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Experimentally investigation on solar hydrogen production efficiency of different gallium nitride films

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Abstract

This study experimentally investigates hydrogen production efficiency under sunlight exposure for gallium nitride (GaN) films. GaN is a semiconductor with a wide bandgap (3.3 eV). It photoelectrochemical (PEC) effect brings about water splitting under ultraviolet light (wavelength less than 0.375 μm) and hydrogen generation. Characteristics of each thin film sample are measured, and their generation efficiency is compared. The film samples vary in thickness (100 nm, 400 nm, 1000 nm), preparation methods (RF Sputter and MOCVD), and the presence absence of a zinc oxide (ZnO) anti-reflective layer. The measured target quantities include electrochemical performance, film characteristics, electrical properties, and radiative properties. The results will demonstrate the feasibility of sustainable hydrogen production using GaN thin films through green energy methods. The potential applications of wide bandgap semiconductors in the hydrogen energy industry will also be explored.

Introduction

Gallium nitride (GaN) has gained interest due to its wide bandgap (3.3 eV) and excellent optoelectronic properties.This study investigates the performance of GaN thin films with different thicknesses and fabrication methods in photocatalytic water splitting, and experimentally verifies the effectiveness of anti-reflection coatings, aiming to enhance the hydrogen production efficiency of GaN.

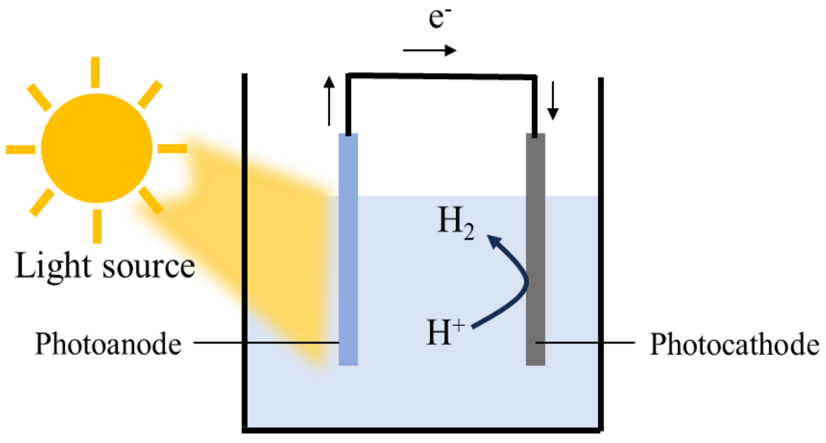

Fig. 1 Photoelectrochemical water splitting

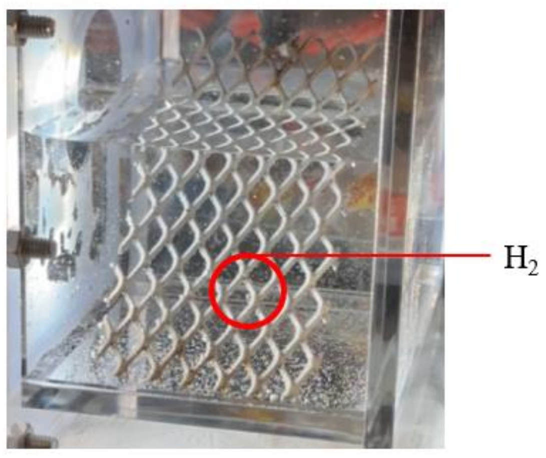

Fig. 2 Hydrogen production

Methodology

Fig. 2 shows the ultraviolet spectrum measurement system used in this study. Ultraviolet light (0.2 μm – 0.4 μm) emitted from a deuterium-tungsten halogen lamp serves as the light source. By using different optical path designs, the system can separately measure the transmittance (τ) and reflectance (ρ) of the samples. Then, using the law of energy conservation (τ + ρ + α = 1), the absorptance (α) is calculated.

