Consequence of the Pulsed Laser Ablation Experimental Variables in Synthesizing of Nano Colloids from Magnetic Materials

Mustabi Mustafa Chowdhury and Md. Enamul Hoque*
Department of Physics, Shahjalal University of Science and Technology, Sylhet - 3114, Bangladesh
Corresponding Author: mjonyh-phy@sust.edu

Abstract

In the Pulsed Laser Ablation (PLAL) experiment, the bombardment of an intense laser on a metal surface immersed in a liquid fabricates nanoparticles (NPs) as colloids from their plasma. We have used Nd:YAG laser of 300mW/pulse at 532 nm on three types of magnetic materials as Iron (Fe), Aluminum (Al), and Lead (Pb) sink in double-distilled water for a variable ablation duration. To analyze the impact of ablation duration as one of the experimental variables, we have utilized the bandgap energies of the fabricated NPs. Using the absorption spectrum of the prepared samples from metal for five different ablation times, we obtained the bandgap energies with the help of Tauc's formalism. We have found that the bandgap energies remain similar for various ablation duration with 30 minutes frequency of a metal despite the increase in absorption. In addition, we observed that there are incremental indirect bandgap energies for Al (4.1 ± 0.46 eV), Pb (3.61 ± 0.21eV), and Fe (2.15 ± 0.04eV). Thus, we conclude that the ablation duration will only increase the number of products having similar bandgap energies for materials in a liquid.

Introduction

The synthesis of metallic NPs has been a widely studied area of research recently due to its enormous range of potential applications in diverse sectors such as Industrial, Biological [1,2]. Among various methods of preparing nanoparticles, the PLAL technique is a good approach due to its simplicity and independence in controlling the environment [3]. The study of the experimental conditions is essential to know if the properties of NPs get modified. In the literature, we found that the investigation on the impact of ablation time on the PLAL technique is absent. This work aims to find the consequence of the ablation time and find the stability of the NPS over time.

Objective

1.Preparation of nano-colloids of magnetic metals
   1. Ferromagnetic: Iron (Fe)
   2. Diamagnetic: Lead (Pb)
   3. Paramagnetic: Aluminium (Al)
2.Optical characterization of the prepared nano-colloids with UV-Visible spectroscopy
3.Bandgap measurements for suitable applications.

Experimental setup and methods

In the PLAL method (Fig. 1), we immersed a small slug of target material in 80 ml of distilled water. A highly intense laser-focused at the metal surface with a 7cm biconvex lens. We have collected the samples every 30 min, 15 ml for 150 min. These are the five different ablation time samples.

We characterized the prepared Fe, Al, and Pb nano colloids with UV-vis spectroscopy. The SEM images confirmed the size of the nanoparticle size.

