Торайғыров университетінің
ҒЫЛЫМИ ЖУРНАЛ

НАУЧНЫЙ ЖУРНАЛ
Торайгыров университета

ТОРАЙҒЫРОВ УНИВЕРСИТЕТІНІҢ ХАБАРШЫСЫ

Физика, математика және компьютерлік ғылымдар сериясы
1997 жылдан бастап шығады

ВЕСТНИК ТОРАЙГЫРОВ УНИВЕРСИТЕТА

Серия: Физика, математика и компьютерные науки
Издается с 1997 года

ISSN 2959-068X

№ 4 (2024)
Павлодар

НАУЧНЫЙ ЖУРНАЛ
ТОРАЙГЫРОВ УНИВЕРСИТЕТА

Серия: Физика, математика и компьютерные науки
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания, информационного агентства и сетевого издания
№ KZ91VPY00046988
выдано
Министерством информации и общественного развития Республики Казахстан

Тематическая направленность
публикация материалов в области физики, математики, механики и информатики

Подписной индекс – 76208

https://doi.org/10.48081/OOZM3500

SRSTI 29.19.31, 29.31.26

https://doi.org/10.48081/UYVL9716

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INVESTIGATION OF THE EFFECT OF REDUCED GRAPHENE OXIDE ON THE STRUCTURAL PROPERTIES OF TITANIUM DIOXIDE

This paper investigates the effect of reduced graphene oxide (rGO) on titanium dioxide's (TiO_2) structural and physico-chemical properties. Using rGO as a TiO_2 modifier is essential for increasing its photocatalytic activity and improving its mechanical and electrical characteristics. During the study, TiO_2/rGO nanocomposites of various concentrations of reduced graphene were obtained, which were subjected to structural analysis using scanning electron microscopy and atomic force microscopy. The results showed that adding rGO contributes to a change in the crystal structure of tio2 and improves its textural characteristics, such as porosity and surface. The effect of the rGO concentration on the properties of nanocomposites was also studied, which allowed us to identify the optimal ratio for increasing the photocatalytic activity of TiO_2. Additionally, spectroscopic studies were carried out, confirming the improvement of the conductive properties and stability of TiO_2 with the addition of rGO. The results open prospects for developing highly efficient TiO_2-based materials with improved water purification, solar energy, and sensor functional properties.

Keywords: reduced graphene oxide, titanium dioxide, nanocomposite material, photocatalysis, photodetector.

Introduction

The study of the effect of reduced graphene oxide on the structural properties of titanium dioxide is an important topic in materials science. Such hybrid materials can demonstrate unique physicochemical characteristics that are functional for various applications, including catalysis, solar cells, sensors, and batteries [1-4].

rGO is a form of graphene in which parts of oxygen-containing oxide groups are reduced, which improves the material's conductivity compared to graphene oxide (GO). Recovery can be achieved by various methods, including chemical reduction, thermal reduction, or reduction using electricity, etc. [5-7] rGO has a high specific surface area and good conductivity, which makes it interesting for creating composite materials with other semiconductors, such as tio2 [8; 9]

TiO_2 is one of the most widely used semiconductors in photocatalysis and energy applications. It exists in several crystalline forms (anatase, rutile, and brutal), with anatase and rutile being the most stable and frequently used catalysts. TiO_2 has good chemical stability, but its effectiveness in processes such as photocatalysis is limited due to the band gap and the tendency to rapid recombination of charge carriers [10–12].

The use of rGO in the composition of nanocomposite materials with TiO_2, its presence can significantly affect the structural and functional properties of the latter. The interaction between rGO and TiO_2 usually leads to improved electrical and optical characteristics and increased photocatalytic activity. Using rGO as a conductive material can serve as a conductor for charges formed when tio2 is excited by light. This reduces the likelihood of recombination of charge carriers and improves the efficiency of photocatalysis. The addition of rGO can affect the crystal structure of TiO_2. In some cases, this may lead to a change in the phase composition or an improvement in the distribution of crystallites. In other instances, rGO can act as a structural template, helping TiO_2 form more stable structures with an increased surface area.

rGO can contribute to a more uniform distribution of TiO_2 nanoparticles in the material, preventing their aggregation. This is especially important to maintain a high contact surface and catalyst activity.

