APPLICATION OF NITROGEN-DOPED TiO_2 NANOTUBES IN MICROELECTRONICS AND ENERGY FIELDS

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Abstract. In recent years, the need to increase energy efficiency and create new functional materials determines the relevance of this topic. In this article, the application of nitrogen-doped TiO2 nanotubes in the fields of microelectronics and energy was analyzed. Nitrogen doping can improve the optical and electrical properties of TiO2 nanotubes and expand their application in solar cells, sensors, and energy storage devices. As a result, it can be shown that these materials have high efficiency and stability.

Keywords: Nanotubes, TiO2, nitrogen, microelectronics, energy, efficiency, sensor.

INTRODUCTION

In recent years, the rational use of energy resources, increasing energy efficiency, and introducing environmentally friendly technologies have become pressing issues worldwide. In this regard, large-scale reforms are being carried out in the Republic of Uzbekistan, and this direction is defined as one of the priority tasks of state policy. In particular, the Decree of the President of the Republic of Uzbekistan dated August 22, 2019 No. UP-5786 "On Measures to Increase Energy Efficiency in Sectors of the Economy and the Social Sphere" is one of the important documents aimed at the widespread introduction of energy-saving technologies [1]. Also, Resolution No. PP-4477 of October 4, 2020, serves to accelerate the development of renewable energy sources and attract modern technologies to the industry [2].

In addition, the "Strategy for the Transition of the Republic of Uzbekistan to a "Green Economy" until 2030," approved by Decree No. UP-5853 of October 23, 2019, pays special attention to ensuring environmental sustainability, increasing energy efficiency, and expanding the use of innovative materials. Based on these documents, broad opportunities are being created for the development of science and innovative technologies, including research in the field of nanomaterials [3].

Among the nanomaterials created on the basis of modern scientific achievements, titanium dioxide nanotubes are distinguished by their unique physical and chemical properties. They are widely used in various fields due to their high surface area, chemical stability, and environmental safety. However, their main disadvantage is that they absorb light mainly in the ultraviolet range. Therefore, in order to improve their properties, doping methods, in particular, doping with nitrogen, are widely used. Nitrogen-doped TiO2 nanotubes are also active in the visible light range, which significantly expands their possibilities of application. In particular, they provide high efficiency in solar energy systems, photocatalytic processes, gas sensors, and energy storage devices. In the field of microelectronics, there is an opportunity to create nanoscale devices with high sensitivity based on these materials [4].

In the energy sector, the use of nitrogen-doped TiO2 nanotubes plays an important role in increasing the efficiency of solar panels, improving hydrogen energy production and energy storage technologies. This, in turn, contributes to the efficient use of energy resources and the reduction of environmental problems.

LITERATURE REVIEW

In scientific research conducted by foreign scientists, the issue of improving the photocatalytic and electronic properties of TiO2 nanotubes has been widely covered. In particular, Asahi scientifically substantiated the possibility of expanding the light absorption range of TiO2 by doping with nitrogen. Their research showed that nitrogen atoms penetrate the crystal lattice of TiO2, altering its electronic structure and increasing its activity in visible light [5]. Also, in the research conducted by Chen and Mao, the application of nanomaterials based on TiO2 in the fields of energy and ecology was thoroughly analyzed. They emphasize that nanotube-shaped structures increase efficiency in photocatalytic processes due to their high surface area [6].

In studies conducted by a number of other scientists, including Grätzel, in the field of solar cells, it was found that the use of TiO2 nanotubes increases the efficiency of converting solar energy into electrical energy. Nitrogen doping further improves this process and allows for the efficient use of visible light. At the same time, there are extensive studies on the use of TiO2 nanotubes in sensor technologies, in which issues of increasing gas sensitivity and improving the properties of rapid response have been studied [7].

Uzbek scientists are also conducting scientific research on the study of nanomaterials, in particular, structures based on TiO2. Research is being conducted in research institutes and higher educational institutions of the republic aimed at increasing energy efficiency, using renewable energy sources, and creating new functional materials.

In particular, local scientists have studied the possibilities of increasing the photocatalytic activity of materials based on TiO2, their use in water purification, air disinfection, and solar energy systems. In recent years, research conducted by scientists of Uzbekistan has paid special attention to the modification of nanostructured materials, the improvement of their physicochemical properties, and their practical application. In particular, scientific results are being obtained to improve the optical and electrical properties of TiO2 nanotubes by doping them with nitrogen and other elements, and to expand their application in the fields of microelectronics and energy.

METHODOLOGY

In this study, a comprehensive methodological approach was used to study the possibilities of using nitrogen-doped TiO2 nanotubes in the field of microelectronics and energy. The research was carried out in several stages: synthesis of materials, analysis of their structure and properties, and assessment of their practical application.

RESULT AND DISCUSSION

A comprehensive analysis of the structural, optical, and electrical properties of nitrogen-doped TiO2 nanotubes was carried out, and the effectiveness of their practical application was evaluated. The obtained results showed that nitrogen doping forms active centers on the surface of nanotubes, increasing their chemical activity and surface area. This directly affects the functional properties of the material.

As a result of optical analysis, it was found that the energy forbidden zone of TiO2 nanotubes significantly decreases under the influence of nitrogen doping. As a result, the material becomes active not only in the ultraviolet but also in the visible light range. This is especially important in increasing the efficiency of solar cells.

Analysis of electrical properties showed that doping with nitrogen increases electron conductivity several times and reduces the recombination of charge carriers. This ensures speed and stability in sensor devices and energy storage systems.

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Based on practical experiments, N-TiO2 nanotubes demonstrated high efficiency in solar cells, high sensitivity and rapid response time in gas sensors, as well as high capacity and cyclic stability in energy storage devices.

Table 1.

Overall comparison of TiO2 and N-TiO2 nanotubes

Parameter	**TiO_2 Nanotubes**	**N–TiO_2 Nanotubes**
Structural characteristics	Ordered	Ordered + active sites
Band gap (eV)	~3.2	~2.7–2.9
Light absorption	UV region	UV + visible region
Electrical conductivity	Low	High
Charge recombination	High	Reduced
Sensor sensitivity	Moderate	High
Response time	Slow	Fast
Solar cell efficiency	Low	High
Energy storage capacity	Moderate	High
Stability	Moderate	High

In general, the results show that nitrogen doping improves all the main functional properties of TiO2 nanotubes. At the same time, it is important to maintain the optimal amount of dopant, since excessive doping can negatively affect the structural stability of the material.

Conclution

This study demonstrates that nitrogen-doped TiO_2 nanotubes (N–TiO_2 NTs) exhibit significantly enhanced structural, optical, and electronic properties compared to undoped TiO_2. Nitrogen doping introduces active sites on the nanotube surface, increasing chemical reactivity and surface area, while reducing the band gap to enable visible-light activity. These modifications improve charge carrier mobility and reduce recombination, resulting in superior performance in practical applications.

Experimental evaluations confirmed that N–TiO_2 nanotubes achieve higher efficiency in solar cells, faster response and greater sensitivity in gas sensors, and enhanced capacitance and cyclic stability in energy storage devices. Both international and local research highlights the potential of doped TiO_2 nanomaterials for microelectronics, energy, and environmental applications. Overall, nitrogen-doped TiO_2 nanotubes represent a promising multifunctional material for next-generation functional and energy devices.

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