editorial

Shiny condensates

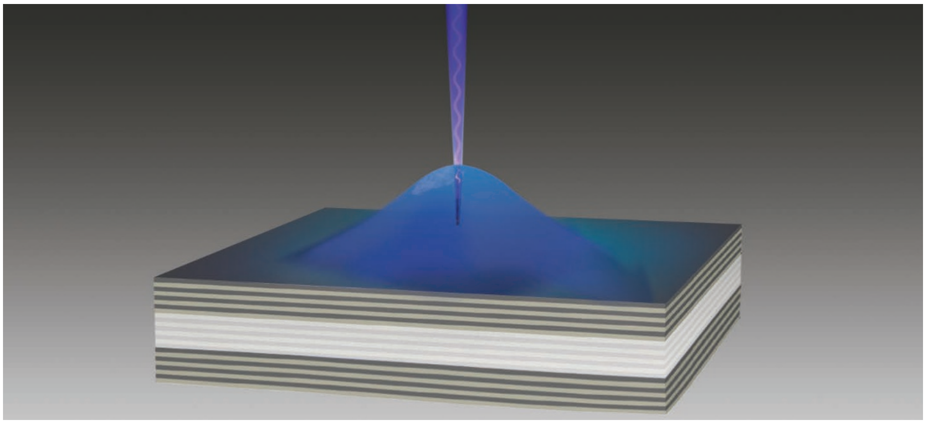
Commercialization of exciton–polariton research as well as investigation of exciting physical phenomena in exciton–polariton condensates relies on improving material properties.

The first demonstration of the semiconductor laser[1] in 1962 is a notable example of how understanding the dynamics of electric charges and photons in semiconductors, as well as in growth techniques, triggered a revolution in everyday life, from telecommunications to data storage. Progress in mastering the epitaxial growth of these materials enabled the realization of sophisticated architectures, such as vertical microcavities where excitons and photons can be trapped and forced to interact, that proved to be effective tools for the investigation of complex light–matter phenomena. Using such structures, it was shown in 1992 that the coupling strength between excitons and photons[2] could be increased to the point that a new quasiparticle, the 'microcavity exciton–polariton', was created.

The discovery of these quasiparticles soon triggered intense theoretical and experimental work, aimed at understanding the unique characteristics — such as bosonic character, light effective masses and strong inter-particle interactions — resulting from the combination of exciton and photon properties. In 1996, Imamoglu *et al.* theoretically discussed how the bosonic character of exciton–polaritons could be used to create an exciton–polariton condensate that would be able to intrinsically emit coherent light[3]. This milestone shaped exciton–polariton research around two main axes: the investigation of exotic quantum phenomena inspired by atomic physics, such as Bose–Einstein condensation, and the development of low threshold lasing devices. Twenty years after this pivotal proposal, the field has come a long way.

In their Commentary on page 1049 of this issue, Yoshihisa Yamamoto, Sven Höfling and Michael Fraser discuss the basic physics behind the formation of an exciton–polariton condensate with spatial coherence and the subsequent emission of coherent light without the need for population inversion. Recent studies have clarified however that, given their 2D confinement (instead of 3D) without thermal equilibrium, exciton–polariton condensates are very distinct from Bose–Einstein condensates.

The vast majority of experiments to date have been performed in microcavities based on inorganic semiconductors (nominally GaAs and CdTe) that operate at cryogenic temperatures. The drive for room-temperature operation shifted the interest towards GaN and ZnO but also organic materials[4,5] and very recently, transition metal dichalcogenide monolayers[6,7]. Daniele Sanvitto and Stéphane Kéna-Cohen explain in their Review on page 1061 the characteristics of several classes of materials where exciton–polariton condensates have been demonstrated. Some of the most fascinating results, like nonlinear effects and logic gates, remain exclusive to devices that operate at cryogenic temperatures. However, successful demonstrations of electrically injected polariton lasers have also been reported at room temperature, using GaN as the active material[8].



Formation of an exciton–polariton condensate in a planar microcavity. Figure adapted from ref. 11, Nature Publishing Group.

Thresholdless lasing is not the only application of interest. Exciton–polaritons can also come into play in the field of spintronics, which aims at exploiting spin as an additional degree of freedom for quantum information processing. As they are chargeless quasiparticles, exciton–polaritons suffer less than electrons from interaction with the environment whereas their spin can be easily read out via the polarization of the emitted light. On page 1074, Jeremy Baumberg and colleagues report an electrically controlled polariton spin switch operating with sub-femtojoule energies, significantly lower than other spintronic switches.

So what lies ahead? Engineering polariton nonlinearities in materials that operate at room temperature is crucial for applications and real-life devices. The main obstacle in this direction, however, is extending the exciton–polariton lifetimes. The state of the art in organic materials at room temperatures is only few picoseconds, about two orders of magnitude lower than what can be achieved with GaAs (at cryogenic temperatures). On the other hand, the quantum nature of exciton–polaritons (which would allow applications in quantum cryptography and information) has not been fully explored yet, despite several attempts to observe genuine quantum behaviour[9], such as squeezed states[10]. It is also clear that exciton–polaritons have still a lot to offer in the context of quantum simulators, for the solution of complex many-body problems.

Decades after their first observation, exciton–polariton condensates have revealed many of their secrets, but it seems they haven't reached yet the end of the road. The new materials currently under study will hopefully enable cost-effective and powerful laser devices that operate at frequencies relevant for applications (like the telecom band), as well as the demonstration of exciting physical phenomena. ❐

References

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