Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 6, No. 2, PP 43-50 (2010)

355nm Wavelength Generation of Nd:YAG Laser Using Olive Oil

Aqeel S. Fadhil*   Anwaar A. Al-Dergazly   Ziad T. Al-Dahan****

* *Ministry of Oil/ State Company for Oil Projects*

Email: akeel_man_utd@yahoo.com

** *Department of Laser and Electronic Optic/ College of Engineering/ University of Nahrain*

(Received 27 April 2009; accepted 22 February 2010)

Abstract

This project introduces a prospective material for photonic laser applications. The material is olive oil which is classified as organic compound, having a good nonlinear optical properties candidate to be used in photonic applications. A high purity sample of olive oil has been used. The theoretical calculation to generate third harmonic wave using olive oil has been determine using MATLAB program. THG (λ=355nm) intensity has been determined at two cases of sample thicknesses 1mm and 10mm. The minimum threshold incident intensity to obtain THG intensity are equal I_ω=7530 mW/cm^2 at L=1mm and I_ω= 6220 mW/cm^2 at L=10mm. The possibility of generation of third harmonic in olive oil inside the cuvette has been experimented using different powers (90-120) mW of CW Nd:YAG laser. The signal of third harmonic generation has been detected using UV-340 Light Meter.

Kewords: *Olive oil, Third harmonic generation, THG intensity.*

1. Introduction

The phenomenon of third harmonic generation (THG) is a well-known manifestation of the cubic optical nonlinearity of materials, $\chi^{(3)}$. The efficiency of THG depends on the material nonlinearity, incident light (fundamental) intensity and the length of coherent interaction (sample thickness). High third-order nonlinearities are often reported for various materials, in particular organics [1]. Olive oil an organic material consisted of two main groups of substances: saponifables and unsaponifables. A Saponifables compound contains strong π-electron conjugation. This is a crucial factor in attaining high optical nonlinearities and, indeed olive oil have been considered for applications in which a high value of the nonlinear refractive index, n_2 would be of advantage to obtain all-optical switching of optical signals at relatively low light intensities. Also, olive oil can be used in biochemical application because of simplicity and compactness of the system.

2. Theoretical Results and Discussion

Firstly, the transmission spectrum of olive oil is determined using UV-VIS spectrophotometer as shown in figure 1. THG intensity can be determined theoretically using the following equation [2].

$$I_{3\omega}=\frac{(3\omega)^2}{n^4_{\omega}c^4\varepsilon_o^{2}}\frac{\sin^2[\Delta k(L/2)]}{[\Delta k(L/2)]^2}\left|\chi^{(3)}\right|^2 L^2 I^2_{\omega} \qquad ...(1)$$

This equation shows THG parameters, which are represented by fundamental frequency ω, which are represented by fundamental frequency ω, interaction length or sample thickness L, third order nonlinear susceptibility $\chi^{(3)}$ of the material which is determined experimentally using z-scan technique has a value of ≈ 10^{-12} m^2/V^2.

