PAPER • OPEN ACCESS

Effect of Solar radiation induced and alpha particles on Nonlinear behavior of PM-355 film

To cite this article: Abdalrahman Al-Salihi *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **928** 072056

Effect of Solar radiation induced and alpha particles on Nonlinear behavior of PM-355 film

[1]Abdalrahman Al-Salihi, [2]Rusul D. Salim, [3]R. K. Fakher Alfahed , [2]Hussain A. Badran

[1]Department of Basic Sciences, College of Dentistry, University of Basrah, Basrah, Iraq
[2]Physics Department, Education College for Pure Sciences, Basrah University, Basrah, Iraq
[3] Al-Nahrain University, Al-Nahrain Nano- renewable Energy Research Center, Baghdad, Iraq

rosalh7975@gmail.com
Corresponding author's E-mail: badran_hussein@yahoo.com

Abstract: In the current work of radiology, polymeric sheets of the PM-355 nuclear track detectors (SSNTDs) were exposed with α-particles and solar radiation for several exposure times. The absorption spectrum of samples exposed to the sun showed that the edge of the absorption accidentally changed to longer wavelengths. An investigation of continue waveguide laser effects on the nonlinear absorption properties of nuclear track polymer has been done. Non-linear absorption increases with increasing levels of exposure to sunlight and is highly connected to revealed surface morphology and chemical structural modifications. In case of high solar radiation flux and α-particles irradiation, the nuclear track detectors showed high nonlinearities, represented by the appearance of a number of diffraction rings.

Keywords: PM-355 polymer; Alpha particles; Absorption edge; Laser; Solar radiation

Introduction:

The polymeric detector PM-355 has many applications in various subjects such as industry and medicines [1]. This detector responds to numerous types and effect of radiations, including α-particles [2], Irradiation by neutrons [3], protons [4], slow and heavy charged particles [5], Gamma irradiation [6], UV [7], laser irradiation [8-11] and solar radiation [12]. The interaction of different types of radiation with PM-355 nuclear track detectors (SSNTDs) modifies chemical compositions, optical properties, chemical and mechanical properties and polymer structures [13]. The value of these modifications relies on the primary chemical composition of the polymer and methodology exposure conditions such as dose of gamma rays or alpha particles, induced solar radiation energy and wavelength of incident radiation of the laser beam.

In the present work, x-ray diffraction (XRD) spectra and absorption spectra resulting from irradiation of alpha particles and different degrees of solar exposure were explored on PM-355 detectors. The aim is to correlate these effects with changes in the non-linear reflection index, in the properties of non-linear absorption of this polymer after laser irradiation and in the pattern of self-induced rings.

2. Materials and methods

A set of two PM-355 SSNTD polymer films was used (at 1.32 g/cm^3 as density and 125 µm thick by Pershore Moulding, England). The dimensions of 1 x 1 cm^2 were removed from the PM-355 polymer. Irradiation was performed in the air, so the results did not suffer from the effect of vacuum in track properties. One piece of the set remains non-irradiated, only affected by the natural background, for use as a control sample and the other is irradiated as indicates.

2.1. Solar radiation

The SSNTDs polymer has been exposed to solar radiation at various temperatures on August month in Basrah (Iraq). PM-355 sheets were fixed to a horizontal concrete surface and located in an uncover area and hence, they are usually facing the sun and are not in the shade of anything at any time. The degree of temperature usually changes between 49 ° C and 52 ° C . The irradiation of samples was achieved during August 2019 in Basrah, Iraq, while protection the same environmental and engineering conditions for the samples at different time periods.

2.2. Alpha particles

The PM-355 SSNTDs samples were exposed to vertically exposed α- particles (main energy 5.49 MeV) emitted from a source of ^{91}Ci ^{241}Am. The irradiation was carried out in the air at a distance of 0.5 cm from the source, which corresponds to the energy of the 5 MeV α- particles. The ^{241}Am source was free of stabilizers to ensure that the area of the nuclear polymer material (4 cm^2) was completely radioactive. The corresponding irradiation time was calculated to be 6.79 x 10^{+9} particles/cm^2.

