Non-linear optical response of plate-like titanate-based nanoparticles in the region of fundamental absorption

Gorokhovsky A.V., Zimnyakov D.A., Ushakova O.V., Tretyachenko E.V., Pravdin A.B., Kudryashova A.

Saratov State Technical University, Saratov, Russia
algo54@mail.ru

The development of highly effective nonlinear optical (NLO) and optical limiting (OL) materials for application in protection from strong laser radiation is urgent [1]. Oxide semiconductors with high dielectric constants are good candidates for NLO and OL applications [2, 3]. Some homogeneously translucent titanate nanobelt suspensions demonstrated interesting physical and chemical properties due to strongly anisotropic structure different from those of the corresponding bulk material and those of isotropic nanoparticles. Such samples display remarkable NLO and OL effects at 532 nm, originating from nonlinear scattering [1].

This research is related to the NLO response of the potassium titanate nanoparticles characterized with plate-like shape as well as their aggregated forms. The NLO properties of the titanate suspensions were investigated in the region of fundamental absorption band using the Z-scan technique with open aperture at 337 nm and measurements of extinction spectra in UV and visible regions (300-600 nm). Various potassium titanate systems based on amorphous $K_2O{\cdot}4.2TiO_2$ were examined. The parent potassium polytitanate was produced by molten-salt synthesis with the treatment of TiO_2 particles in the molten mixtures of KNO_3 and KOH at 500 ^{o}C [4]. Further, potassium polytitanate particles were ultrasonically dispersed in distilled water and treated with different cationic and non-ionic surfactants to obtain the suspensions characterized with different particles size distribution. The NLO response of the two suspensions was investigated: 1) consisted of single platy potassium titanate particles (effective diameter of 158 nm and thickness of 28 nm); 2) consisted of aggregated particles with the effective diameter of 1.93 µm.

The aqueous dispersions of pure TiO_2 (anatase) nanoparticles (25 nm) and colloidal Ag nanoparticles (40 nm) were also examined to compare non-linear optical response.

Z-scan measurements with open aperture were carried out with nitrogen laser radiation (λ=337 nm, average output power 40 mW, pulse duration 10 ns, repetition rate 1 kHz). The focal length of the used lens (fused silica) was equal to 30 mm, which gave the waist diameter and length in our Z-scan system equal to 6.5 µm and 390 µm, respectively. The peak value of power density of laser radiation was equal to $1.0{\cdot}10^{12}$ W/cm^2 approximately. The wavelength used corresponds to the spectral region of fundamental absorption of the wide variety of titanate-based systems.

It was shown that Ag and titanate-based systems exhibited different character of non-linearity. The extinction of Ag nanoparticles, for which a surface plasmon resonance near 400 nm is characteristical, falls down with a power density increasing. This phenomenon is obviously caused by positive non-linear absorption at the edge of surface-plasmon resonance [5-6].

At the same time, all the studied titanate samples exhibit the decreasing extinction with a power density increasing for the probe light (optical bleaching). For titanate-based nanoparticles the non-linear extinction can be approximated by the following relationship [7]:

$$\mu(I) = \mu_0 / \left[1 + (I/I_{sat})^{\beta_1}\right]^{\beta_2}, \qquad (1)$$

where μ_0 is the “base-line” for the extinction coefficient (evaluated, e.g., from spectral measurements at low intensities of the probe light; I_{sat} is the characteristic value of saturation intensity; β_1, β_2 are the dimensionless parameters, which are determined by predominating type of the optical bleaching mechanism. It was noted that, besides the non-linear absorption, the non-linear scattering also can contribute to optical bleaching near the fundamental absorption maximum.

The results of comparative analysis of phenomenological parameters I_{sat}, β_1, β_2 for the examined titanate-based systems are presented; the potential of their application for characterization of dispersed nanomaterials with specific optical properties (e.g., photocatalysts, dye-doped random media with optical gain, etc.) are discussed.

References

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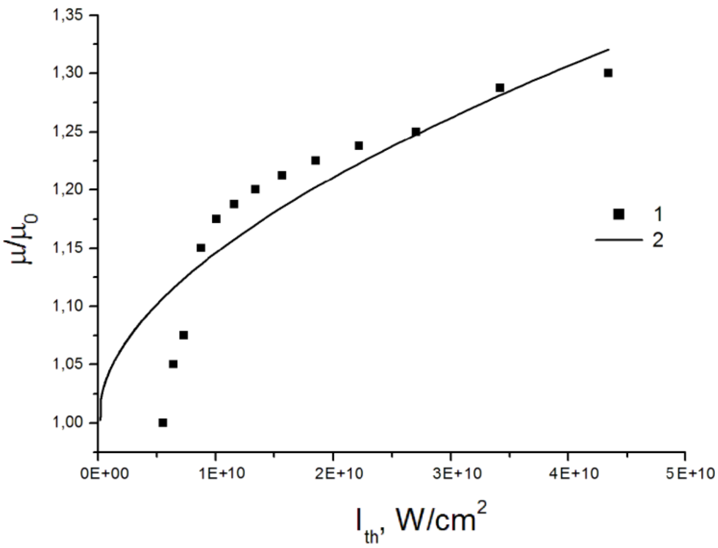
Figure



Experimental (1) and theoretical (2, Eq. 1) data on the normalized extinction coefficient μ/μ_0 *versus the probe light intensity* I_{th}. *(for 2:* $\beta_1 = 0.5, \beta_2 = 3.2$, $I_{sat} = 5.26\times10^{12}$ *W/cm*^{2}.