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SYNTHESIS OF $SrTiO_3$ AND ITS SIZE-DEPENDENT PHOTOCATALYTIC PROPERTIES

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Abstract. This study focuses on the synthesis of strontium titanate ($SrTiO_3$) nanoparticles and the investigation of the effect of their particle size on photocatalytic activity. $SrTiO_3$ was synthesized using the sol-gel method with varying thermal treatment conditions, which allowed control over the crystallite size. Structural and morphological properties were characterized by XRD, SEM, and BET methods. The photocatalytic activity was evaluated through the degradation of methylene blue under UV irradiation. A clear correlation was established between particle size and photocatalytic performance. The highest photocatalytic activity was observed for particles with an average size of 30–40 nm. The obtained results are promising for the development of efficient $SrTiO_3$-based photocatalysts.

Keywords: $SrTiO_3$, sol-gel, photocatalysis, nanoparticles, size effect, dye degradation.

$SrTiO_3$ nanozarrachalarini sintez qilish va ularning o‘lcham-fotokatalitik xossalari

Annotatsiya. Ushbu ilmiy ishda stronsiy titanat ($SrTiO_3$) nanorachasining sintezi va ularning o‘lchamiga qarab fotokatalitik faolligi o‘rganildi. $SrTiO_3$ nanomateriallari sol-gel usuli orqali sintez qilindi va har xil termik ishlov berish sharoitlari asosida kristallit o‘lchamlari nazorat qilindi. Ularning struktura va morfologik xususiyatlari XRD, SEM va BET usullari bilan o‘rganildi. Fotokatalitik xossalar metilen ko‘ki bo‘yog‘ining UF-nur ostida parchalanishi orqali baholandi. Tadqiqot natijalariga ko‘ra, zarracha o‘lchami bilan fotokatalitik faollik o‘rtasida bevosita bog‘liqlik mavjudligi aniqlandi. Eng yuqori fotokatalitik faollik zarracha o‘lchami 30–40 nm bo‘lganda kuzatildi. Ushbu natijalar $SrTiO_3$ asosidagi samarali fotokatalizatorlar yaratishda foydali bo‘lishi mumkin.

Kalit so‘zlar: $SrTiO_3$, sol-gel, fotokataliz, nanozarrachalar, o‘lcham effekti, bo‘yoq parchalanishi.

Синтез $SrTiO_3$ и его размерно-фотокаталитические свойства

Аннотация. Настоящая работа посвящена синтезу наночастиц стронцийтитаната ($SrTiO_3$) и исследованию влияния их размеров на фотокаталитическую активность. $SrTiO_3$ был получен методом золь-гель с варьированием условий термообработки, что позволило контролировать размер кристаллитов. Структурные и морфологические характеристики были изучены методами XRD, SEM и BET. Фотокаталитические свойства оценивались по деградации метиленового синего под действием УФ-излучения. Установлена прямая зависимость между размером частиц и их фотокаталитической активностью. Максимальная активность наблюдалась при среднем размере частиц 30–40 нм.

Полученные результаты могут быть полезны для создания эффективных фотокатализаторов на основе $SrTiO_3$.

Ключевые слова: $SrTiO_3$, золь-гель, фотокатализ, наночастицы, размерный эффект, деградация красителя.

Introduction. Perovskite-like oxides of alkaline earth metals, particularly $SrTiO_3$, represent unique photocatalytic materials characterized by high chemical and thermal stability, a wide band gap (Eg ~3.2 eV), and the ability to form nanostructured systems. Due to the growing interest in renewable energy sources and environmentally friendly technologies, $SrTiO_3$ is actively studied as a catalyst in processes such as water photolysis, degradation of organic pollutants, and electrochemical detection of toxic substances. These properties make $SrTiO_3$ a key material in the fields of nanomaterials, photo- and electrocatalysis [1].

A variety of synthetic strategies allow for control over the morphology and phase composition of $SrTiO_3$. Among the most effective methods are sol-gel and solution combustion synthesis [2], hydrothermal methods without alkali [3], mechanochemical synthesis (ball milling) [4], and molten salt synthesis [5]. These methods enable the production of nanoparticles ranging from 10 to 70 nm in size at temperatures lower than those required for traditional solid-state reactions (600–900 °C vs. 1200–1300 °C). According to X-ray diffraction analysis, $SrTiO_3$ crystallizes in the cubic system (space group $Pm\bar{3}m$). The crystallite size and morphology depend on the synthesis conditions, pH of the medium, and the reagent ratios. SEM and TEM analyses reveal spherical or cubic morphologies with particle sizes between 10 and 70 nm, while BET analysis indicates a surface area of up to 26.5 m^2/g [2,6,7]. Anisotropic $Sr_3Ti_2O_7$ crystals can be obtained by modifying molten salt growth conditions [8].

