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Research Article

Ultrasensitive Technique for Deep Study in Nonlinear Optical Nanostructures: Z-scan Imaging Technique with Interference Pattern Indicator in Real Time

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Abstract

To detect a flexible ultrasensitive response's material particularly with the nonlinear photonics characters, one needs a precise measurement. An excellent experimental setup to study such materials for flexible electro-optics and electronics requires not only the points of important physical parameters, but also the interaction's mapping. In this communication work, a proposed newly technique of z-scan imaging method is introduced to tackle such high quality achievement. The setup was tested by light-matter interaction observation in as single aggregation of silver (Ag) nanoparticles with the number of nanoparticles in an aggregation target was estimated by 474,552 nanoparticles. According to the first time nonlinear light-matter interaction, an interference pattern was identified in each z position during the measurement of nonlinear absorption coefficient. Such interference pattern was formed due to nonlinear processes. This z scan imaging technique suggest a wide range application to study various flexible photonics materials.

Keywords: *Interference pattern, Z-scan imaging technique, flexible photonics detection, single Ag aggregation.*

INTRODUCTION

Over 1 million word of "Z scan" as well as about 80,314 words of "Nonlinear Optics" embedded in various ten thousands scientific published papers with vary significant impacted publications based on the search in Science Direct, Elsevier have been publishing with multitasking physical impacts since the discovery of the conventional work of Sheik-Bahae *et al.* in 1990 (Sheik-Bahae, Said, Wei, Hagan, & Van Stryland, 1990) and still continuing to be more productive in the last few decades by using such z scan technique (Butenko et al., 1990; Rahaman, Sarkar, & Kemp, 2019; Ricard, Roussignol, & Flytzanis, 1985; Vellekoop, Lagendijk, & Mosk, 2010; J. Zhang et al., 2019; X. Zhang & Yang, 2019). This z-scan method is very well-known as a simple conventional method to measure both nonlinear absorption coefficient (α_2) and refractive index coefficient (n_2) which are associated with the real and imaginary susceptibilities of a nonlinear optical (NLO) material. In current year (Hendry Izaac Elim, 2021) has invented a clever way to improve the z-scan method (Sheik-Bahae et al., 1990; Sutherland, 2003) called as z-scan imaging technique by investigating a single aggregation of silver (Ag) nanoparticle.

The conventional response of all natural conservation laws in this universe is normally showing that there is no problem at all and it can be always like that in space-time. On the other hand, in quantum mechanics of microscopic scale of natural sciences, the standard formulation of all conservation laws has to involve the probability distribution of at least two to three conserved variables over the entire unchanged ensemble. The associated proof of such thought is that the energy shift (Δ*E*) in each excited state is bigger and bigger as the electron excites higher and higher in the excited states, or in general based on Elim in 1995, and in 1999 (H. I. Elim, 1995): $\Delta E_0 < \Delta E_1 < \Delta E_2 < \ldots < \Delta E_n$, where ΔE_0 is the ground state energy shift, and ΔE_n *is* the energy shift in excited state n^{th}.

From the way of thinking in the above mentioned entire aspects, the mystery of conventional z-scan (Sheik-Bahae et al., 1990)and its impacts to over a million of publications (Sheik-Bahae et al., 1990; Sutherland, 2003; Zhidkov, Kurmaev, Cholakh, Fazio, & D'Urso, 2020) had never known about what happened actually during the measurement of nonlinear optical parameter of α_2 and n_2 associated with imaginary and real parts of third order susceptibilities ($\chi^{(3)}$), respectively. In this paper, the z-scan imaging technique is introduced to explain the mystery for over 30 years outcome of over 1 million published papers using *z*-scan method (Sheik-Bahae et al., 1990) for a wide range of materials and crystals. Based on this study, it is discovered that there was a kind of interference pattern happened during the NLO measurement due to the NLO responses of light-matters interaction. Such newly observation was conducted in a single $_{47}$Ag nanoparticles (NPs) aggregation with *d*~1.56 μm which contains large nonlinear absorption coefficient, 8.90×10^9 cm/GW in wavelength of ~ 407 nm (H. I. Elim, 1995; H. I. Elim et al., 2004; Hendry I. Elim, Yang, Lee, Mi, & Ji, 2006). The detail interference patterns in each z-position were recorded to investigate the NLO behavior of a single μm aggregation of the sample.

MATERIALS AND METHODS

Figure 1 shows a proposed experimental setup of *z*-scan imaging technique with on target object in the scale of nanometer or an aggregation from few nanoparticles/ nanotructures. The acronyms of OL1, OL2, L1, L2, BS2, A2, CCD (model DP72 from Olympus) and F stand for objective lens1, objective lens 2, lens 1, lens 2, beam splitter, attenuator, high resolution camera, and neutral density filter, respectively. While the sample target is controlled by viewing it in CCD connected with a laptop under the adjustment of 3D translational stage. In order to reach a beam waist of ω_0 = ~8 μm, OL1 with the 8.8 mm focal length was employed so that the Rayleigh range, z_0 of the focused beam was detected with $z_0 = \pi\omega_0^2/\lambda$= 770 μm measured at λ~407 nm. To detect and measure the transmittance of z-scan, the light source of deuterium and halogen (model Avalight-DHS from Avantes) were employed to pass through a fiber behind objective OL1, and its spectrometer head (model Avaspec-3648 from Avantes) located just behind the sample.

