Iraqi J. Laser, Part A, Vol.15, pp.19-23 (2016)

IRAQI JOURNAL OF LASER

Investigation of Nonlinear Optical Characteristics of the Multi-Wall Carbon Nanotubes (MWCNT's) Suspensions using Nonlinear Self-Diffraction of a Laser Beam

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(Received 19 June 2016; accepted 29 June 2016)

Abstract: Nonlinear diffraction patterns can be obtained by focusing a laser beam through a thin slice of the material. Here**,** we investigated experimentally the formation of the far field nonlinear diffraction patterns of cw laser beam at 532 nm passing through a quartz cuvette containing multi-wall carbon nanotubes (MWCNT's) suspended in acetone and in DI water at concentrations of 0.030.wt.%, 0.045 wt.%, 0.060 wt.%, and 0.075 wt.%. Our results show that increasing the concentration of both types of suspensions (MWCNTs in acetone and $MWCNT_s$ DI water) led to increase in the number of pattern rings which indicates an increase in their nonlinear refractive indices. Moreover, $MWCNT_s$ DI water suspension at a concentration of 0.075 wt. % was more efficient for achieving a high optical nonlinearity.

Introduction

Nonlinear optical effects have attracted much attention for their immense potential in applications dependent on nonlinear processes, such as frequency conversion, multiple-photon absorption, self-phase modulation, and so on [1]. Materials with high third- order nonlinear refractive indices are always of large interests for their potential applications on many nonlinear optical devices such as optical limiting, beam flattening, optical switching, weak absorption measurement, spatial dark solution transmission and so on [2, 3]. Self-Diffraction represents a common effect produced in a nonlinear material under conditions that the beam intensity is high enough [4, 5].This process can be utilized to measure the nonlinear refractive index of materials for characterizing the nonlinear optical properties of material which represents the main parameter to determine their applicability in a nonlinear device [6]. Recently the increasing interest in self-diffraction shows promise tool of optical limiting elements for the protection of optical sensors [7].

Experimental Work

Gaussian cw laser (model DPSSL- MGL-III-532nm, CNI, China) at wavelength of 532 nm, attenuator, Lens, CCD Camera, Laser Power-Meter and PC have been used in this work, as it is shown in Figure 1.

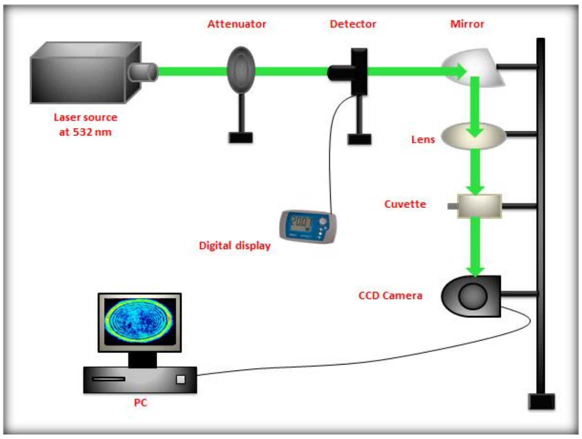

Fig. (1): Schematic diagram of the experimental set-up

The MWCNT's suspensions have been prepared by two-steps method. The concentrations of each of MWNT's acetone suspension, and MWCNT's Deionized (DI) water suspension were at 0.030 wt. %, 0.045 wt %, 0.060 wt %, and 0.075 wt %.

Results and Discussion

All the prepared concentrations of suspensions were tested using UV-VIS spectrophotometer for achieving their absorption spectra. Figure 2 shows the absorption spectrum of MWCNT'S acetone suspension at a concentration of 0.060 wt. %., and the peak wavelength was ~ 532 nm. Zeta potential analysis also used for selecting appropriate suspensions possesses a good stability to be utilized in the present experiment.

