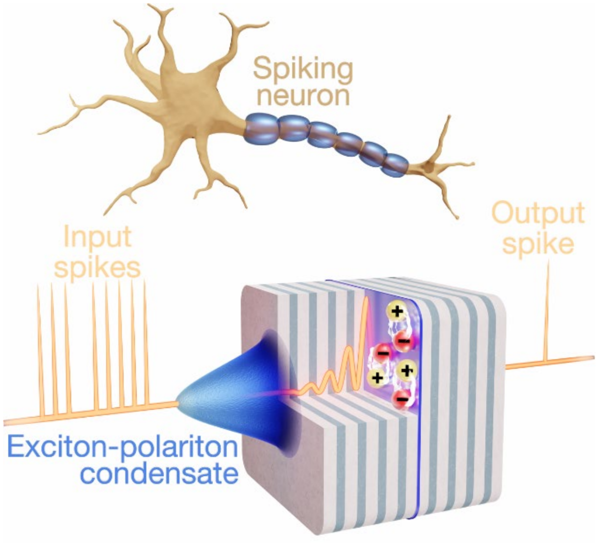

In the 1990s, neurobiology scientists demonstrated that a single cortical area in a macaque monkey's brain is capable of analyzing and classifying visual patterns in just 30 ms even though in the same time each of the neurons involved in the process sends only less than 3 messages in the form of electric pulses. This is possible because of a large number of interconnects between neurons (so-called synapses) within the neural network of the macaque's brain. Similarly, the human brain, which is believed to be one of the most complex systems in the universe, has approximately 100 billion neurons, and each neuron is connected to up to 10 thousand other neurons via a myriad of synapses. The brain capable of simultaneous recognition, reasoning, and movement control performs trillion operations per second while consuming only 20 - 25 W of power. In comparison, conventional processors require rates on the order of gigahertz (10^9 Hz) and expend about 250 W to be able to perform recognition among only 1,000 different classes of objects. This stunning difference and exceptional performance of the brain are in part due to the neuron biochemistry, its underlying architecture, and the biophysics of neuronal computation. No wonder then that scientists became interested in the possibility of implementing the way the brain works in today's computational systems. As society's appetite for information continues to grow, so does our need to process this information with increasing speed and versatility. Many believe that conventional computing may not cope with the increasing demand for higher computational power and simultaneously ensure energy efficiency. So-called neuromorphic computing platforms (i.e. inspired by the human brain) may overcome both limitations simultaneously. To achieve this, such devices have to incorporate not only the biological architecture of spiking neural networks but also the computational paradigm based on encoding information using pulses.

One solution that meets these requirements is based on the use of photons in a way that allows the creation of spiking neural networks within the concept of neuromorphic photonics. Photonic systems give access to communication at the speed of light, low losses, and low energy consumption. However, one aspect that hinders successful implementation is the fact that it is difficult to force photons to interact with each other in a way that allows complex computing operations known from digital electronic devices. This weak nature of interactions is an inherent property of photons.

As part of our research, we propose a solution in which photons interact strongly with matter-like particles called excitons. Strong interactions are possible when photons and excitons are trapped together in an optical microcavity, which forces cyclical energy exchange between them. This kind of synergy generated in a microcavity between photon and exciton is so durable that physicists consider it as a separate quasi-particle called in short polariton. Polaritons have unique properties, especially can undergo a transition into a state of matter called Bose-Einstein condensate. In such a state previously independent multiple polaritons team up and begin to collectively oscillate. Based on our recent experiment, we are the first to notice that when polaritons are excited by laser pulses, they emit "spikes" of light in a way that mimics the spiking behavior of biological neurons. This effect is directly related to the Bose-Einstein condensation phenomenon which either inhibits or enhances spikes emission.

In this project, based on our recent observations, we plan to build an optical artificial neuron using the spiking behavior of polaritons. To evaluate our proposal we will use trains of laser pulses to excite polariton microcavity similarly to how neuronal signals excite biological neurons. Our goal is to use the physical properties of polaritons in a way that will allow not only the processing of artificial neuronal signals in the optical domain but also connectivity between multiple optical neurons. We believe that adopting the unique properties of polaritons to build spiking neural networks may bring us closer to the ultimate goal of building a photonic neuromorphic processor.

Until now the path toward efficient neuromorphic computing hardware was strewn with challenges and it is clear that the optimal brain-inspired implementation is still ahead. This convinces us that there is great room for further improvements and new solutions need to be pursued.