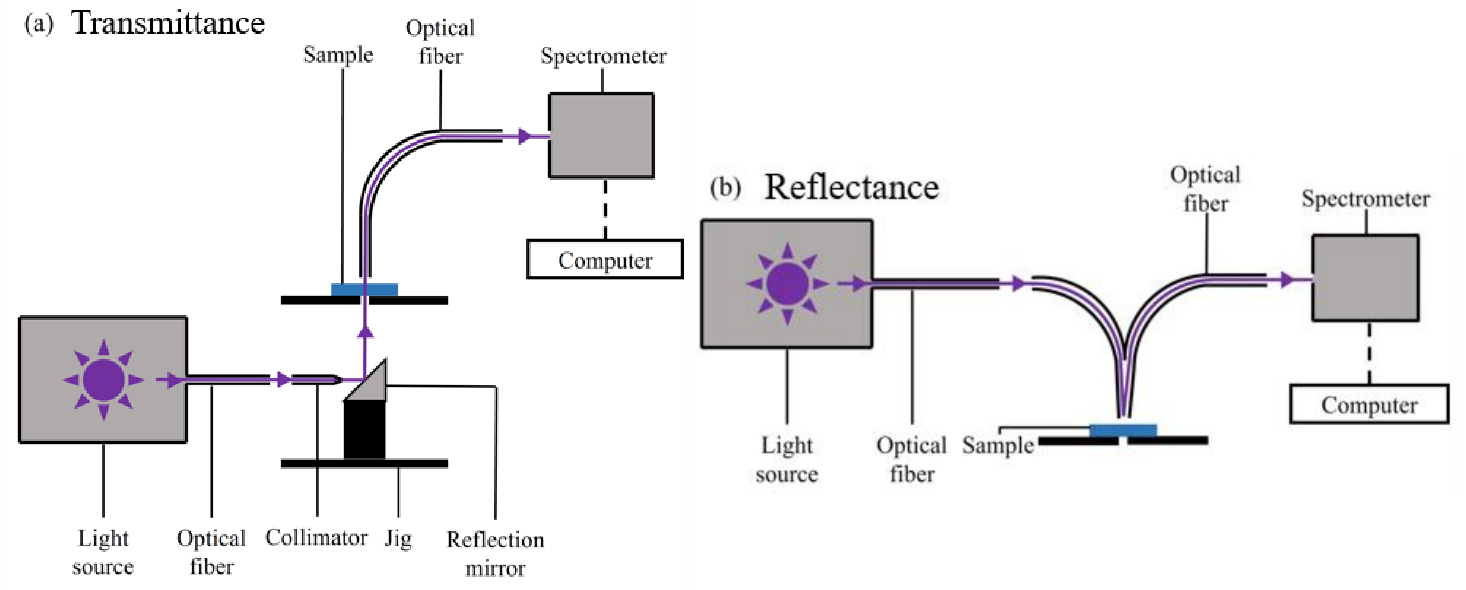

Fig. 2 Ultraviolet (0.2 - 0.4 μm) Spectrum Measurement :
(a) Transmittance Measurement;(b) Reflectance Measurement

Fig. 3 illustrates the schematic diagram of the electrochemical experiment system constructed in this study. The system includes a potentiostat, a water electrolysis cell, a collimating lens assembly, a platinum titanium mesh, and a UV light source. Above the water electrolysis cell, there is a circular cover with three circular holes, which are fixed at a specific distance. These holes are used to place the platinum mesh, the GaN sample, and the reference electrode.

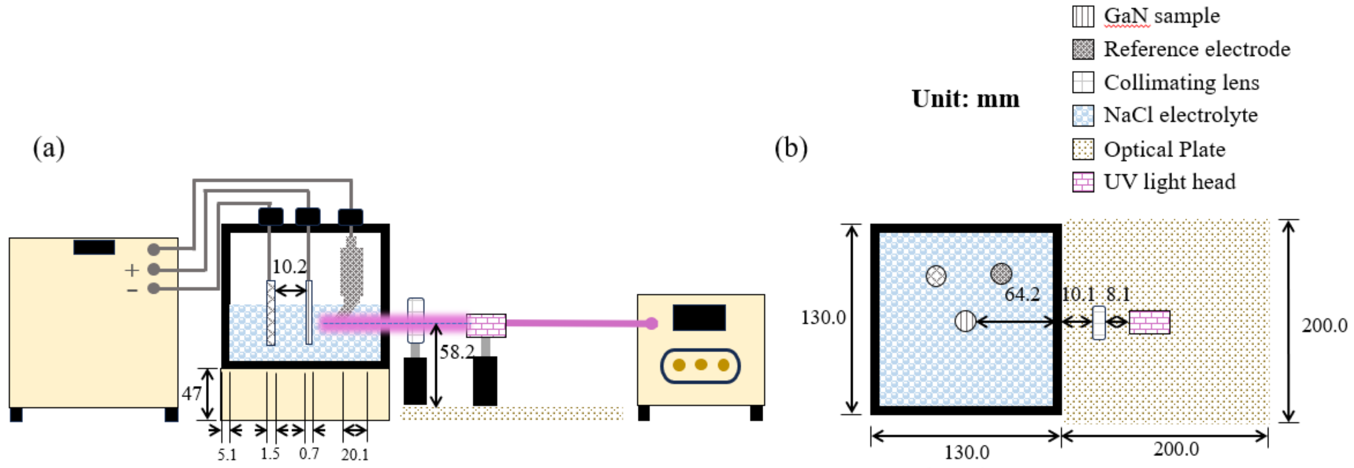

Fig. 3 Schematic diagram of the electrochemical system:
(a) Side view; (b) Top view

Results and disscussion

Fig. 4(a) illustrates the reflectance results of GaN thin films before and after applying an anti-reflection layer, showing a significant reduction in reflectance, which improves light absorption and enhances hydrogen production efficiency. Fig. 4(b) demonstrates that the GaN thin films, especially with the anti-reflection layer, exhibit greatly increased absorptance, contributing to better photocatalytic performance.

