DEVELOPMENT STATUS OF LINEAR FOCAL CHERENKOV RING CAMERA

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Abstract

Linear focal Cherenkov ring camera (LFC-Camera) has been developed for single shot measurement of longitudinal phase space distribution of quasi-relativistic electron beam, where the electron's velocity still depends on its energy. The LFC-camera employs velocity dependence of opening angle of Cherenkov light produced by electron beam to observe its energy (momentum) distribution. Since the Cherenkov light contains the time information if the radiator medium is thin enough, we can get the longitudinal phase space distribution measuring both time and energy spectra simultaneously using a streak camera. We employ a thin silica aerogel with water-free hydrophobic treatment as Cherenkov radiator. We have evaluated characteristics of the silica aerogel radiator, and demonstration of the LFC-camera at a beam diagnosis section of t-ATCS is being proceeded.

LINEAR FOCAL CHERENKOV-RING CAMERA

Concept and Principle

A test accelerator for an intense coherent THz light source project (test Accelerator as a Coherent THz Source: t-ACTS) has been developed at Tohoku University [1]. In order to generate the coherent THz light, the electron bunch length is required to be shorter than a few hundred femtosecond. The t-ACTS employs velocity bunching scheme in accelerating structure for bunch compression [2, 3]. The longitudinal phase space distribution at the entrance of the accelerating structure affects the final bunch length. The LFC-Camera has been developed to confirm the proper electron beam prior to the injection into the accelerating structure [4, 5]. Figure 1 shows schematic principle of the LFC-camera.

Cherenkov Radiator

The Cherenkov radiator, which is one of the most important components in the LFC-camera, is required to be high-transparency, sufficient mechanical strength and low refractive index. The refractive index is an important parameter to identify the energy of the electrons. A derivative of Cherenkov angle $d\theta_c/dE$ is preferred to be large value for the precise measurement. Meanwhile, small refractive index material is very weak in mechanical strength, and the generated number of photon is smaller than one of the large refractive index. We have chosen the thin hydrophobic silica aerogel with ultra-low refractive index (n =1.05) developed at Chiba University [6, 7].

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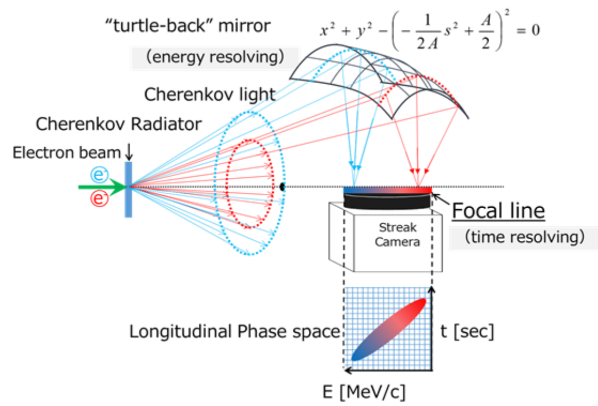

Figure 1: Conceptual drawing of the LFC-camera. Electron radiates the Cherenkov light when it passes through the Cherenkov radiator made by silica aerogel. A turtle-back mirror is used to resolve the Cherenkov light with different opening angles into specific focal positions along the focal line. The streak camera can resolve the relative arrival time of the light with sub-picosecond time resolution.

BEAM TEST OF SILICA AEROGEL RADIATOR

Setup

The LFC-camera employs a hydrophobic silica aerogel placed in vacuum as the Cherenkov radiator. In order to measure the longitudinal phase space distribution accurately, it is important to extract the clear ring image of Cherenkov light without any distortion. We should explore characteristics of the Cherenkov light from the aerogel radiator. In addition, since RF-gun need ultra-high vacuum about 1×10^{-6} Pa for operation, we must evaluate the effect on the vacuum pressure brought by the beam passing through the silica aerogel.

We have constructed a test system for Cherenkov radiator at the beam diagnosis section of the t-ACTS (Fig. 2). The silica aerogel radiator is attached with a special holder that equips a fluorescent screen for beam profile measurement. The Cherenkov light is transported by a tilted plane mirror to an exit window. These components are assembled on the same linear actuator, thus we can move the radiator and the screen in the holder by rotary motion of stepper motor. The tilted plane mirror is aligned along a beam axis by a guide laser. In order to observe the Cherenkov light spatial profile, we have employed a gated

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CCD Camera BASLER acA1300-30gm (1280×960 pixels). In the beam test, we irradiated the aerogel radiator by the 50 MeV electron beam with peak current of 8 mA at 1 pps pulse repetition. The electron beam was focused onto the radiator and measured to be $\sigma_x = 0.23$ mm and $\sigma_y = 0.35$ mm.

