

LASER SYSTEMS FOR INVERSE COMPTON SCATTERING GAMMA-RAY SOURCE FOR PHOTOFISSION*

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Abstract

One approach for detecting special nuclear material (SNM) at a distance is to use highly penetrating gamma-rays (>6 MeV) to produce photofission. We are investigating inverse gamma-ray sources (IGS), based on inverse Compton scattering (ICS) of a laser pulse on a relativistic electron bunch. Nearly monochromatic gamma rays with high brightness, very small source size and divergence can be produced in IGS.

For the interaction drive laser recirculation it is necessary to meet the repetition rate requirements. Three implementations of laser recirculation are proposed for the interaction drive laser, which can significantly reduce the requirements on the interaction drive laser average power. It is found that the recently demonstrated recirculation injection by nonlinear gating (RING) technique offers unique advantages for beam recirculation in IGS.

INTRODUCTION

Available techniques for detecting special nuclear materials (SNM) using passive interrogation are limited to short range and can usually be defeated by shielding or using masking isotopes. Atomic radiography addresses some of the shortcomings of passive detection, but it is poorly suited to stand-off detection and lacks isotopic specificity. Thus standoff detection of SNM would greatly benefit from the use of active, nuclear-specific interrogation techniques. One approach is to use highly penetrating gamma-rays (>6 MeV) to produce photofission in SNM, resulting in prompt fission gamma-rays and/or neutrons. What is needed most is a convenient gamma-ray source that can be used to induce photofission. Electron accelerators, which are a very mature technology, can be used to produce gamma-rays via bremsstrahlung. Unfortunately, gamma rays produced using this method have many limitations, such as the large source size and divergence, low spectral density, and high background signal, which make them impractical for this application.

We are investigating inverse gamma-ray sources (IGS), based on inverse Compton scattering (ICS) of a laser pulse on a relativistic electron bunch. IGS has some very important characteristics that are suitable for the active interrogation. A bunch of nearly monochromatic gamma rays with high brightness, very small source size and divergence can be produced during the ICS process. In addition, the signatures of decay products can be detected with high signal-to-noise ratio due to short pulse gating of

the signal. Long-range detection can also be achieved due to good directionality of the source.

INVERSE COMPTON GAMMA-RAY SOURCE

Work on IGS is in process at several institutions [1-3]. IGS systems are based on two complementary technologies: electron linear accelerators and short-pulse lasers. The system specifications were chosen to produce a measurable flux of delayed neutrons from photofission at a detector co-located with the source 1 km away from a target consisting of 500 g of ²³⁸U [4]. It was estimated that 10¹⁴ gammas/s should be produced by the source. This requires the laser to produce the pulse energy of 620 mJ with pulse length 10 ps at a wavelength of 532 nm or the pulse energy of 63 mJ with pulse length 1 ps at a wavelength of 400 nm. The corresponding e-beam energies are 478 MeV and 547 MeV, respectively. Here we focus on the study of the options for the laser system for the interrogation via photofission, possibly also use for nuclear resonance fluorescence (NRF) spectroscopy. It is notable that photofission does not benefit from the narrow spectral bandwidth of the source to the same extent as the NRF, which allows the selection of laser technologies for IGS which do not necessarily operate close to the Fourier transform limit.

LASER SYSTEM DESIGN

The laser system requires production of the photocathode drive pulses and the interaction drive pulses, with very different characteristics. Since the IGS exhibits stringent tolerance requirements on the electron-laser timing in the interaction region, typically both the photocathode and the interaction drive laser pulses are derived from the same source. We discuss two types of IGS laser systems, with the key difference being the pulse duration (1 ps or 10 ps). In the case of 1 ps, the laser system produces 400 nm pulses (the second harmonic of Ti:sapphire laser), while in the 10 ps case the laser system produces pulses near 532 nm (the second harmonic of a Nd:YAG laser)

For the photocathode drive laser, ~50 μJ pulses are needed, with the macropulses produced at a 1 kHz repetition rate, consisting of 30-50 micropulses spaced ~10 ns apart. The wavelength can be either the 3rd harmonic of a Ti:sapphire laser system, or the second

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harmonic of a Nd/Yb laser system. Ti:sapphire shows a few significant advantages. Ti:sapphire is not only capable of supporting very broad spectral bandwidth, sufficient to be used as a photocathode drive pulse directly, but also compatible with both Serafini-Luiten and the “beercan” pulse shaping. Diode-pumped Yb:fiber laser technology can be the most elegant solution to this problem, which is arbitrarily scalable in repetition rate when sufficiently powerful pump is used. Unfortunately, Yb:fiber lasers with sufficiently high pulse energies are not mature at this time. However, given the fast-paced improvement in the fiber technology, they would be a strong candidate for this application in the future. Several methods of production of the photocathode drive UV pulse in the pulse format compatible with the interaction drive laser system can be considered, including the use of active and passive recirculation.

Choices of laser materials for interaction drive laser systems are similarly driven by the specifications of the source and the maturity of laser technology. For the interaction drive laser recirculation is necessary to meet the repetition rate requirements. Three implementations of laser recirculation can be considered for the interaction drive laser, which can significantly reduce the requirements on the interaction drive laser average power. One of the most important laser design parameters is the beam quality that is instrumental to beam focusing and efficient production of gamma-rays by IGS. Since the beam quality is affected by B-integral, we use the accumulation of total B-integral in 100 recirculation passes as the criteria to compare various recirculation schemes. It is found that the recirculation injection by nonlinear gating (RING), which has been recently proposed and demonstrated [5], offers unique advantages for beam recirculation in IGS. The recirculation in RING is established by the injection of the beam via frequency conversion in a thin optical switch (nonlinear crystal like beta-barium borate), which offers the immediate benefit

of frequency upconversion besides the evident advantages in simplicity and low cost. In addition, the high B-integral usually associated with beam injection is avoided by the use of a thin optical crystal, the thickness of which is the critical design choice in RING. The cavity enhancement factor (Q) in RING is very sensitive to the total loss. It has been demonstrated to date that the Q factors of 30 can be achieved, and factors of 100 should also be achievable with particular attention to cavity mirrors. It is therefore advantageous to consider cavity and focusing arrangements, which minimize the number of optics in the system. The focusing will be done by reflective optics (off-axis parabolas). With the chosen beam size of 3 cm incident on the parabola, the focal length of the parabola is approximately 70 cm. The maximum crystal length is 2.5 mm, with which good conversion efficiency can be achieved.

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