Multi-spatial mode quantum optics: fundamentals and applications

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Owing to the Heisenberg uncertainty principle, light is subject to unavoidable fluctuations in its phase and amplitude. Quantum opticians have learned how to reduce these fluctuations by squeezing the light, effectively shifting the quantum noise from one quadrature (e.g. the amplitude) to the other one (e.g. the phase). Squeezing can be interpreted as ordering the photons inside the beam.

In recent years, the advent of efficient four-wave mixing in atomic vapours [1] has made it possible to manipulate the quantum fluctuations not only in the temporal dimension but also in the spatial dimensions. A striking realisation has been the production of "entangled images" [2], that is to say beams of light which are entangled "point per point" across their transverse profiles. It has also been possible to transversally order the photons inside the beam, effectively reducing the "quantum roughness" of the beam profile [3].

The introduction of the spatial degrees of freedom in quantum optics lets us envision novel applications for quantum light, for example multichannel quantum information, quantum sensing protocols, and quantum imaging applications. In addition, the emitted quantum light is naturally (near) resonant with an atomic transition and is therefore well suited for applications based on atom-light interaction, for instance atom magnetometers.

After reviewing the fundamentals of squeezed light generation by four-wave mixing in hot atomic vapours, I will show how the spatial properties of such quantum light are well suited to the measurement of the displacement of a laser beam with sensitivity beyond the shot-noise limit. This may bring the advantages of quantum measurement to robust quantum devices based on MEMS [4], such as atomic force microscopes.

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