ble with the methods of molecular beam epitaxy and metal-organic vapour-phase epitaxy enables electronic engineers to build up quantum-well structures. A typical structure is made from alternating layers of gallium arsenide (GaAs) and aluminium arsenide (AlAs). The two materials have different band gaps and electrons are confined to the layer with the smaller gap (GaAs). For a layer with a thickness of molecular size (1 nm or less) the electrons are confined to move within the layer. Perpendicular to the layer the electrons behave as a particle in a box and the energy levels no longer form continuous bands but are forced to have discrete values. These reduced-dimensionality structures have novel physical properties, exploited in new devices[4]. The use of quantum-well structures in lasers provides emission at shorter wavelengths than can be obtained from the bulk material. This is because emission occurs from the discrete energy levels which have an energy separation greater than the energy gap of the bulk material.

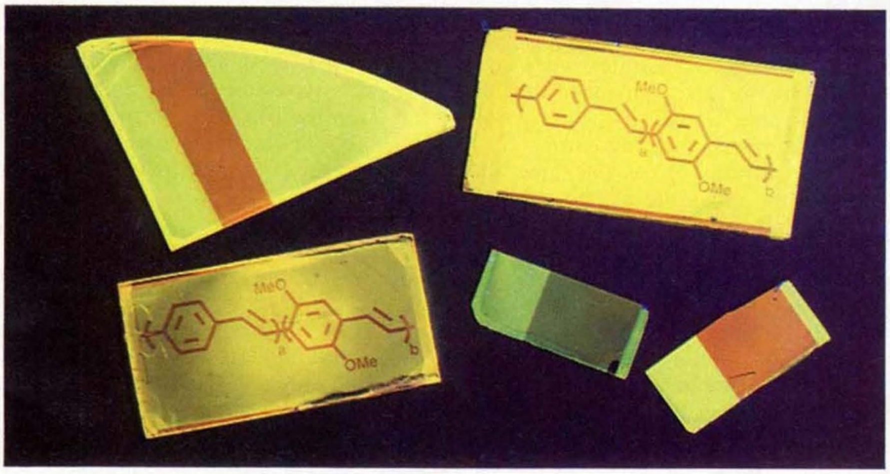

FIG. 2 Several samples of the new copolymer films prepared by Burn *et al.* fluorescing under ultraviolet light. The alternated block copolymer is made from two precursors, one of which has readily removed leaving groups to make the radiating, conjugated sequences. Differing treatments can leave the intervening sequences either nonconjugated or conjugated (but with a different band gap), so that one has a choice of radiating colour. In two samples, this choice has been used to etch the molecular structure of the fully conjugated copolymer into the film, so showing off another of the material's potentials.

The behaviour of electrons confined in a small region accounts for the observed size dependence of absorption and emission wavelengths of both small conjugated molecules and semiconductor quantum wells. However, in other respects the structure and properties of the polymers described by Burn *et al.* and the III–V semiconductor quantum-well structures are very different. The latter are crystalline materials with regular, controlled variations in composition. The electrons are free to move in the plane of the layers and this two dimensional motion, which occurs with very high carrier mobility, is used to advantage in devices[4]. The polymers, however, are amorphous and the conjugated blocks vary in both size and separation and are randomly distributed in the polymer film. The behaviour of idealized polymeric quantum-well structures has been explored theoretically[10,11]. However, the synthesis of polymers with precise block size and an ordered, chain-extended structure has not yet been achieved. For the disordered materials studied by Burn *et al.*, the properties reported are closer to those of isolated small molecules than quantum-well structures.

Despite this, these new materials are a further step along the road towards practical polymer-based electronic devices. The production of films capable of optical waveguiding and the definition of lateral structures by simple lithographic techniques (Fig. 2) illustrates the unique properties that can be realized with polymers, and demonstrates their potential for technological exploitation. □

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1. Bloor, D. *Nature* **335**, 115–117 (1988).
2. Bloor, D. *Nature* **349**, 738–740 (1991).
3. Burn, P. L., Holmes, A. B., Kraft, A., Bradley, D. D. C., Brown, A. R., Friend, R. H. & Gymer, R. W. *Nature* **356**, 47–49 (1992).
4. Weisbuch, C. & Vinter, B. *Quantum Semiconductor Structures, Fundamentals and Applications* (Academic, Boston, 1991).
5. Griffiths, J. *Colour and Composition of Molecules* (Academic, London, 1976).
6. Batchelder, D. N. *Contemp. Phys.* **29**, 3–31 (1988).
7. Friend, R. H. *et al. Phil. Trans. R. Soc.* A**314**, 37–49 (1985).
8. Kuhn, H. *J. chem. Phys.* **17**, 1198–1212 (1949).
9. Bredas, J. L., Silbey, R., Boudreaux, D. S. & Chance, R. R. *J. Am. chem. Soc.* **105**, 6555–6559 (1983).
10. Ruckh, R., Sigmund, E., Kollmar, C. & Sixl, H. *J. chem. Phys.* **85**, 2797–2801 (1980); **87**, 5007–5011 (1987).
11. Ruckh, R., Sigmund, E., Sixl, H. & Roth, S. *Synth. Met.* **21**, 305–312 (1987).

DAEDALUS

Unshellfish

CALCIUM carbonate seems to be one of the few waste products of biology. Once a shellfish, for example, has taken up dissolved calcium and turned it into a calcium carbonate shell, the resulting mineral is permanent. The white cliffs of Dover are not part of any life cycle.

Daedalus disagrees. He points out that in water containing carbon dioxide, calcium carbonate dissolves reversibly to give calcium bicarbonate. If the carbon dioxide is removed, the carbonate is redeposited — stalactites, stalagmites and kettle scale are formed in this way. Molluscs, like shellfish, use an enzyme, carbonic anhydrase, to control and direct this reaction. But no enzyme can shift the position of a chemical equilibrium. With enough carbon dioxide in the water, the equilibrium would favour soluble calcium bicarbonate, and shellfish would be frustrated.

So Daedalus proposes that ships whose wetted surfaces get fouled with barnacles, and power stations whose cooling-water outlets become blocked with mussels, should blow their exhaust gases through the water. The carbon dioxide of combustion would dissolve. This would virtuously avoid releasing a greenhouse gas into the atmosphere, and (in the case of a ship blowing its smoke into the water ahead of it) would reduce drag by filling the water with small bubbles. Young barnacles and mussels would be unable to grow shells in the carbon dioxide-rich water; shipworms and other marine borers would find themselves impotent and toothless; all would drift away disconsolately to more congenial waters.

Animal lovers will be glad to know that the treatment should be quite humane. The water will still contain plenty of oxygen, so no sea creatures will be suffocated. They may even be stimulated by a bit of extra carbon dioxide, just as we are — oxygen with added carbon dioxide is used to revive victims of suffocation. Fish will not be crippled with arthritis by the dissolution of their skeleton, for its mineral component is calcium phosphate. They may, however, be disoriented. Fish otoliths (the little granules in the ear that give them their sense of gravity and inertia) are indeed made of calcium carbonate. If these dissolve in the carbon dioxide-rich water, severe vertigo and sickness may result.

DREADCO biologists are now testing these notions. They are growing clams, oysters and so on, in oxygenated water enriched with carbon dioxide, hoping to rear them intensively in shell-less and (sadly) pearl-less varieties for human consumption. The same treatment should turn snails into slugs, and ought to make fish seasick. DAVID JONES