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Recent results on aerogel development for use in Cherenkov counters ☆

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Abstract

Synthesis of silica aerogel for Cherenkov counters is being studied for more than 10 years at the Boreskov Institute of Catalysis in collaboration with the Budker Institute of Nuclear Physics. Index of refraction, light scattering length and light absorption length are optical characteristics which determine the quality of aerogel Cherenkov counter. These parameters were measured for the aerogel produced. The results are presented.

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1. Introduction

Synthesis of silica aerogel for Cherenkov counters is being studied for more than 10 years at the Boreskov Institute of Catalysis in collaboration with the Budker Institute of Nuclear Physics. Silica alcogel blocks are synthesized via two-step method from tetraetoxysilane [1]. High-temperature supercritical extraction of alcohol solvent is performed to process wet alcogel to aerogel. Then aerogel blocks are baked at 640°C to remove organic residuals and to improve aerogel transparency.

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2. Index of refraction

The method developed at our institutes allows to prepare highly transparent aerogel blocks in a wide range of densities from 0.04 to 0.4 g/cm^3. Using thermal sintering the aerogel with density of 0.6 g/cm^3 was also prepared.

Aerogel index of refraction n can be connected with aerogel density ρ according to known equation $n = 1 + k\rho$. This formula is the approximation for the small values of $n-1$ of the more exact formula $\varepsilon = n^2 = 1 + \alpha\rho$, where ε is the dielectric permeability of the material.

The $\alpha = (n^2-1)/\rho$ coefficient for aerogel samples with different densities is presented in Fig. 1. Refractive index was measured at $\lambda = 633$ nm. The fit with $\alpha = \text{const}$ has $\chi^2/N_{df} = 0.94$, $\alpha = 0.424 \pm 0.001$ (solid line on Fig. 1). The fit

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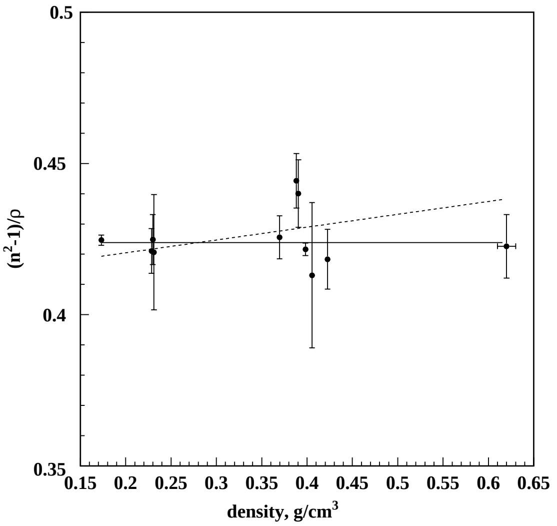

Fig. 1. The dependence of α coefficient on aerogel density: (- - -) approximation by $\alpha = \text{const}$; (—) $k = \text{const}$.

$k = \text{const}$ $(k = (n-1)/\rho)$ has $\chi^2/N_{\text{df}} = 3.0$, $k = 0.206 \pm 0.001$ (dashed line in Fig. 1). Taking into account that the maximum of the spectrum of detected photons is near 400 nm, we calculate α and k coefficients at 400 nm using data for quartz dispersion [2] $\alpha_{400} = 0.438 \pm 0.001$, $k_{400} = 0.213 \pm 0.001$.

Different aerogels of equal density prepared as described above and prepared from low-density aerogel using additional sintering have the same α value.

3. Light absorption length

The light absorption length in aerogels with different refractive indices is presented in Fig. 2. The procedure of light absorption length measurement was described earlier [3]. The aerogels in the whole range of refractive indices have high absorption lengths except aerogel with $n = 1.13$.

