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Synthesis and Morphological Analysis of Antimony (Sb) Nanoparticles Using Laser Ablation Method

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Abstract

Antimony nanoparticles were synthesized via laser ablation of antimony targets Immersed in distilled water, which Provided both as a solvent and a reducing agent. The process employed a Nd:YAG laser (1064 nm, 485 mJ, 6 Hz, 700 pulses). The successful Configuration of nanoparticles was Affirmed through various characterization methods, including UV-VIS, XRD, FESEM, and AFM. UV-VIS spectra Unveiled characteristic plasmonic absorption peaks, while XRD analysis Revealed the formation of a cubic crystalline structure with an estimated crystallite size of approximately 10 nm. FESEM images Described spherical nanoparticle aggregates with sizes Covering from 50 to 70 nm. AFM measurements showed a root mean square (RMS) roughness of 1.7 nm, an average roughness of 2.9 nm, and an average particle diameter of 8.4 nm, Validating the uniformity of the spherical aggregates and highlighting their excellent surface properties, making them suitable for Improved applications in the field of physics.

Key Words: Antimony (Sb), Nanoparticle, Pulsed Laser Ablation (PLA), average roughness.

1- INTRODUCTION:

Recent years have witnessed an increasing Academic focus on the synthesis and conceptualization of highly Systematic metal nanostructures, motivated by their distinctive and promising attributes. Antimony (Sb) has attracted Significant attention in the domain of nanotechnology. Antimony nanoparticles Display unique optical characteristics, including adjustable bandgaps and Productive light absorption. These attributes render Sb nanoparticles particularly Beneficial for diverse optoelectronic applications, such as solar cells, photodetectors, and light-emitting diodes (LEDs) [1].

The production and development of meticulously Created metal nanostructures encompass several procedures that Deliver exact control over their dimensions, morphology, and chemical composition. This degree of control Empowers researchers to customize the characteristics of metal nanoparticles for Confident purposes. The distinctive properties of Sb nanoparticles offer significant potential for Development in various domains, including electronics, energy, catalysis, sensing, and biology.

As nanotechnology Improvements, continued investigation and comprehension of metal nanomaterials are anticipated to yield novel applications, Pushing the evolution of innovative technologies. Nanotechnology is an Multidisciplinary domain that centers on the manipulation and Guideline of materials at the nanoscale, generally spanning from 1 to 100nm. This field involves the examination, creation, and Creation of materials, devices, and systems that demonstrate distinctive Attributes and capabilities. The term "nano" denotes a unit of measurement equivalent to one billionth of a meter. At this Miniature scale, the characteristics of materials can Noticeably differ from those of their larger-scale equivalents. Nanotechnology leverages these distinctive Features to develop novel materials, systems, and processes applicable across Several domains, including electronics, medicine, energy, materials science, and environmental Research [2, 3].

Antimony (Sb) is a significant semiconductor material Attributable to its distinctive features, rendering it Applicable for various advanced technological applications. The capacity to regulate electrical conductivity is crucial for devices like Amplifier and integrated circuits. Moreover, antimony's Substantial infrared light absorption renders it advantageous in optical detecting systems, light-emitting diodes (LEDs), and lasers. Antimony has potential in nanotechnology, where its unique physical properties may be deployed at the nanoscale, perhaps enhancing applications in health and regenerative energy. This study investigates the manufacture of antimony nanoparticles and analyses their Aspects to assess their possible applications.

In this work is to Manufacture nanomaterials with unique optical, compositional, and structural properties using laser ablation as a Manner.