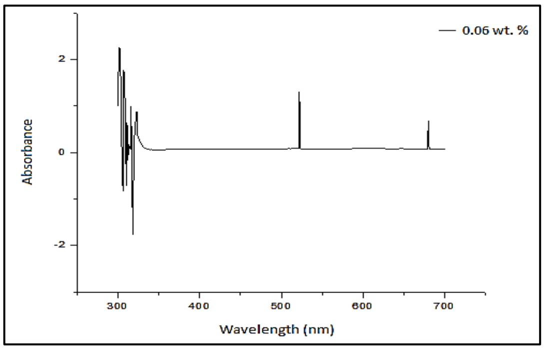

Fig. (2): The absorption spectrum of MWCNT'$_S$ acetone suspension at a concentration of 0.060 wt. %

When Gaussian laser beam focused through the nanoparticles suspension, the light illuminates a solution; it is strongly absorbed and changed to heat. Due to the heating by the absorbed laser beam, the thermal and the concentration diffusion of particles in nanofluid can be initiated. The heated fluid expands and its refractive index changes, then the temperature of the fluid rises, resulting in a high refractive index, and thus the self-diffraction of laser beam can be obtained [8]. Therefore, various values of laser intensity were used in order to obtain many numbers of the nonlinear diffraction patterns which lead to obtain many values of the maximum change in the nonlinear refractive index ($\Delta_{nl,max}$) of the suspensions. It has been shown from Figures 3 and 4 that the number of pattern rings increases with increasing of the laser intensity incident on MWCNT'$_S$ DI water suspension and MWCNT'$_S$ acetone suspension respectively.

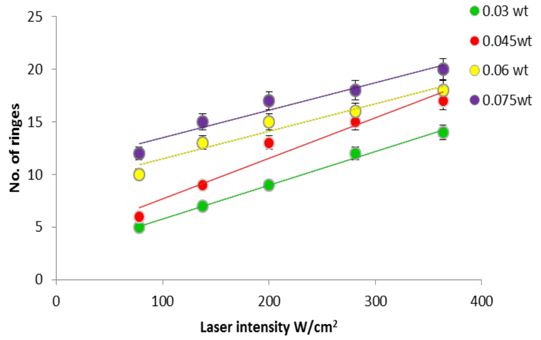

Fig. (3): The number of diffraction rings formed using MWCNT$_S$ DI water suspension at various concentrations irradiated by various laser intensities

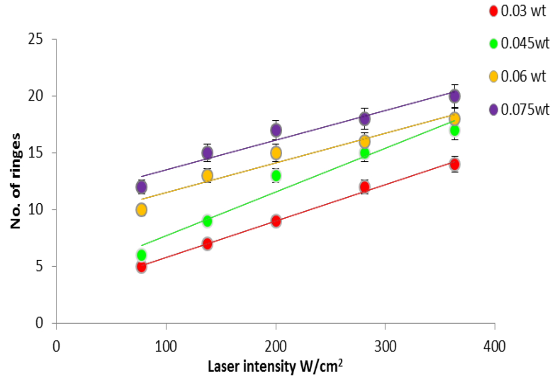

Fig. (4): The number of diffraction rings formed using MWCNT$_S$ acetone suspension at various concentrations irradiated by various laser intensities.

The maximum change of nonlinear refractive indices ($\Delta_{nl,max}$) for both of the previous suspensions have been calculated from the following equation [9].

$$\Delta n_{nl,\,max} = \frac{\lambda}{d} N_{rings} \qquad (1)$$

where $\lambda, d,$ and N_{rings} are the laser wavelength, the cuvette thickness, and the number of formed diffraction pattern respectively. The cuvette width was 5mm.

The nonlinear refractive index (n_2) of each of the tested suspensions was calculated according to equation 2 [10].

$$\Delta n_{nl} = n_2 I \qquad (2)$$

where I is the laser intensity

Therefore, the variation of $\Delta n_{nl,\,max}$ and (n_2) for both of MWCNT$_S$ dispersed in deionized water and in acetone at various concentrations can be shown in Figures 5 and 6 respectively.

