PhD THESIS DEFENSE: "Photon counting with a single neutral atom: quantum efficiency, dark counts, and background rejection"

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10:30
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This thesis studies the use of a single trapped neutral 87Rb atom as a photon counter. Detection of quantum jumps (QJs), i.e., abrupt changes between atomic states observable by a change in atomic fluorescence, is used to infer the arrival of single photons. This is referred to as the quantum jump photodetection (QJPD) technique.

The thesis first situates QJPD in the context of photodetection. Compared to traditional detectors, QJPD technique has lower speed and quantum efficiency (QE), but has exceptional performance in other figures of merit: QJPD is intrinsically narrowband, has strong out-of-band rejection, and very low dark counts (DCs). These features make the QJPD interesting for applications that detect weak optical signals in the presence of a strong broadband background.

Experimental methods to study QJPD are described. A 87Rb atom is loaded from a magneto-optical trap (MOT) into a far-off resonance trap (FORT) at the center of four orthogonal, co-focal, high numerical aperture lenses. These lenses create the FORT, couple probe light onto the atom and collect the atomic fluorescence, which is used to identify the atomic state. A typical QJPD sequence is presented, which consists of trapping and cooling an atom in the FORT, optically pumping it into the dark state, illuminating with probe light, illuminating with readout light and collecting fluorescence photons, and checking that the atom has not left the FORT during the sequence.

Statistical methods for measurement of QE and DC contributions are introduced. These compare the observed fluorescence count distribution against measured hyperfine-state fluorescence distributions. A QE of (2.4±0.1)×10?3 is demonstrated, a record for sing
e photon absorption by a single atom in free spac
. Dark count contributions are measured. To produce low DC, the QJPD technique
s implemented in two time windows: an exposure time for the single photon absorpti
n followed by a short fluorescence time to read out the atomic state. This implies distin
t acquisition and readout DC contributions, similarly to CCD and CMOS detectors. A dark ju
p rate (analogous to CCD/CMOS dark current) is measured of (5 ± 10) × 10?3 jump
/s, consistent with zero and limited by measurement statistics. The measured rea
out contribution is (4.0 ± 0.4) × 10?3 jumps per ms of fluorescence readout. For a 1 Hz r
adout rate, with 1 ms readout pulses, a net dark count rate of (15 ± 10) × 10?3 counts/acquis
tion is demonstrated, which is already competitive with any non-cryogenic d
tector. The background rejection capabilities of the system are tested by measuring quan
um jump rates when the atom is illuminated with direct sunlight, and with light scattere
by the atmosphere (skylight). A rate equation model is developed to describe QJ probabilitie
in the presence of both intense broadband background and weak resonant probe light. Th
s model is used to interpret experiments in which a weak signal beam competes wit
strong broadband background and validated using direct sunlight. Measurements where the
atom is illuminated with skylight show no observable background-induced QJs.
inally, measurements of sky brightness and its fluctuations are presented, showi
g large fluctuations even on mostly clear days, a factor that further increases the
eed for background re
ection. A number of contemporary applications of extreme photodetection, including fr
e-space quantum communication in daylight, classical optical communications in sp
ce, and fundamental physics experiments, are discussed as possible applications of
he QJPD technique. A realistic scenario where the demonstrated QJPD capabilities surpass the
current performance of commercial single photodetectors is pr
sented. Finally, potential improvements are discussed. It is shown that existing atomic and

optical technologies could be applied to reach different wavelength ranges, narrower ban widths, higher quantum efficiency, and lower dark

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