

The theoretical prediction of Bose-Einstein condensation dates back a century ago. Inspired by work sent to him by an Indian scientist named Bose on the statistics of photons, Einstein has extended this idea to a gas of non-interacting massive particles with integer spin, later to be named bosons. He concluded that, below a critical temperature of the gas, a large fraction of the total number of particles would occupy naturally the single-particle ground state of the system. In analogy to hot vapours condensing on a cold plate, this phenomenon has been called a Bose-Einstein condensation and it is characterized with macroscopically coherent properties. The world waited for the experimental observation of such a novel quantum phase of matter till the end of the 20th century. These condensates have been obtained in an ultracold gas of alkali atoms at temperatures close to the absolute zero. These experiments were a realization of a Bose-Einstein condensate in a weakly interacting gas of bosons. The discovery was awarded a Nobel Prize in 1995, shared by C. E. Wieman, E. Cornell and W. Ketterle. Weak interactions in the condensate are related to its superfluid properties, which means that the Bose-Einstein condensate can flow without viscosity and loss even after encountering an obstacle.

In the meantime, the researchers have realized that a most abundant bosonic gas in nature, light itself – a gas of photons, should follow the same principles and a condensate of photons should be observable. The most common model of photon gas, black body radiation, does not condense, even though photons are in thermal equilibrium with the walls of the container (the black body cavity). This is because the photon number decreases with temperature and one cannot reach a low-temperature gas of photons, as it approaches an empty box. It appears, that this obstacle can be tackled in a different photon container in a semiconductor device, a laser microcavity with active material fulfilling specific criteria.

In this project, we will realize a Bose-Einstein condensate of photons in a commonly known laser architecture: a vertical-cavity surface-emitting laser (VCSEL). We aim to present a detailed study of how light confined in the laser can equilibrate to the temperature of the device and investigate the fundamental properties of a photon condensate and show its relation to a standard laser operation. Moreover, we will put a lot of effort into obtaining experimental evidence of effective interactions between photons. This is, of course, not possible without a mediating medium inside a laser, as photons do not interact in free space. Therefore, we will explore the fundamental properties of the building material of the VCSEL – III-V semiconductors, which are characterized with naturally strong nonlinear parameters. This means that the properties of the material change with a high density of the trapped photon gas within the laser, i.e. strong light intensity. This is the mechanism causing an effective interaction of photons, as they start to feel their presence each other at higher densities. This, eventually, will allow us to perform novel experiments on the superfluid properties of light condensate trapped in a semiconductor device.

Our results will pave the way to study quantum states of matter in semiconductor devices, being an alternative to already existing platforms where Bose-Einstein condensation has been observed. We will show, that an ordinary laser device is much more than meets the eye.