Experimental observation of the far field diffraction patterns of
functionalization single and multi-walled carbon nanotubes using
nonlinear diffraction technique

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Abstract
Nonlinear diffraction pattern can be induced by focusing CW laser into a thin quartzes cuvette containing nano fluid. The number of revealed pattern rings indicates to the nonlinear behavior of fluid. Here, the nonlinear refractive index of each of functionalized single wall carbon nanotube (F-SWCNTs) suspension and multi wall carbon nanotube (F-MWCNTs) suspension have been investigated experimentally. Each of CNTs suspension was at volume fraction of $13 \times 10^{-5}$ and $6 \times 10^{-5}$. Moreover the laser source at wavelength of 473 nm was used. The results show that SWCNTs suspension possesses higher nonlinearity than other at the same volume fraction.

Key words
Nonlinear, nano fluids, nonlinear diffraction.

Introduction
Nonlinear optics has been a section of optics that was studied the interactions between the media and electromagnetic radiations [1, 2]. The interaction means, this issue respond in a non-linear way incident radiation fields. The nonlinear optical effects take much attention in the last decade because of their useful application in science and industry such as frequency conversion phase modulation, and multi absorption [2]. Therefore, the nonlinear pattern concentric rings can be detected as far field diffraction [3] when a Gaussian laser beam irradiates
a thin slice of nanofluid [4-6]. This phenomenon had been revealed in many nonlinear materials like organic substance [7-9] nanofluids [9, 10], dye [11], graphene and CNTs [12]. The most application of nonlinear diffraction effects as optical power limiting, optical switching, and beam modulation [13, 14].

**Experimental work**

The experimental set up Figs.1 and 2 consist of Diode laser [model MBL-FN- 473 nm-299.1 mW-15050466] operates at wavelength of 437 nm, attenuer, power meda [Edmund Industrial Optics Barrington, NJ. Polarizing 24 mm Japan] lens with focal length of 7 cm, quartz cuvette (5 mm) containing nanofluids, CCD camera [model Beamage- CCD12, genetic-EO, Canada] and PC with a certain software. Moreover, the nanofluids consist of either functionalized single wall carbon nano tube F-SWCNT's or multi wall carbon nano tube F-MWCNT's suspended in DI water, or functionalized multi wall carbon nano tube (F-MWCNT's) suspended in DI water, also. Each of those suspensions was at volume fraction $13 \times 10^{-5}$ of and $6 \times 10^{-5}$.

![Fig.1: Graphical diagram of the experimental set-up.](image1)

![Fig.2: A photograph of the experimental setup.](image2)
Results and discusses

Absorption spectra of (F-SWCNTs) suspension at volume fraction $13 \times 10^{-5}$ was about 405 nm checked by using UV–VIS spectrometer. The absorption peaks were detected at 415 nm as shows in Figs.3 and 4 show the absorption spectra to SWCNTs suspension at volume fraction $(6 \times 10^{-5})$ was about 454 nm.

Fig.3: The UV–VIS absorption spectra of S-WCNTs DI water, suspension at volume fraction $13 \times 10^{-5}$.

Fig.4: The UV–VIS absorption spectra of S-WCNTs DI water suspension at volume fraction $6 \times 10^{-5}$.

While Fig.5 shows that the peak of MWCNTs suspension at volume fraction $13 \times 10^{-5}$ was about (405 nm). It can be concluded from all previous absorption spectrum of both of two suspensions that the laser source at 473 nm was suitable for all the process of this experiment, where the peak was around 485 at the volume fraction $6 \times 10^{-5}$, as shows in Fig.6. For all the previous absorption peaks the laser source at wavelength 473 nm was suitable for the process.
Table 1 and 2 show that the nonlinear refractive index change $\Delta n_{nl}$ has been increased for both F-SWCNT's and F-MWCNT's suspensions by increasing of their volume fraction using the same value of laser power density. This can be attributed to fact that increasing of suspension volume fraction means increasing its density and finally leads its nonlinear refractive index to be increased. Also it can be noticed that F-MWCNT's suspension possess higher nonlinear refractive index change than that of F-MWCNT's suspension at the same volume fraction (Table 1 and 2). The calculation of the maximum nonlinear refractive index change ($\Delta n_{nl,\text{max}}$) was from the following equation [15].

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

where $\lambda$ is the laser wavelength, $\lambda$ and $L_{\text{material}}$ are the cuvette thickness and $N_{\text{rings}}$ number of diffraction rings.
respectively, for each volume fraction value.

Figs. 7 and 8 show the relationship between the incident laser intensity and the maximum change the nonlinear refractive index of nanofluids in different volume fractions.