4. Light scattering length

As the light scattering length in aerogel is much smaller than the absorption length, the scattering length can be measured through the transmittance of an aerogel block. The wavelength dependence of the transmittance can be described by the formula of Rayleigh scattering:

$$T = A \exp\left(-\frac{d}{L_{\text{sc}}(\lambda/400)^4}\right) = A \exp\left(-\frac{Cd}{\lambda^4}\right),$$

where d is the thickness of a sample, λ the light wavelength in nm, L_{sc} the light scattering length at 400 nm, A the surface scattering coefficient. Sometimes, clarity coefficient C is used instead of L_{sc}.

The aerogels with "standard" thickness of 19–28 mm in the whole range of refractive indices have high light scattering length except aerogel with $n = 1.13$ which was prepared by sintering (Table 1). During sintering the enlargement of composing aerogel structure silica particles ($d \sim 4$ nm) takes place. This leads to the decrease of the light scattering length.

The development of highly transparent aerogels makes it possible to employ them in RICH detectors. Aerogel layer of certain thickness must be used to detect enough Cherenkov photons with good unscattered–scattered ratio. The thickness of

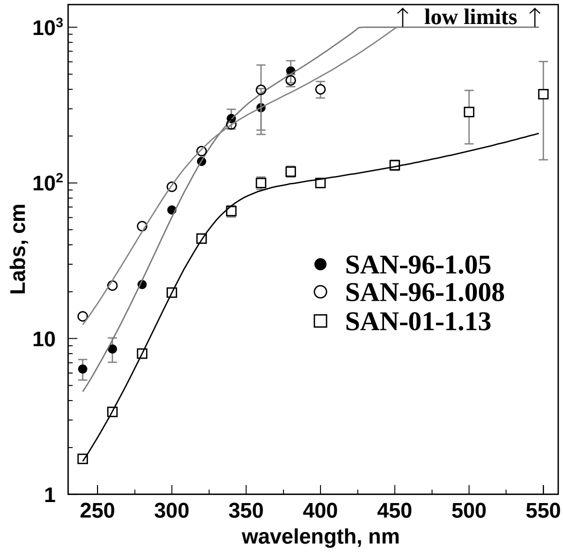

Fig. 2. The dependence of the light absorption length over wavelength for aerogels with different refractive indexes: SAN-96-1.05, $n = 1.05$; SAN-96-1.008, $n = 1.008$; SAN-01-1.13, $n = 1.13$.

Table 1
The light scattering length (L_{sc}) at $\lambda = 400$ nm for aerogels with different refractive indexes. The surface scattering coefficient A is 0.9–0.96 for measured blocks

Refractive index	1.008	1.03	1.05	1.08	1.13
L_{sc} (mm)	42	54	55	44	19

Table 2
The light scattering length (L_{sc}) at $\lambda = 400$ nm and clarity coefficient for aerogels with different thicknesses. The surface scattering coefficient A is 0.9–0.96 for measured blocks

Block thickness (mm)	25	40	55
L_{sc} (mm)	54	40	43
Clarity (m km^4/cm)	0.0047	0.0064	0.0059

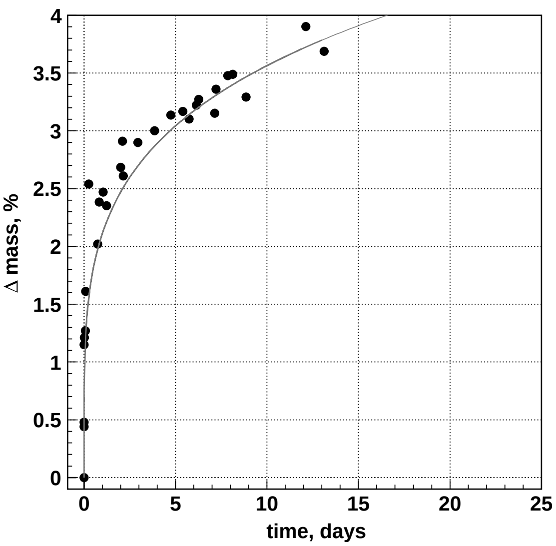

Fig. 3. The time dependence of aerogel block mass increase under atmospheric conditions.