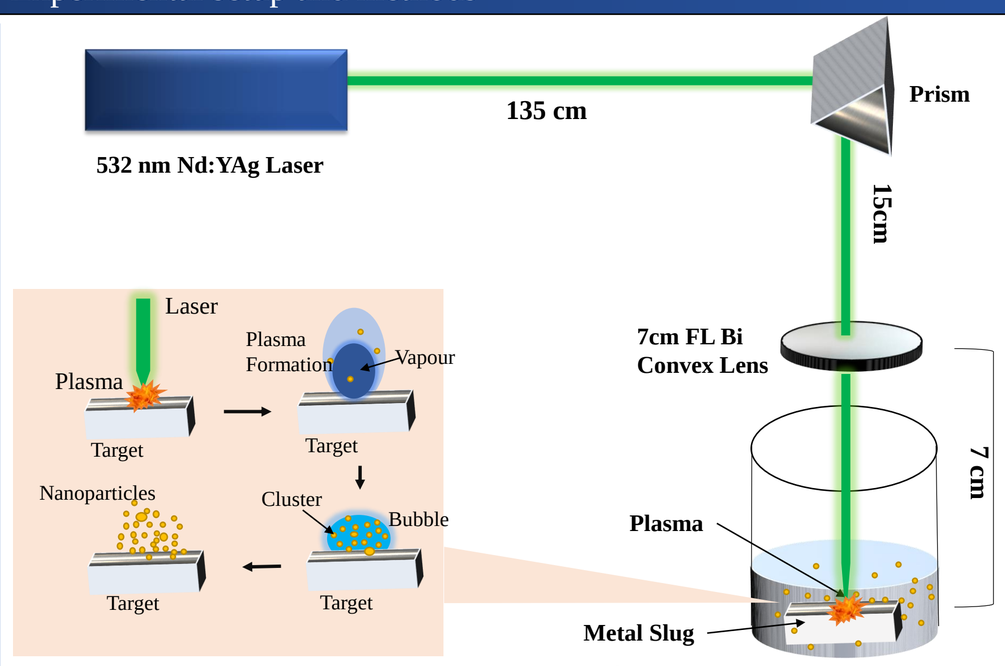

Fig. 1: PLAL technique and NPs formation

Results

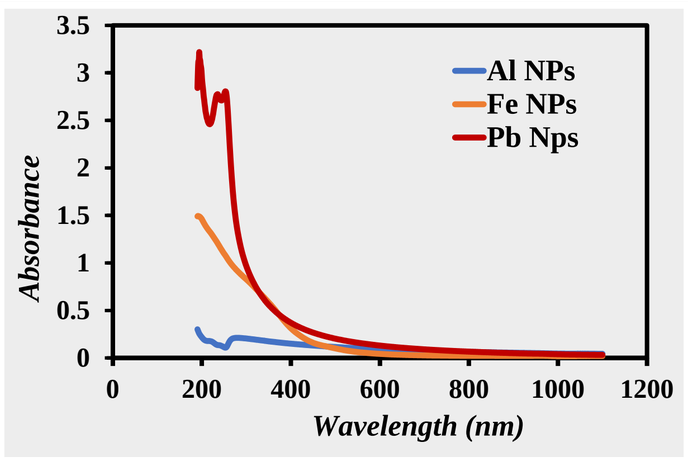

Fig. 2a: UV-Vis spectrum of different NPs

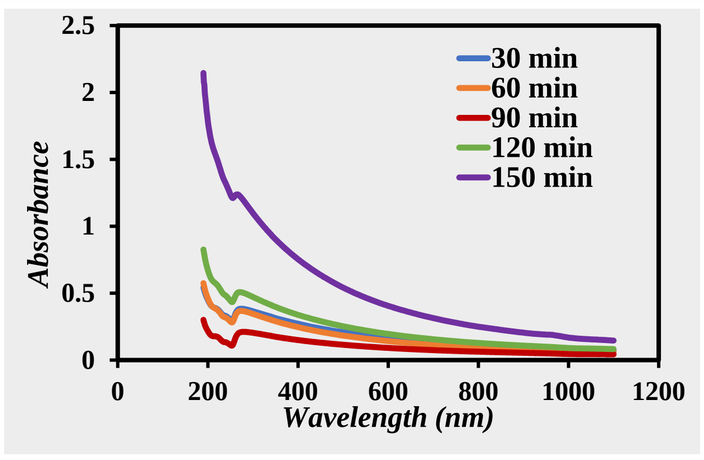

Fig. 2b: UV-Vis spectrum of Al NPs at initial stage

The obtained UV-vis spectra of ferromagnetic, diamagnetic, and paramagnetic materials are in distilled water. Fig. 2a and 2b show the absorption spectra after 90 min of ablation time for all the samples and Al NPs at different ablation times, respectively. We found that the peak absorbance corresponds at 190 nm, 198 nm, 199 nm wavelength for Al, Fe, and Pb NPs, respectively. The nature of the absorption curve suggests that the ablation time will only increase the concentration of the NPs with the absence of plasmonic responses.

Using Taucs formalism, we obtained the direct and indirect transition energy for all the samples. Fig. 3a shows the direct-allowed transition energy of prepared Fe NPs in different ablation times. It confirms that the increase in ablation times does not change transition energies.
We observed a similar nature for all types of magnetic materials. We found that the direct bandgap transition energy of Al NPs is much higher than that of the Fe and Pb NPs where the latter two hold similar direct-allowed transition energy (Fig. 2b). For indirect transition energy, Eg (Al) > Eg (Pb) > Eg (Fe).

