DEVELOPMENT OF AN OPTICAL RESONANT CAVITY FOR THE LCS EXPERIMENT AT cERL

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Abstract

A nondestructive assay method of isotopes by using quasi-monochromatic gamma-rays based on laser-Compton scattering (LCS) is under development. In order to demonstrate the accelerator and the laser performance required for the gamma-ray source, a LCS experiment is planned at Compact ERL (cERL) at KEK. An optical cavity which can achieve high finesse and small waist size is under construction for the LCS experiment. The new optical cavity comprises two sets of planar 4-mirror cavities.

INTRODUCTION

Gamma-ray source by means of laser-Compton scattering (LCS) has several features such as compactness, energy tunability, quasi-monochromaticity, and polarization control. The LCS gamma-ray source can generate high energy photons with relatively low energy electrons compared with synchrotron radiation. The energy of gamma-rays depends on scattering angle, therefore we can obtain quasi-monochromatic gamma-ray by cutting out in a small angle. Polarization of gamma-rays are easily controlled by controlling polarization of the laser photons.

A nondestructive assay method of isotopes by using quasi-monochromatic gamma-rays is under development for the nuclear safeguards and security purposes [1]. In order to demonstrate the accelerator and the laser performance required for the gamma-ray source, a LCS experiment is planned at Compact ERL (cERL) at KEK [2]. The cERL is a superconducting test accelerator for a future ERL project [3]. The cERL can produce low-emittance and high-current beams suited for a LCS gamma-ray source. The design parameters of the cERL are summarized in Table 1. In order to generate high-flux and high-brightness LCS gamma-rays, a high-power laser system is necessary. It can be achieved by accumulating laser pulses in an optical cavity. A home-built Yb-doped fiber based chirped-pulse amplification system for the LCS experiment is under development at Kansai Photon Science Institute, JAEA [4].

Table 1: Design Parameters of the cERL

Beam energy	35 MeV
Beam current (initial goal)	10 mA
Normalized emittance	1 mm·mrad
RF frequency	1300 MHz
Bunch length	3 ps

We are developing an optical cavity for the LCS experiment. The optical cavity should realize high finesse, small waist size and high stability. In this paper, we describe design of the optical cavity and the present R&D status.

DESIGN OF THE OPTICAL CAVITY

In order to generate high intensity gamma-rays by LCS, it is necessary to achieve a high finesse and a small laser waist size simultaneously. A 2-mirror Fabry-Perot cavity is unstable for small waist size. Therefore, we developed a 4-mirror ring cavity which con sits of two plane mirrors and two concave mirrors. It is more tolerant of misalignment of mirrors than a 2-mirror cavity [5]. The design parameters of the optical cavity are summarized in Table 2. The length of the round-trip optical path is 1845 mm which corresponds to the repetition rate of 162.5 MHz. The repetition rate of the optical cavity has an integer relation with the RF frequency of the cERL to achieve collisions of laser pulses and electron pulses.

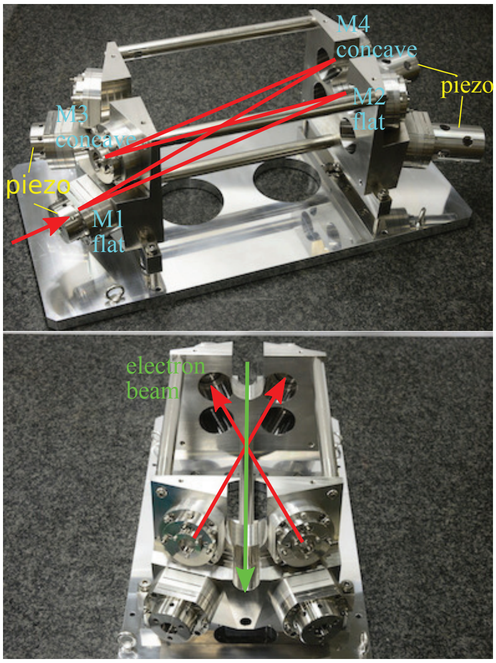

Figure 1: Optical cavity.