2.3. Z-scan

The z-scan technology is depended on the basic values of beam spatial distortion [14]. It provides simplicity and high sensitivity to measure the signal and magnitude of non-linear index of refraction (n_2) and the non-linear absorption coefficient (β) [15]. Experimental configuration details according to [16]. The excitation source is a 473 nm solid-state continuous wave laser and an input power of 22 mW. The laser beam was focused using a focal length lens of 5 cm. The beam waist $(\omega_{\circ})$ and Rayleigh range (Z_R) of the CW laser beam are determined. The transmitted laser power was calculated by a sensitive photodetector fed to the digital meter of optical power (PM320E, Thor Labs).

3. Results and Discussion

The pristine configuration and radioactive PM-355 SSNTDs samples were studied in the 2θ range between 6° and 70° using X-ray diffraction analysis (PM-355 by radiation with alpha particles and 49 ° C and PM- 355 with alpha particles and 52°C) as shown in Fig. 1. For the pristine PM-355, the peaks observed at 2θ=21.7^{o} indicate the formless nature of the PM-355 polymeric films. The peak at 21.5° and 21.3° corresponds to the PM-355 polymers irradiation with α-particles and treated with sun exposure at numerous solar exposure degrees in the same period of time. Fig. 1 illustrates the spectra of X-ray diffraction for pristine and two kinds of the samples irradiated in August at $52^{\circ}C$ and $49^{\circ}C$. Fig. 1 shows the existence of a wide and large peaks at 2θ=21.7°, 21.5° and 21.3° for pristine and irradiation samples, respectively.

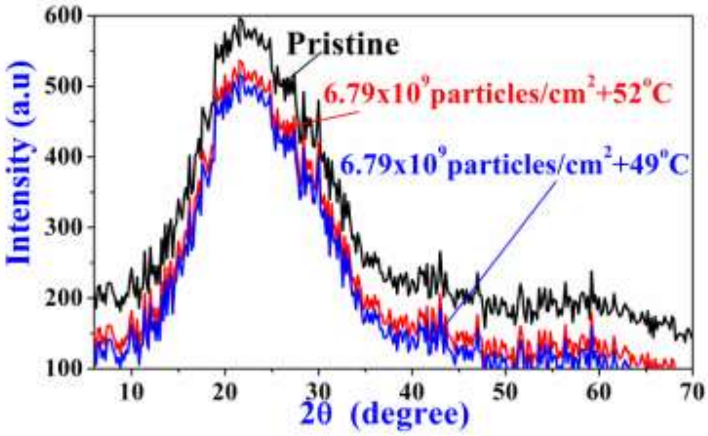

Fig.1. X-ray spectra of nuclear polymer PM-355.

Fig. 2 represents the UV-Visible absorbance spectroscopy ranged between (300 and 700 nm) was performed for solar-irradiated and pristine samples at various degrees of sun exposure in the same month, August. It can be seen that a sudden decline in absorption with a growing wavelength to a specific data, accompanied by a plateau section in its UV-Visible spectrum. To properly verify the exposure, there are three samples irradiated to solar radiation with several degrees of exposure and it has been selected only the best one for each degree for this study. On the other hand, the general tendency for absorption is similar to that of the virgin sample. In the system of track polymer, the absorption edge is usually caused by π-π* electronic transformations. Π-electron excitation needs low energy and, therefore, transmission of this kind happens at extended wavelengths that can be achieved in the specified wavelength range [17-20]. The behavior of the oscillation was observed in the absorption of samples exposed to the sun. The temperature result in various degrees could lead to these differences. The energy absorbed by the temperature degree can caused to the consistency of large-scale conjugated schemes that yield defects and carbon clusters. In addition, in this scheme, C-O-C, C-H, C=O, and –CH=CH- bonds are placed with the ultraviolet and visible bands obtainable due to exposure to the sun and this can lead to a change in the morphology and chemical structure of PM-355 SSNTDs samples [21].