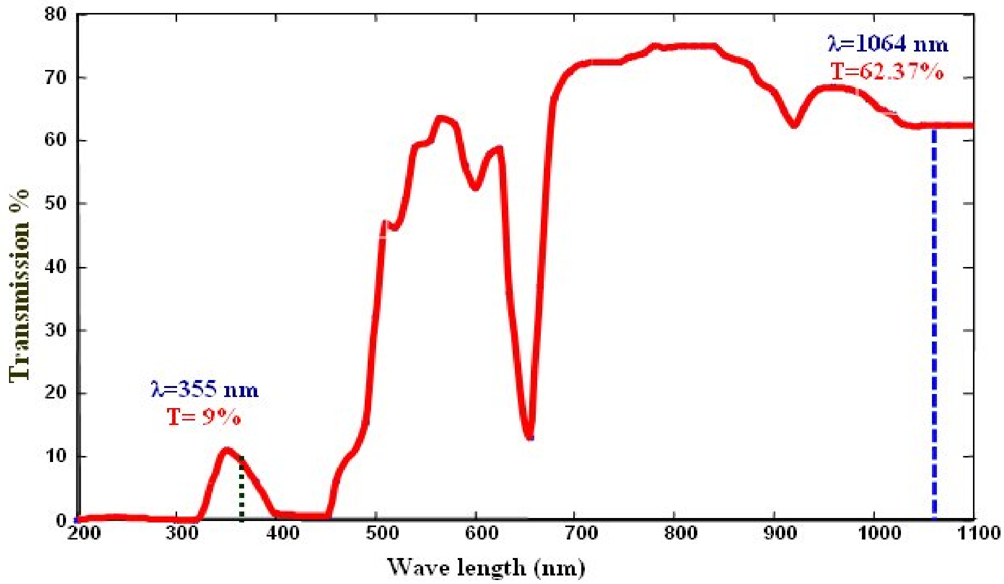

Fig. 1. Olive oil Transmission Spectrum.

I_ω represents the excitation intensity of laser beam. c and ε_o represents, the speed of light and vacuum permittivity.

The wave vector at THG signal Δk is determined from the following equation [2]:

$$\Delta k = k_{3\omega} - 3k_\omega = \frac{6\pi}{\lambda}(n_{3\omega} - n_\omega) \qquad ...(2)$$

n_ω and $n_{3\omega}$ respectively, the refractive index at fundamental and THG frequency, which is equal 1.46 and 1.4789 [3]. ω is the fundamental frequency at λ=1064nm, which equals 1.77×10^{15} Hz. the wave vector Δk equals 334.8mm^{-1}.

THG intensity is determined using the first equation at different input excitation intensity and by using computer program (MATLAB). Two values of interaction length were used in calculations (L=1mm, L=10mm) as shown in figure 2.

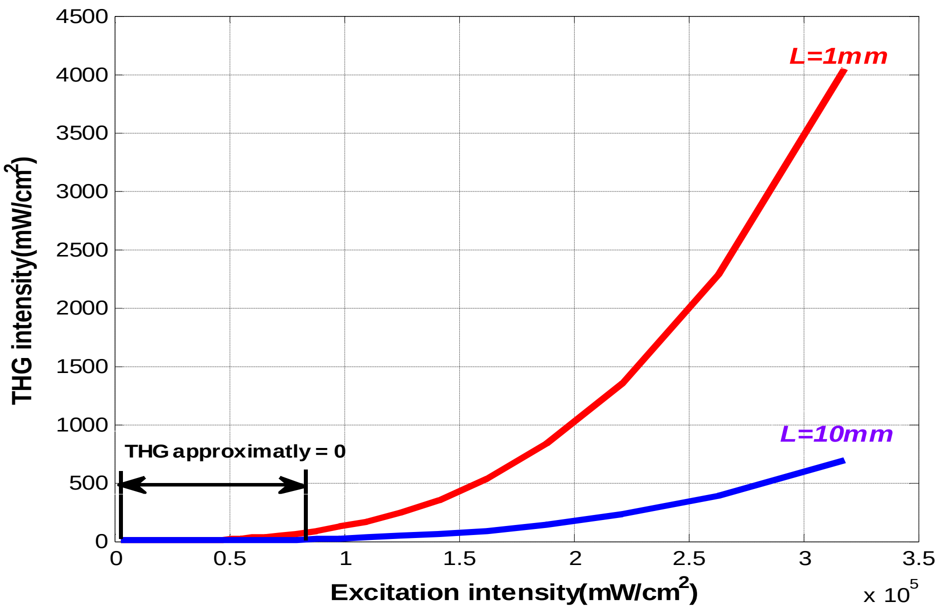

Fig. 2. THG light Intensity Versus Input Excitation Intensity for Different Interaction Length.

From figure 2, the variation in THG intensity is proportional to the square of excitation intensity; the variation is low at (0.0318×10^5 – 0.122×10^5 mW/cm^2) while after 0.138×10^5 mW/cm^2 for L=1mm and 0.18×10^5 mW/cm^2 for L=10mm the variation increases rapidly until to reach the maximum value at 3.25×10^5 excitation intensity in this figure. The interaction length L affects the THG intensity.

