Development of a Picosecond CO_2 Laser System for a High-Repetition γ-Source

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The concept of a high-repetition-rate, high-average power γ-source is based on Compton backscattering from the relativistic electron beam inside a picosecond CO_2 laser cavity. Proof-of-principle experiments combined with computer simulations allow evaluating the promise of this approach for novel applications in science and technology.

Gamma-ray beams of high average power and peak brightness are of demand for a number of applications in high-energy physics, material processing and medicine. One of such examples is gamma conversion into polarized positrons that is under consideration for projected electron-positron colliders. A γ-source based on the Compton effect (laser photon scattering on relativistic electrons) is a promising candidate for this application [1]. To compare with other high-power ultra-fast laser drivers for the Compton-based γ-source, an IR CO_2 laser offers the advantage of producing much higher number of photons per Joule of laser energy. At the same time, the development of a high-power picosecond CO_2 laser technology suitable for this application presents certain technical challenges. Finding solutions to these problems is the scope of the current effort conducted at the Accelerator Test Facility at Brookhaven National laboratory (ATF-BNL).

Our approach to the CO_2 laser based high-repetition γ-source assumes placing the Compton interaction point inside a ring laser cavity. When the period in the train of electron bunches produced by a linear accelerator matches the resonator round-trip time, a laser pulse interacts with electrons on each round-trip inside the laser cavity producing the corresponding train of γ pulses. The round-trip optical losses can be compensated by amplification in the active laser medium.

The major challenge for this approach is in maintaining stable amplification rate for a picosocond CO_2-laser pulse during multiple resonator round-trips without significant deterioration of its temporal profile. Addressing this task, we elaborated on a computer code based on numerical solving of Maxwell-Bloch equations [2]. The newly developed code that features realistic pumping/relaxation dynamics in a high-pressure gas discharge allows us to identify the directions and priorities in the development of a multi-pass picosecond CO_2 laser. In particular, it has been demonstrated that the desired flattening of the pulse train intensity envelope requires intricate interplay between several laser parameters such as gain, pressure, optical losses, etc. A promising trend in reducing the laser working pressure while keeping the gain spectrum broad and smooth (which is required to avoid the Fourier-splitting of a picosecond pulse) can be achieved by using a multi-isotope mixture of CO_2 gases.

Proof-of-principle experiments help to verify the computer code and show the viability of the concept. In these tests we demonstrated extended trains of picosecond CO_2 laser pulses circulating inside the cavity that incorporates the Compton interaction point which is configured exactly in the way that allows achieving the desired electron/x-ray conversion efficiency [1]. Presently, we progress towards the experimental demonstration of the laser regime on the scale of the proposed ILC positron source and similar advanced projects that require γ-sources of multi-kW average power.

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