Assembly of a Silica Aerogel Radiator Module for the Belle II ARICH System

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Abstract. We report recent progress in the development of a silica aerogel radiator module for its application in the aerogel-based ring-imaging Cherenkov (ARICH) counter that is to be installed in the forward end cap of the Belle II spectrometer, which is currently being upgraded at the High Energy Accelerator Research Organization (KEK), Japan. We produced approximately 450 large-area (18 cm × 18 cm × 2 cm) hydrophobic aerogel tiles with refractive indices of either 1.045 or 1.055 and characterized their optical performance. Installation of 248 water-jet-trimmed aerogel tiles into a support structure segmented into 124 containers was finally completed.

Keywords: Silica Aerogel, Optical Material, Cherenkov Radiator, Particle Identification, Cherenkov Ring Imaging, Belle II.

1 Introduction

Our research group has been undertaking the development of the aerogel-based ring-imaging Cherenkov (ARICH) counter [1]. This device is used for identifying charged π and K mesons at momenta between 0.5 and 3.5 GeV/c in a super-B factory experiment, Belle II using the SuperKEKB electron–positron collider at the High Energy Accelerator Research Organization (KEK), Japan. The ARICH system is a proximity-focusing ring-imaging Cherenkov counter that uses silica aerogel as a radiator and hybrid avalanche photo-detectors [2] as position-sensitive photo-sensors, which will be installed as a particle identification subsystem at the forward end cap of the Belle II spectrometer. This system is an upgraded version of the threshold-type aerogel Cherenkov counters used in the previous Belle spectrometer. The design objective is a π/K separation capability exceeding 4σ at a momentum of 4 GeV/c.

The particle identification performance of the ARICH counter is determined using the Cherenkov angular resolution and the number of detected photoelectrons. A scheme for focusing the propagation pass of emitted Cherenkov photons

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on the photo-detectors is introduced using dual layers of 2-cm-thick aerogel tiles (i.e., total radiator thickness = 4 cm), wherein each layer has a different refractive index (n) [3]. To achieve high angular resolution at momenta below 4 GeV/c, we chose $n = 1.045$ and 1.055 for the upstream and downstream layers, respectively [4]. To increase the number of detected photons, the aerogel needs to be highly transparent. A cylindrical aluminum support structure for installing the aerogel tiles was used and had an outer and inner radii of 1.11 and 0.44 m (i.e., total radiator area ~ 3.3 m^2), respectively. It is important to reduce the number of the aerogel tiles used to cover the large radiator area (i.e., to reduce adjacent boundaries between the aerogel tiles) because particles cannot be clearly identified in these gaps. Therefore, large, crack-free aerogel tiles are preferred. Installing the tiles onto the module by trimming them with a water-jet cutter and avoiding optical degradation of the aerogel via moisture adsorption during long-term experiments should ultimately result in highly hydrophobic conditions [5].

By 2013, we had established a method for producing a high yield of large-area aerogel tiles (18 cm × 18 cm × 2 cm; approximately tripled that of previous tiles [6]) with $n \sim 1.05$ that fulfilled the requirements of ARICH application (transmission length ~ 40 mm at 400-nm wavelength) [7]. This enabled us to divide the module into 124 fan-shaped segments (comprising four concentric rings) to install the 248 trimmed aerogel tiles. After specific production technology transfer to the Japan Fine Ceramics Center, mass production of the aerogel for the actual ARICH counter began in September 2013 and was completed in May 2014. Approximately 450 tiles (16 lots) were manufactured and delivered to KEK [8].

2 Results

2.1 Optical Characterization of Mass-produced Aerogel Tiles

The yield of tiles with no damage was 344 out of 448 tiles (77%). In addition to the required 248 tiles, 96 spare tiles were delivered. Tile damage was classified into physical/mechanical (tile cracking, chipping, and other related phenomena) and chemical/optical (e.g., milky tile due to problems associated with the sol–gel process) damages. The number of physically and chemically damaged tiles were 77 (17%) and 27 (6%), respectively.