The threshold intensity I_{th} to obtained THG were found from figure 2 by changing the incident powers in two cases of interaction length, L=1mm and L=10mm as shown in Tables 1 & 2 respectively where the spot area $A=\pi d^2/4$, d represents the spot diameter was changed between d=0.2mm and 2mm. Then, $I_{th}=4p/\pi d^2$ [2], P is the incident power.

Table1,
Threshold Values of THG Intensities at L=1mm.

Power (mW)	I_{th} (mW/cm^2)	$I_{3\omega}$ (mW/cm)	Spot area (mm^2)
80	6220	0.01	1.286
100	6310	0.01	1.583
120	13600	0.1	0.882
140	13720	0.1	1.02

Table2,
Threshold Values of THG Intensities at L=10mm.

Power (mW)	I_{th} (mW/cm^2)	$I_{3\omega}$ (mW/cm^2)	Spot area (mm^2)
80	7570	0.1	1.0568
100	7530	0.1	1.327
120	7170	0.1	1.628
140	15860	1	0.882

The maximum values of THG intensities were observed in the case of phase-matching or non-collinear. Phase-matching can be obtained when the wave vector $\Delta kL=0$ by changing the thickness of sample. Efficient THG is difficult to achieve in the olive oil because the wave vector $\Delta k\neq0$ and $n_{3\omega}>n_{\omega}$ [2]. In the case of different thickness of sample L, phase-matched THG intensity can be achieved as shown in figures 3. Figures 3 shows the phase-matching and phase mis-matching of THG intensity, which is determined at four values of spot diameter of the fundamental beam ***d*** (0.1, 0.12, 0.14, 0.16) mm and for different values of sample thickness ***L*** from 10-100 μm in step of 1.

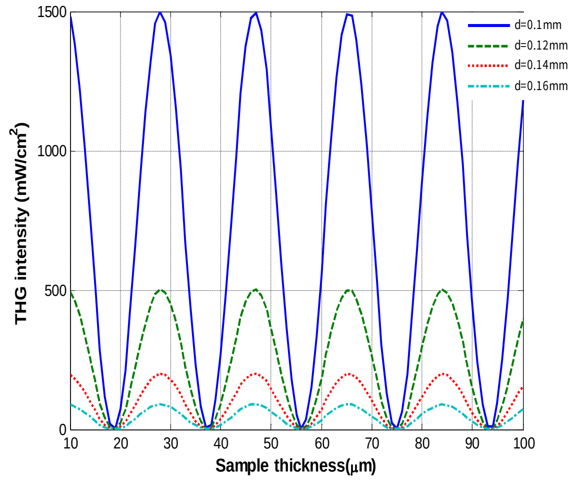

Fig.3. Phase-Matched THG Intensity at 80mW Input Power.

As a result, phase-matched THG intensity was obtained at the values of sample thickness (10, 28, 46, 66) μm. Phase mis-matched THG intensity was obtained at the values of sample thickness (18, 37, 56, 75, 93) μm. The phase mis-match occurs periodically every 18μm (i.e. the coherent length L_c equal 18μm). Also, the variation of the THG intensity is proportional to the value of spot diameter into phase matching and mis-matching. For the value of spot diameter (d=0.1mm), THG intensity has become at maximum value, while at the value of spot diameter (d=0.16) it has become at minimum value. The reason of this effect is that the incident intensity is increased by reducing the spot diameter. So, for small spot diameter the intensity of incident laser beam becomes very high and THG intensity is increased by increase the intensity of excitation beam.

3. Experimental

THG intensity is measured experimentally using a simple set-up in laboratory as shown in figure 5. The set-up was consisted of the following components:

1- Nd:YAG CW infrared laser (λ=1064nm).
2- The sample, which represented the solution of olive oil filled in 1mm quartz cuvette.
3- UV-light meter, which is shown in the figure 5.

Figure 4 shows the block-diagram of THG measurements:

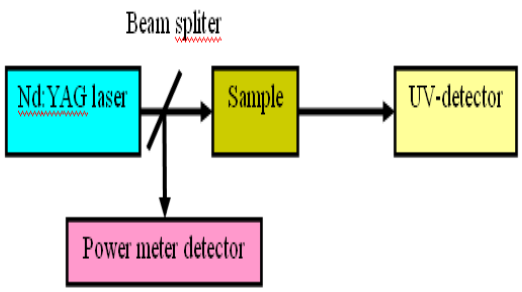

Fig. 4. Block-Diagram of THG Measurements.