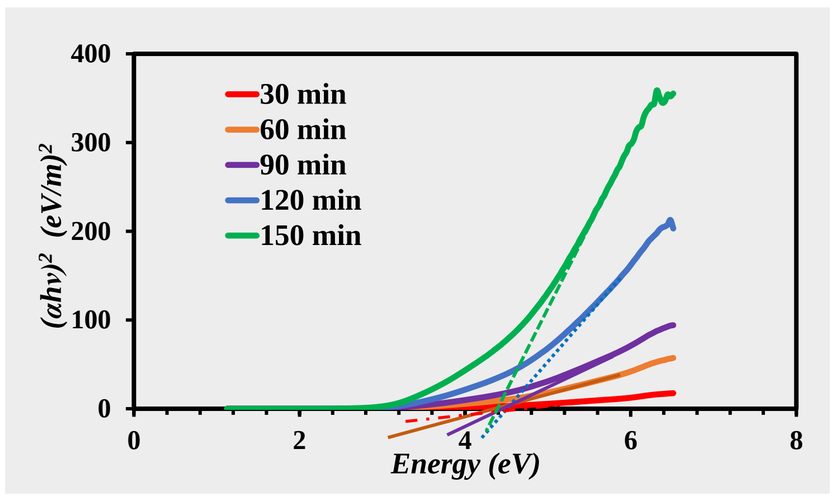

Fig. 3a: Direct Bandgap of Fe NPs at initial stage

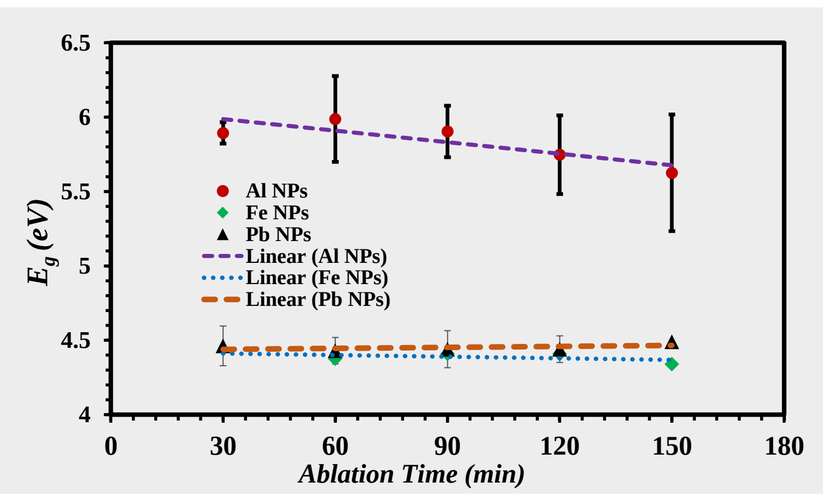

Fig. 3b: Direct bandgap energies of different NPs in different ablation time

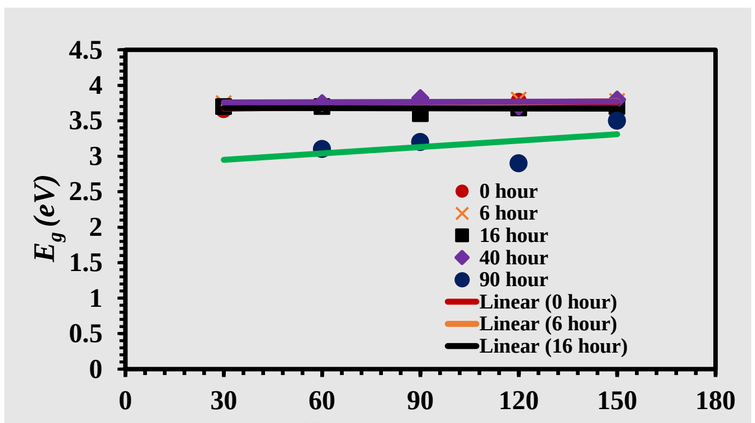

Fig. 4a

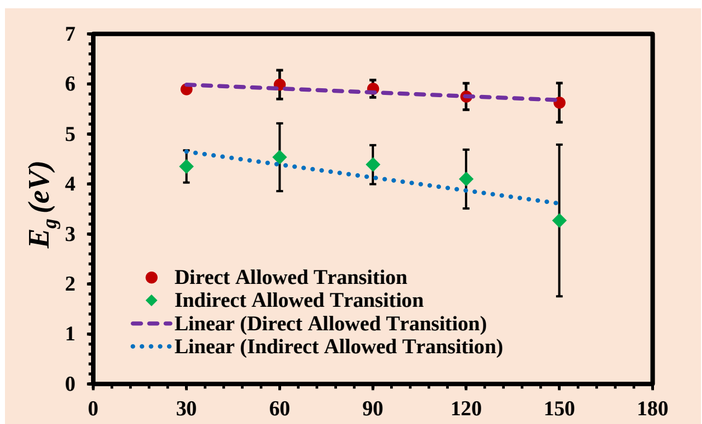

Fig. 4b

Considering the impact of aging time, we have found that the change in transition energy varied with the aging time with a slope of order 10^{-3} . Sometimes it even stays constant over time. From Fig. 3a we can see that the indirect bandgap of Pb NPs remains unchanged till 40 hour and have slight ups and downs for 90-hour sample. In Fig. 3b we can see how much deviation of bandgap over time has for each ablation time Al NPs sample. For Al NPs the direct bandgap stays more stable and has higher magnitude than the indirect bandgap unlikely Pb an Fe which have the both stable direct and indirect bandgap energy.

Discussions

Fig. 3a and Fig. 4a. show that the absorbance and the bandgap does not alter with the ablation time or degradation time. From the table we can see that our NPs have wider bandgap energy. This suggest that we have particle smaller than a bulk state since due to the quantum confinement the bandgap energy will increase as the particle size decreases. SEM images confirms the particle of Fe NPs to have nanosize (Fig. 5). Paramagnetic Al-NPs show greater bandgap value then diamagnetic Pb NPs and Ferromagnetic Fe NPs. But Pb NPs have a greater production rate than others. We can also see our experimental data resembles with some other work.