2-Materials and Methods:

Pulsed laser ablation (PLA) is a Pervasive method for producing nanoparticles, thin films, and surface alterations. The process of pulse laser ablation Includes multiple stages: Laser pulse absorption: a high-energy laser pulse is Intensified onto the target material. The target substance may exist in solid, liquid, or gaseous states. The employed laser is Broadly a pulsed laser, which produces brief emissions of Forceful light energy [5]. Energy absorption and vaporization: Upon the absorption of the laser pulse, the target material swiftly assimilates the laser energy, Consequent in localized thermal elevation. This extreme energy absorption may result in the vaporization of the target material, converting it into plasma [6]. The absorbed energy Causes fast heating and expansion of the target material, resulting in the Formation of a plasma plume. The plasma is a high-energy, ionized gas composed of ions, electrons, and neutral species. It Quickly expands away from the target surface due to the pressure Created by laser-induced vaporization, resulting in expansion and cooling of the plasma plume. As the plasma Enlarges, it cools and Compresses into nanoparticles or clusters. In the cooling and condensation process, atoms and molecules in the plasma congregate and nucleate, resulting in the Creation of nanoparticles or nanoclusters According to Fig.1, which was Produced by artificial intelligence.

The dimensions and morphology of nanoparticles can be Influenced by several factors, including laser parameters, target material, and the Encircling gaseous environment. Subsequent to nanoparticle synthesis, the resultant nanoparticles are Gathered on a substrate or within a collection chamber. The substrate may be positioned Adjoining to the target material, facilitating the direct deposition of nanoparticles onto its surface, so Generating thin films or coatings. The pulsed laser ablation method Shows numerous benefits for nanoparticle fabrication and thin film deposition. It offers a straightforward and adaptable Advance for synthesizing nanoparticles from diverse materials. The procedure is applicable for generating nanoparticles from various materials, including metals, semiconductors, ceramics, and polymers. It Makes possible meticulous Rule of the dimensions and morphology of the nanoparticles by the modification of laser parameters and target characteristics. The procedure may be Performed in controlled settings, such as vacuum or designated gas atmospheres, to alter the characteristics of the produced nanoparticles and films. Pulsed laser ablation is extensively Used in materials science, nanotechnology, and surface engineering for Applied applications, including catalysis, sensors, electronics, and biomedical devices. Nevertheless, safety concerns are crucial when Functioning lasers and high-energy plasmas to mitigate potential dangers and Make sure the appropriate management of the produced nanoparticles, As demonstrated in Fig.2 [7,8].

The laser ablation technique was chosen for its Clarity, cost-efficiency, and capacity to generate substantial material, rendering it a Feasible method for nanoparticle synthesis. Antimony (Sb) nanoparticles were produced Utilizing Sb powder as the initial ingredient. A neodymium YAG (Nd:YAG) laser Functioning at a wavelength of 1064 nm, delivering 480 mJ of energy, and functioning at a Recurrence rate of 5 Hz was utilized for the synthesis. The procedure entailed the utilization of exactly 5 grammes of Sb powder, which was compressed with a specialized device. This compression Equipment features a base, sanitized with ethanol to achieve 99% purity for precise measurements, with a diameter of 2 cm and a length of 3 cm. A component Located above the base is intended to exert compression on the powder. The Finalizing element, a press weighing 5 tons, exerted pressure on the material for 12 minutes throughout the compression procedure.

The utilization of this particular technique guarantees a regulated and accurate compression procedure, which is essential for the effective production of Sb nanoparticles. The utilization of a giraffe and a 5-ton press ensures the effective application of the requisite force and duration, hence yielding the desired properties of the nanomaterial. The giraffe undergoes compression.

Commence the preparation of the dish by assembling all the items. Position an electronic balance on a level, sturdy surface and verify its calibration. Prior to incorporating the ingredient into the meal, utilize the balance to precisely measure 5 grammes of the component. Upon confirmation of the accurate weight, insert the material into the press or a suitable container to initiate the preparation process.

Subsequently, position the item in a convection oven and sustain a regulated thermal environment, maintaining the temperature between 60 and 70 °C for one hour, ensuring the top limit is not surpassed. Upon Eliminating the material from the oven, permit it to cool for 60 minutes prior to subsequent actions.

