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Entangling photons with electricity（图）

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Researchers in Cambridge in the UK have succeeded in generating entangled photons using electricity alone, with a new device called an "entangled light-emitted diode" (ELED). The device converts electrical current directly into entangled light rather than relying on laser power as in previous technology. The technique could be a practical way to integrate many entangled light sources together on a single chip – something that will be crucial for making a real-world optical quantum computer.

LED entanglerEntanglement allows particles to have a much closer relationship than is possible in classical physics: if two particles are entangled, we can automatically know the state of one particle by measuring the state of the other – despite the state of either being impossible to guess before the measurement. For example, two photons can be entangled such that they are always measured to have the same linear polarizations, even though we cannot predict that polarization beforehand.

Quantum mechanics also says that the particle can exist in a superposition of two states at the same time. Such a phenomenon could be used to advantage in a quantum computer, which in principle could outperform a classical computer for certain tasks. This is because ordinary computers use bits of information that are assigned either 1 or 0, while a quantum computer would use quantum bits of information, or qubits, that can be in a superposition of both 1 and 0 at the same time. A 1 could represent, say, a horizontally polarized photon, while 0 could represent a vertically polarized one.

Crafting the light

Andrew Shields and Mark Stevenson of Toshiba Research Europe together with colleagues from the University of Cambridge made their ELED using a standard semiconductor fabrication technique similar to those used to make ordinary LEDs. This involved growing semiconductor layers using molecular beam epitaxy followed by processes to define the active area of the LED and add electrical contacts. The ELED differs from an ordinary LED in that it contains quantum dots – tiny nanometre-sized islands of semiconductor.

The quantum dot can be tuned to capture two electrons and two holes, which puts the system into a "biexciton" state. This then decays into a ground state through one of two intermediary exciton states, the pathway determining the polarization of the resulting pairs of photons. If the fine structure splitting between these two states is approximately zero then the only way to determine the decay path is to measure the polarization of the photons – the photons are, therefore, said to be entangled.

Although this process has been used previously to emit single pairs of photons, it has never been able to entangle photons in large quantities. Key to achieving this was optimizing the thickness of the semiconductor material surrounding the quantum dot to control the supply of current to it, to prevent electrons from tunnelling into the quantum dot from the n-doped region, which would destroy the entanglement. It was also important to carefully tailor the single quantum dot at the heart of the device to ensure that it emitted photons with an energy of 1.4 eV that have a very small fine split between their two production routes.

High fidelity photons

The device emits individual entangled pairs of photons when a pulsed current is applied and has an "entanglement fidelity" of 0.82 – a figure that is high enough for it to be used in quantum relays, which are related to core components of quantum computing such as teleportation). Entanglement fidelity is a measure of how pure the entangled light is: if the value exceeds 0.5, light is entangled, with 1 being the maximum value.

Although the researchers previously created entangled light that had a higher fidelity of 0.91, this involved more complicated methods that required shining an intense laser beam onto quantum dots in crystals. The new device, on the other hand, is simply powered by a voltage source. Other laser-driven techniques, such as "parametric down conversion" of photons, can produce entangled light with an even higher fidelity still but these are random processes, which means that the number of entangled photons created in a cycle varies. Indeed, zero, two, or more pairs can be created – something that is a problem for quantum computing applications.

"Quantum dot sources such as the ELED do not suffer from this fundamental limitation and in principle, operate 'on demand' generating one entangled photon pair every cycle," Stevenson told physicsworld.com. "The fidelity of our ELED is remarkable considering this is the first device of its kind. In theory, it could be much higher."

The Cambridge team hopes that its device could eventually help make practical optical quantum computers that require many entangled l ight sources on a single chip. This is difficult with other methods that rely on laser light as the power source because the hardware associated with generating, distributing and focusing the light quickly becomes too big and complex. Stevenson says that quantum computing could help to tackle many intractable problems such as climate modelling and in pharmaceutical research.

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