The effects of laser intensities on nonlinear properties for Ag nanoparticles colloid

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Abstract

A huge potential from researchers was presented for enhancing the nonlinear optical response for materials that interacts by light. In this work, we study the nonlinear optical response for chemically prepared nano- fluid of silver nanoparticles in de-ionized water with TSC (Tri-sodium citrate) protecting agent. By the means of self-defocusing technique and under CW 473 nm blue laser, the reflected diffraction pattern were observed and recorded by CCD camera. The results demonstrate that, the Ag nano-fluid shows a good third order nonlinear response and the magnitude of the nonlinear refractive index was in the order of 10^{-7} cm^2/W. We determine the maximum change of the nonlinear refractive index and the related phase shift for the material at six input laser intensities.

Key words

Self-defocusing, nonlinear refractive index, Ag nanoparticles.

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تأثيرات شدات الليزر على الصفات اللاخطية لعالق الفضة النانوية

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الخلاصة

تم بذل مجهود كبير من قبل الباحثين لغرض تحسين الاستجابة البصرية اللاخطية للمواد التي تتفاعل مع الضوء. وفي هذا العمل تم دراسة الاستجابة البصرية اللاخطية للعالق النانوي المحضر كيميائيا لجسمات الفضة النانوية في الماء منزوع الايونات مع وجود عامل الحماية *TSC* باستخدام تقنية التشتت الذاتي وتحت موجة مستمرة من الليزر الازرق بطول موجي 473 نانومتر، ان انماط الحيود المنعكسة تم ملاحظتها وتسجيلها باستخدام الكاميرا. لقد اثبتت النتائج ان عالق الفضة النانوي اظهر استجابة لاخطية جيدة ومن المرتبة الثالثة وان قيمة معامل الانكسار اللاخطي كان بالرتبة 10^{-7} cm^2/W لقد قمنا بحساب مقدار التغير الاكبر وفرق الطور الناتج عنه للمادة تحت تأثير ست قراءات لشدة الليزر.

Introduction

Changes in refractive index induced by an optical field can give rise to various nonlinear phenomena in optical materials [1]. A related phenomenon is a self –defocusing, which is interesting in it, from the standpoint of nonlinear optics, and because it can modify the process of interaction between laser radiation and matter [2]. When a Gaussian laser beam passes through a nonlinear medium, it may exhibit a characteristic diffraction ring pattern resulting from spatial self-phase modulation (SSPM) [3], this far-field diffraction ring pattern has caused much attention since first reported in 1967s for its unique properties and potential applications [4]. Metal nanoparticles and clusters in a colloidal solution have special properties compared to those of their bulk representative. The very small size of the particles originates specific chemical and physical properties [5]. On the other hand, the applications with these nanostructured systems can be found in several areas, for example in catalysis [6], biomedicine [7] and in linear and nonlinear optics [8]. The use of the silver nanoparticles as non-linear optical materials seems to open a new area for such materials [9]. Additionally, silver nanoparticles have a surface plasmon resonance absorption in the visible region. The surface plasmon band arises from the coherent existence of free electrons in the conduction band due to the small particle size effect [10]. In this work, we report measurements of the nonlinear optical responses of silver nanoparticles in de-ionized water with mean particle size of 50 nm under six input power of continuous-wave blue laser using the self-defocusing technique.

The experimental set-up

The used experimental setup for the self-defocusing technique is depicted in Fig.1.

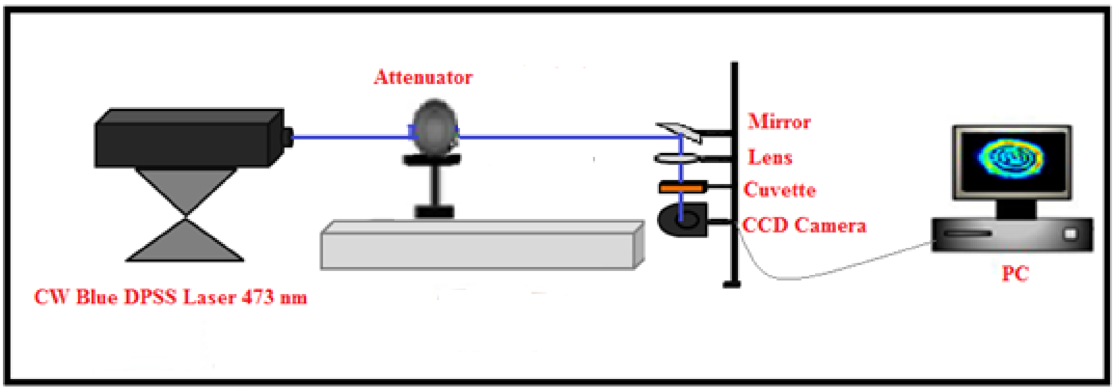
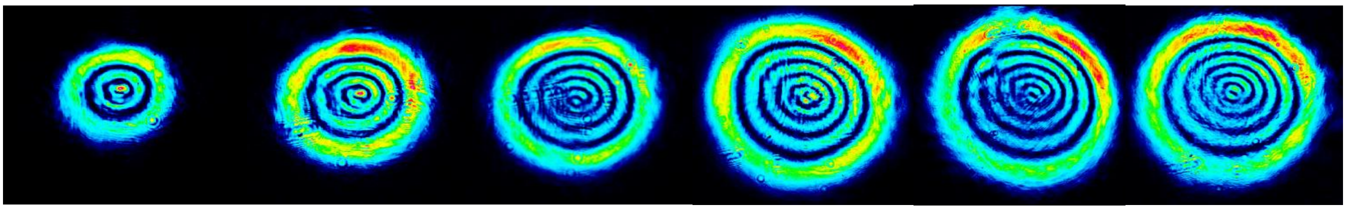


Fig.1: Schematic diagram of the experimental set up.

