Two photons are better than one

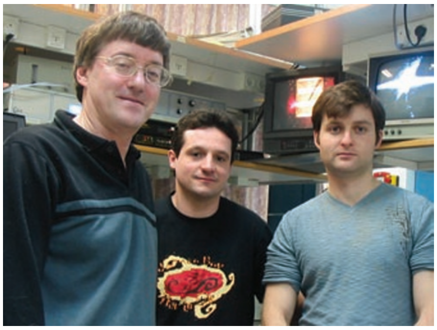
Single-photon emission is a well-explored process. But in recent years interest in two-photon emission has grown. *Nature Photonics* spoke to Meir Orenstein and Alex Hayat in Israel about their latest work, which reports two-photon emission in a semiconductor.

What is the interest in two photons rather than one?
Two-photon emission (2PE) is a process in which an electron transition between quantum levels occurs through the simultaneous emission of two photons. Two-photon emission is interesting because it could be used to create entangled-photon pairs, useful for quantum information processing. Two-photon absorption has been widely studied, but 2PE has not been observed in semiconductors so far.

What have you done?
First, we observed the basic effect of 2PE in a bulk GaAs semiconductor that was optically pumped. Next, we implemented this in an actual practical device — an electrically driven LED-like quantum-well-based device that emits two photons when excited by a current. Neither of these things had been done before.

Aside from being a 'first', why are these achievements important?
The main advantage of semiconductor-based 2PE is that it is much more efficient than 2PE in an atomic system, because the density of atoms in a semiconductor is much higher than in, say, gases or other media that have been used previously. Solid-state systems can have more than 10^{22} atoms per square centimetre, which is many orders of magnitude more than in gas systems. Semiconductor devices also allow electrical excitation, which is more efficient than optical excitation and enables integration of such devices into compact photonic circuits, using mature semiconductor fabrication technology.

Ultimately, 2PE work is useful because it could offer a compact source of entangled photons, which would form the basis of future quantum computers. Existing sources of entangled photons are fine in the lab but they are not very practical — some need cryogenic cooling to tens of kelvin or very powerful lasers and exotic nonlinear materials, for example. What we've done is produce room-temperature, microscopic LED-like devices that emit correlated photon pairs.



Meir Orenstein, Alex Hayat and Pavel Ginzburg (left to right) in their quantum photonics lab.

What are some of the challenges you faced?
Two-photon emission is a relatively weak emission process, about five orders of magnitude weaker than the usual single-photon emission that occurs in semiconductor lasers or LEDs. So we had to use special photon-counting equipment and very sensitive detectors to observe this effect. However, it should be said that our 2PE method is much more efficient than other approaches for obtaining entangled photon pairs, such as parametric down-conversion. Two-photon emission in a solid-state emitter could potentially be a much stronger and more useful effect.

How can you be sure that the photons you are measuring are 2PE and not single-photon emission or something else?
There are a couple of ways we check this. The main method is to follow the emission of two photons with complementary wavelengths. In 2PE you produce pairs of photons whose combined energy adds up to the electron-transition energy in the semiconductor. So by measuring the energy (wavelength) of one photon, you can deduce information about the energy (wavelength) of the other. The two photons are emitted at complementary wavelengths.

Another important method is to perform coincidence measurements. Because the photons are correlated, both photons are emitted at the same time. This is how we can be sure we are measuring 2PE.

Are your photons entangled?
At present, the only indication we have that we are producing entangled photons is through the emission of photons with complementary wavelengths. The true proof of entanglement will come when we apply 'Bell test' experiments. We haven't yet done that, but we're working on it right now.

What other technological implications does your work have?
We have demonstrated two-photon gain (stimulated 2PE), which could ultimately lead to new types of two-photon lasers or nonlinear optical switching devices. In addition, 2PE could have promise in biomedical applications. The emission is very broadband, and the photons are also correlated. As such, the photons could be used to perform very efficient spectroscopy in the mid- and maybe far-infrared, something that is difficult to achieve using normal semiconductor lasers and room-temperature detectors.

Where next for you?
Our ultimate goal is to benefit the field of quantum information with a useful, compact source of entangled photons, but this is more difficult to implement and is a longer-term goal. More immediate applications of our work will lie in creating single-photon sources. With a pair of correlated photons emitted in different colours, you can detect one photon and precisely know that you have another one in a correlated colour. Researchers have come up with single-photon sources using nonlinear parametric down-conversion approaches, but our solid-state-based approach is much more efficient and our sources are much more compact.

Interview by Amber Jenkins.

Hayat and his colleagues have a Letter on 2PE on page 238 of this issue.