The rGO- TiO_2 nanocomposite material can demonstrate improved properties at the phase boundary, where efficient separation and transport of charge carriers occur, contributing to enhanced catalytic and sensor characteristics.

Many studies confirm that adding rGO to TiO_2 can significantly improve its photocatalytic activity [13-15]. Due to the improved conductivity of rGO, electrons generated in TiO_2 by light can be efficiently transferred to graphene, reducing their recombination and increasing the efficiency of photocatalysis. rGO helps to improve the effective surface of TiO_2, which increases the contact area with reagents and accelerates photochemical reactions. In some cases, rGO can prevent the aggregation of TiO_2 particles, maintaining stability and improving the material's durability.

However, optimal results are achieved at a certain concentration of rGO. Excessive amounts of reduced graphene oxide can cause poor particle distribution or even lead to deterioration of material properties due to aggregation of graphene sheets.

Applying TiO_2-rGO nanocomposite materials has excellent properties for decomposing organic pollutants and hydrogen from water using sunlight. In photovoltaic devices, rGO can help improve electron transport and energy conversion efficiency. As sensors, TiO_2-rGO can detect gases or change the concentration of pollutants.

This work obtains an ultraviolet detector of a nanocomposite material based on rGO and TiO_2. It is assumed that adding rGO to TiO_2 in the complex will improve the optoelectronic characteristics of the photodetector since their use has led to an increase in the efficiency of photocatalytic properties [16].

Materials and methods

The preparation of nanocomposite materials was carried out using hydrothermal synthesis according to the works [16, 17]. The preparation was carried out based on rGO (Cheaptubes, USA), TiO_2 (d>21 nm, anatase, 99.7 %, Sigma Aldrich), deionized water (Drawel water purification system), and ethanol (anhydrous). The concentration of rGO in the resulting nanocomposite material is 10 %, as studies have shown that at this concentration, the materials have highly effective catalytic activity [17]. All reagents were analytically pure and used without additional purification.

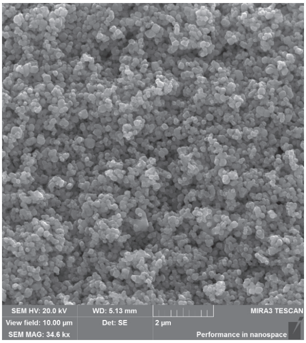
The surface morphology of the obtained composite materials was studied using a scanning electron microscope (SEM, Tescan Mira3). Films of TiO_2 or TiO_2-rGO nanocomposite were prepared from a paste obtained by continuous mixing of 150 mg of TiO_2 and TiO_2-rGO powder with 1 ml of ethanol for 24 hours. The finished paste was applied to the surface of the substrates using the "spin-coating" method at a rotation speed of 3000 rpm. After application, the film was annealed in an Ar atmosphere for 2 hours at a temperature of 450 °C (Tmax).

Results and discussion

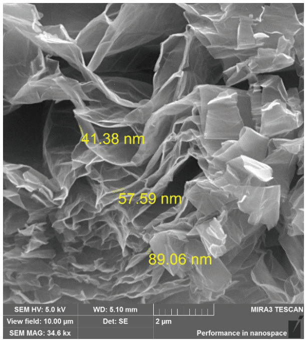
Figure 1 shows the low-frequency TiO_2 structures of anatases. It can be seen from the figure that the woofers are distributed on the surface of the substrate. Next, Figure 1b shows SEM images of rGO, which has a sheet thickness from 40 nm to 90 nm. In this case, thick sheets of rGO are most likely superimposed on each other since they are rare in the sample. Or it can be called multilayer rGO sheets. In these samples, rGO has a layered structure distributed over the entire substrate volume.

The arrangement of the rGO sheets can also be observed through the AFM, shown in Figure 1, B. The AFM indicates precisely the same surface distribution as in SEM images. Once again, these data show the distribution of rGO sheets.