$SrTiO_3$ is effectively used in the photocatalytic decomposition of organic compounds (methylene blue, Congo red, rhodamine B) and water photolysis processes. Doping with elements such as Cr, La, Ag, and Ni [9,10], and the formation of heterostructures with TiO_2, g-C_3N_4, $BiVO_4$, and AgInZnS enhance light absorption and charge carrier separation, increasing quantum efficiency. The degradation of organic dyes under UV light follows first-order kinetics [6], and mechanocatalysis via ball milling achieves up to 70% degradation of methylene blue within 1 hour [4].

Hybrid systems such as $SrTiO_3$/ TiO_2 and TiO_2 nanotubes coated with $SrTiO_3$ demonstrate high activity due to increased surface area, enhanced light absorption, and efficient charge separation [11]. These structures are applicable for hydrogen generation under solar irradiation, wastewater treatment, and as photoanodes in electrochemical sensors.

Recent research focuses on modeling the properties of $SrTiO_3$ using machine learning methods, including neural networks and ELM algorithms. Utilizing data on crystal distortions and crystallite sizes allows for the prediction of band gap values and the optimization of synthesis conditions [1]. These approaches offer promising prospects for the targeted design of next-generation photocatalysts.

Strontium titanate ($SrTiO_3$) is a promising perovskite material for creating photocatalytic systems. A wide range of synthetic approaches, doping capabilities, heterostructure formation, and support from AI-based modeling enable flexible tuning of its properties. $SrTiO_3$ is already widely used in photocatalysis, sensing, and water purification, and its future development is linked to environmentally friendly energy and nanotechnology.

Against the background of increasing interest in the development of eco-friendly, energy-efficient, and multifunctional materials, the study of structure–property relationships in perovskites based on alkaline earth metals acquires special scientific and practical significance.

The aim of the present study is the synthesis of $SrTiO_3$ nanoparticles with tunable sizes and the investigation of the effect of their dimensional characteristics on photocatalytic activity in the degradation of an organic dye under ultraviolet irradiation.

Materials and methods. The following starting materials and reagents were used: strontium nitrate $Sr(NO_3)_2$ (analytical grade, Sigma-Aldrich), titanium(IV) isopropoxide $Ti[OCH(CH_3)_2]$

(analytical grade, Merck), anhydrous ethanol (p.a.) as the solvent, ammonia solution (25%) for pH adjustment, distilled water, and methylene blue (analytical standard), which was used as a model organic dye to evaluate the photocatalytic activity of the synthesized materials.

$SrTiO_3$ synthesis method (sol-gel). The synthesis was carried out using a modified sol-gel method. $Sr(NO_3)_2$ was dissolved in 100 mL of ethanol under stirring. Separately, a solution of $Ti[OCH(CH_3)_2]$ in ethanol was prepared and added dropwise to the $Sr(NO_3)_2$ solution under vigorous stirring. Water with ammonia was then added to adjust the pH to ~9, initiating hydrolysis and sol formation. The resulting sol was kept at room temperature for 12 hours, then dried at 80 °C for 24 hours and calcined at 500–900 °C (depending on the sample series) for 4 hours.

Characterization techniques. To comprehensively understand the structure and properties of $SrTiO_3$, modern analytical techniques were employed. X-ray diffraction (XRD) was used to identify the crystalline phase and estimate the crystallite size using the Scherrer equation. Particle morphology and size distribution were analyzed by scanning electron microscopy (SEM), allowing visualization of surface structure and aggregation state. Nitrogen adsorption at low temperature (BET method) provided quantitative data on specific surface area and porosity, which are critical for evaluating catalytic and sorption properties. The band gap energy was determined using UV–Vis spectroscopy and the Tauc plot method, which enables assessment of the material's photoactivity in different spectral regions.

The calcination temperature is the main factor determining the crystallite growth of $SrTiO_3$: as it increases, diffusion and sintering processes become more active, leading to particle enlargement. At 600 °C, nanoparticles of approximately 25–30 nm are formed; at 700 °C — around 35–40 nm; and at 900 °C — ≥85–90 nm. The optimal size (30–40 nm), which ensures high photocatalytic activity and good dispersity, is achieved at a calcination temperature of 700–750 °C.

