interview

Photon echoes

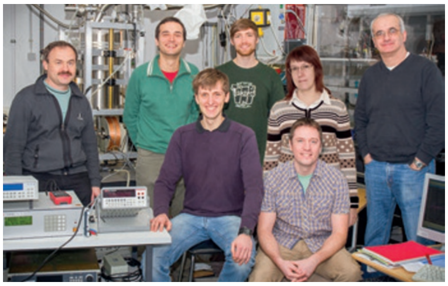
Ilya Akimov talks to *Nature Photonics* about employing trions in semiconductor quantum wells to store optical information.

What are the principles behind your experiment?

We executed a photon echo experiment using the trion transition in a semiconductor quantum well and an externally applied magnetic field. The exciton cannot be used for such a scheme as there is no remaining particle following recombination. Instead, we focused on the negatively charged trion as there is always one electron left behind when it recombines. Although we draw this picture by discussing single electrons, we actually work with an ensemble of electrons. The magnetic field is essential: it becomes possible to mix the electron and trion states in a way that permits the transfer of the optical excitation onto the spin of the resident electron. This is what allowed the demonstration of long-term, long-lived photon echoes. Such a study focusing on the trion in a magnetic field had previously never been performed.

What is the main significance of your work?

The main achievement is the demonstration of photon echoes in semiconductor nanostructures on timescales that are three orders of magnitude longer than the lifetime of optical excitation. In fact, the initialization of the resident electron's spin has already been reported in the literature, but we made the next step. After saving the first pulse, one can obtain a copy of it in the stimulated photon echo. The core of our work is transferring the optical field onto the electron spin ensemble and then retrieving it, with all of this occurring in the very well-studied system of a semiconductor quantum well. In this sense, we believe we have presented a significant and solid first step towards optical storage in networks. Whereas the optical coherence in our system is 70 picoseconds, we showed optical storage over tens of nanoseconds. We believe we can extend this to times on the order of microseconds if we use certain spin resonance techniques to prevent the dephasing of the electrons' spin or employ other nanostructures such as quantum dots. Although our work is relevant for optical storage schemes, the timescales in the current implementation are still too short.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From left to right: Dmitri Yakovlev, Ilya Akimov, Matthias Salewski, Lukas Langer, Irina Yugova (top), Sergey Poltavtsev (bottom) and Manfred Bayer at TU Dortmund University, Germany. The team has demonstrated long-term optical memories using photon echoes.

What is the benefit of working with an ensemble of trions?

The absorption of a transition is very low when using a single quantum system. When working with an ensemble, however, the advantage is large absorption and therefore greater efficiency. For optical memories, it is important to save all of the information. At the same time, for the photon echo effect one needs inhomogeneous broadening and working with an ensemble provides this unavoidably. In this sense, our implementation allows the study of the evolution of spin in an ensemble that has zero net spin polarization. Most studies include pump–probe techniques, where one induces some spin polarization in the system and then observes its evolution in time while always maintaining some net spin polarization. Our system, on the other hand, is polarization-free, as each electron spin in the ensemble is oriented differently after optical dephasing. We perform optical rephasing to retrieve any information from the electron spin ensemble. Therefore, the net polarization is zero and, in this sense, our system constitutes an interesting playground for fundamental spin studies.

What are the advantages and disadvantages of your system?

In our case, the very short timescales constitute both the main advantage and disadvantage. As the Bohr radius of the excitons in semiconductors is much larger compared with the hydrogen case, the oscillator strength is very high, rendering the light–matter coupling significant. Although faster (sub-picosecond) and more efficient excitation of the system is possible, it suffers from very fast decay times (100–1000 picoseconds). Let's keep in mind that efficient excitation in atomic systems would take more than a nanosecond. Although quantum wells can be considered model systems in many ways, there is a limit to the intensities they can withstand. When the optical densities are high, there are some extra dephasing processes that reduce the coherence quickly.

What was the biggest experimental difficulty?

Ordinarily, photon echo experiments with rare-earth crystals or atomic systems are not performed with pulsed lasers. In this context, the excitation is usually electronically 'sliced up' as there is no need for ultrashort pulses. In our case, however, given the short timescales of the system itself, we need ultrafast laser pulses and, in particular, picosecond pulses. Another challenge was combining four-wave-mixing techniques with ultrafast laser pulses while applying magnetic fields. Combining all of these ingredients was the biggest experimental difficulty.

What will the next step be experimentally?

We need to work with some other system with trions or similar transitions that will allow us to further enhance the timescales. Now our goal is to perform similar experiments for strongly localized trions, found in, for example, quantum dots. Self-assembled quantum dots seem like good candidates for such experiments as there is always a preferential growth axis and the optical selection rules are well defined. All protocols and energy schemes would remain the same but we would be able to apply high intensity π pulses and thus greatly increase the efficiency when in the strong-field limit. ❐

INTERVIEW BY MARIA MARAGKOU

Ilya Akimov and co-workers have an Article on photon echoes on page 851 of this issue.

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