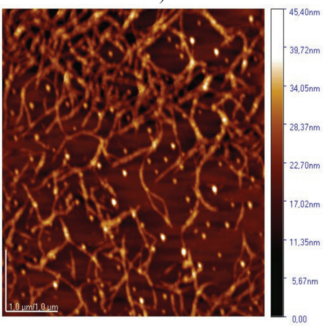
SEM images were obtained after synthesizing the nanocomposite material, as shown in Figure 1. TiO_2 NPs are distributed on the surface of rGO sheets. The study of the structure using SEM shows that an island film is formed when rGO is added to TiO_2. TiO_2 NPs are wrapped in sheets of rGO, creating a conductive network in the nanocomposite material. This network is probably responsible for the recombination of TiO_2 charge carriers. Thus, the TiO_2 electrons are transferred to the surface of the rGO sheets, and they, in turn, move to the FTO and transmit a signal for registration. The images indicate the formation of a nanocomposite material based on rGO and TiO_2.



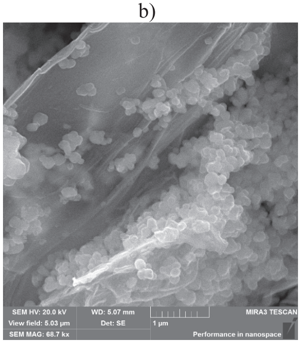
a)



b)



c)



d)

Figure 1 – SEM images samples: a – TiO_2,
b – rGO, d – TiO_2-rGO, and AFM image rGO

Next, Figure 2 shows the Raman spectra of the starting materials and the nanocomposite material. The Raman spectra of TiO2 correspond to previous work. The Raman spectra of rGO also have characteristic peaks for graphene and its derivatives. These are the D- and G-peaks, which characterize the defect and crystallization of the material. In the Raman spectra, as can be seen from the figure, there are peaks of the source materials.

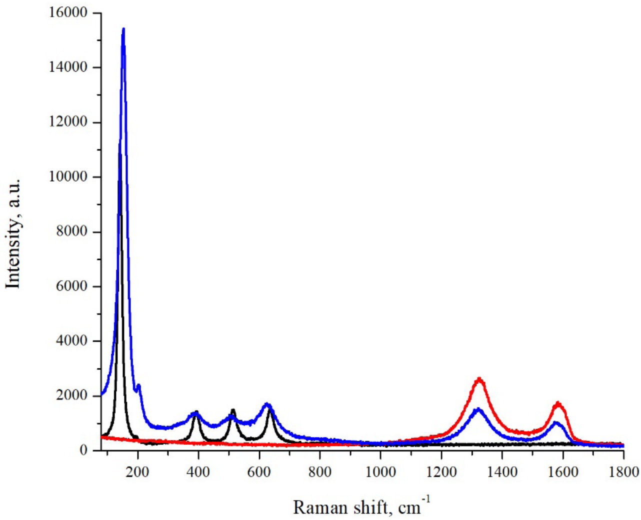


Figure 2 – Raman shift samples: dark – TiO2,
red – rGO, blue – TiO2-rGO

Thus, the formation of a TiO2-rGO nanocomposite material can be observed using the Raman spectrum.

Conclusions

A study of the effect of reduced graphene oxide on the structural properties of titanium dioxide has shown that rGO significantly improves the photocatalytic, photodetectable, optical, and other functional characteristics of TiO2. This approach has great potential in creating highly efficient materials for environmental, energy, and sensor applications.

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Received 12.10.24.
Received in revised form 12.10.24.
Accepted for publication 20.12.24.

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Қазақстан Республикасы, Павлодар қ.
12.10.24 ж. баспаға түсті.
12.10.24 ж. түзетулерімен түсті.
20.12.24 ж. басып шығаруға қабылданды.

