate is covered with dots of red, green and blue filters, topped off with a transparent electrode. The space between the substrates is filled with the liquid crystal material. The transparent electrodes at the substrates serve to apply an electric field across the liquid-crystal layer, and the response of the liquid crystal translates electronic data into an image.



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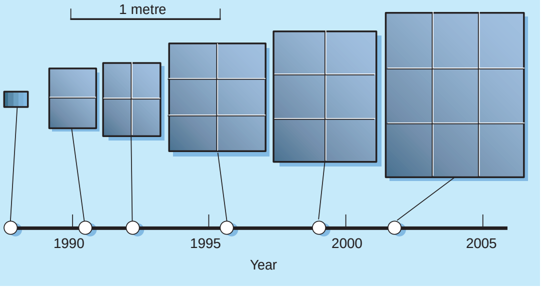

Figure 1 **Clean-room operator holding a glass substrate with six liquid crystal displays (above). Over the years, there has been an increase in both the size of the displays and the number of displays manufacturers can make from a single substrate (right). This has led to an increase in productivity and a reduction in cost price. Sizes of glass substrates that are now being designed are about 1 m^2. This calls for better processes for, among other things, liquid-crystal alignment. At present, manufacturers use an anachronistic method to align liquid molecules: rubbing polymer films with a velvet cloth. The ion-beam technology developed by Chaudhari and co-workers[1] offers an attractive alternative.**

Liquid crystals form an intermediate phase between disordered liquids and crystalline solids. Their appearance in a bottle is that of a viscous, turbid fluid (Fig. 2a, overleaf). Like in a liquid, individual molecules rotate relatively easily, and a liquid crystal will completely fill the gap between two glass substrates. Liquid crystals also have some solid-like properties, such as natural ordering, so that the molecules within a small volume all point in the same direction (Fig. 2b). The direction of the molecules can be influenced by the walls of the container or by an electric field. Changing the direction of the molecules also changes the optical and electrical properties of the liquid-crystal layer. So applying a small voltage across the liquid-crystal layer in an LCD will change the amount of light transmitted by the display.

The dual nature of liquid crystals is essential for the operation of displays, but it also creates technological challenges. The liquid crystal molecules must all have the same, controlled orientation to produce a uniform display with high contrast. If an LCD television screen were the size of a football field, the pixels would be the size of a banknote, and the liquid-crystal layer would be only 1.5 mm thick. It is not trivial to align the liquid crystals in each pixel over such a large area. To produce a high-contrast display, individual molecules have to be tilted relative to the plane of the substrate.

The rubbing process used by manufacturers to produce a defect-free display dates back to at least 1925 (ref. 2) and the earliest studies of liquid-crystal properties. All LCDs on the market today have thin polymer films that cover the side of the glass substrate in contact with the liquid crystal, and so influence its orientation. The direction of the polymer chains in these films is defined by rubbing the surface with a velvet-like cloth[3]. This process is tolerated because it aligns the polymers well enough, but it introduces

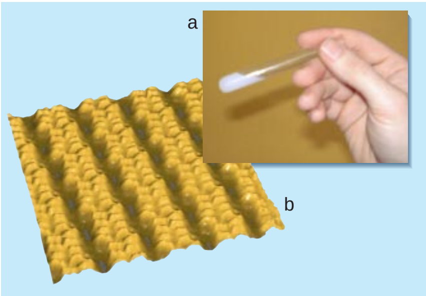

Figure 2 **The dual nature of liquid crystals.** a, **In a bottle the liquid-crystal material looks turbid, owing to the imperfect alignment of the liquid crystal.** b, **Like a solid, liquid crystals can also show surprising amounts of order. Perfect alignment of individual liquid crystal molecules (an alkylated cyanobiphenyl) on a graphite surface, as observed with a scanning tunnelling microscope (J. Gerritsen, Univ. Nijmegen, The Netherlands; see also ref. 8).**

debris, making it incompatible with a clean room environment. Rubbing can also leave streaks and produce electrostatic charge, which degrade image quality. Manufacturers go to great lengths and expense to avoid any sort of contamination, so a contact-free process would be a better long-term solution.