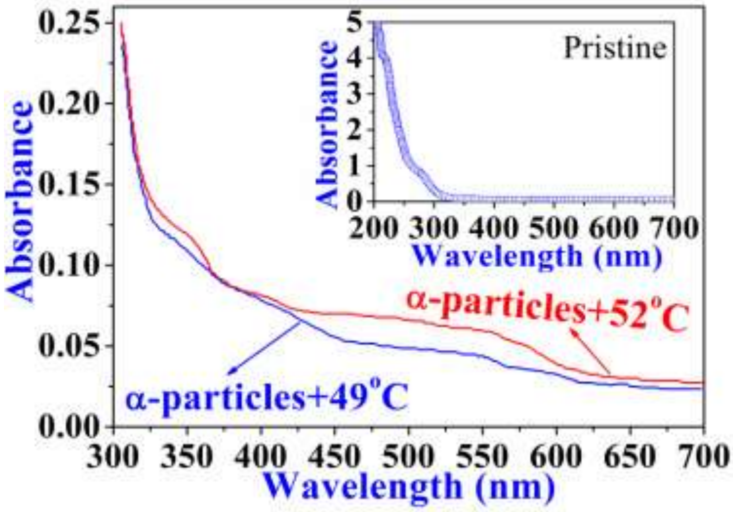

Fig. 2. Show UV–Vvisible spectra of the pristine and PM-355 irradiation with Alpha- particles and different solar exposure degrees.

3.2. Nonlinear studies

For the calculation the nonlinear coefficient of absorption (β)' along with nonlinear index of refraction (n_2), the z-scan setups were achieved for "PM-355 irradiation with Alpha-particles and 52 degrees Celsius and PM-355 irradiation with Alpha-particles and 49 degrees Celsius" nuclear detectors in both open and closed aperture configurations. Z-Scan experiments for Open aperture technique and closed aperture technique were applied in find β and n_2.

The experiment setup with TEM_{oo} diode laser, where a positive converging lens (focal length = +5 cm) was applied to focus the beam of laser. The waist of beam ω_o at the focal point was 24.04 μm and the length of diffraction (Z_r) was determination according to [22,23]:

$$Z_r = \frac{2\omega_\circ^2}{\lambda} \quad (1)$$

From the diffraction length, the calculated Z_r was 3.83 mm which pleased the significant Z-scan technique condition which is the great diffraction length compared to the pristine and the thickness of irradiation samples. The transmittance of laser was determined by a detector of photo which fed to a digital meter of power (PM320E, Thor Labs). For a Z-scan of open aperture, a lens which substitutes the aperture was applied to obtain the entire transferred beam over the sample**.** The OA data in the experimental technique was replaced in formula below to find the nonlinear coefficient of absorption β [24].

$$T(z) = \sum_{m=0}^{\infty} \frac{(-q_\circ)^m}{(m+1)^{3/2}} \tag{2}$$

For $q_\circ < 1$, where $q_\circ(z)$ is a function of incident laser beam, sample' effective thickness and nonlinear absorption coefficient,

$$q_\circ(z) = I_\circ L_{eff} \beta \big/ (1 + z^2 / z_\circ^2) \tag{3}$$

For linear absorption coefficient << 1 and solving the summation;

$$T(z) = 1 - (I_\circ L_{eff} \beta) \big/ [2^{3/2} (1 + z^2 / z_\circ^2)] \tag{4}$$

At the focusing point, the intensity of the incident beam is equal to 2.42 KW/cm^2 and the intensity of the laser I_o was determination according to equation [25,26]:

$$I_o = 2P / \pi\omega_o^2 \tag{5}$$

For the open aperture case ΔT is the one basin transmissions of Z-scan bend. Equation 6 connects Δn with the total index of refraction (n) of the medium and the index of refraction $(n_\circ)$ [27,28]:

$$n = n_\circ + \Delta n \quad \& \quad \Delta n = n_2 I_0 \tag{6}$$

The normalizing peaks participate with valley transmittances by [29]:

$$T(z, \Delta\Phi) = 1 - \frac{4\Delta\Phi x}{(x^2+9)(x^2+1)} \tag{7}$$

ΔΦ is the on-axis phase shift correlated with the 3rd-order n_2 by [30-32]:

$$\Delta\Phi = k n_2 L'_{eff} I_\circ \tag{8}$$

where $k=2\pi/\lambda$, $L'_{eff} = (1 - \exp(-\alpha_{abs} th)) \big/ \alpha_{abs}$ [33,34], L'_{eff} is the effective thickness of sample, α_{abs} is the linear coefficient of absorption, th is the sample thickness, $x = Z / Z_\circ$ and T is the normalized transmittance for CA/CO curve. The light ratio crossing the aperture to that opposite side can be represented by linear transmission (S) of the aperture was determination according to equation [35,36]:

$$S = 1 - \exp(-r_a^2 / \omega_a^2) \tag{9}$$

The S value is equal to 0.73, where the aperture radius is r_a and ω_a is the radius of beam at the aperture.

