Development of single-photon source based on single trapped barium ions

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Abstract
We are developing a single photon source based on the pulsed laser excitation of trapped barium ions. It has simple structure, high repetition rate and potential application in quantum communication and computation.

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OCIS code: (230.6080) Sources; (320.5550) Pulses

Controllable single photon sources have important applications in quantum cryptography and quantum information. We are developing such a source, where single photons are generated from a single, trapped Ba$^+$ via the $P - S$ spontaneous decay and coupled into a single-mode optical fiber for a well-defined spectral and spatial mode.

We are currently using the $^{138}$Ba$^+$ isotope’s $6P_{3/2} - 6S_{1/2}$ transition whose energy levels are shown below. The ion is localized in a Paul trap and laser-cooled by a 493 nm and a 650 nm diode lasers. A Coherent Inc. Mira-900 modelocked titanium-sapphire laser at 910 nm is frequency-doubled to 455 nm to excite the ion to the $6P_{3/2}$ state, while a bright 615 nm LED is used to clean the $5D_{5/2}$ metastable state. Following every pulse, the ion spontaneously decays back to the ground state ($\tau_{6P_{3/2}} \sim 6.3 \text{ ns}$) and emits a single 455 nm photon. The photon is collected by a home-made, large N.A. objective and coupled into a single-mode fiber with the efficiency of $\sim 60\%$. Ideally, the ion radiates single photons at the repetition rate of the laser pulses (76 MHz), but the low desheling, collecting, coupling and detecting efficiencies greatly reduce the usable single photon rate.

Our next step is to use the $^{137}$Ba$^+$ isotope which possesses a hyperfine structure whose $F = 1$ and $F = 2$ sublevels can serve as the atomic qubit. The pulsed Ti-Sapphire will be running at 986 nm and frequency-doubled to drive the 493 nm transition. Each photon generated by $6P_{1/2} - 6S_{1/2}$, $F = 1$ or $2$ spontaneous emission will then be entangled with the atomic qubit state.

Another option for producing single photons suitable for quantum cryptography is to drive Ba$^+$ with 493 nm pulses and collect the $6P_{1/2} - 5D_{5/2}$ spontaneous emission with the branching ratio of about 0.25. This 650 nm photon source is more suitable for efficient transmission through optical fibers at the cost of somewhat lower single photon generation rate.