Chaudhari and co-workers[1] have developed a cleaner and more reliable process for aligning liquid crystals. They have replaced the polymer film with a thin, transparent inorganic material, known as diamond-like carbon. Exposing materials like diamond-like carbon or amorphous silicon to a low-energy beam of ions causes a rearrangement of the atoms on the surface. Placing these atoms in contact with a layer of liquid-crystal material causes the liquid crystals to align in one direction. By changing the energy and the angle of incidence of the ion beam, Chaudhari and colleagues are able to vary the tilt angle of the liquid crystal between 0° and 10°.

The IBM team have previously used ion beams to align polymer films without rubbing[4], but now they can do away with the polymer entirely. They show that light transmission through LCDs containing diamond-like carbon films was typically 97% of that of polymer-based displays. They have also manufactured a laptop with an LCD using the diamond-like carbon film as the alignment layer. Chaudhari and his team have also shown that ion-beam alignment can be used to make monitor displays that have good image quality under different viewing angles. They use a metal mask to selectively overwrite parts of a prealigned film with the ion beam, thereby creating a two-domain display with better contrast at oblique viewing angles.

Other manufacturers are likely to follow up the IBM work with their own studies. Replacing rubbing by ion-beam alignment is an attractive idea, but the costs of this new technology in terms of processing time and equipment need to be studied. Processing reliability, product durability and image quality will need to be investigated. Chaudhari and co-workers have paid attention to this in their prototype displays, but an industrial release of the technology is a separate and significant task. An alternative to rubbing that has not yet made it into factories is using light to align the polymer films[5,6]. Another option developed by Fujitsu[7] uses a type of liquid crystal that is aligned perpendicular to the substrate, rather than tilted. This configuration is radically different from conventional LCDs and leads to new issues in manufacturing and display operation.

Monitors with LCDs are currently more expensive than those with bulky cathode-ray-tubes. New manufacturing methods could bring down the costs, opening up the huge but highly price-competitive television market to LCDs. The main efficiency improvements in the past decade have come from LCD production on larger and larger glass substrates (Fig. 1) and from changes in factory layouts. A rubbing machine for even larger substrates will be a nightmare for engineers to build and operate. Contact-free alignment, whether using ion beams or another technique, is a way to avoid the rubbing process on this scale. ■

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Protein interactions

Unspinning the web

Jeff Hasty and James J. Collins

A large-scale study of the protein network in yeast cells demonstrates the merit of taking an integrated approach to cellular dynamics, and shows the value of databases.

In the climactic scene of the movie *Independence Day*, a massive alien spacecraft, hovering just above the Earth, appears to be immune to the petty assaults mounted by the earthlings. In a last-ditch effort, the character played by Randy Quaid decides to fly his jet fighter on a kamikaze mission into the spacecraft's primary weapon. It turns out that the primary weapon is a highly connected node in the spacecraft's defence architecture. So although Quaid's attack constitutes only a pinprick, it induces an avalanche effect through the defence network, leading to the ultimate annihilation of the spacecraft.

On page 41 of this issue[1], Jeong *et al.* show that protein networks in yeast cells have wiring characteristics that are analogous to those of the alien spacecraft. These characteristics include both high resistance to random assaults, or mutations, and vulnerability to targeted attacks on specific, highly connected nodes in the network. Their data support the idea that tolerance to mutations, which has been linked to genetic redundancy, is also derived from the organization of interactions and topological position of individual proteins.

Jeong *et al.* derive their results by cleverly combining information from several different databases. First, by using data on protein–protein interactions in yeast[2,3], they show that the associated network follows a power-law distribution; that is, the system contains a large number of proteins with a small number of connections and a small number of proteins with many connections. This type of network architecture, which is common to other complex systems including the Internet[4] and metabolic networks[5], should be both error-tolerant and vulnerable to attack[6]. Jeong and colleagues demonstrate that these properties do indeed exist by using protein-deletion data[7] to show that the connectivity of a protein in the network is directly correlated with the likelihood that its removal will be lethal to the cell. For instance, they show that roughly two-thirds of proteins that have more than 15 connections are essential, in the sense that deleting them is lethal, whereas only one-fifth of proteins with five or fewer connections are essential.

These findings are, in many ways, intuitive. One would expect, for example, that the removal of a highly connected node in a complex network would be especially disruptive to network function. Likewise, it has been pointed out[8] that the protein product of the *p53* tumour-suppressor gene is one of the most highly connected proteins in human cells and that mutations of *p53* can have severe consequences on basic cellular functions. Jeong *et al.* quantify this effect on a larger scale, and show how the topology of a cellular network can be related to biologi-