Innovation briefs: Single Photon Sources

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INSIGHT

Reliable and efficient single-photon sources ("SPS"), devices that emit one photon at a time, are the building blocks of quantum computers and quantum cryptography. Herein lays some daunting engineering challenges but equally exciting investment opportunities.

Quantum computing

Classical computers run programs which process definite input states and produce correspondingly definite outputs. By comparison, a quantum computer can process a superposition of many different classical inputs and produce a superposition of outputs, and so-called quantum entanglement means that the number of superposed states can be increased exponentially by linearly increasing the physical resources. In theory, such quantum parallelism can be utilized for solving problems which are intractable on any classical computer, such as the factorization of large composite integers.

Quantum cryptography

Quantum cryptography supports perfectly secure cryptosystems, guaranteed unbreakable by the laws of physics. The most important application to date, quantum key distribution, allows two people to exchange secret messages in such a way that any eavesdropping can be detected before eavesdroppers have a chance to obtain any secret information. Quantum key distribution via photon signals has already been implemented over standard optical fibres, with a range of tens of kilometres, and through free space, with a range of several kilometres.

INNOVATION

Practical requirements place stringent requirements on SPS properties, including stable photon generation, room temperature operation, and efficient light extraction. Single photon light emitting devices based on fluorescent dye molecules, quantum dots, diamond vacancies, parametric downconverters, and carbon nanotube material systems have been explored, but none have demonstrated all criteria simultaneously.

NV diamonds

Over 500 impurities and defects are known to emit single photons when embedded into ultra-pure diamond. Of these, the negatively charged nitrogen-vacancy ("NV"), composed of a diamond lattice vacancy and adjacent substitutional nitrogen atom, has attracted much interest due to its uncompromised photo-stability at room temperature and potential for combining photonic and spin qubits in an on-chip device architecture.

For devices based on an NV center in a bulk diamond crystal, the majority of emitted photons are lost to the substrate via total internal reflection. To overcome such losses, researchers are investigating an assortment of coupling techniques including metal nanowires, photonic crystal fibers, and nanocrystals embedded into optical fiber facets.

Quantum dots

Single Quantum dots ("QDs") emit a stream of single polarized photons under suitable electrical current injection. Furthermore, with judicious control of fine structure splitting of the excitonic energy levels it is also possible to generate entangled photon pairs, the building block of quantum computing.

Alas the exploitation of QD sources has been forestalled by the requirement for cryogenic cooling. To operate within the range of thermoelectric coolers (200K), research has started migrating towards gallium nitride materials. Blue-emitting GaN QDs are additionally attractive due to relevancy to free space quantum cryptography and the high sensitivity of single photon detectors in this spectral range.

An additional problem with QD-SPSs is that each one has a unique emission wavelength and radiative lifetime. Therefore, two single-photon sources built with QDs may not be mutually compatible for quantum information processing operations.

To improve efficiency, researchers leverage the so-called Purcell effect, whereby the single-photon emission rate is enhanced by placing the emitter inside a high-Q microcavity. Though successful, this approach has several drawbacks, related to the implementation of high-Q microcavities. Firstly, it cannot be applied to spectrally broad emitters, such as QDs at room temperature. Secondly, the properties of high-Q cavities display a great sensitivity on structural imperfections. Thirdly, it is difficult to apply electrical contacts to high-Q microcavities.

Despite these limitations, QD-SPS activity may be spurred by the recent launch of GaAs QD lasers for telecommunications applications, whilst oxide confinement techniques exploited by the VCSEL community may be adopted for boosting SPS coupling efficiency.

Single photon sources are crucial to the realization of quantum computing and quantum cryptography. In this brief, David Nugent highlights the outstanding technological challenges facing this innovation and the investment opportunities that may arise.

INVESTMENT

Single-photon sources, applications and detectors are attracting investment at commercial research laboratories such as Toshiba, Hewlett Packard, and Sharp Laboratories. Academic contributors include Quantum Communications Victoria, Harvard University, Humboldt-Universität zu Berlin, Stanford University, Cambridge University, and the QPHOTON and EQUIND academic/industrial collaborations. Conceivably, strategic or spin-out investment opportunities could arise from any of these institutions.

Privately-owned innovators include D-Wave Systems Inc, ID Quantique, MagiQ Technologies Inc. Further early-stage investment opportunities may soon emerge.