The CW Blue laser with a wavelength of 473 nm was used. The incident power tuned through an attenuator and measured by a laser power- meter. The nonlinear material sample was colloidal solution of spherical shaped silver nanoparticles in de-ionized water prepared by chemical method, using sodium borohydride $NaBH_4$ to reduce silver nitrate $AgNO_3$ in the presence of TSC (Tri-sodium citrate) as a stabilizer. The average nano-silver particle size was 50 nm, and the concentration for the sample was about 70 ppm. A Gaussian light beam was focused by a lens of 5 cm focal length, propagated through a cell containing the prepared colloidal silver. By using a mirror, vertical alignment on the sample cell was obtained. The far-field diffraction patterns were collected by a CCD camera, and the results were recorded and analyzed by a computer with certain software, the patterns rings has been counted and obtained in two-dimension images. The aim of this work are to study the effects of different laser intensities on the emerged diffraction pattern, the maximum change of nonlinear refractive index, the phase shift and the nonlinear refractive index for the Ag nanoparticles colloid.

Results and discussion

In this experiment, the irradiation is done by 473 nm CW laser beam. This wavelength is near the resonance absorption peak of the prepared silver nanoparticles which is around 430 nm. While the spot size of the laser beam is 209.5 µm, the formation of the diffraction patterns was analyzed in order to study the influence of the incident beam at different powers 120 mW, 150 mW, 180 mW, 220 mW, 240 mW and 270 mW on the sample. The far-field pattern was recorded by a CCD camera as shown in Fig. 2.



(1) (2) (3) (4) (5) (6)

Fig.2: CCD camera photographs for the sample of the colloidal silver-nanoparticles in DI in the presence of TSC as a stabilizer with mean particle size of 50 nm show: The two –dimension image for the far-field diffraction ring patterns at different intensities:
(1) 348, (2) 436, (3) 523, (4) 639, (5) 697 and (6) 784 W/cm^2.

As can be noticed, the generated rings were larger and thicker for the outer rings than they are for the inner ones. The formation of these patterns refers to the behavior of the nonlinear material as a third order nonlinear lens-like behavior of self-defocusing phenomenon. The experimental results demonstrated that, the number of rings was increased by increasing the laser intensity till it reached to a specific number, after that the number of rings would stayed constant even of increasing the intensity as the colloidal sample was suffer a saturation case as can be seen in Table 1. When the intensity start to increase from 348 W/cm^2, the number of rings is increased to 2 rings till its reach to 6rings at 697 W/cm^2, then it would be stayed constant at 6 rings even if the intensities were increased to high values.

Table 1: Illustrates the number of diffraction rings formed by the prepared silver nanoparticles in DI in the presence of TSC as a stabilizer at different laser intensities.

Laser intensity (W/cm^2)	Number of rings for the silver nano-fluid sample with mean particle size of 50 nm
348	2
436	3
523	4
639	5
697	6
784	6

The values of the maximum change of nonlinear refractive index $\Delta n_{nl,max}$ for the sample at different intensities were determined and listed in the Table 2 by the Eq. (1) [11]:

$$\Delta n_{nl,max} = \frac{\lambda_{beam}}{L_{material}} N_{rings} \quad (1)$$

where λ is the wavelength of the light, $L_{materiel}$ is the thickness of the sample, N is the number of rings. In this experiment λ_{beam} equals 473 nm and $L_{materiel}$ is 5 mm respectively.
With increasing the laser intensity, the maximum change of nonlinear refractive index was increased too as can be seen from Table 2 the value of $\Delta n_{nl,max}$ increased from 1.89 x 10^{-4} up to 5.67 x 10^{-4} with the intensity increment. From Eq. (2), we estimated the effective nonlinear refractive index n_2 [12]:

$$\Delta n_{nl,max} = n_2 I \quad (2)$$

The results illustrated in Table 2 show that the nonlinear refractive index is found to be in the order of 10^{-7} and increased with increasing the input intensity which indicates that, by increasing the laser intensity, the nanofluid would possess more nonlinearity, we determine the phase shift for the nano-fluid sample since the laser beam used in the experiment has a Gaussian distribution, the relative phase shift (Δ φ), suffered by the beam while traversing the sample of thickness (L) can be written in Eq.(3) [13]:

$$\Delta \varphi = kL\Delta n \quad (3)$$

where k=2π/λ is the wave- vector in vacuum and λ is the laser beam wavelength.

Table 2: The values of the maximum change of nonlinear refractive index, the related nonlinear refractive index values and the phase shift for silver nano-fluid sample with the mean particle size of 50 nm.

Laser intensity (W/cm^2)	**$\Delta n_{nl,max}$ x 10^{-4}**	**n_2 x 10^{-7} cm^2/W**	**(Δ φ)**
348	1.89	5.4	4 π
436	2.83	6.4	6 π
523	3.78	7.2	8 π
639	4.73	7.4	10 π
697	5.67	8.1	12 π
784	5.67	7.2	12 π

Here the phase shift was increased with particle size increment from (Δ φ= 4 π) up to (Δ φ= 12 π) as recorded in Table 2. This increasing of phase shifting can be observed by the expanded on the rings number in the self-diffraction patterns while the input intensity increased. This results from wave front distortions inflicted on a beam by itself while traversing a nonlinear medium [14].

Conclusions

In summary, we found that by increasing the intensity, the number of rings would be increased till it reached to a specific number, after that it would stay constant even of increasing the intensity. By determine the nonlinear parameters for the prepared Ag nanoparticles in DI in the presence of the TSC as a stabilizer, the material shows good third order nonlinearity.

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