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Aerogels with high optical parameters for Cherenkov counters

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Abstract

Using a two-stage sol-gel method and high temperature supercritical solvent removal, blocks of SiO_2 with a refractive index n = 1.01-1.05 have been prepared. Measurements show that these aerogels have high values of scattering and absorption lengths.

1. Introduction

Silica aerogels with high optical parameters are successfully used as radiators of Cherenkov counters. For years the Boreskov Institute of Catalysis and the Budker Institute of Nuclear Physics have been carrying out joint work on the synthesis and study of silica aerogels [1-4].

2. Aerogel preparation

Aerogel preparation may be divided into three stages: alkogel synthesis, solvent removal and baking. Alkogel is synthesized by the interaction of alkoxide silicon derivatives with water:

$$Si(OR)_4 + 2H_2O \Longrightarrow SiO_2 + 4HOR$$

alkoxide water silica alcohol.

During this reaction, the homogeneous solution of silicon derivative, water and catalyst in an organic solvent becomes dense and is converted to a gel. The reaction of gel formation is performed in two stages: first it is carried out with a small amount of water under acid conditions, and then it is completed with an excess of water in the presence of a base.

Alkogels represent a two-phase system. The structure consisting of the most thin fibers of solid silica forms one phase, and the liquid filling its volume forms the other. The peculiarities of the alkogel structure depend on the silicon compound used, synthesis procedure, water and catalyst amount, reaction temperature and some other conditions.

Because of the action of capillary forces, the usual drying of alkogel leads to strong compression, deformation and cracking of blocks. To avoid this, the solvent is removed in an autoclave under supercritical conditions: a temperature of 280°C and a pressure of 120 atm.

The aerogels obtained after supercritical solvent removal contain some organic impurities and water which impair their optical parameters. To improve these parameters, the aerogels are baked in air. For this purpose the samples are put in an oven. The temperature in the oven is slowly increased up to 500°C during three hours and is kept constant during two hours. The samples are being cooled inside the oven during 24 hours. The baking increases the scattering length of aerogels by 10-50%.

3. Aerogel properties

Some properties of the aerogel prepared with our production procedure are presented in Table 1.

For application of aerogels in Cherenkov counters, their most important characteristics are those which determine the production of the Cherenkov light (refractive index) and its loss (scattering and absorption length). The refractive index n of an aerogel and its density are related according to the empirical formula:

$$n = 1 + 0.21\rho,$$

where ρ is the density in g/cm^3. Varying the amount of solvent when preparing the alkogel, it is possible to alter

Table 1
Properties of the silica aerogel SAN-95.

Composition	SiO_2
Refractive index	1.01-1.05
Contamination of metals	$<10^{-7}$
Block size	$17 \times 17 \times 3$ cm^3

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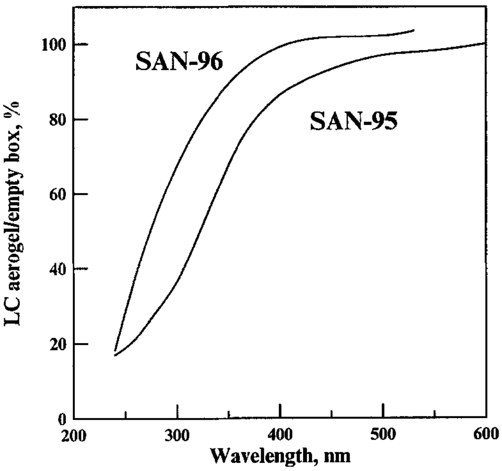

Fig. 1. The relative light collection coefficient for two types of aerogels with $n = 1.05$.

the volume occupied by the alkogel and, consequently, the density.

The scattering length L_{sc} in aerogels is determined by their structure elements, which have a size significantly less than the wavelength λ of incoming light. L_{sc} depends on the wavelength according to the Rayleigh law: $L_{sc} \sim \lambda^4$.

The absorption length L_{abs} is defined by impurities. Because of the relation $L_{sc} << L_{abs}$, the scattering length in aerogel can be measured by the attenuation of a light beam in the aerogel block itself.

We developed a special method to measure the absorption length. The block of aerogel was put inside a rectangular box with a size $75 \times 75 \times 32$ mm^3. This box was wrapped by teflon PTFE which has a high reflectivity. The results of reflection coefficient measurements of PTFE are presented in Ref. [5]. The light from the monochromator goes into the box and is detected by a photomultiplier with a 25 mm photocathode diameter working as photodiode.

The relation between the amount of detected light in the

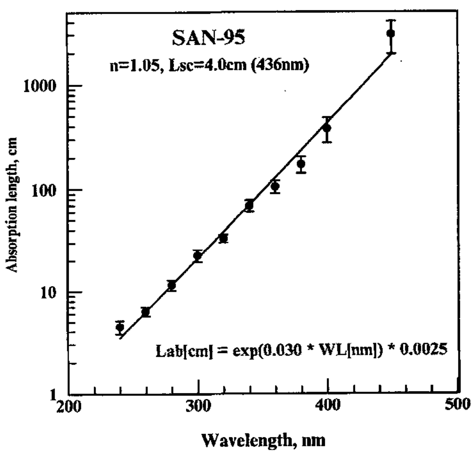

Fig. 2. Absorption length of aerogel as a function of wavelength.

Table 2
Scattering length in aerogels SAN-96 at a wavelength of 436 nm.

Refractive index n	L_{sc} (cm) at $\lambda = 436$ nm
1.010	8.2
1.038	7.7
1.050	8.2

box filled with aerogel and the amount of light in the empty box is the relative light collection coefficient.

The data on the relative light collection coefficient for SAN-95 aerogel with refractive index $n = 1.05$ are shown in Fig. 1.

This aerogel was used in the prototypes of the aerogel counters for the BaBar detector [6] and in the prototype for the KEDR detector [5]. The scattering length of this aerogel is 4 cm at $\lambda = 436$ nm.

The dependence of the absorption length L_{abs} on the wavelength λ in the region 240–450 nm for aerogel SAN-95 was obtained by a Monte Carlo simulation of the scattering and absorption processes in the box with aerogel (Fig. 2).

The absorption of the silica aerogel within 240–800 nm occurs due to impurities of metal ions, probably mainly iron ions Fe^{3+}. Its intensive maximum lies near 240 nm [7]. According to the data of the spectrochemical analysis, the contamination of metals in the aerogels does not exceed 10^{-7}.

A relative comparison of the optical parameters of our aerogel and an aerogel from Airglass was done by our French colleagues from LAPP [6]. For this purpose, the prototype with aerogel which has a size $10 \times 10 \times 6$ cm^3 was tested at a particle beam at CERN. The Cherenkov light was detected by a photomultiplier. The number of photoelectrons for the farthest point was 2.5 times higher for our aerogel.

Recently we produced samples of the new aerogel SAN-96, which have better optical parameters. The relative light collection coefficient for $n = 1.05$ is shown in Fig. 1. The scattering length of this aerogel for different refractive indices is presented in Table 2.

For comparison, the best aerogels have $L_{sc} = 3.2$ cm ($n = 1.013$) [8] and $L_{sc} = 2.64$ cm ($n = 1.024$) [9].

4. Conclusions

A method of synthesis of silica aerogel blocks with a refractive index $n = 1.01–1.05$ and high optical parameters for use in Cherenkov counters was developed. A new method of absorption length measurement was applied. The pilot-industrial setup for aerogel blocks production up to $17 \times 17 \times 3$ cm^3 was constructed.

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