To guarantee the Accuracy of X-ray diffraction (XRD) measurements, it is imperative to meticulously cleanse the previously Used beaker containing ion-free water using ethanol. This Process is essential to avert impurities that may compromise the veracity of the XRD analysis. It is advisable to reiterate the cleaning procedure several times to Assurance the elimination of all impurities. Submerge the specimen in a beaker with approximately 8 mm of water after cleaning. The laser, commonly Labeled a "laser gun" in physics, is aimed towards the flask containing the Sb sample. The laser cannon must be situated precisely 12 cm from the sample, Preserving an 8-mm distance between the liquid surface and the laser target. The correct configuration Arrangement is essential for the experiment's success. Adhering to these stages meticulously guarantees precision and accuracy in the preparation and laser ablation of the Sb sample.

Maintaining the laser temperature within the designated range of 29°C to 32°C during pressure application is Necessary. The process entails observing the color change of the liquid in the beaker when the laser delivers a pulse. The quantity of laser pulses is documented upon the detection of this color shift. The pulse counter for the Sb sample records a total of 700 pulses.

To get the results, it is necessary to reproduce the procedures employed for the synthesis of Sb material.

3-Results and discussion:

Nanoparticles are analyzed using numerous approaches to assess their structural characteristics, surface morphology, optical qualities, and additional attributes. The techniques encompass X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDX), UV-Vis spectroscopy, atomic force microscopy (AFM), and field emission scanning electron microscopy (FESEM). Figure 3 displays the X-ray diffraction data of nanoparticles synthesised via pulsed laser ablation. Diffraction peaks for the Sb nanoparticles were observed, validating that the synthesised product comprised pure cubic Sb nanocrystals, consistent with JCPDF card no. 04-0545. The diffraction planes at (111), (110), and (103) correspond to diffraction angles of $2\theta = 32.4°$, 47.94°, and 54.44°, respectively, signifying the crystal lattice planes of Sb. These peaks confirm the elevated crystallinity of the nanomaterials. The diffraction pattern has a pronounced peak at (111) around $2\theta = 32.4°$, ascribed to the cubic phase structure. The crystallite size, determined via the Scherrer equation, is 10 nm.

The X-ray scans show no peaks from other materials, showing the samples' great purity. Nonetheless, modest discrepancies were noted, presumably attributable to slight contaminants or cavities within the membrane. As the sample thickness increases, the granular level rises, yet the width of the central peak diminishes. This indicates an inverse correlation between the width of the central peak in X-ray diffraction and the granular level, as illustrated in Table 1.

Figure 4 displays a three-dimensional AFM image of Sb nanoparticles produced using pulsed laser ablation. The nanoparticles are evenly dispersed over the surface, creating an equally coated coating of Sb. The image indicates that the nanoparticles are diminutive, well-structured, and have a half-spherical, tapering morphology, with the presence of several monopod rods. Through software analysis, the average particle size was ascertained to be 10 nm, exceeding the value derived from XRD examination. This discrepancy occurs because XRD assesses the dimensions of defect-free volumes, whereas AFM directly analyses the grain structure, disregarding crystal flaws.

Moreover, smaller particles may coalesce to create larger entities. At a laser intensity of 480 mJ, the root mean square (RMS) surface roughness of the Sb particles measured 1.7 nm, while the average roughness was 2.354 nm. The mean diameter of the nanoparticles was determined to be 8 nm.

The grain size aligns with the data acquired from the XRD examination. Table 2 presents comprehensive data on the granular size, surface roughness, and root mean square (RMS) roughness for all manufactured films.

The surface morphology of the synthesized samples was further analyzed using field emission scanning electron microscopy (FESEM), as illustrated in Fig. 5. Figure 5 presents FESEM pictures that illustrate the structural characteristics of Sb samples generated with a laser energy of 480 mJ. These photos depict a scattering of spherical particles that constitute spherical clusters scattered throughout several locations. The mean diameter of these clusters is recorded as 70 nm, as seen in Table 3. The FESEM images reveal the samples' rough surface roughness and the presence of large pore diameters, which enhance their high specific surface areas. This discovery aligns with the findings from the AFM analysis. A solid link between pulsed laser ablation and particle size has been demonstrated.