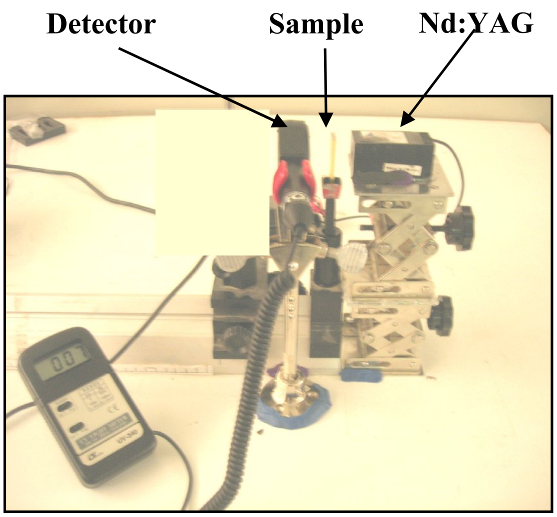

Fig. 5. Set-Up of THG Experiment.

Assuming a plane wave and non-depleting fundamental power, the THG output power was measured for different incident angles in the range from -30° to 30° increments of 5°step. The measurements of intensity based on two values of sample thickness 1mm and 10mm. The incident angle of fundamental beam θ was changed by tilt the sample forward to the left of the optical axis to make a positive angle and backward to the right of the optical axis to make a negative angle. Bevel-square was used to measure the incident angle.

THG output signal intensity was measured with respect to the reference value when the quartz cuvette is blank. At the reference, very low UV radiation was detected, which represented the Rayleigh-scattering or stimulated Raman scattering. This value is regarded in measurements. The efficient values of THG output signal intensity was found as shown in figures 6 to 9:

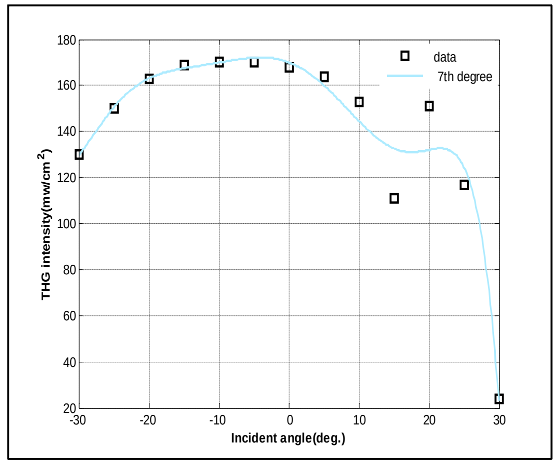

Fig. 6. THG Output Intensity Excited at 90mW Input Power Versus Incident Angle for L=1mm.

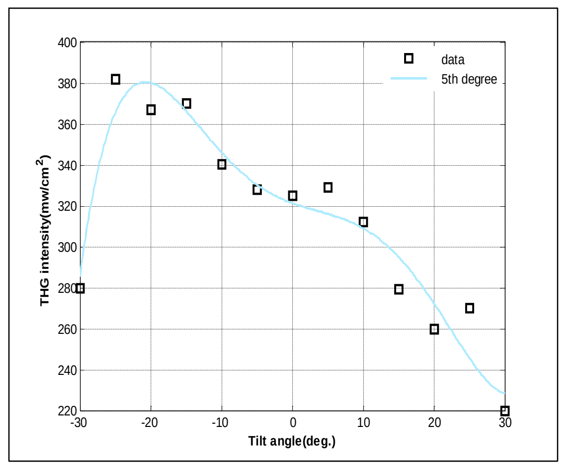

Fig. 7. THG Output Intensity Excited at 100mW Input Power Versus Incident Angle for L=1mm