The duration of thermal treatment significantly affects the particle size of $SrTiO_3$: longer times improve crystallinity but also lead to particle growth. For example, calcination for 2 hours results in particles around 35 nm, while extending the duration to 6 hours at the same temperature increases the size to ~55 nm. The optimal treatment time of 3–4 hours provides good crystallinity without excessive growth or aggregation of the nanoparticles.

The heating rate strongly influences the morphology of $SrTiO_3$: slow heating (1 °C/min) promotes gradual grain growth and the formation of larger, denser particles, whereas fast heating (10 °C/min) limits growth and leads to the formation of fine powders with smaller particle sizes. Therefore, a controlled rapid heating regime is recommended to minimize particle growth and obtain nanostructured samples.

The precursor concentration in the sol has a key effect on the size and uniformity of $SrTiO_3$ particles: high concentrations of Sr^{2+} and Ti^{4+} ions lead to rapid saturation of the system, resulting in aggregation and particle enlargement. In contrast, diluted solutions promote more controlled nucleation and the formation of small, uniform nanoparticles. For optimal size control, it is recommended to maintain a Sr:Ti molar ratio of 1:1 with a solution concentration of 0.1–0.3 M in ethanol.

The pH of the medium during sol formation plays a crucial role in nanoparticle formation: at pH < 6, the sol becomes unstable, and particles tend to aggregate, forming irregular structures. In contrast, a slightly alkaline environment (pH 8–9) ensures system stability and controlled growth of nanoparticles with uniform size distribution. To achieve sol stability and obtain a well-dispersed material, it is recommended to maintain pH in the range of 8–9 using ammonia as the pH-regulating agent.

Additives and surfactants (SDS, CTAB, PEG) significantly affect the size and stability of $SrTiO_3$ nanoparticles: introducing surfactants like CTAB or PEG reduces aggregation and promotes the formation of smaller, more uniform particles by stabilizing the surface during growth. Additionally, the use of dopant ions (e.g., La^{3+} or Fe^{3+}) can limit crystallite growth by acting as

sintering inhibitors. To obtain highly dispersed nanoparticles with a narrow size distribution, it is recommended to use organic stabilizers during the synthesis process.

Thus, targeted control of $SrTiO_3$ particle size requires careful regulation of key synthesis parameters, including calcination temperature and duration, composition and concentration of the sol precursor solution, pH of the medium during sol formation, and heating rate. The additional use of surfactants and stabilizers such as CTAB, PEG, or doping ions allows for effective prevention of aggregation and restriction of crystallite growth. Comprehensive control over these conditions enables the synthesis of $SrTiO_3$ nanoparticles with tailored size characteristics optimized for photocatalytic applications.

The photocatalytic activity was evaluated based on the degradation rate of methylene blue (10 mg/L) under UV irradiation (365 nm, 15 W). The concentration of $SrTiO_3$ was 0.5 g/L. Prior to irradiation, the solution was stirred in the dark for 30 minutes to establish adsorption equilibrium. Sampling was performed every 10 minutes, and the residual dye concentration was measured using a UV–Vis spectrophotometer (λ = 664 nm).

The hydrodynamic properties of $SrTiO_3$ nanoparticles were studied using dynamic light scattering (DLS) in aqueous dispersion at approximately pH 7. The obtained data reflect the behavior of particles in a colloidal environment, indicating their stability, degree of aggregation, and potential suitability for aqueous photocatalytic processes.

The hydrodynamic diameter (Dh) of $SrTiO_3$ nanoparticles was shown to depend on calcination temperature, reflecting their dispersity and tendency to aggregate in colloidal systems. At a calcination temperature of 700 °C, corresponding to a crystallite size of ~35 nm, the average Dh was 45–55 nm, indicating low aggregation and good dispersion stability. In contrast, samples calcined at 900 °C exhibited a sharp increase in Dh to over 100 nm due to particle agglomeration, attributed to decreased specific surface area and stronger interparticle interactions.

The measured zeta potential (ζ-potential) at pH 7 ranged from –28 to –35 mV for samples calcined at 700–750 °C, indicating high colloidal stability. For larger particles (T > 850 °C), the ζ-potential dropped to –15 mV, suggesting a tendency toward aggregation.

Rheological measurements showed that $SrTiO_3$ dispersions with concentrations up to 1 g/L in water exhibit Newtonian behavior with low viscosity (1.2–1.5 mPa·s), ensuring good flowability and the potential for use in dynamic reactor systems.

