TECHNOLOGY

# Plastic lasers shine brightly

*Donal Bradley*

LASERS have progressed rapidly from being a solution in search of a problem to being a widespread part of modern technology, used in compact disc players, optical-fibre-based telecommunications and laser surgery. Lasers also offer a fascinating view of the quantum world, in which photons act as particles and interact in a sheep-like manner to produce concerted emission, with the special properties of coherence, directionality and high intensity. The search for new lasing media to extend the wavelength range and to reach new temporal regimes (in pulse profile) has been a consuming passion for several decades. Now Nir Tessler, Graham Denton and Richard Friend (on page 695 of this issue[1]) describe experiments that indicate lasing in a conjugated-polymer microcavity. This is a new class of medium for compact laser sources (in their miniature device the active volume of polymer is only $5 \times 10^{-9}$ cm$^3$).

Polymers are chain-like organic molecules that consist of many individual segments, or repeat units, linked in a well-defined sequence. The conjugated polymers are a subset of these materials in which electronic states can delocalize, allowing stable optical excitations (without bonds being broken) and mobile charge carriers. They have attracted widespread attention over the past twenty years, first as 'synthetic metals' (man-made materials of high conductivity) and increasingly as semiconductors for electronic, optoelectronic and nonlinear optical applications.

Their emissive properties are particularly attractive, especially when combined with low materials costs and the possibility of large-area device fabrication. The property of electroluminescence, in which light emission follows the combination of electrons and holes injected from electrodes in a diode structure, is the subject of intense research and development worldwide. Emission across the whole of the visible spectrum has been demonstrated, and efficiencies, brightnesses and device lifetimes are rapidly approaching commercially useful target figures for lighting and displays[2].

One way to optimize the performance of electroluminescent diodes is to sandwich a polymer film between two mirrors. When the film thickness is of the order of the wavelength of the emitted light, the structure acts as a planar microcavity resonator. This structure couples the emitting dipoles in the polymer film to an electromagnetic standing wave, and allows control of the emission line width, directionality and decay rate.

The microcavity resonator is also a structure that lends itself to the attainment of stimulated emission and lasing. Certain types of inorganic semiconductor laser already make use of just this device configuration. But can it be done with the more versatile conjugated polymers?

In their article[1], Tessler *et al.* study the properties of a polymer-based microcavity (see Fig. 1 on page 695) under intense optical excitation, or 'pumping'. They observe three intensity-dependent phenomena with a clear threshold behaviour. First, at high pump intensity the device selects a single specific mode to which the emission strongly couples — this occurs at the expense of two other low-intensity cavity modes. Second, the emission lines narrow and third, the directionality increases, so more light comes out normal to the mirror surfaces. Taken together, these characteristics are strong evidence for lasing.


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A plastic laser. This 1-cm-thick cuvette contains a conjugated polymer solution which lases at 446 nm. Amplification occurs even without an external cavity. Widely tunable lasers may be possible in the future, using solid films of this and other polymers.

Organic dye solutions are used widely as tunable lasers, and lasing with conjugated polymers has been seen before in dilute solutions where the polymers mimic conventional laser dyes[3–5], but solid films were thought to be unusable because of strongly competing induced absorptions that kill net gain[6]. The article of Tessler *et al.* argues against this perceived wisdom, and is supported by recent experiments on thin polymer films, both undiluted[7–9] and containing $TiO_2$ nanocrystals[10]. These films also show strongly narrowed emission spectra and increased intensity above a well defined pumping threshold. But in all these cases some caution is necessary in concluding that lasing occurs. Superradiance and superfluorescence are phenomena that involve collective excitations of an ensemble of dipole-coupled molecules. Both of these increase intensity and produce emission-line narrowing above a specific threshold of excitation density, mimicking laser action.

Whether such phenomena play a role here remains to be seen. But note that the solid-state photoluminescence quantum yields of 70 per cent and higher indicate that lasing should be possible. Whatever the conclusion, it is clear that conjugated polymers are now entering a new phase of study as highly emissive solid state materials. That is important for understanding their fundamental photophysical processes, and it may also open new ways of studying collective phenomena shown by excitons (bound electron–hole pairs) at high excitation densities.

For most purposes, electrical pumping would be much more convenient than optical. Low-cost electrically pumped lasers operating at wavelengths across the visible and near-ultraviolet spectral ranges would be very attractive if good power conversion efficiencies could be achieved. Tessler and colleagues' microcavity can be modified for electrical excitation by inserting a transparent anode (indium tin oxide, for example) on top of the Bragg reflector. Practical devices look a long way off at the moment because simple estimates[10] suggest that current densities of $10^5$ to $10^6$ A cm$^{-2}$ may be needed at present to reach the threshold excitation density achieved by optical pumping, but with foreseeable improvements in performance that figure might well be drastically reduced. It is also possible that some of the features of optically pumped conjugated-polymer lasers may prove attractive in their own right. For example, wide tuning ranges are anticipated[5], which would mean that a single polymer could replace several more conventional dyes.

Whatever the outcome of this new chapter in conjugated polymer research, the chase will certainly be fun. Many surprises undoubtedly lie in wait on the way. □

*Donal Bradley is in the Department of Physics, University of Sheffield, Sheffield S3 7RH, UK.*

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