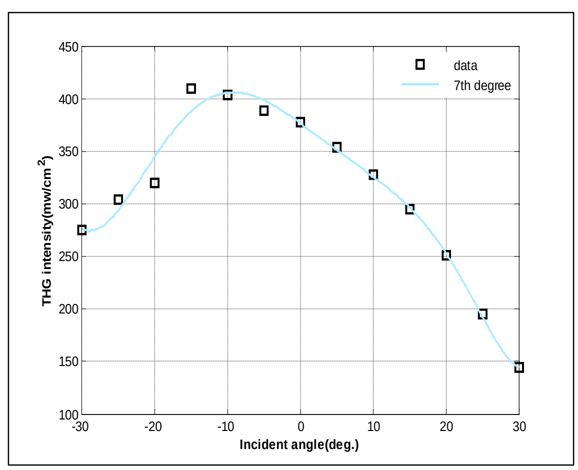

Fig. 8. THG Output Intensity Excited at 120mW Input Power Versus Incident Angle for L=1mm.

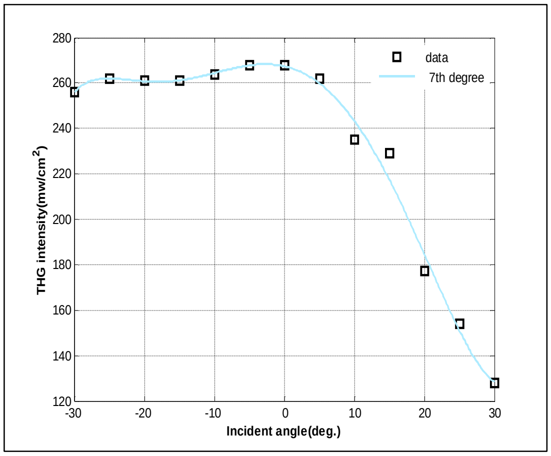

Fig. 9. THG Output Intensity Excited at 110mW Input Power Versus Incident Angle for L=1mm.

The result shows different values of THG intensity at each input power due the change in the incident angle of fundamental beam. The reason of change the incident angle of the fundamental beam is to obtain on efficient THG intensity. The change in the incident angle of fundamental beam was induced change in the re-orientation of the olive oil molecules, which induced change in refractive index

For L=10mm, THG output signal intensity was measured with respect to the reference value. Very low UV radiation of scattering was detected at the reference (when the cuvette is blank). The efficient THG output signal intensity was found as shown in figures10 to 13:

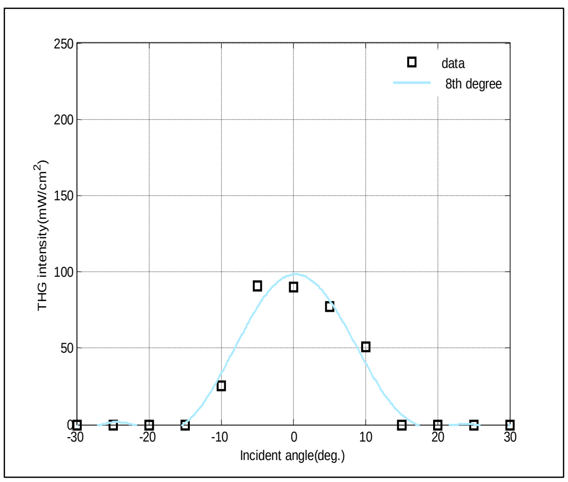

Fig. 10. THG Output Intensity Excited at 90mW Input Power Versus Incident Angle for L=10mm.

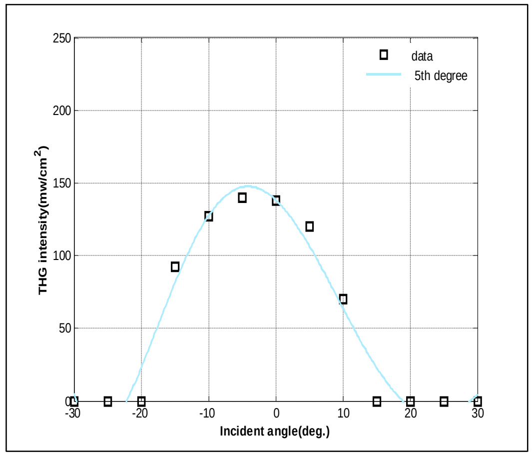

Fig. 11. THG Output Intensity Excited at 100mW Input Power Versus Incident Angle for L=10mm.

