it provided a strategy for sustained progress in a range of areas, including seismic assessment and rehabilitation of existing buildings, urban planning, education, and risk and disaster management.

Earthquake risk management measures are now being implemented in Istanbul and in other cities in Turkey, including a 20-year, 400 billion USD urban renewal program that foresees the demolition and rebuilding of about seven million fragile housing units, most of them residential. It is to be hoped that when the next earthquake strikes at or near one of the major cities in Turkey, these measures will reduce the numbers of lives lost.

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10.1126/science.1238945

APPLIED PHYSICS

Triggering an Optical Transistor with One Photon

The coherent absorption of a single photon by atoms in an optical cavity can control the transmission of a more intense light beam.

Jürgen Volz and Arno Rauschenbeutel

Transistors are the key element in all electronic circuits, and a single computer chip may contain billions of these elements. However, in recent years, data communication underwent a paradigm shift away from electronic schemes to light-based communication with optical fibers. In the wake of this transformation, a considerable amount of research has gone into trying to replace active electronic circuits with optical ones. One major research direction focuses on all-optical transistors that allow a large optical "source" signal to be controlled by a weak "gate" light field. On page 768 of this issue, Chen *et al*. (*1*) report on the realization of such a device and demonstrate that even the smallest possible gate field—a single photon—can control the transmission of a source optical field consisting of hundreds of photons.

Under normal circumstances, pulses of light do not interact with each other. This property enables the simultaneous use of multiple-wavelength channels for transmitting data over optical fibers. However, the absence of direct interaction prevents the direct implementation of active photonic elements such as optical transistors. To circumvent this problem and to realize a strong effective light-light interaction, Chen *et al*. combined two central elements of modern quantum optics research in their experiment: a high-finesse optical cavity (one that has very low absorption losses) and an optical quantum memory (*2*, *3*). The latter enables light to be stored in an ensemble of laser-cooled atoms and to be retrieved later on.

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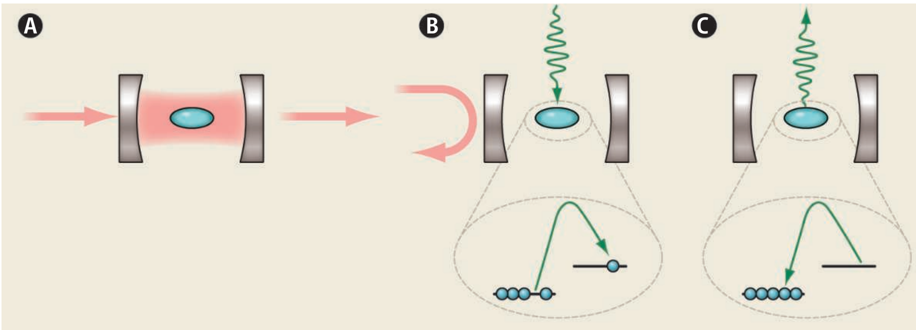

An optical "light switch." The schematic setup and operation principle of the all-optical transistor is shown. (**A**) An ensemble of laser-cooled atoms (blue) is trapped inside an optical resonator in the off-resonant ground state. As a consequence, the incident source field (red) is transmitted though the cavity. (**B**) In the first step of the switching process, the gate light field (green) containing about one photon is stored in the ensemble. A collective state is formed in which one atom is transferred to a state resonant with the cavity, which blocks the transmission of source photons through the cavity. (**C**) If the source field is weak enough, no information on the position of the transferred atom becomes available and the gate photon can be retrieved.

The high-finesse optical cavity consists of two highly reflective mirrors that can reflect light back and forth about 25,000 times. Inside the cavity, an ensemble of around 20,000 cesium atoms were trapped by means of optical tweezers (*4*) and laser-cooled to a temperature of a few microkelvin. Initially, all of the atoms were prepared in an internal state that did not interact with the light in the cavity. The atomic ensemble was thus transparent for the cavity light, and, because the length of a round trip between the cavity mirrors equaled an integer multiple of the wavelength of the incident source light field, the cavity transmitted the source light.