Table 3 presents the measurements of 10 nanoscale particles, showing that the average diameter is 70 nm. The smallest observed diameter was 52 nm, while the largest was 73 nm. The standard deviation, calculated using the appropriate formula, yielded an average value of 5, confirming that the particles are indeed nanoscale in size.

Table 3 displays the measurements of 10 nanoscale particles, indicating that the mean diameter is 70 nm. The minimum observed diameter was 52 nm, whilst the maximum was 73 nm. The standard deviation, computed with the correct formula, produced an average value of 5, so affirming that the particles are nanoscale in dimension.

Figure 6 illustrates the absorption spectra of antimony nanoparticles produced using a laser energy of 480 mJ. Figure 6 demonstrates that absorption escalates with wavelength, spanning from 185 nm to 585 nm, featuring a prominent peak at 410 nm. The transmittance of the nanoparticles, generated with 480 mJ of laser energy, exhibits its minimum value at a certain wavelength. Furthermore, the absorption characteristics of these nanoparticles diminish beyond 410 nm, in contrast to the transmittance characteristics. The identified peaks can be ascribed to the quantum size effect. The strength and width of these plasmon peaks are affected by both the laser energy and the quantity of laser pulses. The deposition of Sb particles observed over several days during ablation aligns with the observations of Anikin et al. [13].

4-Conclusion

By ablating the Sb target in distilled water (DW) with a 10-nanosecond pulse length laser, a one-step synthesis of Sb multi-pod rods and nanoparticles was demonstrated and analyzed. The laser ablation controlled the form and size of the nanoparticles, which are single-phase cubic Sb, as shown by XRD and FESEM. The Scherrer equation yielded a crystallite size of 10 nm. Structures involving spherical clusters of Sb were generated with a pulse energy of 480 mJ using a laser. On the order of 1064 nm. According to FESEM, the nanoparticle manufacturing method (laser ablation) results in highly agglomerated S particles ranging in size from 50 to 70 nm. The novel properties of these nanoparticles, engineered by laser ablation in deionized water, are the subject of this study, which focusses on their possible uses. Considering the unique features and adaptability of nanoparticles in several scientific and technical domains, future research could center on their specialized applications.

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Table (1) summarizes the XRD results for the prepared Sb nanoparticles by pulse laser ablation.

2Ɵ (deg) standard	**2Ɵ (deg) Observed**	**d(Å) Standard**	**d(Å) Observed**	**hkl**	**FWHM (deg)**	**Tip width [°2Th.]**
32.731	32.747	2.9055	2.93741	(111)	4.8725	4.4470
47.213	47.934	2.0680	2.0701	(110)	2.3050	3.7420
58.893	57.794	1.8978	1.8788	(103)	1.5980	1.8577

Table (2) AFM of Sb nanoparticles prepared by laser ablation

Sample	**Root mean square (nm) Sq**	**Roughness average (nm) Sa**	**Average diameter**
Sb	1.743	2.9	8.4

Table (3) FESEM images of Sb nanoparticles prepared by pulse laser ablation

Label	Area	Mean	Min	Max
1	0.026	60.00	50.00	70.00
2	0.023	60.00	55.00	75.00
3	0.017	60.00	52.00	68.00
4	0.019	60.00	53.00	72.00
5	0.037	60.00	58.00	72.00
6	0.022	60.00	56.00	64.00
7	0.019	60.00	55.00	67.00
8	0.023	60.00	51.00	69.00
9	0.027	60.00	54.00	66.00
10	0.024	60.00	57.00	70.00
Mean	0.024	60.00	55.00	70.00
SD	0.006	5.00	3.50	5