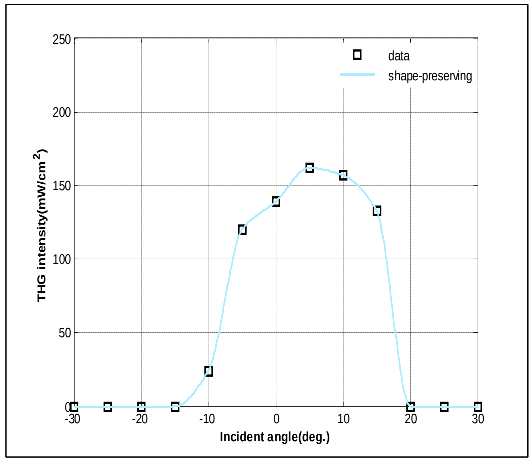

Fig. 12. THG Output Intensity Excited at 110mW Input Power Versus Incident Angle for L=10mm.

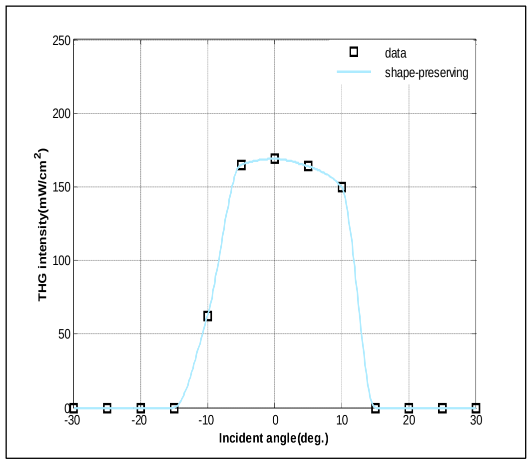

Fig. 13.THG Output Intensity Excited at 120mW Input Power Versus Incident Angle for L=10mm.

The results show different values of THG intensity for each input power due to the change in the incident angle of fundamental beam. Also, the efficient THG intensity was approximately obtained at incident angle in rang from -15° to 15° because no signal will be detected at the incident angles -20° and 20°. These angles represent the best angles of THG signal because of high re-absorption of THG intensity occurred at these angles.

The experimental results were compared with theoretical results as shown in figure 14.

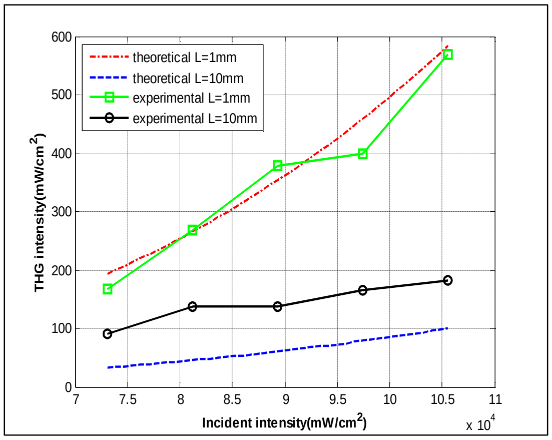

Fig. 14. Theoretical and Experimental Values of THG Intensity.

From figure 14, the experimental values of THG intensity are in good agreement with theoretical values. This case was obtained when the excitation beam (fundamental beam) was incidence in the medium.

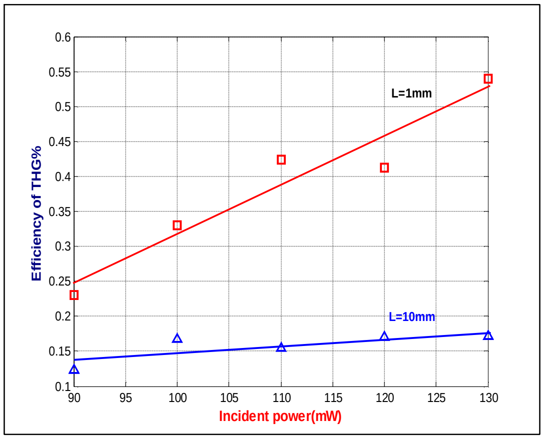

Fig. 15. Efficiency of Conversion The Fundamental Beam into THG for L=1mm & L=10mm.

