GEMaC
Groupe d'Étude
de la Matière Condensée

GENERATION OF INDISTINGUISHABLE PHOTONS VIA RESONANT LASER CONTROL OF DEFECTS IN A 2D MATERIAL

Physicists have controlled the quantum state of an artificially created crystal defect using a resonant laser. This approach enabled them to generate indistinguishable photons, the building blocks of quantum optical information. This work was featured in a CNRS Physics highlight.

Hexagonal boron nitride (hBN) is a rather unique transparent crystal. It belongs to the family of so-called van der Waals materials, whose atomic layers are weakly bound to one another. These layers can be manipulated, moved, and stacked using specialised techniques. This material can thus be used to create complex devices, with thickness control down to the single atomic layer. It can also be combined with other materials that do not necessarily have the same crystal lattice. This flexibility sets it apart from more traditional semiconductors such as silicon, diamond, and gallium arsenide. In previous studies, a team from the Condensed Matter Research Group (GEMaC) developed a technique to generate on-demand point-like crystal defects in hBN using an electron beam. These defects, known as colour centres, behave like artificial atoms and can emit single photons, a building block of quantum information.

Nevertheless, to build an efficient quantum processor, the colour centre must then emit photons that are perfectly indistinguishable from one another, that is to say, identical in wavelength, polarisation, and every other property they possess. Often, photons are generated by exciting the colour centre using a laser with a shorter wavelength than the emission from the defects. Unfortunately, this technique disturbs the environment and consequently degrades the quality of the photons, which can then no longer be used for demanding applications such as quantum information protocols. A better way to control the colour centre is to shine on it with a laser having exactly the same wavelength as the photons it emits. With this technique, known as ‘resonance fluorescence’, single photons of optimal quality are generated as the crystal environment is disturbed as little as possible; however, this comes at the cost of making it much more difficult to observe the emitted photons: they are, in fact, drowned out by the laser light that is inevitably collected at the same time, which cannot simply be separated by optical filters.

In a recent paper, the GEMaC team ingeniously used light polarisation – that is, the direction of vibration of the light wave – to achieve this separation. The single photons have a polarisation determined by the microscopic structure of the colour centre, whereas that of the laser can be chosen by the experimenters. By setting the laser’s polarisation to a direction slightly different from that of the colour centre, the single photons can then be separated from the laser light using a polariser placed at the output, which acts as a ‘polarisation filter’. To further optimise the collection of the single photons produced, the researchers also used a layer of silver placed directly beneath the hBN crystal (Figure 1); the assembly formed by the silver and the hBN film directs the photons towards the objective of the microscope observing them.

Using this approach, the scientists succeeded in identifying several regimes bearing the signature of purely quantum effects. Thus, when the laser is continuous and high-power, it becomes quantum-entangled with the emitter, yielding a highly distinctive spectral signature known as the ‘Mollow triplet’—namely, the appearance of a new emission peak on either side of the emission line of the colour centre. In addition to this observation, the team also demonstrated that the degree of indistinguishability of the photons produced was extremely high, a promising result for the use of these photons in quantum technologies.

Whilst hBN is not the first material to be used as a basis for the creation of indistinguishable photon emitters, it offers specific technological advantages. In particular, coloured centres can be created in large numbers and at controlled positions. Furthermore, they all emit at the same wavelength, which has been a challenge for previous platforms, such as InGaAs quantum dots. These results thus open up promising avenues of exploration for the creation of complex, large-scale devices. In the long term, the team aims to build complex demonstrators to establish the application potential of this approach for the manufacture of a quantum computer based on indistinguishable single photons. These results have been published in the journal Nature Communications.

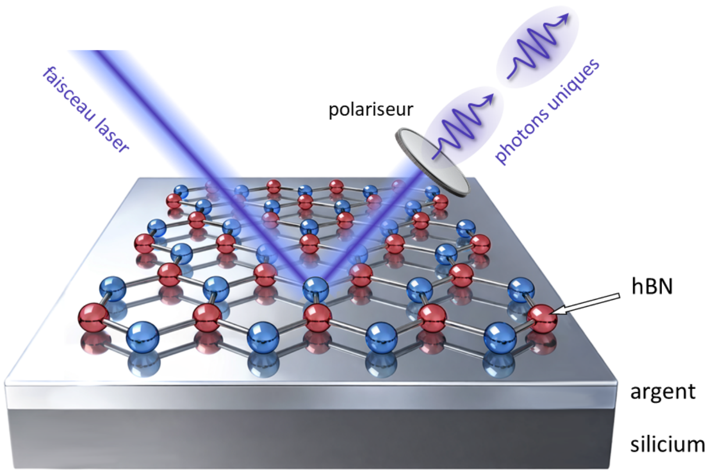

Figure 1: Schematic representation of the principle behind the experiment. A laser excites a crystal defect in a sheet of hBN, composed of boron (red) and nitrogen (blue) atoms. The emitted photons are separated from the reflected laser beam using a polariser. These photons, emitted under resonant excitation, possess properties that are particularly well-suited to quantum information.

References

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"Resonance fluorescence and indistinguishable photons from a coherently driven B centre in hBN",
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Link to CNRS highlight

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ADDITIONAL INFORMATION

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