A seven-segment polymer light-emitting diode display device made by Cambridge Display Technology.

1996 HEWLETT-PACKARD EUROPHYSICS PRIZE

Opening the Door to Bright Prospects

The 1996 Hewlett-Packard Europhysics Prize for outstanding achievements in condensed matter physics has been awarded to R.H. Friend, Cavendish Professor of Physics in the Cavendish Laboratory, Cambridge University, for "pioneering work on semiconducting organic polymer materials and demonstration of an organic light-emitting diode". The prize will be presented at the *15th General Conference of the Condensed Matter Division of EPS* (Baveno-Stresa, Italy; 22-25 April 1996).

There has been a long standing interest in developing solid-state light-emitting devices for displays and the like. Light generation is efficient in direct band gap inorganic semiconductors, but these systems are usually unreliable and difficult to process. Efficient photoluminescence is also common in organic molecular semiconductors so light emission in these materials through charge injection under high applied fields has been investigated for many years. Moving from molecular to macromolecular materials offers better stability, and conjugated polymers are a good choice since they often have good charge transport and a high quantum efficiency for luminescence.

This application of polymers as semiconductors is perhaps not obvious owing to the large number of defects such as bends and twists along a molecular chain. However, there are no unsatisfied bonds at the surfaces of conjugated polymers, so problems associated with surface effects at electrode interfaces can be avoided by preparation under clean conditions. Secondly, the defects naturally weaken the degree of delocalization of the π-electrons distributed along the molecular chain, thereby increasing the energy needed to excite electrons from the valance band into the conduction band. So electronic levels associated with the defects do not in fact play an active role.

Turning to Active Devices

Much of the early work on conjugated polymers dealt with simple transport properties since polyacetylene, the most widely studied of these materials, shows very weak photoluminescence. The Cambridge group led by R.H. Friend was one of the few groups to focus on active devices, being the first to construct working field-effect transistors and electro-optic light modulators based on polyacetylene synthesized by colleagues in the University's Chemistry Department. The group then turned to photoluminescence in other conducting polymers because it was realised that they can have larger semi-conductor gaps than polyacetylene while offering high quantum yields for photoluminescence if prepared in a sufficiently pure form. Among these materials, poly (p-phenylene-vinylene), or PPV, could be conveniently made into high quality films showing strong photoluminescence [1].

The concept of self-localised excited states, either neutral or charged, has been very useful in describing fundamental excitations in conjugated polymers. The softness of the polymeric lattice leads to a strong coupling between the polymer's electrons and vibrations (phonons) such that it is energetically favourable for the local molecular structure to deform around free charges to form lattice-stabilised quasiparticles with spins and effective mass very different to those for electrons and holes. For PPV, these excitations are the neutral polaron exciton, the singly charged polaron and the doubly charge bipolaron. The Cambridge group showed that radiative decay by recombination of the singlet polaron exciton formed by interchain excitation following photon absorption was responsible for photoluminescence in PPV [2].

The First LED

The group then demonstrated [3] that PPV can be used as the active element of a large-area, light-emitting diode (LED). The spectral emission was the same as for photoluminescence, so electroluminescence was assigned to radiative decay of the same excited state (the singlet polaron). In the LED, one applies a voltage across a sandwich structure comprising metal electrodes (one of which is semi-transparent) attached to opposite sides of a film of undoped PPV with an empty conduction band. Holes and electrons are injected and travel as oppositely charged polarons along a chain. The polarons capture each other, forming quasi one-dimensional excitations which decay radiatively. This interpretation contrasted with earlier work based on optical properties suggesting that bipolarons were the most stable quasiparticles in PPV.

It is in fact the group's basic research leading to a detailed understanding of the processes involved in light emission which has contributed much to the development of polymer-based LEDs covering the entire visible range, and to improvement of the quantum efficiency. For example, poly(cynoterephthalylidene) with a greater electron affinity than PPV allows the use of more practical electrodes such as aluminium instead of calcium [4].

Semiconducting organic polymers with delocalized π-electrons are now seen to have possible applications in a wide variety of electronic devices. Owing to the relatively low mobility of charge carriers, the most exciting opportunities at the moment are found in LEDs and photovoltaic cells. The innovative work at Cambridge showing that easily processed polymers such as PPV exhibit good efficiency for light emission has clearly made feasible the fabrication of low-cost, large-area flat-panel displays. This demonstration of the rich possibilities to exploit and control structure, and hence the electronic functionality, of organic materials has opened up a field with a promising future and generated a tremendous amount of scientific and industrial activity.

[1] Burroughes J.H., Jones C.A., Friend R.H., *Nature* **335** (1988) 137.
[2] Bradley D.D.C., Friend R.H., *J. Phys.: Cond. Matter* **1** (1989) 3671.
[3] Burroughes J.H., *et al., Nature* **347** (1990) 539.
[4] Greenham N.C., *et al., Nature* **365** (1993) 628.

Richard Friend *gave his inaugural lecture as Cambridge University's Cavendish Professor of Physics on the day he was notified that he had been awarded the 1996 Hewlett-Packard Europhysics Prize. He graduated in theoretical physics at Cambridge in 1974, received a PhD in 1977 for research carried out in the Cavendish Laboratory, and took up his first academic appointment at Cambridge in 1980 after working as a research fellow. Professor Friend was elected a Fellow of the Royal Society in 1993, was awarded the Institute of Physics Mott Prize in 1995 and the Royal Society of Chemistry Interdisciplinary Award in 1991, and has worked at the University of Santa Barbara, California, and at the Centre de Recherche sur les Très Basses Températures, Grenoble.*

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Amaldi International Prize

The first Amaldi International Prize for a high-school physics textbook was awarded at a ceremony that accompanied the 4th Amaldi Lectures (Università Cattolica del Sacro Cuore di Piacenza; 2 December 1995). The Prize, which was sponsored by the EPS Forum on Education, went to *Physik-Compact* published by Verlag-HPT, Vienna. Lectures were by H. Schopper, the EPS President, on "Physics education and society" and by A. Jaros and L. Mathelitsch, two of the coauthors of *Physik-Compact*, on "Physics teaching in high schools".