The efficiency of the conversion of the fundamental beam into THG beam is determined experimentally using the following formula at L=1mm & L=10 mm for different incident powers as shown in figure 15:

$$Efficiency\ of\ conversion = \frac{I_{3\omega}(L)}{I_{\omega}(0)} \qquad ....(3)$$

4. Conclusions

We have reported on efficient third harmonic generation in self-focusing in olive oil solution. We have theoretically determined the threshold intensity to obtained THG intensity in olive oil for two cases of sample thicknesses. For 1mm the threshold intensity to obtained THG equal I_{ω}=7530 mW/cm^2 and for 10mm the threshold intensity to obtained THG equal I_{ω}= 6220 mW/cm^2. Also, the coherence length of olive oil is equal to 18μm, which is obtained from the simulation results, when third order nonlinear susceptibility equals ~10^{-12} m^2/V^2 for different input powers.

THG intensity is changing with the change in the incident angles. The best incident angles are equal -10, 0, +10 degree for L=1mm and +5, 0 degree for L=10mm to obtained the maximum generation.

Notation

A	Spot area of laser beam
c	Light speed in vacuum
d	Spot diameter of laser beam
I_{ω}, I(0)	Incidence intensity
$I_{3\omega}$	Third harmonic generation intensity
I_{th}	Threshold incident intensity to obtain THG
k_{ω}	Wave number of fundamental beam
$k_{3\omega}$	Wave number of THG beam
Δk	Wave vector phase mis-match
L	Sample length
n	Total refractive index
n_{ω}	Refractive index at frequency ω
$n_{3\omega}$	Refractive index at frequency 3ω
P	Incident power

Greek letters

ε_o Vacuum permittivity

λ Wavelength

ω Angular frequency

5. References

[1] M. Samoc, A. Samoc, B. Luther-Daives, "Third harmonic autocorrelation and wave mixing in poly(p-phenylenevinylene", Optical Society of America: OPTICS EXPRESS, Vol. 11, No. 15, 1787-1792, (2003).

[2] M. G. Pabadopouls, A. J. Sadlej and J. Leszcynski, "Nonlinear optical properties of matter", Springer, Netherlands, (2006).

[3] Aqeel Salah Fadhil," Study of Nonlinear Optical Properties of Olive Oil", M.Sc. Thesis, Nahrain university, (2009).

توليد التوافق الثالث ٣٥٥ نانومتر لليزر النديميوم-ياك باستخدام زيت الزيتون

عقيل صلاح فاضل*　　أنوار عبد الستارالدركزلي　　زياد طارق الدهان****

* شركة المشاريع النفطية/ وزارة النفط

البريد الالكتروني: Akeel_man_utd@yahoo

** قسم هندسة الليزر والالكترونيات البصرية/ كلية الهندسة/ جامعة النهرين

الخلاصة:

يقدم هذا المشروع مادة جديدة مقترحة لتطبيقات الليزر الفوتونية المادة هي زيت الزيتون الذي يمكن تصنيفه كمركب عضوي يمتلك مواصفات لاخطية جيدة تمكنه من استخدامه في التطبيقات الفوتونية. استخدمت عينة ذو نقاوة عالية من زيت الزيتون. ايجاد الحسابات النظرية لتوليد التوافق الثالث باستخدام زيت الزيتون باستخدام برنامج الماتلاب. حيث تم ايجاد شدة الطاقة للتوليد التوافقي الثالث ٣٥٥ نانومتر نظريا على سمكين للعينة ١مم و ١٠مم. اقل قيمة لشدة الطاقة حتى يحصل التوافق الثالث تساوي ٧٣٥٠ ملي واط/سم^{2} لسمك العينة ١مم و تساوي ٦٢٢٠ ملي واط/سم^{2} لسمك العينة ١٠مم.

عمليا, تم ايجاد شدة الطاقة للتوليد التوافقي الثالث على سمكين للمادة ١مم و ١٠مم. تم توليد التوافق الثالث في زيت الزيتون داخل حاوية زجاجية باستخدام ليزر النديميوم-ياك ذو الموجة المستمرة وبمختلف الطاقات (٩٠-١٣٠) ملي واط.