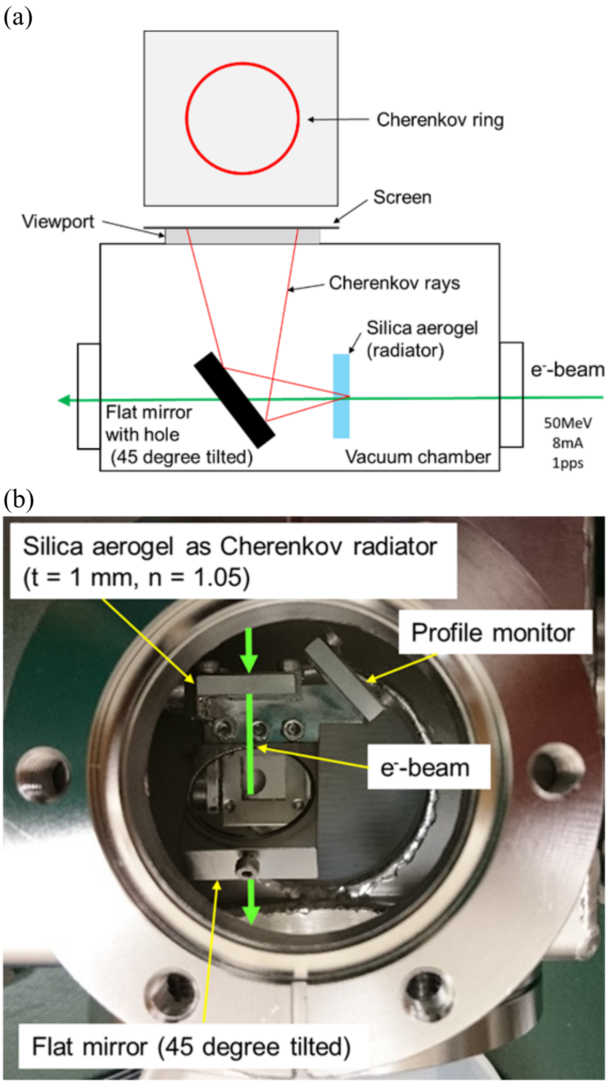

Figure 2: (a)Schematic view of the beam test system for Cherenkov radiator. Silica aerogel radiator is assembled in the special holder. It has another holder with fluorescent screen for beam profile measurement in an identical ladder. The flat mirror with a 4 mm hole along the beam axis is installed behind Cherenkov radiator to reflect the Cherenkov light. Cherenkov ring is observed on the screen through the window. The vacuum chamber is evacuated through an ion pump together with a large conductance duct. (b)Cherenkov radiator and profile mon- itor are attached on the plate to move along the same axis. Those components can be moved in the vacuum chamber by linear actuator with a stepper motor.

Results

Figure 3 shows an observed Cherenkov ring on a rear projection screen. To reduce the number of data, the spatial image of the Cherenkov ring is divided into 128×96 segments of 10×10 pixels. Those segmented image is projected to horizontal and vertical direction to obtain the center of gravity and weight of each image. The observed image includes the shot noise which is very sensitive to an analysis of the Cherenkov ring. Therefore, the region of interest (ROI) with a closed concentric ring was set to eliminate the shot noise by radiation. The size of the ROI was determined by a ring width as well as the ideal Cherenkov angle in experiment. A part of Cherenkov ring was fitted by Gaussian distribution to determine its σ_R, and the ring width of the ROI was set $\pm 3\sigma_R$. Fitting an ellipse to these data, we obtained the radius of horizontal and vertical direction to be 27.4 mm and 27.6 mm, respectively. Since the major axis is almost the same with the minor axis, we may expect that the distortion of the radiator is small and its inhomogeneity should be also small. The radius of the Cherenkov ring on the screen is varied by refraction when the Cherenkov light passes through me-