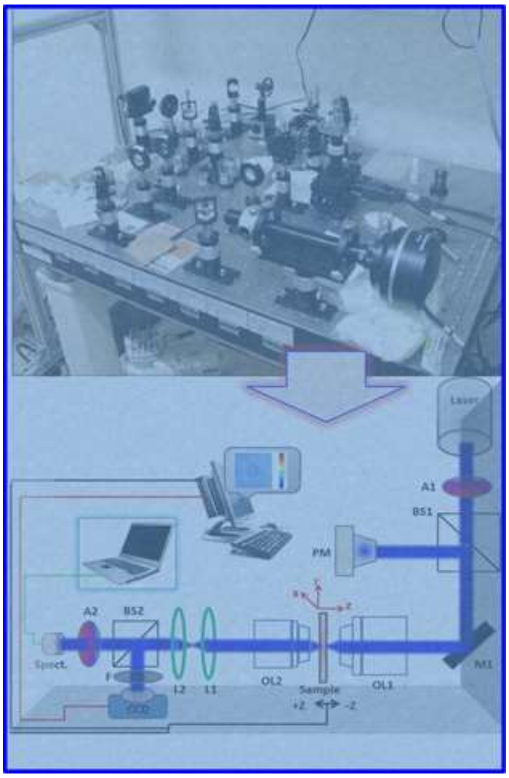

Figure 1. Experimental setup of Z scan imaging technique

RESULTS AND DISCUSSION

To test and solve the mystery of light-matter interactions during the z-scan imaging measurement, the single Ag aggregate with Ag NPs ordered from Nanostructured & Amorphous Materials, Inc. (NanoAmor, USA) was prepared in methanol, and then spin-coated it in a glass substrate. The estimation of total number of the of nanoparticles in an aggregation was 474,552 nanoparticles as shown in Figure 2. The sample was then put in a hot plate at 100 ^{0}C for ~2 hours so that the solvent was fully evaporated. Figure 3 depicts the whole observation of interference patterns in each z-position as a result of NLO response.

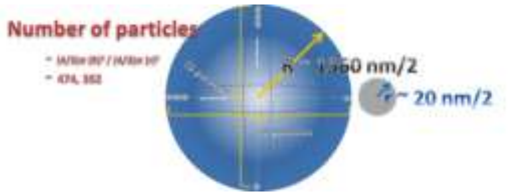

Figure 2. The single Ag aggregation's geometry in which the total number estimation of single Ag nanoparticles was calculated by dividing the total volume of the approximated spherical aggregation (~4π(1560 nm/2)^3/3) with the volume of the single Ag NP (~4π(20 nm/2)^3/3).

Figure 3. Measuring nonlinear optical responses while seeing what happened during the process: an example of positive nonlinear absorption (α_2) in a single silver nanoparticle aggregation with the size of diameter ~1.56 µm. These Ag NPs have the average diameter of ~20 nm so that the aggregation may roughly have ~474,552 NPs according to the nanoscience estimation.

The experimental observation shows an interference pattern as an indicator that is associated with coherence character at the end of the reaction between light-NPs aggregate, implying that the bonding among NPs connected one another in an aggregation could be redistributed through the NPs-exchange process. This chemical physics phenomena was detected to be a three level model, and depicted in Figure 4 (Hendry Izaac Elim, 2021). In Figure 4, *N*, σ_{12} and σ_{23} are the number of electrons in a state, the absorption cross sections for the transition from S_0 to S_1, and the absorption cross section σ_{23} from S_1 to S_2. While τ_{21} and τ_{32} are the related relaxation times from S_1 to S_0 and from S_2 to S_1.

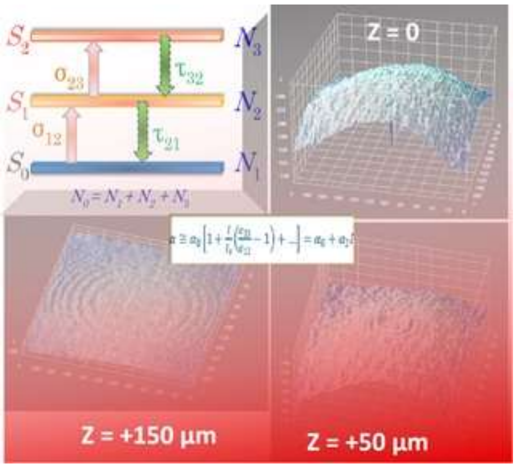

Figure 4. Interference pattern associated with coherence character at the end of the reaction between light-NPs aggregate.

Figure 4 shows there were 3 physical processes (Hendry Izaac Elim, 2021) happened at different irradiance based on the solution of the three level model equation: $\alpha \cong \alpha_0 \left[1 + \frac{I}{I_s}\left(\frac{\sigma_{23}}{\sigma_{12}} - 1\right) + \cdots\right] \approx \alpha_0 + \alpha_2 I$. At low irradiance, it was induced absorption or two photons absorption (TPA) effect as shown in Figure 3. When the irradiance was improved larger than the former one [8], reverse saturable absorption (RSA) process was observed. Lastly, at two-order higher irradiance, the observation of saturable absorption (SA) behavior was found.

CONCLUSION

A remarkable finding in this work has been for the first time focused on the observation of interference pattern using z-scan imaging technique in a flexible photonics material of a single aggregation of silver nanoparticles. The ultrasensitive responses of nonlinear light-matter interaction were accurately observed while measuring it. Such interesting z scan imaging technique will eventually contribute to a various possible study for many types of flexible photonics materials.

AUTHOR'S CONTRIBUTIONS

H.I.E. proposed the idea and then examined, arranged and conducted of the whole experimental work and data processing as well as the novelty thought in computational physics for the experimental observed images for the invention of interference signs during light-matter interaction in measuring nonlinear optical properties.

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