The picture of the constructed optical cavity is shown in Fig. 1. The optical cavity was designed by combination of two planar 4-mirror cavities. Each cavity can resonate with linearly and circularly polarized laser beam. This new optical cavity has switching capability of polarized state of gamma-rays by stacking different polarized light in each cavity.

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The all mirror holders have tilting mechanisms for initial alignment of mirrors. Piezo actuators were attached to the mirror M1 and M2 via a leaf spring as shown in Fig. 2. The length of piezo actuators is 15 mm and 70 mm. The shorter piezo actuator is used to synchronize the laser pulses with the electron pulses. The longer one is used for a slow feedback to adjust the length of the optical path. The dynamic range of 70 mm piezo actuator is about 20 μm.

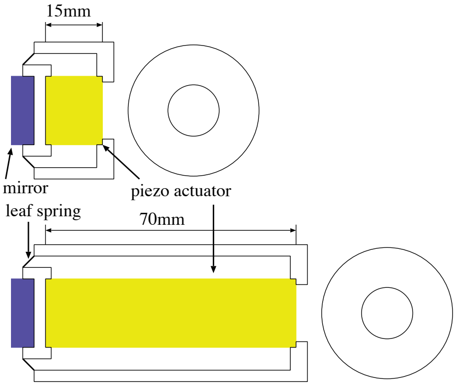

Figure 2: Close view of mirror attachment with the piezo actuator. Two mirrors are attached to the piezo actuator via the leaf spring.

We used two flat mirrors and two concave mirrors for an optical cavity. The radius of curvature of the concave mirrors is 420 mm. The mirrors were provided by REO (Research Electro-Optics, Inc.) and LMA (Laboratoire des Materiaux Avances). The reflectivity of coupling mirror M1 is 99.9% while the reflectivity of M2, M3 and M4 is 99.99%, 99.999% and 99.999%, respectively. The finesse F of the cavity is calculated to be 5660. Therefore, the FWHM width of the resonance is 190 pm.

Figure 3 shows the laser beam spot size along the propagation in the cavity. In the case of a planar 4-mirror cavity, where all 4 mirrors of the cavity are placed in the same plane (the tangential plane), the effective focal length in the plane f_t, and in the plane perpendicular to the tangential plane (the sagittal plane) f_s, is different. Because of the astigmatism, the laser beam profile inside the planar 4-mirror cavity is an ellipse. Since all mirrors are placed in the vertical plane in this optical cavity, the designed waist size in horizontal and vertical axis are 20μm and 30μm at the interaction point.

MEASUREMENT OF PERFORMANCE

We are testing the optical cavity using a low-power mode-locked pulsed laser (GE-100, Time-Bandwidth Products) with wave length, repetition rate, average power, pulse width (FWHM) were, 1047 nm, 162.5 MHz, 500 mW and 7.8 ps, respectively.

Figure 4 shows the intensity of the transmitted light from the cavity while changing the length of the optical path. The optical cavity was resonated with laser pulses repetition rate of 162.257 MHz in the air. We need to tune the length of the round-trip optical path for synchronization with the cERL RF frequency.

Table 2: Design Parameters of the Optical Cavity

Repetition rate	162.5 MHz
Finesse	5600
Collision angle	18 degree
Spot size at IP (σ_x/σ_y)	20/30 μm
Specification of mirrors	
Substrate material	Fused silica
Diameter	25.4 mm
Reflectivity	
M1	99.9%
M2	99.99%
M3 and M4	99.999%

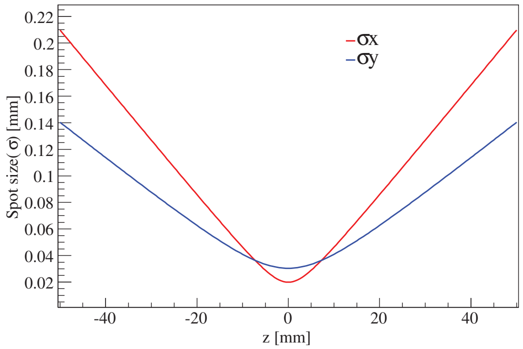

Figure 3: The spot size of laser beam along the propagation in the cavity.