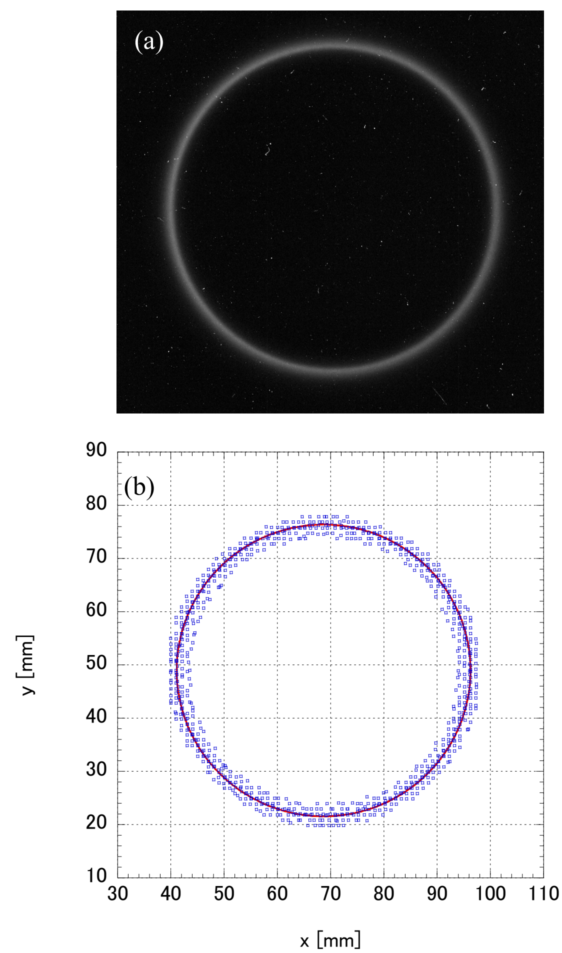

Figure 3: (upper)Spatial image of observed Cherenkov ring on the screen. (lower)Blue dots show the center of gravity of each segmented image. Red line shows fitting result.

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dium such as the radiator and the window. An expected Cherenkov ring radius R on the screen in the experimental setup is expressed as

$$R = t_1 \tan\theta_c + (L - t_1 - t_2)\cdot\frac{n_r \sin\theta_c}{\sqrt{1-(n_r \sin\theta_c)^2}} + t_2 \cdot \frac{n_r \sin\theta_c}{n_w\sqrt{1-\left(\frac{n_r}{n_w}\sin\theta_c\right)^2}}, \quad (1)$$

where θ_c is a Cherenkov angle, L is total pass length, t_1 is thickness of radiator, t_2 is thickness of window, n_r is refractive index of radiator, n_w is refractive index of viewport. The estimated Cherenkov ring radius on the screen in the setup is 27.2 mm from Eq. (1). We presume that the refractive index of aerogel radiator is dominant factor for the radius of Cherenkov ring on the screen from Eq. (1). The measured radius corresponds to the refractive index by about 0.1 % larger than designed value. If refractive index of the radiator differs by only 0.1% compared with an expected value, the absolute value of momentum shifts by about 50 keV/c at the LFC-camera.

In general, the refractive index of aerogel is measured by a laser Fraunhofer method [6, 7]. However it was difficult to measure the thin silica aerogel because enough thickness required for this method. The refractive index n of silica aerogel is expressed as

$$n = 1 + \alpha\rho, \quad (2)$$

where α is a constant, ρ is its density. If silica aerogel is thin and small, it is not easy to determine the refractive index of aerogel by the density, because its object size is

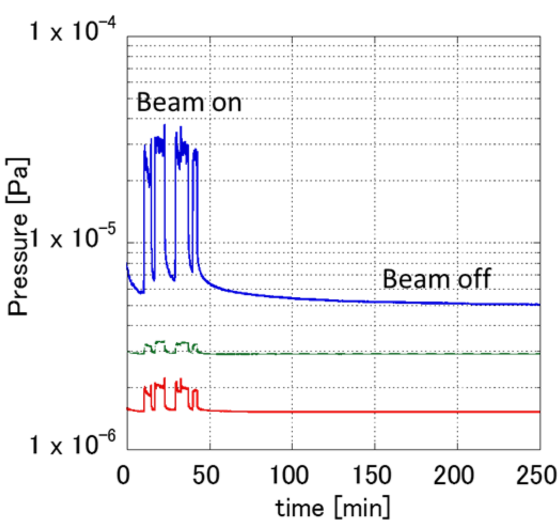

Figure 4: Variation of the vacuum pressure in the vacuum chamber. Blue line indicates the pressure in Cherenkov radiator chamber. Green and red lines represent pressure in downstream and upstream chambers of the Cherenkov radiator, respectively.

too small to measure. In case of electron energy around 50 MeV, the Cherenkov angle is almost constant. It is possible to measure the refractive index at low refractive index medium from the radius of Cherenkov ring using these electron beam.

Figure 4 shows a trend of the pressure in the vacuum chamber when the electron beam was irradiating the Cherenkov radiator. We have not observed significant change in the physical appearance after irradiation in the Cherenkov radiator. Without the beam, the pressure is less than 5×10^{-6} Pa. On the other hand, the pressure has been increased up to 3×10^{-5} Pa by irradiated electron beam. Since the significant amount of outgassing from the silica aerogel was observed with the beam irradiation, there might be a change in a physical property of silica aerogel. By measuring the ring radius regularly, we can monitor the variation of the refractive index of the radiator, which is important to obtain the absolute value of electron energy.

SUMMARY

We performed the beam test of the thin hydrophobic silica aerogel as the Cherenkov radiator using the t-ACTS at Tohoku University. We observed the clear Cherenkov ring without any distortion which has sufficient performance for the LFC-Camera. The measured radius of the Cherenkov ring were almost consistent with the expected radius. When the radiator was irradiated by electron beam, the pressure in the vacuum chamber is increased by the outgassing from silica aerogel. The refractive index of aerogel may vary while it is irradiated. We must measure the refractive index of radiator prior to the experiment to make a precise measurement at the LFC-Camera.

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