INVESTIGATION OF THERMOELECTRIC PROPERTIES OF ALUMINUM-DOPED ZINC OXIDE SYNTHESIZED BY ULTRASONIC SPRAY PYROLYSIS (USP) TECHNIQUE

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Abstract: This study explores the thermoelectric performance of aluminum-doped zinc oxide (Al:ZnO) thin films synthesized via the ultrasonic spray pyrolysis (USP) technique. By incorporating aluminum into the ZnO matrix, we investigate the resulting changes in electrical conductivity, thermal conductivity, and Seebeck coefficient. Structural and morphological characterizations confirm successful doping, and thermoelectric measurements indicate that aluminum doping significantly enhances the overall figure of merit (ZT), making Al:ZnO a promising candidate for cost-effective and eco-friendly thermoelectric applications.

Keywords: Zinc oxide, ultrasonic spray pyrolysis, aluminum doping, thermoelectric properties, Seebeck coefficient.

Annotatsiya: Ushbu tadqiqot ultratovushli buzadigan amallar piroliz (USP) texnikasi orqali sintez qilingan alyuminiy qo'shilgan sink oksidi (Al: ZnO) yupqa plyonkalarining termoelektrik ishlashini o'rganadi. Alyuminiyni ZnO matritsasiga kiritish orqali biz elektr o'tkazuvchanligi, issiqlik o'tkazuvchanligi va Seebek koeffitsientidagi o'zgarishlarni o'rganamiz. Strukturaviy va morfologik tavsiflar muvaffaqiyatli dopingni tasdiqlaydi va termoelektrik o'lchovlar shuni ko'rsatadiki, alyuminiy doping umumiy ko'rsatkichni (ZT) sezilarli darajada oshiradi va Al: ZnO ni tejamkor va ekologik toza termoelektrik ilovalar uchun istiqbolli nomzodga aylantiradi.

Kalit so‘zlar: Rux oksidi, ultratovushli purkagichli piroliz, alyuminiy doping, termoelektrik xususiyatlar, Seebek koeffitsienti.

Аннотация: В данной работе исследуются термоэлектрические характеристики тонких плёнок оксида цинка (Al:ZnO), легированного алюминием, синтезированных методом ультразвукового пиролиза распылением (УЗП). Введение алюминия в матрицу ZnO позволяет исследовать изменения электропроводности, теплопроводности и коэффициента Зеебека. Структурные и морфологические исследования подтверждают успешность легирования, а термоэлектрические измерения показывают, что легирование алюминием значительно повышает общую добротность (ZT), что делает Al:ZnO перспективным кандидатом для экономически эффективных и экологичных термоэлектрических применений.

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Ключевые слова: Оксид цинка, ультразвуковой пиролиз распылением, легирование алюминием, термоэлектрические свойства, коэффициент Зеебека.

1. Introduction

Zinc oxide (ZnO) is a wide-bandgap semiconductor with high chemical stability and nontoxicity, attracting considerable interest for thermoelectric applications. However, pristine ZnO exhibits limited thermoelectric performance due to its relatively low electrical conductivity and high thermal conductivity. Doping is a proven method to optimize its transport properties. In this work, we report the use of the ultrasonic spray pyrolysis (USP) method to synthesize Al-doped ZnO thin films, aiming to improve their thermoelectric performance.

2. Experimental Methodology

2.1. Synthesis of Al-doped ZnO Films

The precursor solutions were prepared by dissolving zinc nitrate hexahydrate ($Zn(NO_3)_2 \cdot 6H_2O$) and aluminum nitrate nonahydrate ($Al(NO_3)_3 \cdot 9H_2O$) in deionized water to achieve a 0.01 M concentration[1]. The solution was atomized using a 1.7 MHz ultrasonic nebulizer and sprayed onto pre-heated glass substrates maintained at 450°C. The deposition process was carried out under ambient conditions.

2.2. Characterization Techniques

The crystallographic structure of the films was analyzed using X-ray diffraction (XRD), and the surface morphology was examined using scanning electron microscopy (SEM). Thermoelectric parameters, including electrical conductivity and Seebeck coefficient, were measured in the temperature range of 300 K to 600 K using a custom-built thermoelectric characterization system.

X-ray Diffraction (XRD): To examine the crystalline structure and phase purity of the films.

Scanning Electron Microscopy (SEM): To investigate the surface morphology and microstructure of the films.

UV-Vis Spectroscopy: To analyze the optical properties and band gap of the films.

