Can Some Semiconductor Lasers Operate as Bose Einstein Condensates?

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Bose Einstein condensates consist of a large number of bosons in a single quantum state. This is strongly reminiscent of laser light, where many photons occupy a single coherent state. Thus, the question about the relation between BEC and laser light is less about the state itself than about the process that leads to said state. In BECs, bosons at equilibrium thermalize and, if their density is large enough for their wavefunctions to significantly overlap, eventually condense to a single state. In semiconductor microresonators, the condensation of quasi-particles known as polaritons is well established [1]. In the absence of excitons, light and matter interact incoherently (weak coupling) through absorption and emission, which is also expected to lead to photon thermalization [2]. In fact, photon BEC has been observed in several experimental devices, first in fluorescent dyes coupled to optical microresonators [3]. On the other hand, Vertical-Cavity Surface-Emitting Lasers (VCSELs) are a mature semiconductor technology, where coherent optical conversion is efficiently obtained from a heterostructure. They are routinely used in applications including telecommunications, sensing or illumination. They are usually described as light emitters where the coherent emission threshold is reached when optical gain compensates losses. Thus, the lasing transition is typically an out of equilibrium process, in contrast to BEC.

Here, we experimentally address the question of Bose Einstein condensation of light in a Vertical Cavity Surface Emitting Laser. We observe emission spectra which are compatible with a room-temperature thermal equilibrium distribution of photons. A phase transition, identified by a saturation of the population at high energy and a superlinear increase at low energy, takes place when the phase-space density is of order unity, as expected for a BEC transition.

Our observations suggest that the photon condensation phenomenon could in fact be more commonplace than originally envisioned. Far from questioning the validity or usefulness of existing laser theory, we propose that measurements which address the concepts of chemical potential of radiation and light emission by local equilibrium bodies [2, 4] can contribute to a broader and deeper understanding of photonic phase transitions.

References

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