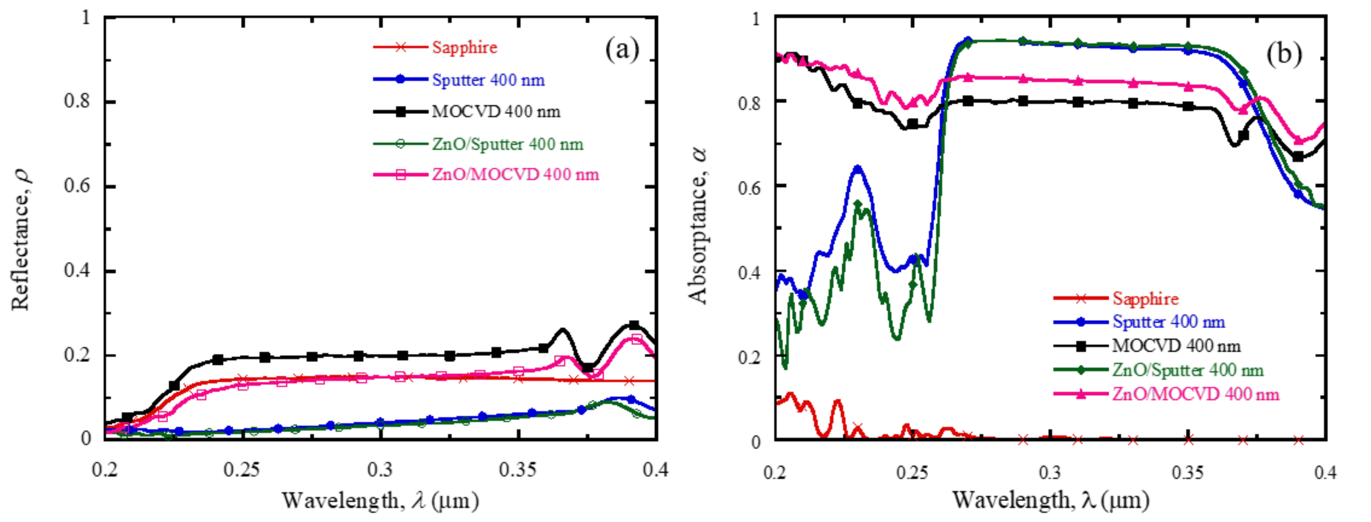

Fig. 4 Radiation property of GaN Samples from different processes:
(a) Reflectance;(b) Absorptance

This study used a potentiostat to measure the photocurrent density of the samples, allowing for the calculation of hydrogen production efficiency. The expression is as follows:

$$\eta = \frac{j_p \cdot 1.23}{I} \times 100\% \qquad (1)$$

which η is the hydrogen production efficiency, I is the incident illumination intensity, and j_p is the photocurrent density.

Table 2 shows that the photocurrent density of sputtered GaN thin films decreased after applying a ZnO anti-reflection layer. After annealing, the hydrogen production efficiency improved by approximately 23%. In contrast, the MOCVD-prepared GaN films exhibited much higher hydrogen production efficiency, with the 400 nm samples increasing by about 710%.Due to the still low hydrogen production efficiency, relative improvements were used for comparison.

Table 2 Photocurrent density measurements of GaN samples produced using different process with ZnO anti-reflection layer (before and after annealing)

Process	Thickness	Anti-reflection layer	Photocurrent (10^4 mA/cm^2)	H_2 production efficiency (%)
Sputter	400 nm	No	2.04 ± 0.13	0.000227
		Yes	1.73 ± 0.03	0.000205
		Annealing	2.22 ± 0.01	0.000252
MOCVD	400 nm	No	14.82 ± 0.12	0.001716
		Yes	3.52 ± 0.03	0.000482
		Annealing	81.93 ± 6.22	0.003908

Conclusion

This study confirmed that GaN thin films, whether prepared by sputtering or MOCVD, exhibited significant improvements in hydrogen production efficiency up to 710% after the application of an anti-reflection layer and annealing treatment. This highlights the crucial role of fabrication methods, film thickness, and post-treatment in enhancing the light absorption and conductivity of GaN films. However, compared to existing literature, there is still room for further improvement.

Acknowledgements

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