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# First studies of 500-nm Cherenkov radiation from 255-MeV electrons in a diamond crystal

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ABSTRACT

The first experiment on Cherenkov light from 255-MeV electrons passing through a 50-μm-thick diamond crystal in a special geometry allowing extraction of 500-nm Cherenkov light at a right angle with respect to the electron beam direction has been performed at the injector linac of SAGA Light Source accelerator facility. The dependence of 500-nm Cherenkov light intensity (separated by a band-pass filter) on the crystal rotation angle was measured by a CCD detector. The experimentally obtained rocking curve with an intense maximum is theoretically explained as the projector effect of Cherenkov light deflected by the exit surface of the crystal. The width of the rocking curve is explained by the convolution of the standard Tamm–Frank angular distribution of Cherenkov radiation with chromatic aberration, the multiple scattering of electrons in a crystal, and initial electron beam angular divergence. In addition, it is found that the Cherenkov light intensity did not change under the (220) planar channeling condition, which is consistent with a recent theory.



## 1. Introduction

Although it has a long history and although there are applications in detector physics for Cherenkov radiation (ChR) [1], many fundamental properties of ChR emanating from different types of relativistic particles and ions have not yet been studied in detail (see, for example, [2–5] and the references therein). Generally, an incident particle is assumed to move linearly within a solid target. In reality, however, the motion of an incident particle is affected by a variety of factors within the target. One factor is multiple collisions with the target atoms, leading to the enhancement of the angular spread of the incident beam and its energy loss. These effects have already been investigated in Refs. [2–5]. Another factor is the crystal-orientation effect. When a charged particle is injected into a single crystal almost parallel to the crystal axis or plane, its transverse motion is governed by the axial or planar potential, and it transversely oscillates around the atomic row or plane. This phenomenon is called channeling. One of the aims of this study is to explore this effect for the first time.

In this paper, we report the first experiment conducted with respect to Cherenkov light from 255-MeV electrons at the SAGA Light Source (SAGA-LS) accelerator facility [6]. The target was a 50-μm-thick diamond crystal. At a definite rotation angle of the crystal, Cherenkov light can be extracted at 90° from the beam direction. The experiment results showed that the ChR intensity detected by a CCD detector depends on the rotation angle, with a sharply defined maximum. This agrees with our calculations on the standard Tamm–Frank angular distribution of ChR taking into account the experimental angular resolution: the chromatic aberration, multiple scattering of electrons in a crystal, and initial beam angular divergence. The Cherenkov light from channeled electrons is also discussed.

## 2. Experimental

Fig. 1 shows a schematic of the experimental setup. A 255-MeV electron beam was provided from the injector linac of SAGA-LS, a synchrotron radiation facility in Japan [6]. The horizontal and vertical beam sizes were $\sigma_x \cong 0.3$ mm and $\sigma_y \cong 0.9$ mm, respectively. The horizontal and vertical angular divergences were $\sigma_x' \cong 0.1$ mrad and $\sigma_y' \cong 0.1$ mrad, respectively. These parameters are summarized in Table 1. A 50-μm-thick diamond crystal (type IIa) was employed as a target. The ⟨001⟩ axis of the crystal was perpendicular to the crystal surface. The crystal was mounted on a two-axis goniometer so that the (220) plane were horizontal. The inset in Fig. 1 shows the definitions of the rotation angles $(\theta, \phi)$ of the goniometer. The normal incidence condition corresponds to

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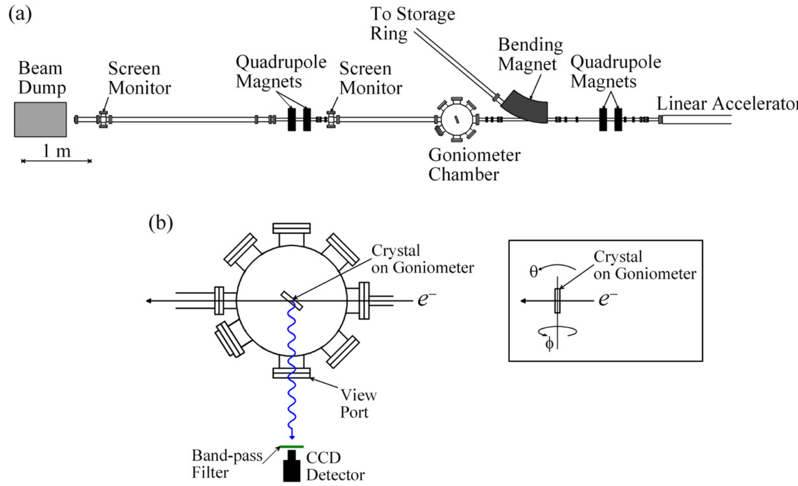


**Fig. 1.** Schematic of the experimental setup (top view). (a) Overall view. (b) Enlargement of the experimental setup. The inset shows the definitions of the rotation angles of the crystal.