IOP Conf. Series: Materials Science and Engineering **928** (2020) 072056 doi:10.1088/1757-899X/928/7/072056

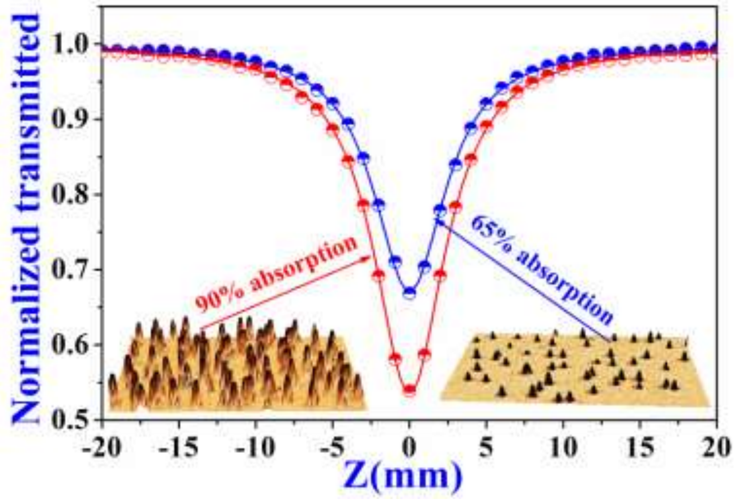

Fig.3. Normalized transmittance/ absorption measured by Z-scan technique(fitting curves obtained from equation 3)for laser irradiated PM-355 with Alpha-particles and different solar exposure degrees.

From the open Z-scan data curve (Fig.3) it is obvious that there is a prompted absorption in the considered samples because the transmission on focus reductions with growing degree of solar exposure. The drop formed at the focus (z=0), indicates carefully that the process in Z-scan open aperture is Reverse saturated absorption (RSA) [37] in the PM-355 SSNTD polymer sheet irradiation with Alpha-particles and 52 degrees Celsius and sample PM-355 irradiation with Alpha-particles and 49 degrees Celsius. Reverse saturated absorption is commonly found in centrosymmetric physical organic compounds and especially in π- composite resources [38].

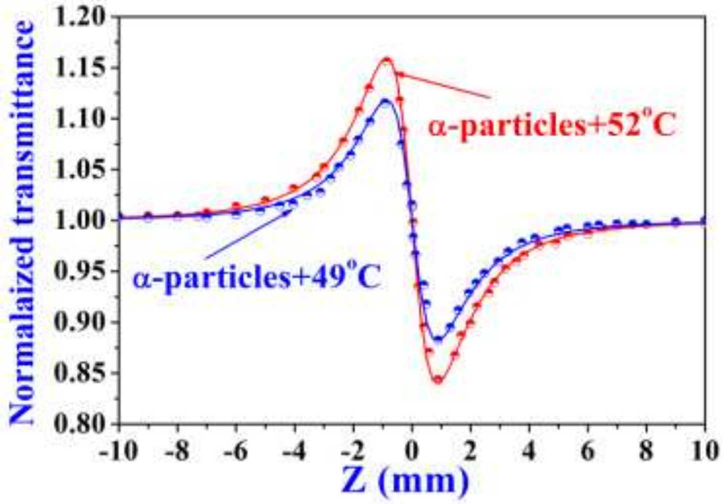

Fig. 4. Pure Normalized transmittance by Z-scan technique (fitting curves obtained from quation 7) for laser irradiated PM-355 with Alpha-particles and different solar exposure degrees.

IOP Conf. Series: Materials Science and Engineering **928** (2020) 072056 doi:10.1088/1757-899X/928/7/072056

The closed aperture technique is carried out by applying an aperture beforehand the sensor, allowing the investigation of the magnitude and sign of n_2 of the designed polymer PM-355 irradiation with Alpha-particles and solar exposure at 52 degrees Celsius and polymers PM-355 irradiation with Alpha-particles and solar exposure at 49 degrees Celsius. Fig.4 is presented the consequent non-linear tracked refraction of the data with theoretic modification. The figure shows a maximum transmittance beforehand the peak and the smallest afterward the valley. This subscription of peak-valley shows self-defocusing, considered by a negative symbol in the 3rd-order n_2. Thus, the sign of the 3rd-order n_2 of a PM-355 is consequently perfect from the sketch of acquired closed aperture Figure. The natural origin of n_2 in solid state nuclear track PM-355 detectors films is because of the thermal nonlinearity in nature, since the excitation source is continuous [39]. The calculated values of nonlinear reflective index, nonlinear absorption coefficient and some nonlinear parameters are tabulated in Table 1.

