COHERENT PHOTONS IN TWO DIMENSIONS

Researchers at GEMaC have published two complementary studies demonstrating that single photons emitted by a two-dimensional material are coherent, a property that is essential for applications in quantum computing. This work was the subject of an INP highlight.

Two-dimensional materials are composed of atomically thin layers that can be separated and manipulated to create complex structures, controlled at the ultimate level of the thickness of an atom. Graphene and the other members of this large family have been the subject of numerous studies to characterise and control their mechanical, electronic and magnetic properties, and are potentially interesting systems for cutting-edge applications such as quantum computing. Some of these materials, such as hexagonal boron nitride (hBN), a transparent material with a structure close to that of graphene, are capable of emitting single photons. This makes them an ideal system for creating qubits, the building blocks of future quantum computers. However, for these single-photon sources to be used in this context, they need to have high levels of coherence, or in other

words, they need to be protected from ambient 'noise', which is present to varying degrees in all materials due to their imperfections, crystal vibrations and thermal fluctuations.

Physicists from the Groupe d'étude de la matière condensée (GEMaC, CNRS / UVSQ), in partnership with NIMS (Japan), have studied a particular source of single photons: a 'colour centre' in hexagonal boron nitride. This is a point defect that is created in a controlled manner using a focused electron beam, and which behaves like a single atom trapped in the material. The scientists have published two studies that demonstrate a high level of robustness with regard to decoherence. In the first study, they used a combination of two quantum optics techniques, resonant laser excitation and photon correlations, to study the sources of noise affecting the quantum emitter at low temperature (4 K). Using a model developed specifically for this purpose, they demonstrated that the photons remain coherent, i.e. insensitive to noise, for times corresponding to the emission of a large number of them (around ten thousand).

In their second study, the researchers took advantage of this property to experimentally demonstrate an elementary process that is important for quantum computation: quantum interference between two successive photons. A large number of quantum protocols are based on this phenomenon, known as the "Hong-Ou-Mandel effect", which is only possible if the photons used are indistinguishable from each other, which requires this abovementioned "coherence". Using a dedicated experimental set-up, the scientists demonstrated this quantum interference phenomenon using non-resonant laser excitation of a colour centre - in other words, by generating photons using a pulsed laser with a shorter wavelength. This technique generates a greater loss of coherence than the resonant excitation mentioned above, which limits the amplitude of the interference phenomenon. Nevertheless, there are several ways of optimising the Hong-Ou-Mandel effect so that it can be used for quantum information. One of these avenues, which will be explored in the future, is to integrate the colour centres into optical microcavities, which will enhance the photon emission and reduce the effect of decoherence on this emission.

These two studies are published in Physical Review B and Physical Review Applied respectively.

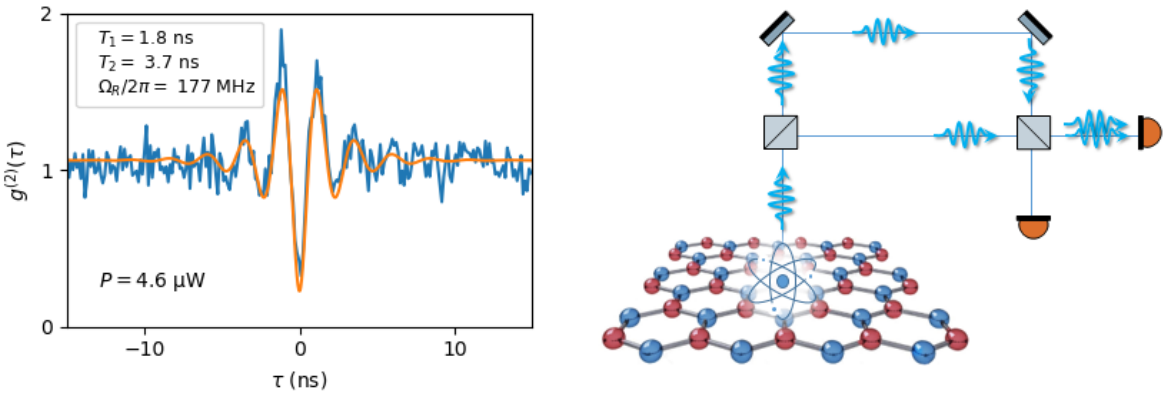


Figure: On the left, the correlation function of photon emission, showing oscillations that prove the coherence of the emitter. On the right, diagram of the Hong-Ou-Mandel effect: photons are collected and guided so that they can interfere.

References

Two-Photon Interference from a Quantum Emitter in Hexagonal Boron Nitride, Clarisse Fournier, Sébastien Roux, Kenji Watanabe, Takashi Taniguchi, Stéphanie Buil, Julien Barjon, Jean-Pierre Hermier et Aymeric Delteil, *Physical Review Applied*, paru le 27 avril 2023.
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Link to INP highlight

Contact: Aymeric Delteil

ADDITIONAL INFORMATION

> Groupe d'étude de la matière condensée (GEMAC-UVSQ/CNRS)
> Laboratoire Léon Brillouin (LLB-CEA/CNRS)