ҚАЛПЫНА КЕЛТІРІЛГЕН ГРАФЕН ОКСИДІНІҢ ТИТАН ДИОКСИДІНІҢ ҚҰРЫЛЫМДЫҚ ҚАСИЕТТЕРІНЕ ӘСЕРІН ЗЕРТТЕУ

Аталмыш жұмыс қалпына келтірілген графен оксидінің (rGO) титан диоксидінің (TiO_2) құрылымдық және физика-химиялық қасиеттеріне әсерін зерттейді. RGO-ны TiO_2 модификаторы ретінде пайдалану оның фотокаталитикалық белсенділігін арттыру, *сондай-ақ механикалық және электрлік өнімділігін жақсарту үшін өте маңызды. Зерттеу барысында сканерлеуші электронды микроскопия мен атомдық күш микроскопиясының көмегімен құрылымдық талдаудан өткен әр түрлі тотықсыздандырылған графен концентрациясындағы TiO_2/rGO нанокомпозиттері алынды. Нәтижелер rGO қосылуы TiO_2 кристалдық құрылымының өзгеруіне ықпал ететінін, сонымен қатар оның кеуектілігі мен беті сияқты текстуралық сипаттамаларын жақсартатынын көрсетті. RGO концентрациясының нанокомпозиттердің қасиеттеріне әсері де зерттелді, бұл TiO_2 фотокаталитикалық белсенділігін арттыру үшін оңтайлы қатынасты анықтауға мүмкіндік берді. Қосымша спектроскопиялық зерттеулер жүргізілді, бұл rGO қосылған кезде tio_2 өткізгіштік қасиеттері мен тұрақтылығының жақсарғанын растады. Нәтижелер суды тазарту, күн энергиясы және сенсорлар саласында қолданылатын функционалдық қасиеттері жақсартылған жоғары тиімді TiO_2 негізіндегі материалдарды әзірлеуге перспективалар береді.*

Кілтті сөздер: қалпына келтірілген графен оксиді, титан диоксиді, нанокомпозиттік материал, фотокатализ, фотодетектор.

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Поступило в редакцию 12.10.24.
Поступило с исправлениями 12.10.24.
Принято в печать 20.12.2024.

ИССЛЕДОВАНИЕ ВЛИЯНИЯ ВОССТАНОВЛЕННОГО ОКСИДА ГРАФЕНА НА СТРУКТУРНЫЕ СВОЙСТВА ДИОКСИДА ТИТАНА

В данной работе исследуется влияние восстановленного оксида графена (rGO) на структурные и физико-химические свойства диоксида титана (TiO_2). Использование rGO в качестве модификатора TiO_2 имеет важное значение для повышения его фотокаталитической активности, а также улучшения механических и электрических характеристик. В ходе исследования *были получены нанокомпозиты TiO_2/rGO различной концентрации восстановленного графена, которые подвергались структурному анализу с использованием сканирующей электронной микроскопии и атомно-силовой микроскопии. Результаты показали, что добавление rGO способствует изменению кристаллической структуры TiO_2, а также улучшает его текстурные характеристики, такие как пористость и поверхность. Влияние концентрации rGO на свойства нанокомпозитов было также изучено, что позволило выделить оптимальное соотношение для повышения фотокаталитической активности TiO_2. Дополнительно проведены спектроскопические исследования, подтвердившие улучшение проводящих свойств и стабильности TiO_2 при добавлении rGO. Полученные результаты открывают перспективы для разработки высокоэффективных материалов на основе TiO_2 с улучшенными функциональными свойствами, применяемых в области очистки воды, солнечной энергетики и сенсоров.*

Ключевые слова: восстановленный оксид графена, диоксид титана, нанокомпозитный материал, фотокатализ, фотодетектор.

Теруге 09.12.2024 ж. жіберілді. Басуға 30.12.2024 ж. қол қойылды.
Электрондық баспа
7,50 Mb RAM
Шартты баспа табағы 10,01. Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: Е. Е. Калихан
Корректор: А. Р. Омарова, Д. А. Кожас
Тапсырыс № 4318

Сдано в набор 09.12.2024 г. Подписано в печать 30.12.2024 г.
Электронное издание
7,50 Mb RAM
Усл.печ.л. 10,01. Тираж 300 экз. Цена договорная.
Компьютерная верстка Е. Е. Калихан
Корректор: А. Р. Омарова, Д. А. Кожас
Заказ № 4318

«Toraighyrov University» баспасынан басылып шығарылған
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