Table 1. Some nonlinear parameters

Sample solar Degree (^{o}C)	β x10^{-3} (cm/W)	$\Delta\Phi$	n_2 x10^{-8} (cm^2/W)	Δn x10^{-4}
49	6.81	0.8	3.8	0.9
50	8.36	1.07	5.9	1.4

4. Diffraction ring patterns

4.1. Experimental study of the patterns

The methodology arrangement used to obtain the stimulated diffraction ring designs in the PM-355 irradiation with α -particles and different solar exposure degrees comprised a continuous-wave solid state at wavelength of 473 nm in the single TEMoo mode. The laser device output coupler with varying output power between zero and 100 mW. A positive 5 cm glass lens was applied to emphasis the solid laser beam. The obtained diffraction ring patterns were casted onto a semitransparent 30 x 30 cm monitor, 80 cm away from the sample cell. The diffraction ring patterns were registered using a digital camera. The obtained diffraction ring patterns are presented in Fig. 5 for laser intensity Io = 6.09 kW/cm^2. It can be seen that the ring number, the area of the pattern and the diameter of the furthest ring in each pattern increase in order with increasing alpha particles and different degrees of solar exposure. Nonlinear parameters of PM-355 irradiation with Alpha-particles and 52 degrees Celsius and PM-355 irradiation with Alpha-particles and 49 degrees Celsius using diffraction ring patterns are tabulated in Table 1.

Sample solar Degree (^{o}C)	Ring patterns number	n_2 x10^{-8} (cm^2/W)	Δn x10^{-4}
49	3	0.7	0.43
50	4	10.7	0.65

4.2. Theoretical study of the ring patterns

The laser beam used in the experiments has a single transverse fundamental, TEMoo, mode distribution of its intensity. The complex electric field of laser beam at the entrance to the sample can be written [40-42] as:

$$E(r, Z_\circ) = E(0, Z_\circ)\exp\left[-\frac{r^2}{\omega_p^2}\right]\exp\left[-\frac{ik_\circ n_\circ r^2}{2R}\right] \qquad (10)$$

The total phase of the beam, ϕ(r), can be written as:

$$\phi(r) = k_\circ \frac{n_\circ r^2}{2R} + \Delta\phi \qquad (11)$$

$\Delta\phi$ can be related to the PM-355 irradiation with Alpha-particles and different solar exposure degrees total change in refractive index, Δn, as follows[43-45]:

$$\Delta\phi = k_\circ \Delta n(z_\circ, 0) d \exp\left[-\frac{2r^2}{\omega_p^2}\right] \qquad (12)$$

The complex electric field of the laser beam can be written as follows [40]:

$$\boldsymbol{E(r, z_0, d) = E(0, z_0)\exp\left[-\frac{r^2}{\omega_p^2}\right]\exp\left[-\frac{\alpha d}{2}\right]\exp[-i\phi(r)]} \qquad (8)$$

Under the Fraunhoffer approximation and Fresnel-Kirchhoff diffraction integration, the far field strength of the laser beam and the diffraction angle of the far field can be written as follows [46]:

$$\boldsymbol{I(\rho) = I_o\left|\int_o^\infty J_o(k_o\theta_r)\exp\left[-\frac{r^2}{\omega_p^2} - i\phi(r)\right]\right|^2} \qquad (9)$$

Fig.5 show the numerically calculated result obtained by solving equation 14 where it can be seen the good agreement compared to the experimental findings.