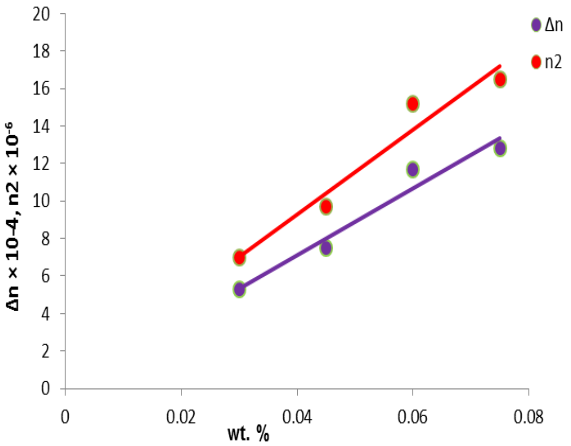

Fig. (5): The variations of both the maximum change of nonlinear refractive index and the nonlinear refractive index of $MWCNT_S$ DI water suspension at various concentrations (0.030, 0.045, 0.060, and 0.075 wt. %), using a constant intensity of 77.5 W/cm^2

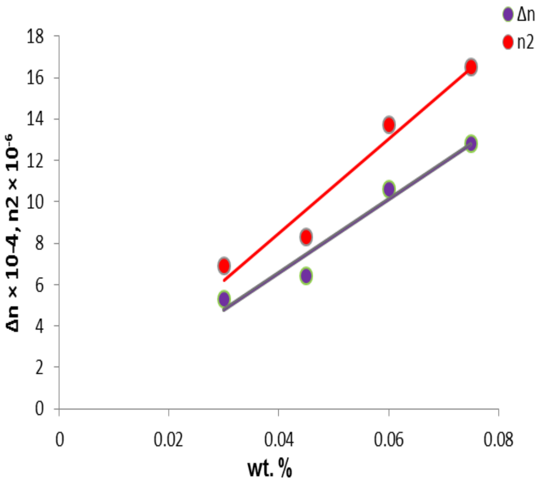

Fig. (6): The variation of both of the maximum change of nonlinear refractive index and the nonlinear refractive index of $MWCNT_S$ acetone suspension at various concentrations (0.030, 0.045, 0.060, and 0.075 wt. %), using a constant intensity of 77.5 W/cm^2

Figures 7 and 8, and Tables 1 and 2 clarify the influence of the concentration of each of both suspensions for achieving various values of $\Delta_{nl,max}$ in spite of using a fixed value of the laser intensity (200 W/cm^2). It has been shown that $MWCNT_s$ DI water suspension at a concentration of 0.075 wt.% was very efficient for achieving a high value of the nonlinear refractive index change($\Delta_{nl,max}$).

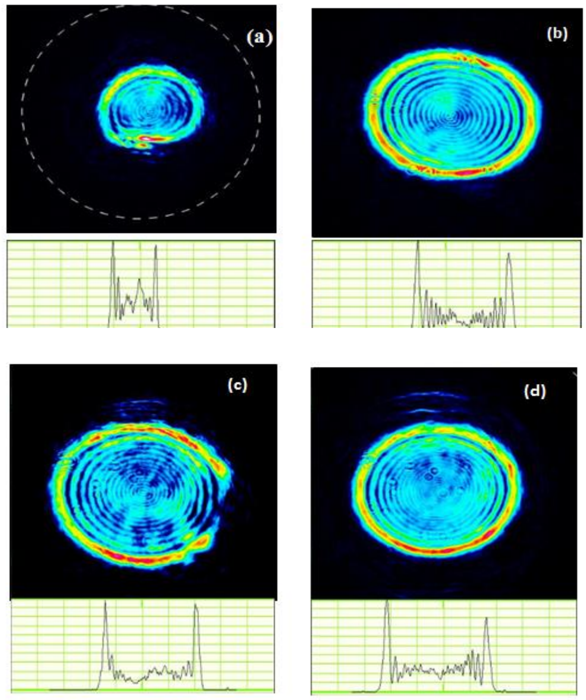

Fig. (7): The change in the number of diffraction rings formed by using $MWCNT_S$ suspended in DI water at concentrations of (a) 0.030, (b) 0.045, (c) 0.060, and (d) 0.075 wt. %, irradiated by a fixed value of laser intensity (200 W/cm^2).