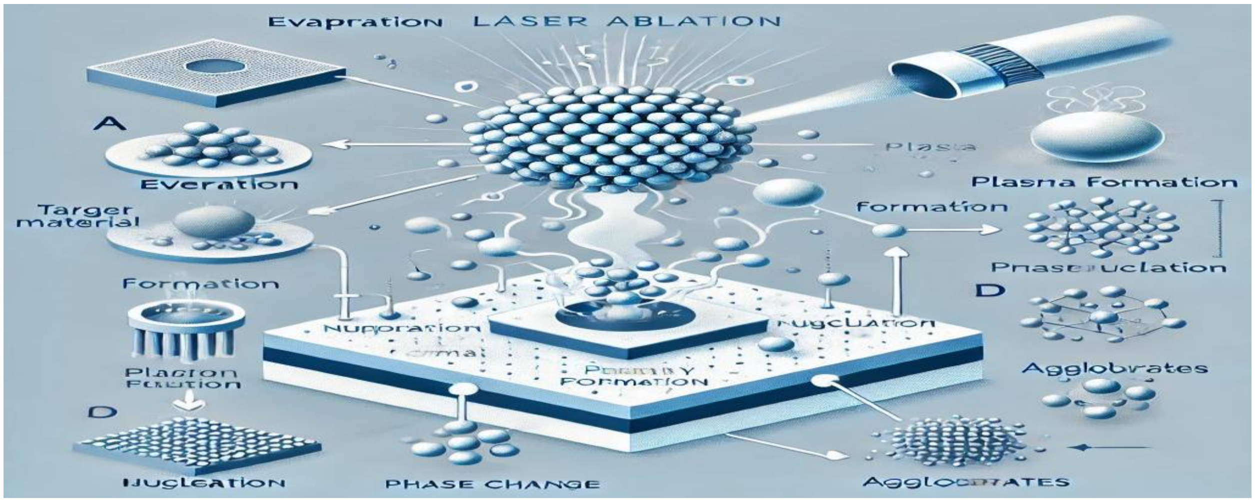

Fig (1) Nanoparticle synthesis by pulse laser ablation.

Fig (2) Nano-liquid materials for a substance Sb.

