Recent rapid growth in the amount of collected and processed data requires the search for a different approach to currently used electronics. Particles of light, known as photons, provide a natural alternative to electrons used in electronic systems. Photons already enable faster data transmission over longer distances. The utilization of light for data processing facilitates the development of faster, more efficient, and higher-capacity systems and represents a crucial step toward the advancement of quantum computing. However, practical implementation of photonic data processing requires the utilization of nonlinear effects, which results are not directly proportional to the manipulated parameter. One example of an optical nonlinear phenomenon is the occurrence of a laser action, where the intensity of emitted light rapidly increases when surpassing the so-called lasing threshold.

Semiconductor microcavities are remarkable structures exhibiting optical nonlinear phenomena. A microcavity consists of an optical resonator localizing light in the region of the quantum wells, where photons can create excitations of matter known as excitons. As a result of the strong coupling between photons and excitons, new quasi-particles called exciton-polaritons are formed. The emission intensity from a microcavity, investigated as a function of excitation power, allows for precise observation of the transition moment to a new phase of matter, which is a non-equilibrium Bose-Einstein condensate, which is also called polariton lasing.

The aim of my project is to reduce the threshold of polariton condensation in semiconductor microcavities by imprinting elliptical microlenses of solid immersion. Due to their immersion properties, such lenses allow for efficient injection of light into the structure. The innovative method of fabricating microlenses, developed by scientists at the University of Warsaw, has been used so far only for studying emission from quantum dots and monolayers of transition metal dichalcogenides. The proposed solution of using elliptical microlenses to decrease the polariton condensation thresholds will allow for the nonlinear processing of optical signals at an extremely low energy level. Our preliminary estimates show that this is possible at the few-photon level, bringing us closer to quantum limits.

Moreover, due to their immersion properties, microlenses allow also for the collection of light emitted from the microcavity at large angles, which are inaccessible to traditional objectives. This will enable the observation of in-plane momenta of polaritons that were previously unattainable experimentally. For wide emission angles from the microcavity, it is possible to observe the creation of a long-lived state called an excitonic reservoir, which supplies the condensate and plays a crucial role in its formation.

Furthermore, printing of a matrix of microlenses at precisely defined distances from each other will enable the creation of the arrays of coupled condensates. Particle exchange between condensates at network nodes leads to highly nonlinear properties, analogous to those observed in artificial neural networks. This allows for complex computations and pattern recognition tasks to be performed.

Advancements in the technique of printing microstructures using two-photon lithography will further enrich measurement methods for photon injection at an angle. This approach will introduce resonantly guided light into the structure with maximum possible efficiency. This method will enable the creation of a microcavity waveguide, facilitating long-distance light propagation within the microcavity.

Additionally, I plan to investigate other nonlinear effects such as optical bistability. This effect occurs when, within a certain range of excitation power, the system can exist in two stable states. Depending on its history, the system can switch between these two states. By utilizing printed microlenses, I aim to lower the excitation power range required for observation of the bistable behavior.

The developed method of printing polymer microstructures on the surface of semiconductor structures at the University of Warsaw will allow for the observation of new physical effects and revolutionize current methods of creating polariton condensates in optical microcavities.