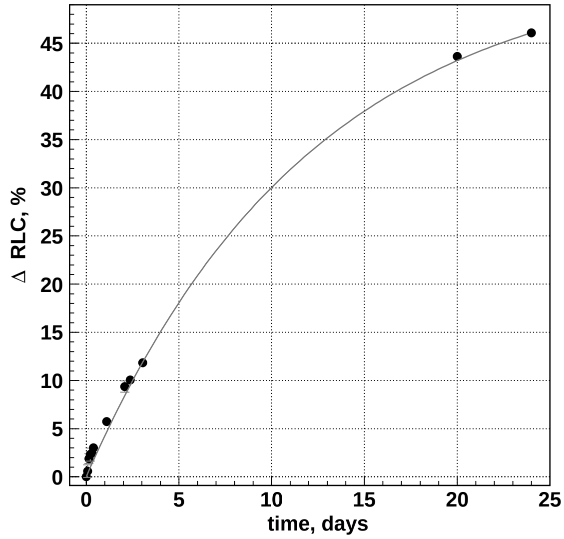

Fig. 4. The time dependence of the descent of the light collection relative coefficient under the atmospheric conditions.

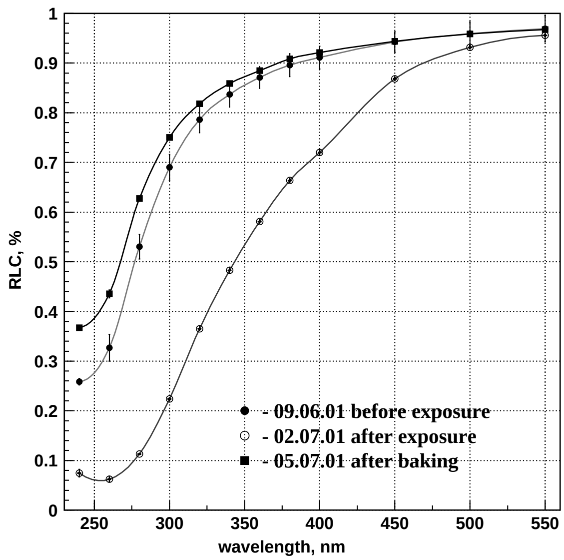

Fig. 5. The relative coefficient of the light collection RLC before exposure to atmospheric conditions, after the exposure and after baking in the oven.

aerogel layer need to be 4–6 cm according to up-to-date estimation [4,5]. The employment of thick layer composed of aerogel blocks with 1–2 cm thickness has at least two important disadvantages. This imposes rigid limits on the variation of the refractive index from block to block as well as increases the light scattering on exterior surfaces of each block. The synthesis of thick aerogel blocks presents a real challenge. Recently, the progress in preparation of thick blocks with $n = 1.03$ has been made at the Institute of Catalysis. Results are presented in Table 2. We have succeeded to produce aerogel block with the thickness 55 mm and high light scattering length $L_{sc} = 43$ mm.

5. Stability of aerogel properties

Stability of aerogel properties is the important problem of counters assembling. Aerogel has a huge specific surface of internal pores of about 700–900 m^2/g (this is 10^6 greater than exterior surface of aerogel block). Under the atmospheric conditions adsorption of liquids vapor takes place on aerogel internal surface. The adsorption of the water vapor is of great importance because of high water vapor concentration and high hydrophilicity of silica. The time dependence of a mass increase under atmospheric conditions (relative humidity 36–43%, temperature 23–25°C) is presented in Fig. 3. The time dependence of the descent of the relative coefficient of the light collection ΔRLC (it characterizes an aerogel optical quality) under the atmospheric conditions is presented in Fig. 4. The deterioration mentioned is reversible and initial values can be restored after baking of the aerogel at 500°C (Fig. 5).

Changing of the relative coefficient of light collection is less than 2.5% after 5 earliest hours of aerogel stay under atmospheric conditions. According to the Monte Carlo calculations this, corresponds to less than 5% decrease of the light collection in the KEDR ASHIPH counter [6].

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