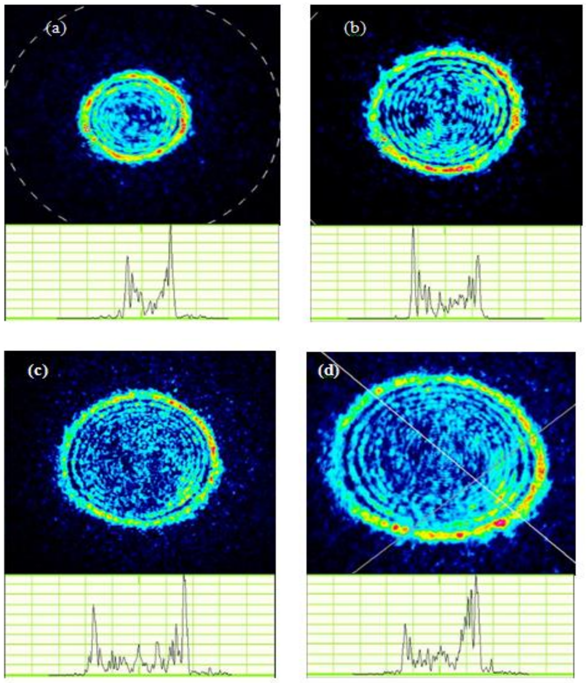

Fig. (8): The change in the number of diffraction rings that formed by using $MWCNT_S$ suspended in acetone at concentrations of (a) 0.030, (b) 0.045, (c) 0.060, and (d) 0.075 wt. %, irradiated by a fixed value of laser intensity (200 W/cm^2).

Table (1): The number of diffraction rings formed using $MWCNT_S$ suspended in acetone at various concentrations, irradiated by a constant laser intensity of 200 W/cm^2.

Concentration (wt. %)	Number of rings
0.030	9
0.050	12
0.060	15
0.080	16

Table (2): The number of diffraction rings formed using $MWCNT_S$ DI water suspension irradiated by a constant laser intensity of 200 W/cm^2.

Concentration (wt. %)	Number of rings
0.030	9
0.050	13
0.060	15
0.080	17

Conclusion

The extracted results of this work conclude that the number of diffraction pattern rings increases by increasing the laser intensity. Increasing of diffraction rings led to the increasing of the nonlinear refractive index change ($\Delta_{nl,max}$) for both of $MWCNT_S$ dispersed in deionized water and in acetone at concentrations of 0.030 wt. %, 0.045wt. %, 0.060 wt. %, and 0.075 wt. %., and this can be attributed to thermally induced refractive index change. Moreover, $MWCNT_s$ DI water suspension at a concentration of 0.075 wt. % was more efficient for achieving a high optical nonlinearity.

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أستقصاء مميزات بصرية لاخطية لمعاليق الكاربون النانوي الأنبوبي متعدد الجدران بأستخدام الحيود اللاخطي لحزمة الليزر

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الخلاصة: يمكن الحصول على أنماط الحيود اللاخطي بواسطة حصر حزمة الليزر خلال شريحة رقيقة للمادة . هنا أستقصينا عمليا تكوين أنماط الحيود اللاخطي للمجال البعيد لحزمة ليزر مستمر الموجة ذو طول موجي 532 نانومتر المار خلال حاوية من الكوارتز فيها معلق لكاربون نانوي متعدد الجدران في ماء منزوع الايونات وفي اسيتون وبتراكيز (0.03wt%, 0.045wt%). اوضحت نتائجنا بأن زيادة تراكيز كلا نوعي المعلق (لكاربون نانوي متعدد الجدران في ماء وفي اسيتون) أدت الى زيادة في عدد حلقات نمط الحيود والتي تشيرالى زيادة التغير في معاملاتها ألانكسارية اللأخطية ، فضلا عن ان معلق الكاربون في الماء وبتركيز % 0.075 كان اكثر فاعلية في تحقيق أعلى لاخطية ضوئية.