Will Excitonic Circuits Change Our Lives?

Transistors that process signals by emitting flashes of light: is this the milestone of a technological revolution in computation? Whether this scenario is science or fiction, only the future will tell.

Light is fast; faster than anything! Efficient signal communication already uses light, but signal processing in electronic devices still uses electrons. The need to convert optics into electronics and vice versa slows down the effective speed of communication. Recently, a transistor which processes signals by emitting flashes of light has been experimentally demonstrated by the collaboration between the groups led by Leonid V. Butov and Arthur C. Gossard at the University of California (California, USA). These two groups have also been able to perform some basic computations by integrating these flashing transistors into a circuit. Is this the milestone of a technological revolution in computation?

In this story there are two protagonists: photons in optical communication and electrons in signal processing. Before transmitting or after receiving a message, signal processing can be carried out on it, mainly by means of semiconductor-integrated circuits. However, these miniaturized circuits, built on fundamental bricks called transistors, currently use electrons to process signals. Like two people from different countries who do not speak a common language, electrons and photons do not interact directly, and the need to mediate between them limits the speed of the communication itself, in exactly the same way it would in a social context.

The direct use of light, both for communication and computation, could speed things up. "Our gallium arsenide transistors process signals using indirect excitons instead of electrons," Butov explains. "They are controlled by gate electrodes exactly like electrons in silicon transistors, but, unlike electrons, they are directly coupled with photons, thus bridging the gap between processing and communication." While computation itself may not be faster than electron-based circuits, signal transmission to other devices or parts of the same chip connected by an optical link will definitely be.

Excitons are electron-hole pairs in semiconductor materials such as gallium arsenide, bound by the attractive force between negatively charged electrons and positively charged holes. Because of this force, excitons tend to recombine fast, releasing a flash of light as a result. Their lifetime, however, can be increased by up to ten microseconds when confining electrons and holes in layers spatially separated, forming what is called an indirect exciton.

The working principle of the exciton-based transistor (EXOT) lies on an electric gate like in a standard field effect transistor (FET), which is employed in most electronic devices. Like a gate can be opened or closed in order to control the flow of people passing through, a gate electrode in transistors is charged to supply a voltage that inhibits or activates the electron flow in FETs or the exciton flow in EXOTs between two terminals. The next step was to give an experimental demonstration of an easy excitonic integrated circuit (EXIC), which can perform basic operations on photonic signals such as switching and merging.

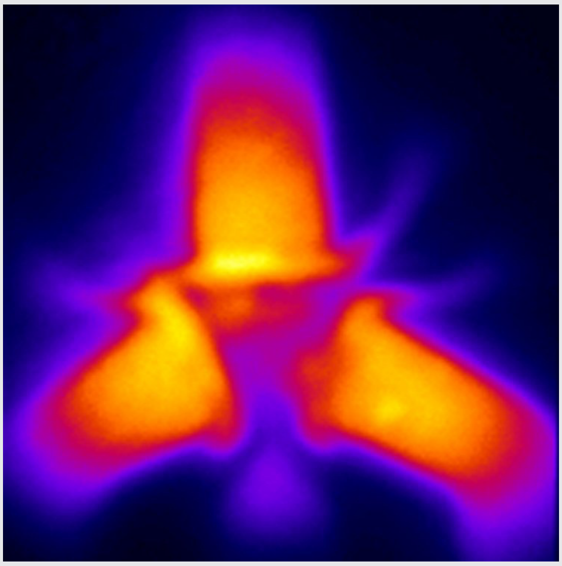

Figure 1: Integrated flashes of light. A simple circuit, where three exciton-based transistors (EXOTs) have been integrated to perform some basic computation. Every EXOT, when processing signals, emits flashes of light as shown in the picture.

Even though the work of Butov and his colleagues offers proof that excitons could be used for computing, many open questions need to be addressed before any technological application comes within reach. As Butov explains, "excitons in gallium arsenide are stable only at low temperature, below 40 degrees Kelvin. At higher temperatures they dissociate easily, but real applications would require stable excitons at room-temperature." Stephan W. Koch at Philipps-Universität Marburg (Germany) is, therefore, sceptical about the applicability in real devices. "There is no inorganic semiconductor material so far that allows stable exciton populations at room-temperature." Alexei L. Ivanov at Cardiff University (UK), instead, affirms that "in some semiconductor materials, such as ZnSe, CdTe, or GaN, excitons can survive up to room-temperature. However, in such conditions the spatial separation between holes and electrons in indirect excitons has to be rather narrow, a few atomic layers." He, therefore, adds that "the main challenge before real applications is the fabrication of high-quality EXICs based on such materials in order to have stable excitons at room-temperature."

Furthermore, in order to process excitons, their energy needs to be transferred before they decay and this may limit the number of transistors which can be integrated into a circuit, a crucial condition for computation. Koch points out that "excitons, which couple well with light do not live very long, typically not more than a few nanoseconds. The excitons used in this application have a longer lifetime, but they couple only very poorly with light." Exciton properties like lifetime and propagation distance put obstacles in the way of real devices, unless a way is found to transfer the exciton energy to other components of the chip before it decays completely by emitting a flash of light.

Is this the milestone of a technological revolution in computation? Koch says that "no application is foreseeable: the demonstrated effects are cute, but not useable in real devices." According to Ivanov, however, "the main message of this work is that conventional solid-state optoelectronics still has a huge intrinsic potential for further development." And Butov adds that "the success of EXICs depends on how well it is possible to address such open questions. If this is the case, we can even aim to build a computer completely operated by excitons, where the direct link to optical communication will improve every device." Exciton-based transistors could pave the way for a technological revolution provided that they can work in real devices. As usual, visions lie at the border between reality and illusion. Whether this scenario is science or fiction, only the future will tell.

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