Atom Camera: Super-resolution scanning microscopy of a light field with an ultracold single atom

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The generation of light patterns using tightly-focused laser beams has become increasingly important in a variety of science and technology fields. Optical tweezers, for instance, are used to capture and control target specimens in biology and single-molecule biophysics, and to manipulate quantum states of atoms and molecules[1-3]. In the context of cold-atom experiments, there is a growing interest in the generation of arbitrarily-shaped far-field light patterns, including beams with sub-wavelength super-oscillatory features, as well as in utilizing the near-field close to nano-photonics devices.

In such experiments, an external diagnostic of the light field with an additional imaging optical system is often not adequate because, for example, some light fields, such as an optical lattice and a near-field light, do not propagate to that external imaging system. There are also some effects that are present only upon tight-focusing with a high-NA lens, and cannot be directly imaged with the finite resolution of the external optical camera. Moreover, the additional optical elements for the external diagnostic could even introduce additional aberration, and degrade the resolution. Therefore, *in situ* observation is essential.

In this talk, I will report on a new method we refer to as an “atom camera” for imaging the intensity and polarization patterns of a light field by using a single ultracold ^{87}Rb atom trapped in an optical tweezers. By scanning the atom position and measuring the perturbation added by the light to the atom’s valence electron energy, we reconstruct a 2D image of the light pattern with a spatial resolution of 25 nm, limited only by quantum uncertainty of the atom position. The distinctive feature of our method is to sense the light field with the electron spin degree of freedom (d.o.f.) of the atom, instead of the electron orbital d.o.f. used in previous works[4,5]. By interrogating the differential light-shift (DLS) of the two hyperfine spin configurations of the ground-state in ^{87}Rb, we benefit from the extraordinary long coherence time of the hyperfine states (up to a second) to achieve a sensitivity 10 times better than in the previous schemes[4].

We also demonstrate for the first time, to the best of our knowledge, that the single atom can be used as a sensitive probe of the light polarization. By interrogating a hyperfine transition sensitive to a magnetic-field, we probe the vector DLS proportional to the degree of light polarization. Using this technique, we were able to map the non-trivial polarization profile of a tightly-focused optical tweezers and obtain results in excellent agreement with the prediction by the vector diffraction theory[6,7].

References:

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