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Vladimir N Antonov, J Laser Opt Photonics 2017, 4:3(Suppl)
DOI: 10.4172/2469-410X-C1-014

2nd International Conference on

QUANTUM PHYSICS AND QUANTUM TECHNOLOGY

September 25-26, 2017 Berlin, Germany

# Quantum wave mixing and resolving photonic classical and non-classical coherent states

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Superconducting quantum systems- artificial atoms are building blocks of novel on-chip quantum electronics, which utilize the quantum nature of electromagnetic waves. Particularly, single atoms can create and reveal quantized light states beyond classical statistics. In this work we demonstrate a novel fundamental physical phenomenon, the Quantum Wave Mixing (QWM), which is attainable only in the systems where light-matter interaction is arranged between an individual photons and a single atom. QWM reveals itself as an elastic scattering of coherent classical and non-classical photonic states of electromagnetic waves on a single artificial atom in a 1D space. We demonstrate two regimes of QWM, comprising different degrees of "quantumness". The most spectacular one is QWM with non-classical coherent states, exhibiting spectra of a finite number of narrow coherent emission peaks. The spectrum is a fingerprint of interacting photon states, where the number of positive frequency peaks (due to stimulated emission) always exceeds by one the negative ones (due to absorption). We also study four- and higher-order wave mixing of classical coherent waves on the artificial atom. In this case the time dynamics of the peaks exhibits a series of Bessel-function quantum oscillations with orders determined by the number of interacting photons.

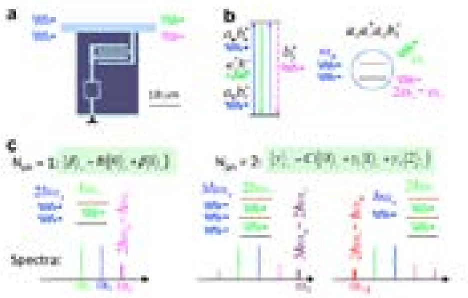

**Figure:** *a) A false colored SEM image of the device a superconducting loop with four Josephson junctions, behaving as an artificial atom, is embedded into a transmission line and strongly interacts with propagating electromagnetic waves. b) Four-wave mixing processes resulting in the single-phoon field creation at $\omega_3=2\omega_+-\omega_-$. In classical mixing, the process operators $a_+a^*_-a_+b^+_3$ come in pair with the symmetric one $a_-a^*_+a_-b^+_3$. In the mixing with non-classical states, the time symmetry is broken resulting in the asymmetric spectrum. c) Schematic representation of QWM with non-classical coherent states. Two sequential pulses of ω+. Single-photon, Nph = 1, state $|\beta>_-$ can only create a peak at $\omega_3=2\omega_+-\omega_-$. Two photon, Nph = 2, coherent state $|\gamma>_-$ results in creation of an additional; peak at $3\omega_+-2\omega_-$. because not more than two photons can be emitted. An additional left-hand-side peak appears at $2\omega_- -\omega_+$ in this case.*

## Biography

Vladimir N Antonov has his expertise in Solid State Nanophysics. He is one of scientists who made a breakthrough in experiments on quantum phenomena in low dimensional hybrid nanostructures, like Andreev interferometer, ferromagnetic/superconducting systems. A single photon terahertz detector based on semiconductors quantum dot developed in collaboration with Profs. Komiyama and Astafiev keeps a record sensitivity and it is used in a number of applications. A recent activity in superconducting quantum circuitry, superconducting resonators of high quality factors, and nanomagnetics is a subject of a number of publications in high ranked journals. He is also involved in development of the technology of high power diode laser for communications as an expert in nanofabrication.

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