$SrTiO_3$ nanoparticles synthesized at 700–750 °C demonstrated optimal hydrodynamic properties—small hydrodynamic diameter, high ζ-potential, and low viscosity. This makes them particularly promising for heterogeneous photocatalysis in aqueous media, including continuous-flow systems.

Kinetic analysis of the photocatalytic degradation of organic dyes with $SrTiO_3$ was performed using the pseudo-first-order model, allowing for a quantitative assessment of process efficiency. The kinetic parameters were calculated using the following equation:

$$ln\left(\frac{C_o}{C}\right) = k \cdot t,$$

where C_0 is the initial dye concentration, C is its concentration at time t, and k is the rate constant of the reaction.

A linear dependence of $\ln(C_0/C)$ on time confirmed the applicability of this model, allowing the determination of kinetic parameters of the photocatalytic process and enabling comparison of the activity of different $SrTiO_3$ samples.

Results and discussion. X-ray diffraction (XRD) analysis showed that at calcination temperatures above 700 °C, a pure cubic perovskite phase of $SrTiO_3$ was formed. At 500–600 °C, amorphous and intermediate phases were observed, indicating incomplete crystallization. The average crystallite size, calculated using the Scherrer equation, increased from 26 nm (at 600 °C) to 85 nm (at 900 °C).

SEM micrographs revealed that at calcination temperatures of 700–750 °C, mainly spherical and weakly agglomerated nanoparticles were formed. At higher temperatures, particle growth and aggregation were observed, leading to a reduction in specific surface area.

The highest specific surface area (67 m^2/g) was recorded for the sample calcined at 700 °C. Increasing the temperature to 900 °C reduced the surface area to 21 m^2/g due to particle enlargement and loss of porosity.

Measurements showed that the band gap width, calculated using the Tauc method, ranged from 3.4 eV (for nanoparticles ~25 nm) to 3.0 eV (for particles ~90 nm). This indicates a quantum size effect: decreasing particle size leads to a blue shift of the absorption edge toward the shorter wavelength region.

The degradation of methylene blue under UV irradiation demonstrated a clear dependence of photocatalytic activity on the particle size of $SrTiO_3$: the highest degradation rate ($k = 0.035\ min^{-1}$) was observed for samples with particle sizes around 35 nm. Reducing the size to ≤25 nm led to decreased activity, attributed to enhanced recombination of photogenerated electrons and holes. Conversely, increasing the size to ≥60 nm resulted in a reduction of specific surface area and the number of active sites, which also negatively affected the photocatalytic degradation rate of the dye.

The photocatalytic process followed pseudo-first-order kinetics. The linear dependence of $\ln(C_0/C)$ on time confirmed a single-reaction degradation mechanism under constant photocatalyst concentration.

These findings confirm the importance of selecting the optimal particle size of $SrTiO_3$ to achieve maximum photocatalytic efficiency. The best combination of crystallinity, band gap energy, and textural properties was achieved at a calcination temperature of 700–750 °C, resulting in nanoparticles sized 30–40 nm. This ensured effective UV light absorption, low recombination rates, and sufficient surface sorption activity.

The data obtained in this study on the synthesis of $SrTiO_3$ nanoparticles by the sol-gel method followed by calcination at various temperatures are in good agreement with the literature. For instance, at a calcination temperature of 700 °C, high crystallinity with crystallite sizes around 35 nm was observed, consistent with [7], which reported that the optimal temperature for nanostructured $SrTiO_3$ formation with good dispersity and minimal aggregation lies in the 600–800 °C range.

The photocatalytic activity of $SrTiO_3$ nanoparticles in the degradation of methylene blue under UV irradiation showed maximum efficiency at a particle size of ~35 nm ($k = 0.035\ min^{-1}$), in line with the results reported in [10], where nanoparticles sized 30–40 nm provided a high degradation rate of organic pollutants. Further size reduction to <25 nm led to a drop in activity, also described in [13,15–17], where high surface defect density and carrier recombination limited photocatalytic efficiency.

As particle size increased to ≥60 nm, activity decreased due to reduced surface area and fewer active sites. This agrees with the results in [12], which identified 20–50 nm as the optimal size range for effective photocatalysis, beyond which efficiency declines significantly.

Thus, the experimentally obtained correlations between morphology, particle size, and photocatalytic activity of $SrTiO_3$ confirm the conclusions reported in [7,10,12,13,14–17], supporting the reliability and reproducibility of the present study's results.

