On-Demand Shaping of Mössbauer Gamma-Ray Photons *Via* Transient Doppler Modulation of the Nuclear Resonant Transition Energy

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Methods for generating single-photon electromagnetic radiation in the form of short pulses with the controlled temporal shape in various spectral ranges from infrared to X-rays have been intensively developed due to applications in quantum information processing and quantum communications. Presently, there are a number of methods for controlling optical photons. However, most approaches well suited for controlling infrared and optical photons are currently not feasible for hard X-ray photons due to their short wavelength.

At the same time, high-energy photons can get into resonance with quantum transitions of atomic nuclei and efficiently interact with them without recoil (Mössbauer interaction) similar to the interaction of optical photons with atomic electrons. Moreover, very high frequencies of the keV nuclear transitions makes the Doppler effect very efficient tool for controlling the frequencies of these transitions relative to the photon carrier frequency *via* motion of the nuclei along the photon propagation direction.

The main sources of single photons in the tens of keV range are radioactive Mössbauer isotopes and synchrotrons after spectral narrowing of extremely broadband X-ray pulses emitted from the synchrotron storage ring. Single-photon X-ray pulses produced by synchrotrons have a short duration of about 100 ps and a huge spectral width of several terahertz due to widely spread carrier frequencies of photons even after strong monochromatization of synchrotron radiation beam. The existing methods of their spectral narrowing have very limiting abilities for controlling the shape of these single-photon pulses. Several methods have been proposed for transforming long waveforms of recoilless single γ-ray photons emitted by radioactive isotopes Co-57 and Ga-67 into short pulses. They also do not allow to obtain single-photon waveforms of arbitrary shape.

We propose a technique based on the transmission of γ-ray photons through a resonant absorber, which allows one to independently control the temporal characteristics of both an individual recoilless γ-ray photon and a continuous stream of photons emitted by a radioactive source. It is based on a rapid reciprocating displacement of the resonant absorber along the propagation direction of photons by a variable distance less than the wavelength of the photon field. With the example of Co-57 and Ga-67 sources, and Fe-57 and Zn-67 absorbers we show that this type of motion makes it possible to (i) produce a single-photon wave packet in the form of variable number of short bursts including a single burst (except for the Sommerfeld-Brillouin precursor); (ii) individually adjust the peak intensity of each burst in the sequence; (iii) individually adjust the duration of each burst in the sequence; (iv) adjust the individual time interval between the adjacent bursts in the sequence; (v) produce on-demand an individual shape (*e.g.*, increasing exponent, triangle, or meander) of each burst in the sequence. This opens up prospects for full acoustic control of the temporal characteristics of recoilless photons for applications in Mössbauer spectroscopy and X-ray quantum optics.

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