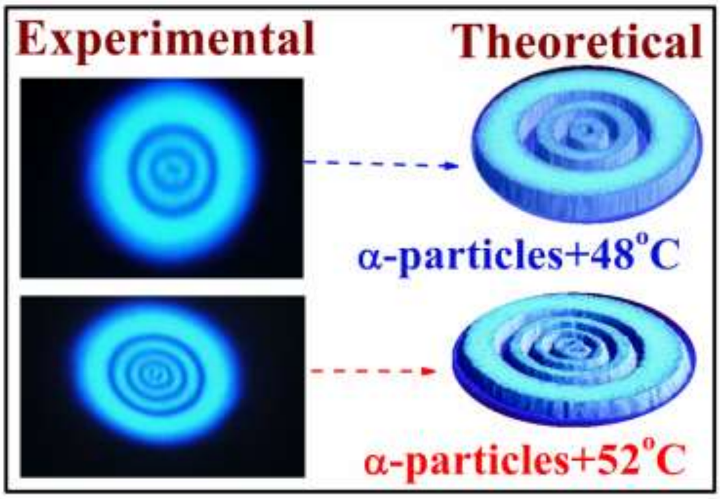

Fig.5. Experimental result and theoretical result obtained by solving equation14 of PM-355 irradiation with alpha-particles and different solar exposure degrees.

5. Conclusions

From the results we have reported and discussed for the α-particles irradiation, emitted from 9 lCi241 Am source and irradiated to solar radiation at various temperature degrees of PM-355 solid state nuclear detectors, our conclusions can be summarized as follows. The peak at 21.5° and 21.3° corresponds to the PM-355 polymers irradiation with α -particles and irradiated to sun at numerous solar exposure degrees in the same month. The calculation from Z-scan method using solid laser with 473 nm wavelength reveal that the index of nonlinear reflective are increase at the sample with alpha-particles irradiation and with further increasing solar exposure degrees. The Self induced pattern shows the generation of multiples diffraction rings on the screen at highest alpha-particles and highest solar exposure degrees. This is associated with the formation of free radicals as a result of the alpha-particles. Theoretical study also shows a significant change in the number of rings after different irradiations.

References

[1] H.G. Rubahn, Laser Applications in Surface Science and Technology (Wiley, New York, 1996)
[2] T. M Salman, A. Y. AL-Ahmad, H. A. Badran, C. A. Emshary. Phys. Scr. 90 (2015) 085302 (8pp)

[3] E. Baradacs, I. Csige, I. Rajta, Radiat. Meas. **43**, 1354 (2008).
[4] P.C. Kalsi, C. Agarwal, J. Mater. Sci. **43**, 2865 (2008).
[5] T. Sharma, S. Aggarwal, A. Sharma, S. Kumar, D. Kanjilal, S.K. Deshpande, P.S. Goyal, J. Appl. Phys. **102**, 063527 (2007).

[6] R. K. Fakher Alfahed, K. K. Mohammad, M.S. Majeed, H. A. Badran, Kamal M. Ali, B. Y. Kadem,

IOP Conf. Series: Journal of Physics: Conf. Series **1279** (2019) 012019

[7] H.R. Zangeneh, P. Parvin, Z. Zamanipour, B. Jaleh, S. Jelvani, M. Taheri, Radiat. Eff. Defects Solids **163**, 863 (2008)

[8] S. Bashir, M.S. Rafique, F. Ul-Haq, Laser Part. Beams **25**, 181(2007).

[9] R. Ch. Abul-Hail, J Mater Sci: Mater Electron (2017) 28:2311–2316

[10] K. Abd AL-Adel, H. A. Badran, Archives of Applied Science Research, 2012, 4 (6):2499-2506

[11] K. Abd AL-Adel, H. A. Badran, Journal of Basrah Researches Sciences, 38(4) A (2012)73-78

[12] K. Alfaramawi, M.G. Al-Rasheedi, M.R. Baig , M.S. Alsalhi, Radiation Measurements 86 (2016) 49-55

[13] M.F. L'Annunziata (Ed.), Handbook of Radioactivity Analysis, third ed. Academic Press(2012).

[14] H. Ali Badran, Results in Physics 4 (2014) 69-72

[15] H. A. Badran, A. A. Al-Fregi, International Journal of Semiconductor Science & Technology (IJSST) vol.2, no.1, pp.26-36, (2012).

[16] H. Ali Badran, M. M. Jafer, International Journal of Engineering and Applied Sciences (IJEAS), 6(10) 2019, 46-49

[17] K.K. Dwivedi, Radiat. Meas. 28, 145 (1997).

[18] M. Zamani, D.Sampsonidis, S. Charalambous, , Int. J. Radiat. Appl. Instr. D. 12, 125 (1986).

[19] T. Portwood, D. L. Henshaw, Int. J. Radiat. Appl. Instr. D. 12, 105 (1986).