Conclusions/

1. $SrTiO_3$ nanoparticles were successfully synthesized via the sol-gel method with controllable particle sizes from 25 to 90 nm by adjusting the calcination temperature from 600 to 900 °C. Formation of a pure perovskite phase was observed at temperatures above 700 °C.
2. The photocatalytic activity of $SrTiO_3$ strongly depends on particle size: the maximum degradation rate of methylene blue ($k = 0.035\ min^{-1}$) was achieved at a particle size of ~35 nm. Smaller or larger sizes reduced efficiency due to increased charge recombination and loss of active surface area.

3. Optimal synthesis conditions for $SrTiO_3$ nanoparticles were achieved with calcination at 700–750 °C, providing a balance between high crystallinity, specific surface area, and photocatalytic activity, making this material promising for environmentally significant applications in water and air purification.

References

1. Sharma N., Hernadi K. The emerging career of strontium titanates in photocatalytic applications: a review //Catalysts. – 2022. – V. 12. – №. 12. – P. 1619.
2. Manjunath K. et al. Combustion Derived SrTiO3: Synthesis, Characterization and Evaluation of Electrochemical Behavior Towards Quantification of Hg (II) Ions //Materials Physics and Chemistry. – 2019. – V. 1. – №. 1. – P. 11-19.
3. Shen H. et al. Low temperature hydrothermal synthesis of $SrTiO_3$ nanoparticles without alkali and their effective photocatalytic activity //Journal of Advanced Ceramics. – 2016. – V. 5. – P. 298-307.
4. Shukla A. et al. Ball milling assisted mechano-catalytic dye degradation using $SrTiO_3$ nanoparticles //RSC Mechanochemistry. – 2024. – V. 1. – №. 5. – P. 465-476.
5. Kumada N. et al. Low temperature synthesis of $ATiO_3$ (A: Mg, Ca, Sr, Ba) by using molten salt //Journal of the Ceramic Society of Japan. – 2013. – V. 121. – №. 1409. – P. 74-79.
6. Merrad S. et al. Physical properties of the perovskite $SrTiO_{3-}$ δ synthetized by chemical route //Journal of Materials Science: Materials in Electronics. – 2023. – V. 34. – №. 3. – P. 206.
7. Zaza F., Orio G., Serra E. Quality by design approach for $SrTiO_3$ perovskite nanomaterials synthesis //Journal of Materials Science. – 2016. – V. 51. – P. 9649-9668.
8. Liu Y. et al. Formation mechanisms of platelet $Sr_3Ti_2O_7$ crystals synthesized by the molten salt synthesis method //Journal of the American Ceramic Society. – 2007. – V. 90. – №. 6. – P. 1774-1779.
9. Kudo A. Photocatalyst materials for water splitting //Catalysis Surveys from Asia. – 2003. – V. 7. – P. 31-38..
10. Mahalingam S. et al. Emerging silver-doped strontium titanate nanostructures as photocatalysts for the degradation of organic pollutants under visible light //Journal of Molecular Structure. – 2024. – V. 1306. – P. 137854.
11. Bissenova M. et al. Synthesis and Study of $SrTiO_3/TiO_2$ Hybrid Perovskite Nanotubes by Electrochemical Anodization //Molecules. – 2024. – V. 29. – №. 5. – P. 1101.
12. Jangir S., Singhal M., Rajawat D. S. Exploring Strontium Titanate: A Review of Its Photocatalytic Properties and Environmental Applications splitting //Catalysis Surveys from Asia. – 2003. – V. 7. – P. 31-38.
13. Baray-Calderón A. et al. Recent Advances in Perovskite-Based Heterojunction Photocatalysts: Synthesis, Properties, and Applications //Korean Journal of Chemical Engineering. – 2025. – V. 1-24.
14. Chislova I. V. et al. Sol-gel synthesis of nanostructured perovskite-like gadolinium ferrites //Glass Physics and Chemistry. – 2011. – V. 37. – P. 653-660.
15. Akbal F., Nur Onar A. Photocatalytic degradation of phenol //Environmental monitoring and assessment. – 2003. – V. 83. – P. 295-302.
16. Araña J. et al. Photocatalytic degradation of phenolic compounds with new TiO_2 catalysts //Applied Catalysis B: Environmental. – 2010. – Т. 100. – №. 1-2. – С. 346-354.
17. Choquette-Labbé M. et al. Photocatalytic degradation of phenol and phenol derivatives using a nano-TiO2 catalyst: Integrating quantitative and qualitative factors using response surface methodology //Water. – 2014. – V. 6. – №. 6. – P. 1785-1806.