NPs	Direct Bandgap eV		Indirect Bandgap eV		Direct Bandgap according to other study	Indirect Bandgap according to other study
	Initial	90 hour aged	Initial	90 hour aged		
Aluminium	**5.9**	**6**	**4.1**	**4.63**	**5.99 eV** [Song, T., Yang, M., Chai, J. *et al*].	**3.0 eV** [*Advances in Condensed Matter Physics*, vol. 2018, Article ID 7598978]
Iron	**4.35**	**4.35**	**2.16**	**2.18**	**2.1 eV** [Deotale, A. J., & Nandedkar, R. V. (2016]	**1.38 - 2.09 eV** [Deotale, A. J., & Nandedkar, R. V. (2016]
Lead	**4.5**	**4.3**	**3.7**	**3.2**	**4.2 eV** [da Silva, A. Ferreira, et al. 2004]	**1.9 - 2.7 eV** [Wilkinson, Tommy J., et al. 2001]

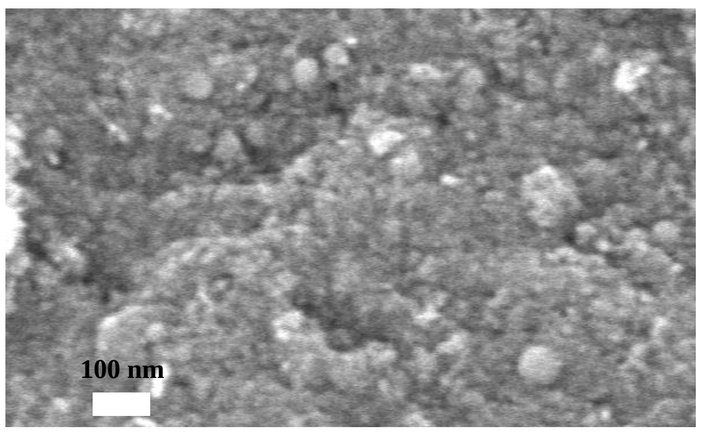

Fig. 5: SEM images of Iron NPs

Conclusions

Three types of magnetic metallic nanoparticles in liquid were successfully synthesized by laser ablation Method . The time of ablation only increase the production of NPs having similar bandgap. Aluminium has higher bandgap value than iron and Lead. Over time the particle got sedimented but the bandgap energy varies at a very low rate. The bandgap energy of Fe NPs corresponds to the red region of the visible spectrum which may have potential application in biomarker optical detection.

References

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[2] Huber, Dale L. "Synthesis, properties, and applications of iron nanoparticles." *Small* 1.5 (2005): 482-501.
[3] G.W. Yang, Prog. Mater. Sci. 52 (2007) 648–698.