In order to realize an all-optical transistor, it is necessary to control the cavity transmission with an external light field that acts as the gate. Chen *et al*. accomplished this feat by sending the gate light field from the side into the cavity where each photon induced—through interplay with an additional control light field—a coherent scattering process that changed the state of just one of the atoms (see the figure) (*2*, *3*). For their experimental conditions, the interaction between the source light and atoms was strongly enhanced because of the high finesse of the cavity. Remarkably, transferring just a single atom to another internal atomic state that was resonant with the optical field inside the cavity sufficed to change the resonance wavelength of the cavity substantially and block the transmission of the source field (*5*). Thus, as soon as a single gate photon underwent a coherent scattering event in the ensemble, the cavity transmission was reduced and most of the source light incident on the cavity was reflected. In this way, the authors showed that a gate field that contained only a single photon could switch between the transmission and reflection of the source light field containing hundreds of photons.

The performance of the device even went beyond that of a classical switch operated by a single photon. As long as no information is available about which atom changed its state, quantum interference allows the coherent scattering process to be reversed. Thus, the initial gate photon could be retrieved from the atomic ensemble after blocking the transmission of the source photons. In this case, the atomic ensemble was operated as a so-called quantum memory (*2*, *3*). Here, the number of source photons that could be redirected was smaller than in this previous experiment: Because of experimental imperfections, a small fraction of the source light will still enter the cavity and can then be scattered outside of the cavity by the atom. This process will more likely occur for a larger number of incident source photons and will reveal which atom changed its state, thereby destroying the quantum interference necessary for retrieving the gate photon. Chen *et al*. found that a single gate photon that was stored in their quantum memory could redirect a source field containing up to two photons before the retrieval of the gate photon was impeded. Although this number seems small, it exceeds 1 and is above the critical threshold for a positive gain of their transistor.

With their experiment, Chen *et al*. demonstrated the feasibility of an all-optical transistor that can be triggered by only a single gate photon. That such a system can be operated in the quantum regime opens the way to future photonic devices that could be used for light-based quantum information protocols (*6*). To this end, the next critical step will be to optimize the performance of such systems, which requires enhancing the absorption probability of the gate light in the atomic ensemble. Moreover, the efficiency of coupling the source light into and out of the optical resonator will have to be improved. In independent experiments, highly efficient quantum memories (*7*) and optical resonators with coupling efficiency close to 1 (*8*, *9*) have been realized. Combining these improvements in the same system would allow the realization of an efficient all-optical transistor, which in turn might enable the implementation of deterministic quantum logical operations between individual photons (*6*)—the key element of an optical quantum computer.

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10.1126/science.1242905

NEUROSCIENCE

Mapping Neuronal Diversity One Cell at a Time

A universal method for classifying neuronal subtypes will increase our understanding of the human brain.

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How many types of nerve cells are there in the mammalian central nervous system (CNS)? We still do not have a satisfactory answer to this deceptively simple question, and yet the precise assignment of nerve cells to well-defined subtype categories is critical both for elucidating the function of neural circuits and for the success of neural regenerative medicine. Amid the anatomical, electrophysiological, and biochemical diversity of nerve cells, the field is struggling to devise simple and clear criteria for neuronal classification. A universally applicable classification system should be based on traits that are objectively quantifiable, sufficiently diverse, and reproducible in independent laboratories. Such a classification method would provide new insights into CNS organization, development, and function, and might reveal unexpected relationships between neuronal subtypes.

To fully characterize nerve cells and appreciate their diversity, they are analyzed at all three phenotypic levels—anatomical, biochemical, and electrophysiological. Complete anatomical mapping was accomplished for the CNS of the worm *Caenorhabditis elegans* by reconstruction of serial electron micrographs (*1*). Ultrastructural mapping is complemented by analysis of anatomy and connectivity based on cell type–specific expression of reporter genes to effectively study the much larger mammalian CNS (*2*, *3*). At the biochemical level, ongoing efforts to map expression patterns of developmentally regulated genes provide fundamental insights into molecular diversity and developmental programs of individual nerve cells (*4*, *5*). And at the electrophysiological level, new research programs, such as the recently announced Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative, are supporting development of technologies for global mapping of neuronal activity in behaving animals (*6*). Although integration of the three complementary approaches is essential for the ultimate understanding of brain structure and function (*7*, *8*), at the single nerve cell level such detailed analysis poses a problem as it allows assignment of each nerve cell to multiple different subtype groups.

Currently we do not have a system to provide a definitive count of neuronal subtypes, even in a small region of the mammalian CNS. A recent review on subtype diversity of neocortical interneurons provided a partial solution by proposing to focus on a few easily distinguishable morphological phenotypes to categorize inhibitory interneurons (*9*). Although such an approach is practical and immediately applicable to classification of cortical interneurons, it is not sufficiently universal to be easily transferable to other types of neurons and might miss important

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