**Table 1:** The maximum change of nonlinear refractive index and their coinciding at two volume fraction in SWCNTs.

| Laser intensity (W/cm$^2$) | Volume fraction ($\times 10^{-5}$) | Number of rings | $\Delta n_{nl, \text{max}} \times 10^{-4}$ |
|---------------------------|-------------------------------|----------------|-------------------------------|
| 353.38                    | 6                             | 17             | 20.1                          |
| 353.38                    | 13                            | 18             | 21.28                         |

**Table 2:** The maximum change of nonlinear refractive index and their coinciding at two volume fraction in MWCNTs.

| Laser intensity (W/cm$^2$) | Volume fraction ($\times 10^{-5}$) | Number of rings | $\Delta n_{nl, \text{max}} \times 10^{-4}$ |
|---------------------------|-------------------------------|----------------|-------------------------------|
| 353.38                    | 6                             | 13             | 17.73                         |
| 353.38                    | 13                            | 17             | 20.1                          |

**Fig. 7:** Maximum change of non-linear refractive index created using F-SWCNTs DI water by fraction different than (6 $\times 10^{-5}$), and (13 $\times 10^{-5}$) irradiated by laser intensity.

**Fig. 8:** Maximum change of non-linear refractive index created using F-MWCNTs suspension in DI water of the volume fraction (13 $\times 10^{-5}$), and (6 $\times 10^{-5}$) irradiated by laser intensity.
At high laser beam intensity and high volume fraction the maximum change of the nonlinear refractive index $\Delta n_{nl,\text{max}}$ will be increases as seen in previous table and figure. Different density values were used to obtain different numbers of nonlinear pattern rings that lead to different values of nonlinear refractive indices and maximum change in previous Nano liquids, as shown in Figs. 9 and 10.

![Graph 1](image1)

**Fig. 9:** The diffraction rings from DI water (F-SWCNTs) suspension different laser densities at volume fraction $13 \times 10^{-5}$ and $6 \times 10^{-5}$.

![Graph 2](image2)

**Fig. 10:** The diffraction rings of DI water (MWCNTs) suspension at different laser densities at volume fraction $13 \times 10^{-5}$ and $6 \times 10^{-5}$.

The impact of nonlinear refractive index of the functionalization single and multi-wall Carbone nanotube at two volume fraction can be measured from the following equation [15]:

$$\Delta n = n^2 I$$

(2)

It has been shown from the Figs. 11 and 12 that the nonlinear refractive index increase with decreases lasers intensity according g to the Eq. (2), and increase with increased volume fraction.
Fig.11: The non-linear refractive index produced at SWCNTs Nanoparticles DI water suspension at volume fractions of $13 \times 10^{-5}$ and $6 \times 10^{-5}$ in different laser intensities.

Fig.12: The non-linear refractive index of F-MWCNTs Nanoparticles DI water suspension at volume fraction of $13 \times 10^{-5}$, and $6 \times 10^{-5}$ in different intensities.

Figs.13-16 show that the number of non-linear diffraction patterns detected by the CCD camera increases exponentially with increased fracture size and laser energy intensity according to the Eq. (1), the number of rings is proportional to the intensity of the laser.
Fig. 13: Non-linear diffraction pattern produced by SWCNTs at volume fraction $13 \times 10^{-5}$ at laser intensity (A) 130.41, (B) 169.81, (C) 238.31, (D) 285.69, and (E) 353.38 W/cm².

Fig. 14: Non-linear diffraction pattern produced by SWCNTs at volume fraction $6 \times 10^{-5}$ at laser intensity (A) 130.41, (B) 169.81, (C) 238.31, (D) 285.69, and (E) 353.38 W/cm².

Fig. 15: Non-linear diffraction produced by MWCNTs at volume fraction $13 \times 10^{-5}$ at laser intensity: (A) 130.41, (B) 169.81, (C) 238.31, (D) 285.69, and (E) 353.38 W/cm².

Fig. 16: Non-linear diffraction produced by MWCNTs at volume fraction $6 \times 10^{-5}$ at laser intensity: (A) 130.41, (B) 169.81, (C) 238.31, (D) 285.69, and (E) 353.38 W/cm².
Conclusions

From this experiment in short, were found that by increasing the intensities, the number of rings will be increased until they reach a specific number, after which they will remain constant even in increasing density. This leads to increasing the nonlinear refractive index change ($\Delta n_{nl,max}$) to both of (SWCNTs and MWCNTs) diffuse in DI water at two volume fraction. By determining the nonlinear parameters of the jaginocytes prepared in DI water. The results show that F-SWCNTs suspended fluid possess higher nonlinearity than other at each volume fraction. The material shows non-linear good grade III(third order non linearity), on the other hand the nonlinearity of the F-SWCNTs and F-MWCNTs at volume fraction $13 \times 10^{-5}$ it was more efficiently than other and also it was noted that the minimum threshold of F-SWCNTs at all volume fraction was lower than F-MWCNTs.

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