Deviations in the refractive indices from the target values were within our expectations. Fig. 1 shows the relation between the refractive index and the transmission length. The acceptable deviation from the designed refractive-index values of 1.045 and 1.055 was ± 0.002 for both the layers. The refractive indices measured were detected between 1.0435 and 1.0463 and between 1.0532 and 1.0558 for the upstream and downstream tiles, respectively.

The transmission lengths were sufficiently long to fulfill our requirements. The minimum transmission lengths measured were 40.9 and 32.6 mm for the upstream and downstream tiles, respectively, which were both longer than the required limits of 40 and 30 mm for the upstream and downstream tiles, respectively. At the tile corners, the refractive index was measured with the minimum

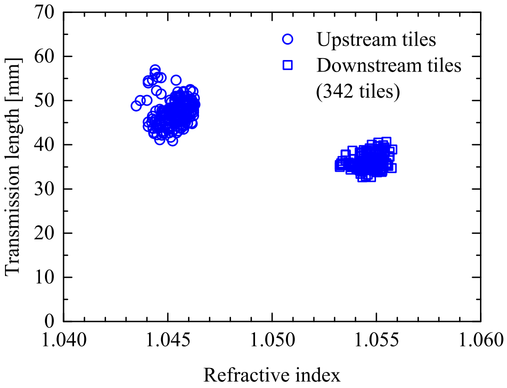

Fig. 1. Relation between the refractive index and transmission length measured at wavelengths of 405 nm and 400 nm, respectively.

deviation method using a laser with a wavelength of 405 nm [6]. The transmission length at 400 nm was calculated using the transmittance measured along the tile thickness direction using a spectrophotometer [6].

2.2 Water-jet Machining of Aerogel Tiles

Square aerogel tiles were cut into fan shapes using a water-jet cutting device at Tatsumi Kakou Co., Ltd., Japan. The edges of the tiles were trimmed to form four different shapes depending on those of the four different concentric rings while maintaining the optical characteristics. A total of 283 tiles were water-jet machined. The success rate of water-jet machining was 90% without volume loss (chipping at the corners), yielding the 248 required tiles and several spares. A total of 161 tiles (57%) had no volume loss. The number of tiles with significant but acceptable volume loss, ≤ 1 cm^2 or approximately $\leq 0.4\%$ of the area of the trimmed tile, was 94 (33%).

2.3 Aerogel Tile Installation

Prior to the installation of the aerogel tiles on the support structure, pairs of upstream and downstream tiles were matched to maximize the photon focusing effect in the dual-layer radiator scheme. The optimum value of the refractive-index difference (Δn) between the upstream and downstream tiles is 0.01, while an acceptable range is between 0.008 and 0.012. The Δn values of 124 installed tile pairs ranged from 0.0095 to 0.0104.

The aerogel installation was completed in December 2016. Each segmented aerogel container was lined with black paper to absorb background Cherenkov photons scattered inside the aerogel. Two aerogel tiles were then installed into the individual containers after removing dust on the tile surface. Two black glass fibers per container were finally glued to the container septum to fix the aerogel tiles. This procedure was repeated for the 124 segments.

3 Conclusion

Progress in the development of the dual-layer silica aerogel radiator module for the Belle II ARICH counter was reported here. Approximately 450 large-area (18 cm × 18 cm × 2 cm) hydrophobic aerogel tiles with refractive indices of either 1.045 or 1.055 were manufactured. The optical characteristics (i.e., refractive index and transmission length) of the produced tiles were confirmed to be suitable for the actual ARICH system. Each aerogel tile was cut into fan shapes using a water-jet cutter to fit the cylindrical support structure. A total of 248 aerogel tiles were successfully installed in the 124 segmented containers of the support structure. The installation of the whole ARICH system within the Belle II spectrometer is scheduled for late 2017.

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