

# Liquid light at room temperature

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In their recent review article Ghosh *et al.* provide an overview of room-temperature polaritonics, which may be also referred to as physics of liquid light<sup>[1]</sup>. The quanta of liquid light, exciton polaritons, combine properties of photons and of excitons, electrically neutral semiconductor crystal quasiparticles. Polaritonics made tremendous steps forward in the 21st century thanks to the experimental observation of bosonic condensates and superfluids of exciton polaritons at elevated temperatures in a great variety of material systems. Coherent fluids of exciton polaritons can be efficiently controlled by laser light and/or by applied electric and magnetic fields. This opens ways to many applications, including but not limited to polariton lasing, optical switching, polariton simulators, neuromorphic computing, quantum computing, and polariton-induced superconductivity. Ghosh *et al.* provide a detailed analysis of the material systems suitable for room temperature polaritonics starting from wide-bandgap inorganic semiconductors such as GaN and ZnO, and carefully discuss also organic microcavities, perovskites, transition metal dichalcogenides, and hybrid structures. They discuss the advantages and disadvantages of these systems emphasizing recent experimental findings in each system. The review also contains a significant theoretical component giving outsiders of the field an opportunity to catch up with the state-of-the-art in polaritonics<sup>[1]</sup>. In this aspect, it provides an excellent development to the recent review on polaritonics for classical and quantum computing<sup>[2]</sup>. Compared to the Ref. [3] the present work is highly complementary as it addresses the progress achieved already after the publication of the book.

Out of all topics discussed in the review article<sup>[1]</sup>, I would like to comment on one of the most intriguing, from my point of view: the polariton qubits. Ghosh *et al.* mostly focus on condensates of strongly interacting exciton polaritons, where, in the regime similar to a polariton blockade, qubits may be based on quantum fluctuations induced by a laser pulse on the top of a confined polariton condensate<sup>[4]</sup>. While this concept is appealing by its similarity to a superconducting Josephson qubit (see, e.g., Ref. [5]), it may suffer from the same major handicap: the inability of the proposed qubit to keep coherence time long enough to enable the realization of 100 or more gate operations. Fast dephasing in all realistic polariton structures, especially those sustaining room temperature condensates, seems to be a formidable obstacle on the way towards the realization of the proposed qubit scheme. My feeling is that more promising might be another type of polariton qubit that is similar to a superconducting flux qubit<sup>[6]</sup> based on superposition of clock-wise and anticlockwise currents formed by millions of Cooper pairs. In superconducting flux qubits, to excite the system in a superposition state, a half-quantum flux of magnetic field

passes through the superconducting circuit containing several Josephson junctions. The system is forced to generate a circular current to either reduce the magnetic flux to zero or to build it up to a full-quantum flux. A polariton counterpart to superconducting flux qubits may be offered by circular superfluid currents of exciton polaritons, propagating in the plane of a semiconductor microcavity or a micropillar<sup>[7]</sup>. Being composed of a large number of bosonic quasiparticles that together form a quantum state of a many-body condensate, circular currents of exciton polaritons mimic the superconducting flux qubits. The essential difference between Cooper pairs and exciton polaritons comes from the fact that polaritons are electrically neutral, and the magnetic field would not have a significant effect on a polariton current. Nevertheless, the system is quantized as the phase of a polariton condensate must change by an integer number of  $2\pi$  when going around the ring. If one introduces a  $\pi$ -phase delay line in the ring, the system is obliged to propagate a clockwise or anticlockwise circular current to reduce the total phase gained over one round-trip to zero or to build it up to  $2\pi$ . It is argued in Ref. [7] that such a  $\pi$ -delay line can be provided by a dark-soliton embedded into a ring condensate and pinned to a weak link created by a specially shaped non-resonant optical pump beam. The physics of resulting split-ring polariton condensates is essentially similar to the physics of flux qubits. I would cautiously argue that qubits based on split-ring polariton condensates may be characterized by very long spatial coherence dephasing times due to the topological protection of superfluid circular currents. Moreover, as the Bose–Einstein condensation and superfluidity of exciton polaritons are now routinely observed at the room temperature, quantum networks based on polariton qubits would not require cryogenic operation temperatures. This makes them a valuable alternative to superconducting qubits<sup>[6]</sup>.

Whatever proposed application will be realized first, it is evident that polaritonics has a very bright future as it is a multi-disciplinary research field being rich both in fascinating fundamental discoveries and in application proposals. I am confident that the physics of liquid light will enter our everyday life no later than in the 2030s.

## References

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