Press Release
http://www.nii.ac.jp/ National Institute of Informatics

大学共同利用機関法人 情報・システム研究機構
国立情報学研究所
National Institute of Informatics

May 14, 2013

New laser producing "quantum light" invented

Researchers from the National Institute of Informatics (Director General: Masaru Kitsuregawa) and the University of Mainz, have succeeded in devising a new light source that produces "quantum light".
Quantum light is similar to laser light, but it has special quantum mechanical properties.

In laser light, the photons making up the light do not feel each other's presence. All the photons have the property of phase coherence. Drawing an analogy with marching soldiers, all the photons walk in step.

In quantum light, in addition to marching in step, the photons try to push each other out of the way. This property gives rise to entanglement between the photons, coined by Einstein as a "spooky action at a distance".

Previously it was thought that it was very difficult to produce such types of quantum light, because photons by their very nature do not interact with each other. Before the discovery, no methods were available that could produce quantum light continuously and reliably.

The research, led by Australian Tim Byrnes and co-authored by Peter van Loock and Yoshihisa Yamamoto, overcame this by taking advantage of some peculiar physics which occurs in semiconductor systems. In carefully fabricated structures the phenomenon of Bose-Einstein condensation can occur, an effect that was the subject of the Nobel Prize in 2001. The light leaking from the semiconductor was found that it possesses unusual quantum characteristics that could be used to create the quantum light.

Such quantum light is expected to be useful for future quantum technology applications such as in secure transmission of information.

Background and further information

Light, as we are familiar from everyday experience, can have very different properties depending on how it is created. For example, sunlight has a different distribution of wavelengths to artificial light, such as from fluorescent or LED lighting. Laser light, is also special in that it is monochromatic, i.e. it has only one wavelength in its output. Even monochromatic light such as lasers can have different states depending on how it is created. Light that comes from lasers are very close to an ideal sine wave. For this reason, laser light is thought to be "classical" in the sense that no peculiar quantum mechanical features such as entanglement are present.

However, it is known that there are special states of light that are completely "quantum" in their nature. In the field of quantum optics, the state of light is characterized by the Wigner function. If the Wigner function is positive everywhere, it is called "classical" light. If the Wigner function has any region that is negative, it has quantum properties, or more precisely, it is called non-Gaussian. Figure 1 has a plot of the light that is produced from the proposed device. It can be seen that there is a negative region to the Wigner function, which signals its quantum nature.

The light is produced in a semiconductor structure as shown in Figure 2. The structure shown, called a microcavity quantum well, allows for particles called "exciton-polaritons" to be excited within the regions marked as red. When a sufficient number of the exciton-polaritons are created, a phenomenon called Bose-Einstein condensation can be made to occur. In Bose-Einstein condensation, the particles spontaneously form coherence, which means that their underlying wavefunction all become phase coherent. Once the exciton-polaritons become phase coherent, they leave the semiconductor by emanating through the top of the structure.

The light that escapes from the structure has a peculiar nature: they are all phase coherent because due to the Bose-Einstein condensation, but they simultaneously repel each other, because of the interactions between the exciton-polaritons. This is quite different to laser light, which are completely non-interacting, so that the photons do not feel each other's presence. This makes for very different light characteristics between the new device and a standard laser.

Previous methods of producing such non-classical light relied on probabilistic methods: they would only work part of the time, and fail with some probability. In the invention proposed by Byrnes, Yamamoto, and van Loock, the light emerges continuously, just as in a laser where it is switched on and light emerges. This should help future quantum technologies, which rely on the use of such non-classical light.

