Organic polariton laser

Can new types of organic semiconductor lasers offer low-power and coherent integrated sources? Stephen Forrest explains that his team's room-temperature polariton laser gives a reason to be optimistic.

■ What is a polariton?

A polariton is a coupled state between a photon and some type of material excitation. In our experiment, the excitation is an exciton, which is an electron–hole bound pair. In an organic medium such as anthracene, the exciton consists of an electron in an excited molecular state and a hole in the ground state. This exciton can migrate from molecule to molecule.

That main difference between excitons in inorganic and organic materials is that excitons are more tightly bound in the organic case. This is a direct result of the typically lower dielectric constant of organic materials; the Coulomb force binding the charges is inversely proportional to the dielectric permittivity of the host medium. This means that organic excitons, and hence polaritons, are far less fragile than their inorganic counterparts.

When an exciton and a photon are placed in a cavity, and the cavity resonance is tuned to the exciton absorption line, they can strongly couple to form a new eigenstate, called a polariton. The polariton is split into lower and upper energy branches in the same way that two identical pendulums form new modes when coupled by a spring, and it's these new eigenstates that lase. Organic polaritons are stable at room temperature owing to their strong exciton binding, and they emit light at visible wavelengths.

■ Why make polaritons lase?

One reason is that polariton lasing may eventually lead to an electrically pumped organic semiconductor laser with an extremely low threshold. Ever since the demonstration that organic semiconductors could lase under optical pumping, there has been a strong desire to pump them electrically. However, several major challenges have made this difficult. For example, in organic materials, losses dominate at high intensity because of polariton–exciton and exciton–exciton annihilation. One solution to this might be to achieve optical pumping indirectly using a nearby electrically pumped source. For example, you might think of electrically pumping an organic light-emitting device positioned near to the laser medium and cavity. That spontaneous radiation could

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Stephen Forrest (pictured) and Stephane Kéna-Cohen have realized room-temperature lasing of polaritons in an organic material.

then be focused to a sufficiently high power density to create stimulated emission in the adjacent laser. However, the thresholds are too high if conventional organic lasing modes are used, and the technical challenge of focusing an organic LED source down to a sufficiently fine and intense beam so that it could pump a material to lasing is very complex. Because my student, Stephane Kéna-Cohen, was investigating a variety of polariton effects for organic molecules in optical cavities, we thought that their potentially very low thresholds — well below those of conventional organic lasers — might solve the problem. Low thresholds are achievable because polaritons don't need a population inversion to lase. Instead, polariton lasing is a result of the bosonic nature of polaritons. What we came up with was something that did lase, at a wavelength of ~400 nm. The threshold of the laser is still high, but it is certainly less than for conventional lasing.

■ Tell us about the experiment and the challenges it involved.

A big challenge was to find the right materials, and then to make single crystals of these materials in a very controlled fashion — it took several years to get this right. First, we deposited a distributed Bragg reflector mirror on top of a quartz slide. On the mirror we grew thin gold spacers that gave the right gap

width for the resonant mode when another distributed Bragg reflector was pressed on top. We then exploited capillary action to pull liquid anthracene into the spacer gaps between the two mirrors; this grew single crystals in the spacer channels. If this were attempted on a free surface and not inside a pre-formed cavity, the resulting crystal would be very rough and disordered, and we would not achieve the required thickness.

Our experimental set-up for achieving optical pumping combines a high-power femtosecond laser source with an optical parametric amplifier to produce high-intensity tunable pulses. This allowed us to reach the polariton densities required for lasing. A pair of goniometers allowed independent tuning of the pump angle and measurement of the angle-resolved luminescence. We pumped the microcavity and measured the emission as a function of angle above and below the threshold. The lower energy polariton mode exhibited emission at angles as large as 40°, implying emission from states with a wide range of momenta. When lasing is achieved, the intensity squashes down mainly to the bottom of the band, hinting at Bose–Einstein condensation.

■ What are the implications of the results?

Near-zero threshold sources that work at room temperature are sought after for all kinds of photonic circuits requiring low-power coherent sources, or even for quantum computing and single-photon sources. Our work gives hope for a lot of these advanced applications. Now that there is a proof-of-concept for polariton lasing in organic materials, there are many directions for future research, including the investigation of better materials or higher *Q*-factor cavities. However, we still have a long way to go before polariton lasing can be used in practical applications. At our current thresholds, we can't yet take an integrated organic LED source and pump it into a polariton mode, but that's where we are heading.

INTERVIEW BY DAVID PILE

Stephen Forrest and Stephane Kéna-Cohen have a Letter on their polariton laser on page 371 of this issue.