Slowing down single photons

Single photons emitted from a quantum dot can be slowed down using a hybrid semiconductor–atomic interface. Nika Akopian from Delft University of Technology in The Netherlands explained to *Nature Photonics* how this non-classical light storage system works.

What is your work about?

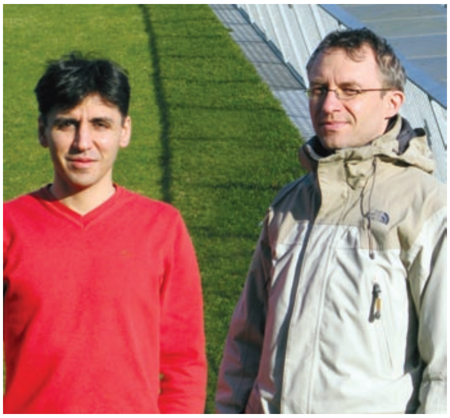
Our work combines two important scientific disciplines: semiconductor physics and atomic physics. We use a single semiconductor quantum dot as a device that emits single photons on demand. These single photons are then guided through a transparent glass cell containing rubidium vapour at low pressure. The cell works as a light-slowing medium, in which single photons travel with velocities much lower than the speed of light in a vacuum. Such a delay line can be viewed as a storage medium whose storage time is determined by the delay. In our work we demonstrate the storage of single photons emitted on demand from a semiconductor quantum dot.

Why didn't you use electromagnetically induced transparency to slow the photons?

There are several ways to slow down light, and electromagnetically induced transparency (EIT) is perhaps the most well-known. For instance, a light velocity of 17 m s^{-1} was reported in 1999 using EIT. However, EIT cannot easily be applied to quantum dot emission because these photons are typically 100 times spectrally broader than the width of the transparency region created by EIT. The figure of merit for slow-light delay systems, known as the fractional delay, is defined as the ratio between the absolute delay and the temporal width of the propagating pulse, and is usually very small in EIT-based schemes.

How did you slow down single photons from a quantum dot?

We explored the combined use of artificial and natural atoms, particularly at the single-photon level. We designed our artificial atom — a gallium arsenide quantum dot — such that it emitted photons at a wavelength of around 780 nm. 780 nm is close to the D_2 transitions of rubidium, which are transitions from the $5^2S_{1/2}$ ground state to the $5^2P_{3/2}$ excited state. The emission was then fine-tuned between the D_2 transitions using an externally applied magnetic field. In this way we were able to use double-absorption resonance in rubidium — a technique recently proposed as a storage medium for spectrally broad light and also used for slowing down classical light — to slow down single photons generated from the quantum dot. The two systems were therefore connected through the electromagnetic field of a single photon, which served as an interface between the single quantum dot and the vapour cell. This allowed us to combine the scalability and functionality of nanostructure devices based on single quantum dots with the uniformity of atomic systems. We believe that this combination of advantages could be of significant fundamental and technological interest.



WOLFGANG PFAFF / TU DELFT

Nika Akopian and Val Zwiller have used a semiconductor–atomic interface to slow down single photons emitted from a single quantum dot.

How are the single photons slowed down?

The emission of the rubidium quantum dot is tuned between its D_2 transitions and the arrival time of the emitted photons is detected for various temperatures of the vapour cell. The ground state of the D_2 transitions consists of two Lorentzian absorption resonances. A dispersion region is created in the spacing between these resonances, resulting in a steep refractive index slope that depends on the atomic density and therefore increases exponentially with temperature. The inverse dependence of the photon speed on the refractive index slope means it decreases inside the cell when the temperature is increased. As a result, these photons are delayed and thus detected later than photons with frequencies outside the D_2 transitions. We demonstrated a fractional delay of 15, and also showed that the polarization of a photon is preserved during its propagation through the cell. Unfortunately, the quantum dots used in our work suffer from charge fluctuations in their vicinity, which cause inhomogeneous broadening of the emission. The development of a better sample with a Fourier-limited emission linewidth will be an important improvement for producing fast single photons, quantum memories and quantum repeaters.

What are the implications of your findings?

We believe that our work is only the first step in a series of novel experiments and research directions. For instance, our hybrid interface can be used to store quantum information encoded in the polarization degrees of freedom of photons. This will be an important step towards the implementation of quantum memories and quantum repeaters for quantum-dot-generated photons. Furthermore, microcells containing atomic vapour can be integrated in semiconductor devices, enabling the creation of scalable on-chip photonic memories. Our work could also lead to the development of all-optical single-photon switches that can be triggered by a single photon emitted from a single quantum dot. We also foresee more work on superluminal (fast) light propagation at the single-photon level, which is an intriguing and exciting research area.

INTERVIEW BY RACHEL WON

Nika Akopian and co-workers have a Letter on their single-photon-slowing technique on page 230 of this issue.