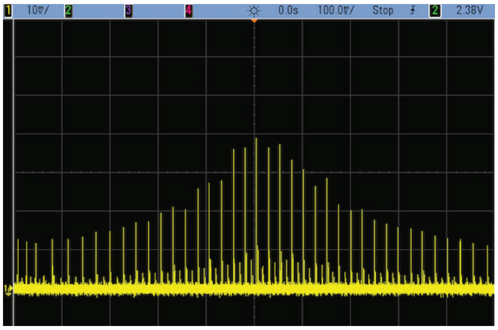

Figure 4: The resonance peaks obtained by scanning the optical path of the cavity.

Frequency Response of Piezo Actuator

The frequency response of the piezo actuator including leaf spring is shown in Fig. 5. In this measurement, a sinusoidal signal applied to piezo actuator from a Frequency Response Analyzer (FRA). The response of piezo actuator was detected by the capacitive sensor. Then, the gain and relative phase with respect to the sinusoidal wave was measured with the FRA. We found that the piezo actuator has a resonance at the frequency of 5 kHz. It is known that the piezo actuator inside the laser oscillator has better response speed than this piezo actuator. Therefore, the piezo actuator inside the laser oscillator is used to keep the cavity on resonance and the piezo actuator which is attached to the optical cavity is used for timing synchronization.

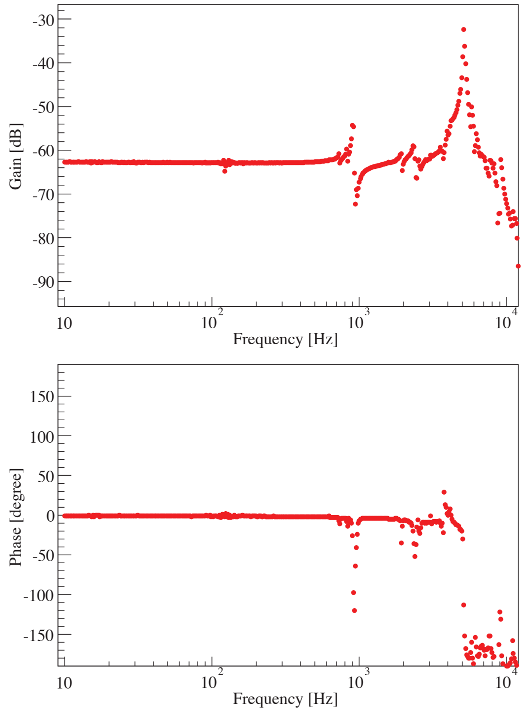

Figure 5: The measured frequency response of the piezo actuator.

Waist Sizes of Laser Beam

Figure 6 shows the transmitted laser beam profile measured behind M2. We obtained the spot sizes of the transmitted laser beam of $\sigma_x = 0.61$ mm and $\sigma_y = 0.51$ mm. From this measurement and a calculation by using the transfer matrix, we can estimate the waist sizes of the laser beam inside the cavity. The estimated waist sizes at the laser-electron interaction point are $\sigma_x = 30\,\mu$m and $\sigma_y = 35\,\mu$m. We can achieve designed waist size by reducing the distance between the concave mirrors by about 2 mm.

SUMMARY

A quasi-monochromatic gamma-ray source by LCS is under development for a nondestructive assay method of isotopes. In order to generate high-flux and high-brightness gamma-rays by LCS, a high-power laser system is necessary. Therefore, we are developing an optical cavity to achieve high finesse and small waist size at interaction point. Since a 2-mirror cavity is unstable for a small waist size, we choose to use a planar 4-mirror cavity. We started to test the optical cavity with a low-power mode-locked pulse laser in the air and obtained the waist sizes of $\sigma_x = 30\,\mu$m and $\sigma_y = 35\,\mu$m.

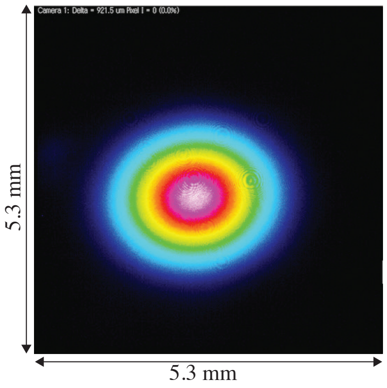

Figure 6: The transmitted laser beam profile from mirror M2.

ACKNOWLEDGMENT

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