EXPERIMENTAL RESEARCHES OF TITANIUM DIOXIDE NANOPARTICLES DETECTION POSSIBILITY IN AIR MEDIUM BY MEANS OF OPTICAL RESONATORS

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In this report the authors provide the results of research devoted to interactions between titanium dioxide nanoparticles and whispering gallery mode optical resonators. They show possibility to determine nanoparticles concentration in air.

The report examines the results of studies on the interaction between nanoparticles of titanium dioxide and optical resonators with whispering gallery modes. The possibility of determining the concentration of nanoparticles in the air is shown.

At the moment, our laboratory develops sensors based on optical dielectric microcavities capable of detecting small concentrations of nanoparticles in liquid and gaseous media. The report examines the results of studies on the interaction between nanoparticles of titanium dioxide and optical resonators with whispering gallery modes in the air.

Optical disc microresonators are now actively used in many areas of photonics, such as the creation on the basis of microresonators of electro-optic modulators, lasers, descriptors, displacement sensors, and others. Particularly noteworthy is the possibility of manufacturing micro and nanoparticle sensors, for example for biological objects [1].

Due to their small size and the use of modern materials with very low optical losses, optical dielectric microcavities with whispering gallery modes combine high quality factor, small dimensions, and high concentration of the optical field.The whispering gallery mode in the ray representation can be represented as an optical wave propagating near the inner surface of an axially symmetric dielectric body so that the angle of incidence at the interface exceeds the angle of total internal reflection, as shown in Fig. 1 (a). Resonance occurs when two conditions are satisfied: the trajectory of the beam must be closed, and also an integer number of wavelengths must be laid on this trajectory. A detailed description of optical resonators of this type is given, for example, in the monograph [2].

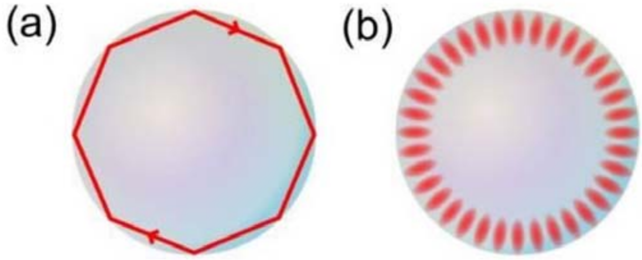


Fig. 1 - Propagation of laser radiation inside a disc microcavity with whispering gallery modes in the approximation of geometric optics (a) and the distribution of the intensity of an optical wave into a microresonator at resonance (b)

Due to the very high optical quality factor and the ability to localize the field in a very small volume, the frequency characteristics of optical dielectric microcavities strongly depend on even very small inhomogeneities in the structure of micro-resonators, which makes it possible to create sensors based on them.

We present the current results of the development of a similar sensor designed for the detection of titanium dioxide nanoparticles. The setup for the detection of titanium dioxide particles is shown in Figure 2.

