Spectroscopic Characteristics of Indium Nitride Nanostructures Prepared by Pulsed Laser Ablation

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Abstract
In this work, indium nitride (InN) nanoparticles were prepared by pulsed laser ablation (PLAL) by irradiation of In target immersed in NH_4OH solution. All functional groups constituting the indium nitride molecule were found in the prepared samples with no trace belonging to other materials, which reflects the high structural purity of the prepared nanoparticles. The absorbance of the prepared nanoparticles was found to depend on the laser energy used to prepare them, which determines the volume concentration of these nanoparticles, and hence the density of the solution to be measured.

Keywords: Indium nitride; Laser ablation; Nanostructures; Spectroscopic characteristics
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1. Introduction

The laser ablation in liquid (LAL) process begins with the interaction of laser light with the surface of a solid target [1]. This triggers chemical reactions between the particles in the resulting plume and the molecules of the surrounding liquid. These collisions lead to the formation of new compounds, typically nanoparticles composed of atoms from both the target material and the liquid. These nanoparticles become suspended in the liquid, forming a colloidal solution [2-4]. As the nanoparticles aggregate, additional reactions may occur due to the presence of laser radiation, which can further alter the composition, size, and morphology of the final product [5,6].

The benefits of the laser ablation in liquid technique are as follows. Laser pulses can reach the surface of a submerged target as long as the liquid is transparent to the laser light [7]. The method is versatile and can be applied to any type of target material [8]. The ablated species, such as atoms and ions, are often in highly excited states, allowing them to emit light [9]. The liquid confines the ablated species to a small region, resulting in high pressure and density during the initial stages of ablation. The technique is cost-effective and straightforward, as it eliminates the need for vacuum equipment [10,11]. Nanoparticles are easily collected after synthesis, as they are stored in the liquid as a colloidal solution [12]. The ablated material can serve as a precursor for chemical reactions, particularly in nanoparticle formation [13,14]. The expansion of particles ejected from the target is significantly limited due to the confinement effect of the surrounding liquid. A cavitation bubble forms after the plasma disappears, accompanied by optical emission [15,16].

Despite the distinct advantages of liquid-phase laser ablation, it has certain limitations. One major drawback is the inability to effectively control plasma properties [17,18]. The nanoparticles produced through this method often exhibit a broad size distribution, which is attributed to the agglomeration of nanoclusters and the potential release of larger target fragments during the ablation process [19]. Additionally, a relatively low product yield is a significant disadvantage of this technique [20]. Indium nitride (InN) is a binary III-V semiconductor composed of indium (In) and nitrogen (N). It crystallizes in a hexagonal wurtzite structure under normal conditions, although a metastable cubic phase can also exist under specific conditions [21,22]. The material has a relatively low bandgap energy of approximately 0.7 eV, making it a promising candidate for infrared and high-speed electronic applications [23]. InN exhibits high electron mobility, typically exceeding 2000 $cm^2/V\cdot s$ at room temperature, which contributes to its potential for high-performance electronic devices [24].

Indium nitride has garnered significant attention due to its unique properties, enabling a wide range of applications [25]. The low bandgap and high electron mobility make InN an ideal material for infrared photodetectors, light-emitting diodes (LEDs), and laser diodes [26-29]. Its ability to cover a broad spectrum of wavelengths enhances its utility in optoelectronic devices. The high electron mobility and thermal conductivity of InN are advantageous for fabricating high-frequency transistors and other electronic components used in wireless communication and radar systems [30-32]. Tunable bandgap of InN enables its use in multi-junction solar cells, where it can capture infrared radiation to improve energy conversion efficiency [33]. InN-based sensors exhibit high sensitivity to gases like hydrogen due to their strong interaction with the material's surface, making them suitable for environmental monitoring and industrial applications [34,35].

2. Experimental Work

The experimental setup for the laser ablation of an indium target submerged in a 20% NH_4OH solution includes a HUAFEI Nd:YAG laser system operating at 1064 nm, with maximum pulse energy of 1000 mJ, pulse width of 10 ns, and repetition rate of 1 Hz. A lens with a focal length of 15 cm was used to focus the laser beam to increase the laser fluence. A pure (0.999) indium target supplied from HIMEDIA measuring $5\times10\times1$ mm^3 was used to produce indium nitride (InN) nanoparticles. The ablation process was conducted at room temperature for durations of 5, 10, and 15 minutes using different laser energies (40, 60, 80, 100 and 120 mJ). The laser ablation experiments involving the indium target in NH_4OH solution were carried out within this sealed cell.