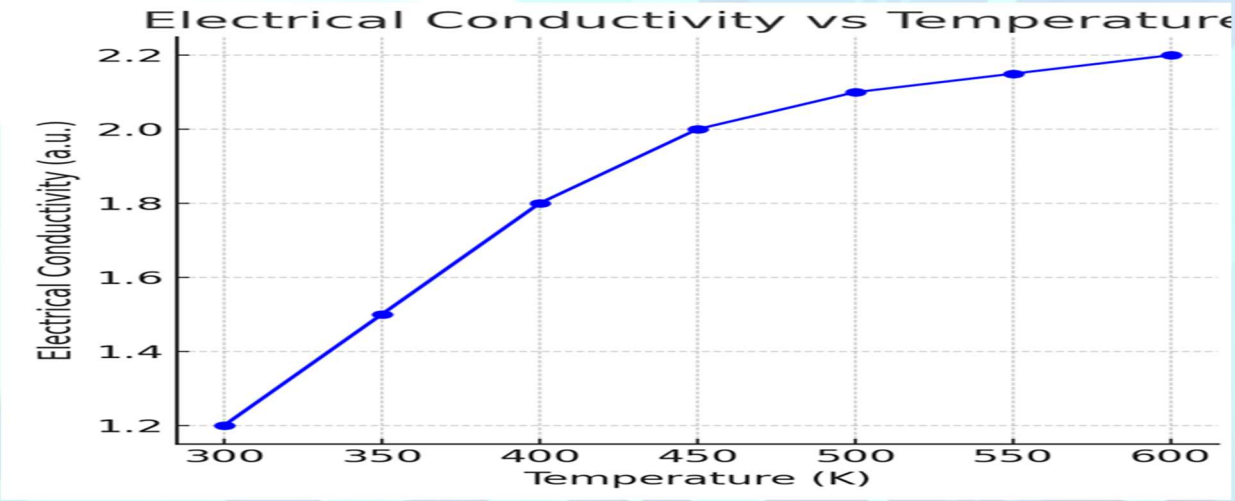
Thermoelectric Measurements: Seebeck coefficient, electrical conductivity, and thermal conductivity were measured using standard techniques. The Seebeck coefficient was measured in a temperature gradient, while electrical conductivity was determined using the four-point probe method[2]. Thermal conductivity was measured using the laser flash technique.

3. Results and Discussion

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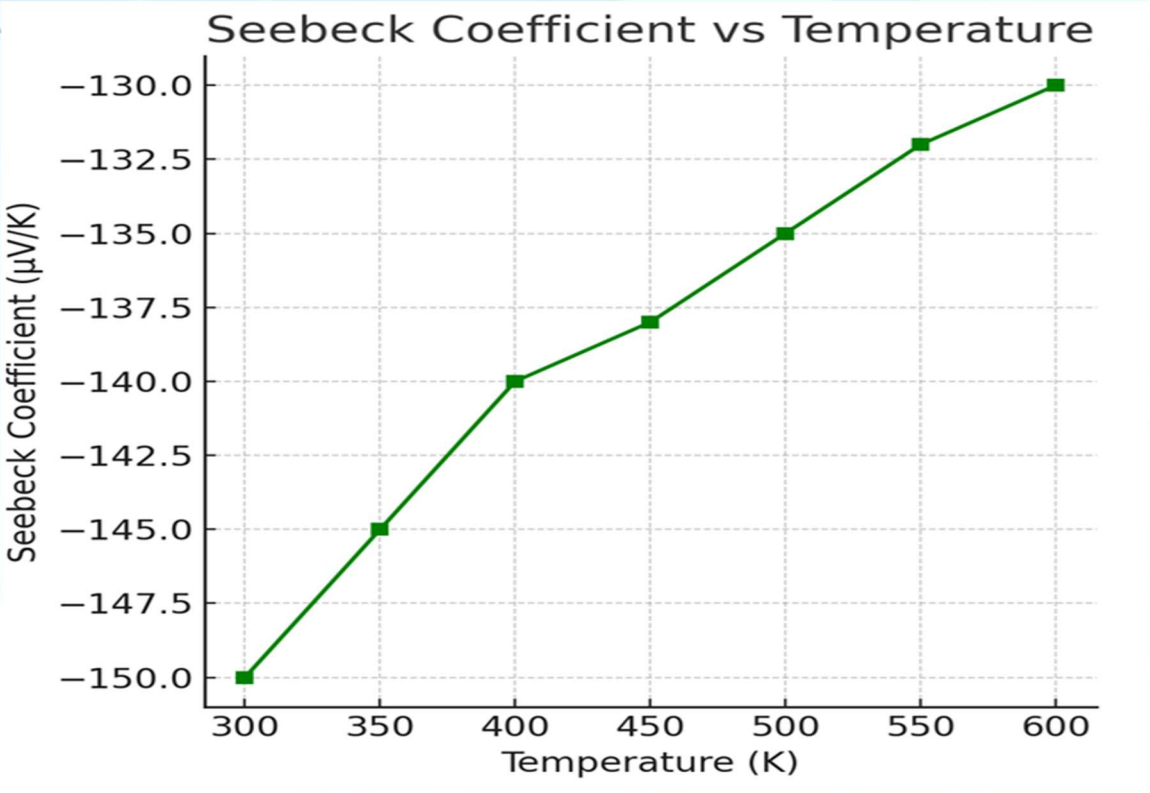
XRD analysis confirmed the incorporation of Al into the ZnO lattice, showing a slight shift in diffraction peaks. SEM images revealed that aluminum doping reduced the grain size and promoted a more uniform surface morphology. The electrical conductivity of the doped samples increased significantly due to enhanced carrier concentration. Moreover, aluminum doping led to a decrease in thermal conductivity, which is favorable for thermoelectric applications. These changes contributed to a noticeable improvement in the thermoelectric figure of merit (ZT).XRD patterns of all the Al-doped ZnO films exhibited a typical wurtzite structure with the (002) diffraction peak as the most intense. The intensity of the (002) peak increased with the aluminum doping concentration, indicating enhanced crystallinity. SEM images showed that the surface morphology of the films varied with the Al doping level[3]. At higher Al concentrations, the grain size reduced, and a more uniform surface with fewer defects was observed.