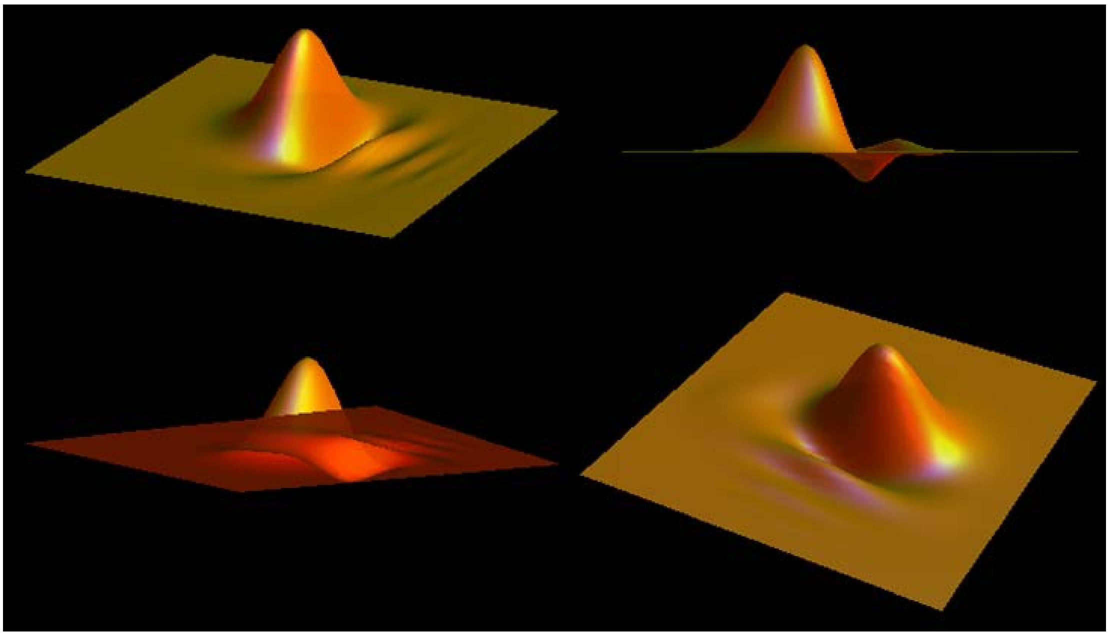

Figure 1 False colour 3D plots of the Wigner function that is produced from the device seen from four perspectives.

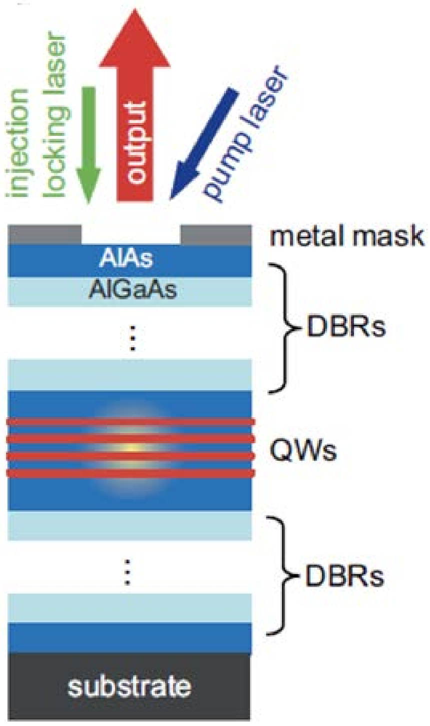

Figure 2 The device schematic that is used to generate quantum light. DBR= Distributed Bragg Reflector. QW=quantum well. The pump laser creates a Bose-Einstein condensate of exciton-polaritons in the quantum wells. By manipulating this with the injection locking laser, light with the desired qualities emerge from the top of the device.

Journal paper: "Unconditional generation of bright coherent non-Gaussian light from exciton-polariton condensates", to appear in *Physical Review B Rapid Communications.*

Patent pending: JP2012-237119

Authors: Tim Byrnes (National Institute of Informatics, Japan), Yoshihisa Yamamoto (Stanford University, U.S.A./National Institute of Informatics), Peter van Loock (Mainz University, Germany)

For further details please contact

Research related queries
Assistant Professor Tim Byrnes
email: tbyrnes@nii.ac.jp
phone: +81-80-5651-9911
website: http://nii.timbyrnes.net

National Institute of Informatics Public Relations
Noriko Bannai
E-mail：bannai@nii.ac.jp
Phone：03-4212-2164 Fax： 03-4212-2150