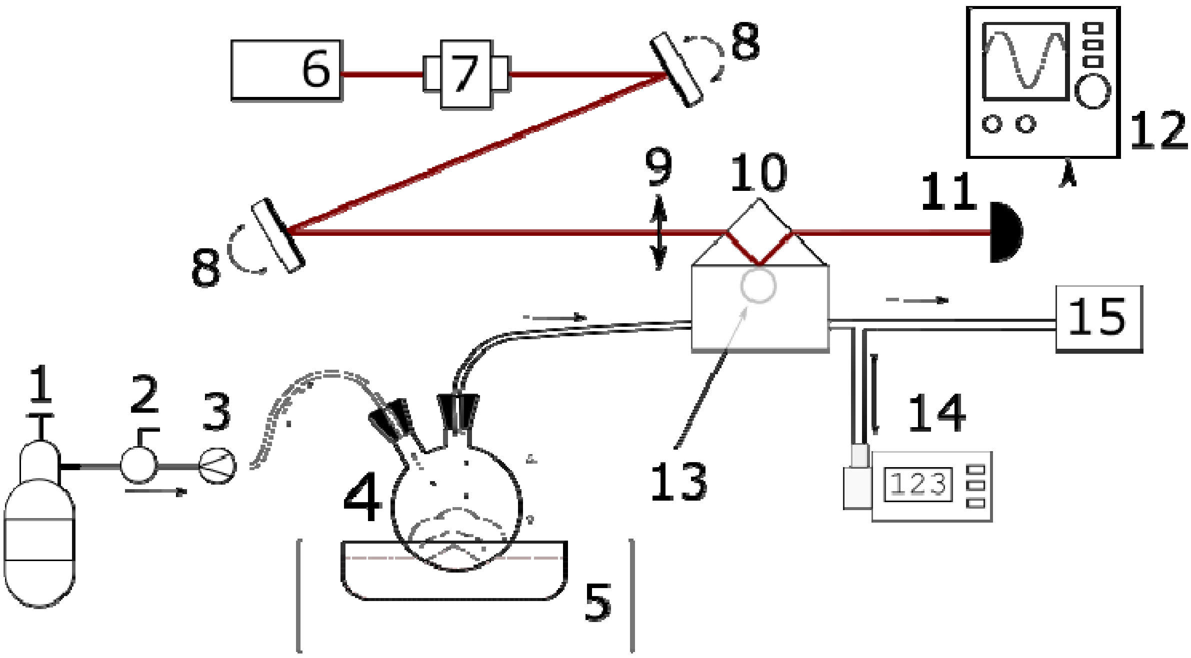


Fig. 2-Scheme of the device for feeding a model mixture of nanoparticles in the air to the experimental sample of an optical disc microcavity
1 - balloon with gas, 2-reducer, 3 - flow meter, 4 - two-necked round bottom flask with titanium dioxide, 5 - ultrasonic bath, 6 - tunable laser with a wavelength of 670 nm, 7 - Faraday isolator, 8 - movable mirrors, 9 - Lens, 10 - cuvette, 11 - photodetector, 12 - storage oscilloscope, 13 - microcavity, 14 - aerosol analyzer «KANOMAX» model 3521, 15 - extractor

Initially, it is necessary to place the microcavity (13) in the cuvette (10), and it is necessary to place 0.1 g of nanopowder dioxide in a two-necked round-bottomed flask (4). Gas from the cylinder (1) passes through the reducer (2) and the flowmeter (3) enters the two-necked round-bottomed flask (4), which is located in the ultrasonic bath (5). The particles to be thrown are picked up by the gas flow and transferred to the microcavity.

Light from a tunable laser with a wavelength of 670 nm (6); Passes through the Faraday isolator (7), the movable mirrors (8) and the lens (9), then the beam enters the inner volume of the cuvette, where it focuses on the base of the rectangular prism (10); The microcavity (13) in the measuring cell is fed to the piezo supply prism; Light emitted from the microresonator enters the photodetector (11); The received signal is processed by the oscilloscope (12). The concentration of nanoparticles is determined using an aerosol analyzer "KANOMAX" model 3521 (14). All unused particles get into the hood (15).

The cuvette, used to study the frequency characteristics of the optical disc microcavity, is hermetically sealed, made of duralumin grade D16T. It has a front window for the transparent cover through which visual control over the microcavity tuning is carried out. Observation of the motion of the optical microresonator, supplied by means of a three-coordinate translator, is carried out both directly, through the transparent front window of the cell, and by its reflected image through a microscope.

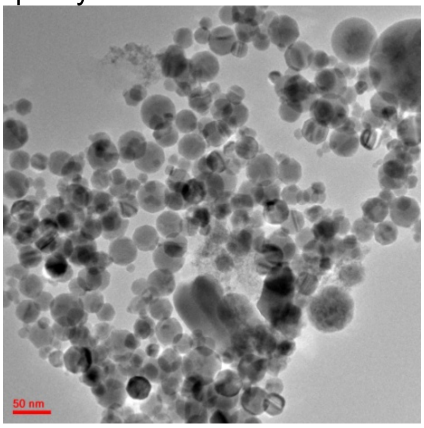
To determine the characteristics of optical disc microcavities, a system was prepared for the preparation and supply of gas mixtures with nanoparticles to a cuvette with a microcavity.

Ultrasonic vibrations in the flask create a gradient of the concentration of titanium dioxide nanoparticles in the volume of the flask. At the same time, the nanoparticle concentration is higher at the bottom of the bulb than in its upper part. The airflow from the balloon mixes the particles in the flask, which causes an increase in the concentration of titanium dioxide nanoparticles in the upper part of the flask. This fact explains the existence of a dependence of the concentration at the outlet from the system on the flow.

Dispersing of particles occurs due to ultrasonic oscillations, which are strongly attenuated in bulk materials. Therefore, the amount of nanoparticle powder in the flask should be kept to a minimum. In addition, the transmission efficiency of an ultrasonic wave increases significantly if a standing acoustic wave forms between the bottom and the walls. To fulfill this condition, the position of the bulb in the bath is adjusted vertically by mixing it in a tripod. Optimum position of the bulb is determined visually by a sharp increase in the intensity of the nanopowder dispersing process and is additionally monitored using the aerosol analyzer KANOMAX model 3521.

A photo of a microresonator with nanoparticles deposited on its surface is shown in Fig. 3. The luminous points are titania particles reducing the quality of the microresontator.

(a)



(б)

Fig. 3 Photo of an optical dielectric microcavity after 500 seconds of feeding a sample of titanium dioxide nanoparticles (a), titanium dioxide nanoparticles (b)

The study used certified samples of nanoparticles. Measurement of the size of titanium dioxide nanoparticles was carried out by transmission electron microscopy, followed by TEM (Fig. 3 (b)), dynamic light scattering was performed on a Zetasizer Nano-ZS particle analyzer and using the differential electric mobility analyzer TSI SMPS 3936. The average particle size 40 Nm.