A Shimadzu 8000S was used to record the Fourier-transform infrared (FTIR) spectra of the prepared samples. The UV-visible spectrophotometry was performed on the prepared samples using a Perkin-Elmer spectrophotometer in the spectral range of 200-1000nm.

3. Results and Discussion

Figure (1) shows the FTIR spectra of the InN nanoparticles prepared in this work at different laser energies. All spectra are identical with some shift in the transmittance but the characteristic peaks corresponding to the vibration modes of the In-N bond can be seen in these spectra. The peak seen at 566 cm^{-1} is ascribed to the In-N stretching vibration, while the two peaks seen at 737 and 895 cm^{-1} are attributed to the In-N bending vibrations. The peak seen at 965 cm^{-1} is resulted from the In-N symmetric stretching vibration. Consequently, all functional groups constituting the indium nitride molecule were found in the prepared samples with no trace belonging to other materials, which reflects the high structural purity of the prepared nanoparticles [36].

Figure (2) shows the UV-Visible absorption spectra of InN nanoparticles prepared in this work using different laser energies and constant ablation period of 10 minutes. These nanoparticles were immersed in suspensions in order to record their absorption spectra. In the UV region (200-400nm), the samples prepared using 100 and 120 mJ showed higher absorbance than other samples prepared using lower laser energies. In the visible region (400-700 nm), all samples approximately show comparable values of absorbance as the slight differences lie in the range 2-2.4. In the IR region (700-1000 nm), the behaviors of the prepared samples differ from each other again with smaller differences than were seen in the UV region. Accordingly, the absorbance of the prepared nanoparticles was found to depend on the laser energy used to prepare them, which determines the volume concentration of these nanoparticles, and hence the density of the solution to be measured [37].

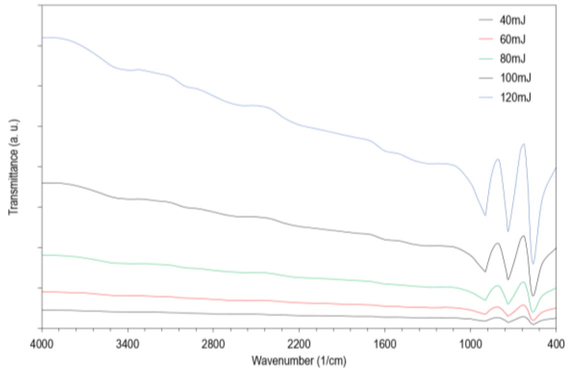

Fig. (1) The FTIR spectra of the InN nanoparticles prepared in this work using different laser energies

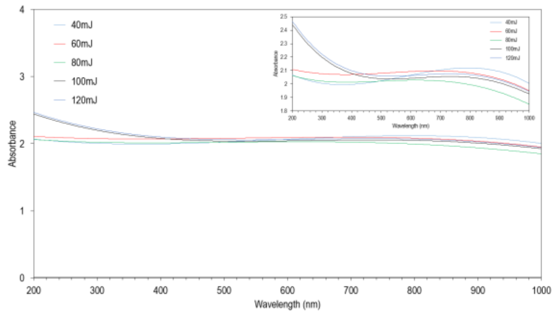

Fig. (2) The UV-visible spectra of the InN nanoparticles prepared in this work using different laser energies

4. Conclusion

In concluding remarks, indium nitride (InN) nanoparticles were prepared by pulsed laser ablation (PLAL) by irradiation of In target immersed in NH_4OH solution. All functional groups constituting the indium nitride molecule were found in the prepared samples with no trace belonging to other materials, which reflects the high structural purity of the prepared nanoparticles. The absorbance of the prepared nanoparticles was found to depend on the laser energy used to prepare them, which determines the volume concentration of these nanoparticles, and hence the density of the solution to be measured.

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