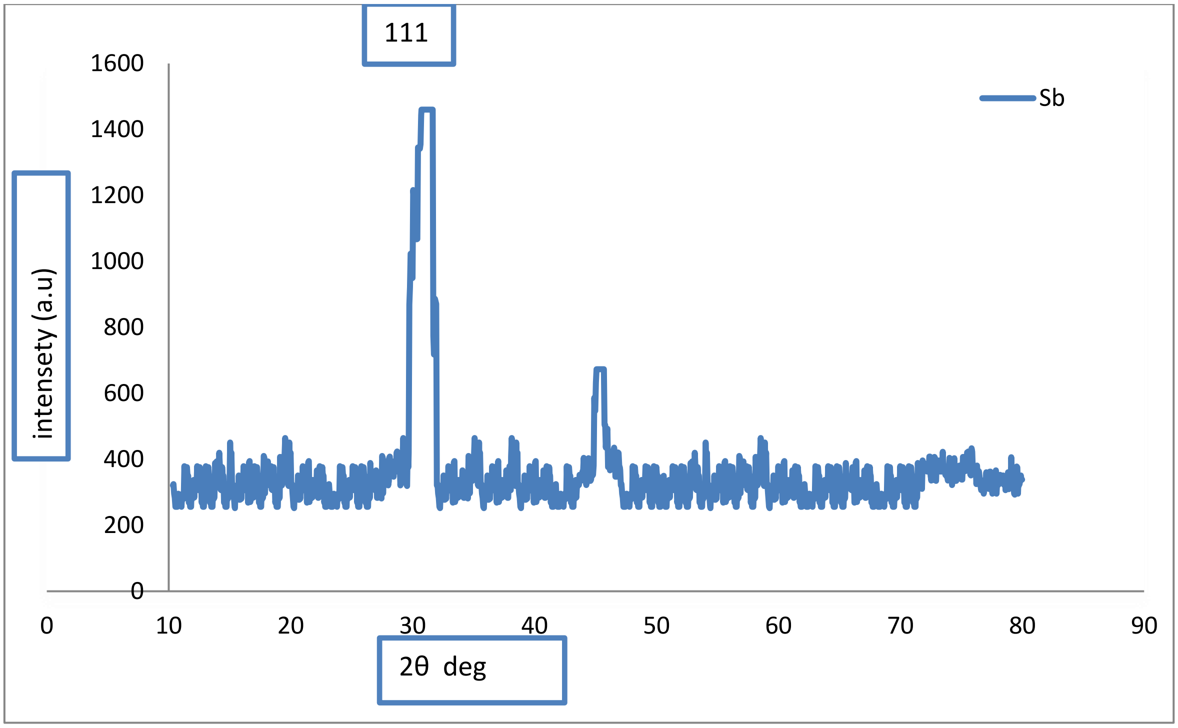

Fig (3) x-ray diffracts grams of the Sb nanoparticles by pLA method**.**

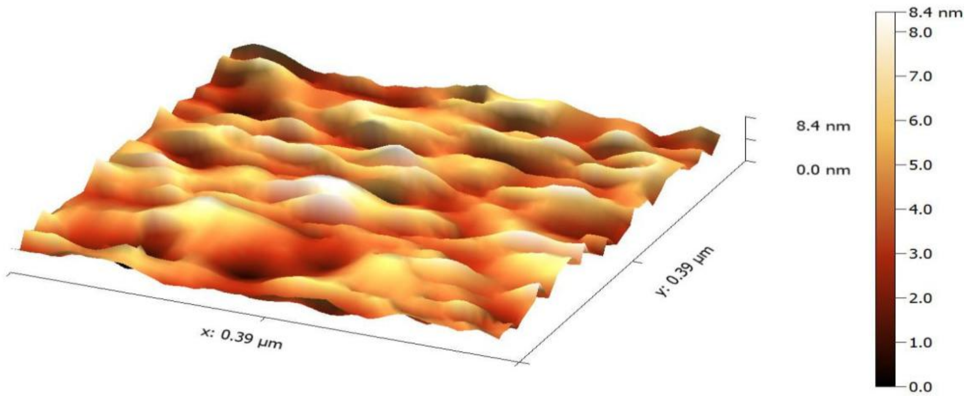

Fig (4) 3D AFM image of Sb nanoparticles by PLA method.