During the mathematical processing of the signal, the dependence of the width of the resonance curve on time is calculated. Examples of such dependences are shown in Fig. 4. The concentration of 5.85 mg / m3 (1) was marked with dotted line in Fig. 4, 3.24 mg / m3 (2) was marked with a dotted line, the solid line indicated a concentration of 3.02 mg / m3 (3).

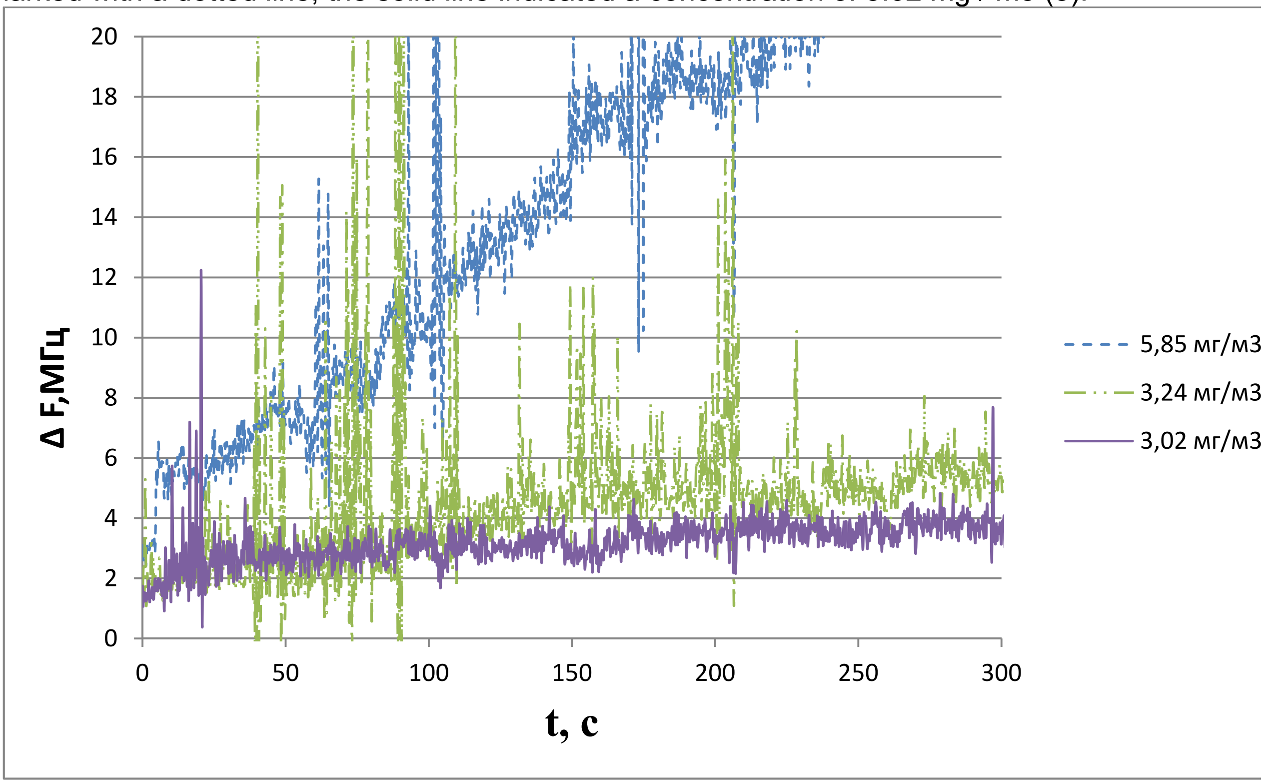


Fig. 3 Graph of dependence of Q-factor broadening for various concentrations of titanium dioxide nanoparticles on time

It can be seen from the graph of Fig. 3 that there is a dependence of the rate of degradation of the Q of the whispering gallery modes on the particle concentration. As a result, it was shown that with the help of this type of sensor it is possible to determine the concentration of titanium dioxide nanoparticles in the air.

However, microresonators in air have less sensitivity compared to sensitivity in water, because because of the greater difference in the refractive indices of the microresonator and the medium, the dropping field falls off at a shorter distance.

The use of high-Q optical resonators as high-sensitivity sensors is capable of solving the problems of ensuring the safety of production in the field of the nanoindustry.

1. Foreman M. R., Swaim J.D., Vollmer F. Whispering gallery mode sensors // Advances in Optics and Photonics, Vol. 7, No. 2, 2015. pp. 168-240.

2. М. Л. Городецкий Оптические микрорезонаторы с гигантской добротность — Москва:Физматлит, 2011. — 416 с.