From electrons to light: towards the future computers

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In recent years, research has focused its attention on the development of new faster ways for information processing. The driving force behind these efforts can be understood as an attempt to solve two pressing needs: on one hand the computational workload continues to increase while, at the same time, the performance improvement of MOSFET transistors, the building blocks of conventional computing systems, is being hindered due to physical and technological limitations. This means that while the amount of data that has to be processed increases, the speed at which this information can be processed does not.

Among the several ways that have been explored, one promising alternative consists in all-optical transistors. These devices could potentially work at incredibly high speeds (500 times faster than current transistors) while using much less energy (100 times less). They would also integrate well with existing optical communication systems. However, creating all-optical transistors has been challenging: a major issue is that photons (light particles) do not interact with each other easily, but transistors need this interaction to work. To solve this, scientists are using special materials that can absorb and emit light, creating strong interactions within small system constituted by two parallel mirrors capable of trapping the light called microcavities. This process produces a type of particle called a microcavity exciton-polariton, which combines properties of light and matter. Polaritons, under certain conditions i.e. when their density is high enough, can undergo a special phase transition called Bose-Einstein Condensation, exhibiting a very non-linear behavior. Polaritons have a low mass and move quickly due to their photonic part, while their excitonic part allows for powerful nonlinear effects at lower powers than in traditional nonlinear optical crystals. This makes them excellent candidates for creating all-optical transistors. Recently, researchers have made progress with polariton-based all-optical transistors. But these new transistors still lack some important features like ultra-fast switching, working at room temperature, and being small enough to fit on a chip. For example, in 2019, a team created a basic all-optical transistor using a special polymer, but it needed a large, impractical setup to work.

In my project, I exploit advanced Silicon fabrication technology to make on-chip microcavities. This approach allows for creating ultra-fast integrated all-optical logic circuits that do not rely on bulky setups. Recently, I have successfully demonstrated that these new devices can switch and amplify signals quickly, achieving the first ultra-fast room-temperature integrated all-optical transistor. This might lead to the development of complex logic circuits and, eventually, ultra-fast all-optical computing systems.