**Table 1**
Main experimental parameters.

| | |
|---|---|
| Beam size at the crystal | Horizontal: $\sigma_x \cong 0.3$ mm<br>Vertical: $\sigma_y \cong 0.9$ mm |
| Angular divergence of the incident beam | Horizontal: $\sigma'_x \cong 0.1$ mrad<br>Vertical: $\sigma'_y \cong 0.1$ mrad |
| Observation angle | $90° \pm 1°$ |
| Errors of $\theta$ and $\phi$ | $\sim 0.01°$ |
| Band-pass filter | 500 nm ± 5 nm (FWHM) |
| CCD angular acceptance | ±4 mrad |

$\theta = \phi = 0°$. A CCD detector fitted with a lens was used as a visible light detector. The lens was adjusted so that the light from the crystal was focused onto the CCD detector. The CCD detector was placed at 90° with respect to the beam direction. A 500-nm band-pass filter was inserted in front of the detector to select the wavelength of the Cherenkov light. The bandwidth of the filter was ±5 nm in full width at half maximum (FWHM). The refractive index at 500 nm is $n = 2.432$ [7]. The acceptance angle of the detection system was estimated to be approximately ±4 mrad.

For diamond crystals, the so-called Cherenkov ring cannot be extracted into vacuum because the Cherenkov light is reflected at the exit surface of the crystal due to its high refractive index under normal electron incidence conditions. From a simple geometrical calculation, when a radiator has a refractive index larger than $\sqrt{2}$, the Cherenkov ring cannot be extracted into vacuum for the normal incidence of relativistic particles ($\beta = v/c \cong 1$, $v$: the particle velocity, $c$: the velocity of light). Of course, the Cherenkov light can be extracted into vacuum if the radiator surface is truncated at a necessary angle. Therefore, in this study, we rotated the crystal to extract the Cherenkov light. Fig. 2 shows a schematic of the Cherenkov light penetration in the crystal for a fixed crystal rotation angle $\theta = 50.3°$, the ChR wavelength equals 500 nm. In this case, the ChR angle $\theta_C = 65.7°$ and the ChR light refraction angle from the crystal $\psi = 40.3°$.

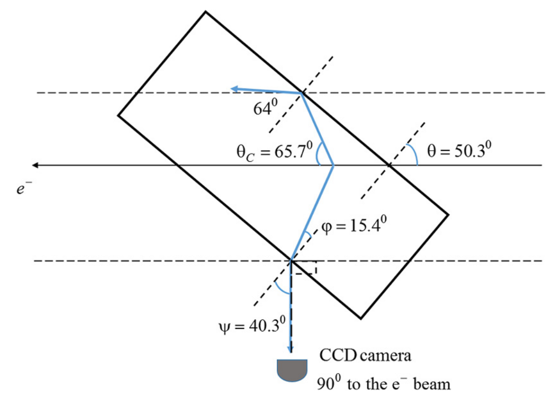


**Fig. 2.** Deflection due to refraction of 500-nm Cherenkov radiation from 255-MeV electrons in a diamond crystal to a CCD detector placed at 90° to the electron beam. Here, the rotation angle $\theta$ equals 50.3°, $\theta_C$ – is the ChR angle, and $\varphi$ and $\psi$ – are the ChR incidence and refraction angles to the crystal surface, respectively.

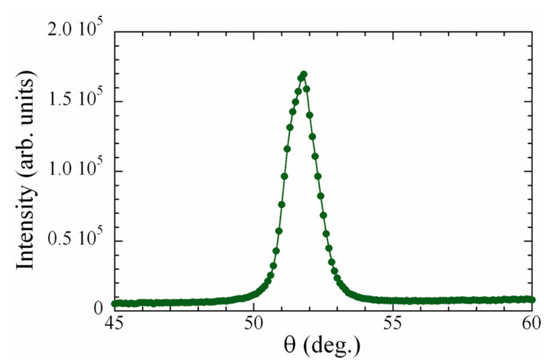


**Fig. 3.** Intensity of 500-nm Cherenkov radiation detected by a CCD detector placed at 90° to the electron beam as a function of the rotation angle $\theta$ (rocking curve).

## 3. Experimental results

A change in the crystal rotation angle $\theta$ allows the extraction of ChR light at different angles $\psi$ and directs it to the CCD detector placed at 90° with respect to the beam direction. The experimental "rocking curve", i.e., the dependence of the ChR intensity detected by the CCD detector on the crystal rotation angle $\theta$, is shown in Fig. 3. In order to avoid the (220) planar channeling condition, we rotated the crystal around the horizontal axis by $\phi \cong -2°$, i.e., these data were taken under random-orientation conditions. The observed rocking curve is characterized by a very sharp maximum and the FWHM of the rocking curve was about 2°. A comparison with the theory is discussed in Section 5.

Subsequently, in order to investigate the (220) channeling effect, we measured the ChR intensity as a function of $\phi$. In this measurement, $\theta$ was fixed at the peak position in Fig. 3 ($\theta = 51.8°$). The obtained result is shown in Fig. 4. The (220) planar channeling condition corresponds to $\phi = 0°$. The critical angle for 255-MeV electrons channeled in the (220) plane is calculated to be $\theta_{crit} = 0.49$ mrad (0.028°). The angular divergence of the incident beam ($\sigma'_x \cong 0.1$ mrad, $\sigma'_y \cong 0.1$ mrad) is sufficiently smaller than