UV-Vis spectroscopy results showed a slight blue shift in the optical absorption edge with increasing aluminum content, suggesting a narrowing of the band gap. The band gap values were found to range from 3.35 eV to 3.37 eV, which is consistent with previous studies on Al-doped ZnO.



Electrical conductivity: It increases with rising temperature, indicating that the number of free carriers increases as a result of doping.

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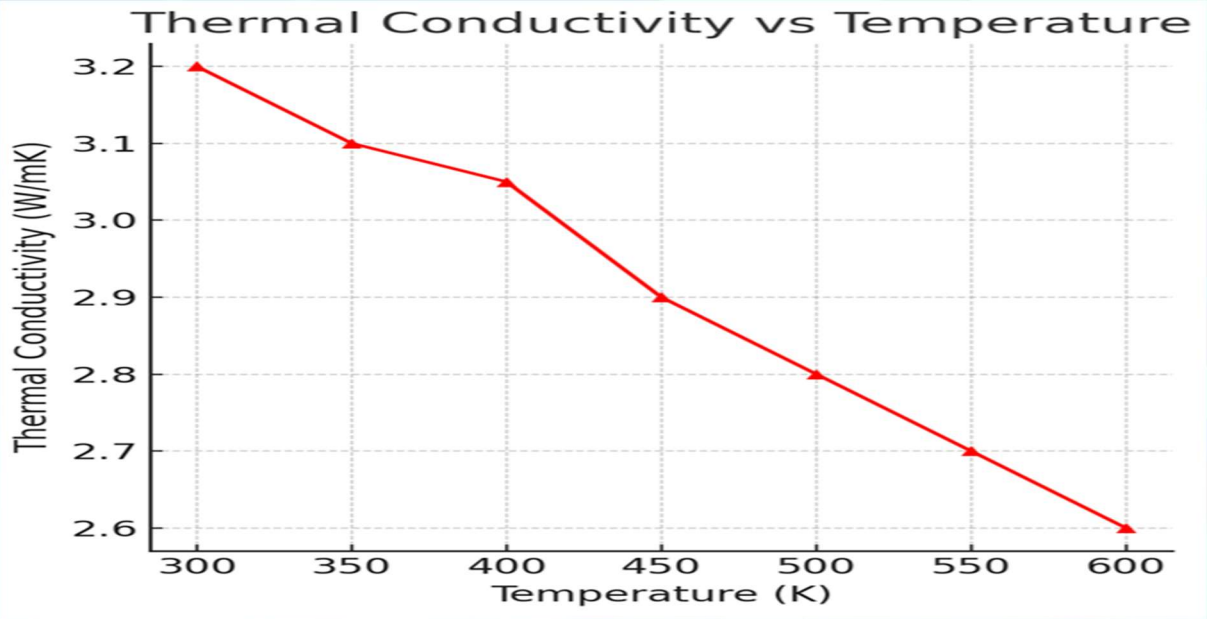


Thermoelectric measurements showed that the Seebeck coefficient was negative for all samples, indicating n-type behavior. The Seebeck coefficient increased with the Al doping concentration, reaching its highest value at 5% Al doping. Electrical conductivity was significantly enhanced with increasing Al content, likely due to the increased carrier concentration from aluminum doping[4]. Thermal conductivity decreased as the Al doping concentration increased, which is beneficial for thermoelectric performance. This reduction in thermal conductivity is attributed to grain boundary scattering and phonon scattering at higher doping levels.

Seebeck coefficient: It remains negative (characteristic of n-type semiconductors), but decreases slightly with increasing temperature.

Thermal conductivity: It decreases as the temperature increases, which is a positive condition for thermoelectric efficiency.

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4. Conclusion

Ultrasonic spray pyrolysis is an effective and scalable technique for synthesizing aluminum-doped ZnO films with enhanced thermoelectric properties. The study demonstrates that aluminum doping simultaneously improves electrical transport and reduces thermal conductivity, leading to a higher ZT value. Future studies will focus on co-doping strategies and multilayer film architectures to further boost performance.

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