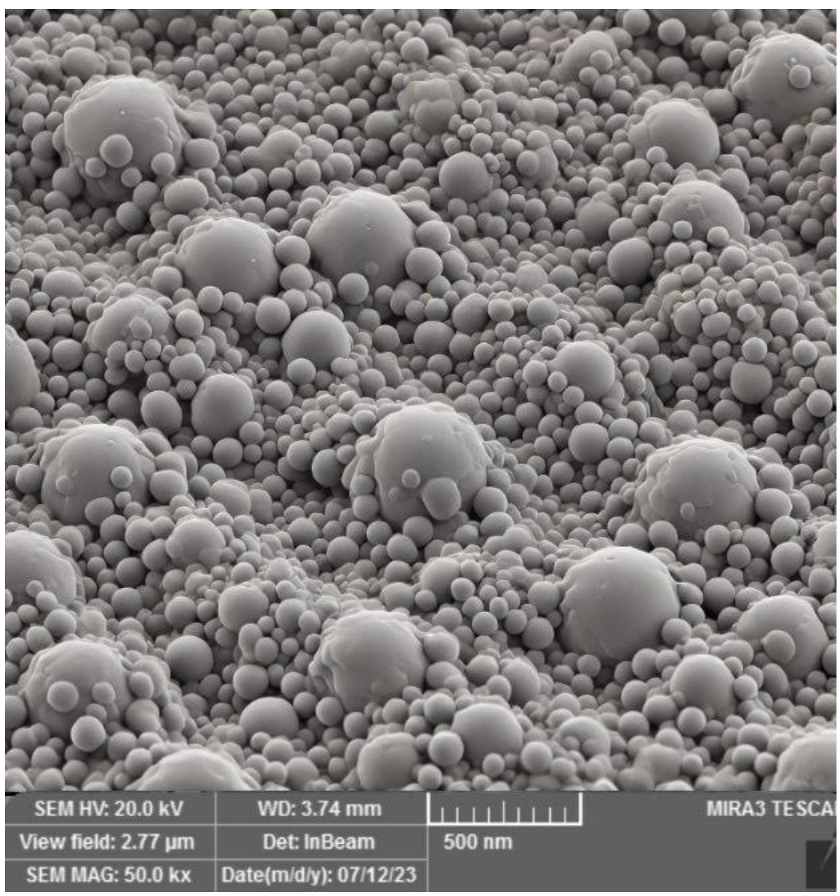

Fig (5) FESEM images of Sb nanoparticles prepared by pulse laser ablation .

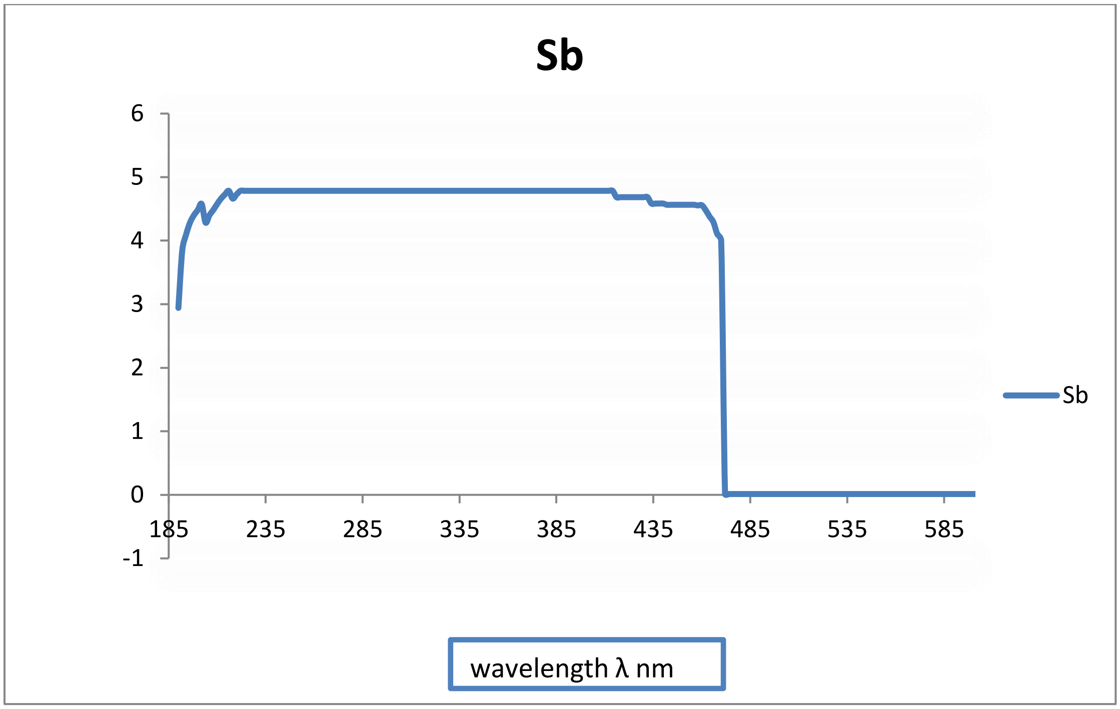

Fig (6) The UV-VIS Absorption spectra of Sb nanoparticles.