[20] D. Sinha, S. Ghosh, A. Srivastava, V.G. Dedgaonkar, K.K. Dwivedi,. Radiat. Meas. 28, 145 (1997).

[21] T. Phukan, D. Kanjilal, T. D. Goswami, H. L. Das, Radiat. Meas. 36, 611 (2003).

[22] K.A. AL-Adel, H.A. Badran, Nonlinear optical properties and diffraction ring patterns of benzo congo red, Eur. J. Appl. Eng. Sci. Res. 1(2012) 66-72

[23] H. A. Badran, K. Abd. AL-Aladil, H. G. Lazim, A. Y. Al-Ahmad, J Mater Sci: Mater Electron (2016) 27:2212–2220

[24] H. A. Badran, A. Yassin Al-Ahmad, Fadhil Al-Mudhaffer, Journal of Basrah Researches (Sciences) A, 37(2) (2011) 57-63

[25] H. A. Badran, A. Al-Maliki, R.K. Fakher Alfahed, B. A. Saeed, A.Y. Al-Ahmad, F.A. Al-Saymari, R.S. Elias, J. Mater. Sci: Mater Electron 29 (2018) 10890-10903.

[26] H. A. Badran, Appl. Phys. B 119, 319 (2015)

[27] H. A. Badran, A. Adil, R.K. Al-Fregi, A.S. Fakher Alfahed, Al-Asadi, , J. Mater. Sci: Mater Electron ,28, 17288 (2017)

[28] N. Al-Huda S.Yakop, H. A. Badran, Int. Journal of Engineering Research and Applications, 4(3) Version 1 (2014) 727-731

[29] H.A. Badran, IOSR Journal of Applied Physics, 1 (2012) 33-37.

[30] R. K. Fakher Alfahed, A. Imran, M. S. Majeed, H. A. Badran, Physica Scripta 95 (2020) 075709 (8pp)

[31] N.A. Huda, S. Yakop, H.A. Badran, Int J. Eng. Res. Appl. 4 (2014) 727-731

[32] H. A. Badran, K. Abd AL-Adel, Misan Journal for Academic Studies, 11(21) (2012) 1-9

[33] H. A. Badran, K. I. Ajeel, H. G. Lazim, Materials Research Bulletin, 76 (2016) 422-430.

[34] H. A. Badran, H. F. Hussain, K. I. Ajeel, Optik 127 (2016) 5301

[35] H. A. Badran, A.Y. Taha, A. F.Abdulkader, C. A.Emshary, J. Ovonic Res., 8 (2012) 161-170.

[36] R. K. Fakher Alfahed, A. S. Al‑Asadi, H. Ali Badran, K. I. Ajeel, Applied Physics B (2019) 125:48

[37] H. A. Al‑Hazam, R. K. Fakher Alfahed, A. Imran, H. Ali Badran, H. S. Shaker, A. Alsalihi, K. I. Ajeel, Journal of Materials Science: Materials in Electronics (2019) 30:10284-10292.

[38] K.K. Nagaraja, S. Pramoddini, A. Santhoshkumar, H.S. Nagaraja, P. Poornesh, D. Kekuda, Opt. Mater. 35 (2013) 431

[39] M. Sheik-Bahae, A. A.Said , E. W. VanStryland, Opt. Lett. 14 (1989) 955.

[40] S. Cavez-Cerda, C. M. Nascimento, M.A.R.C. Alencar, M.G.A. de Silva, M.R. Meneghetti, J.M. Hickmann, Ann. Opt. XXIX ENFMC, 1 (2006)

[41] H. A. Sultan, H. A. Badran, A. Y. Al-Ahmad, C. A. Emshary, Journal of Basrah Researches (Sciences) A39 (2) (2013) 1-12

[42] H. A. Badran, Adv. Phys. Theor. Appl. 26(2013) 36.

[43] A.Y. AL-Ahmad, M.F. AL-Mudhaffer, H.A. Badran, C.A. Emshary, Opt. Laser Technol. 54, 72 (2013)

[44] H. A. Badran, A.Y. AL-Ahmad, M.F.A. Mudhaffer, C.A. Emshary, Opt. Quant. Electron. 74 (2015) 1859

[45] F.A. Al-Saymari, H.A. Badran, A.Y. Al-Ahmad, C.A. Emshary, Indian J. Phys. 87 (2013) 1153

[46] M.H. Majles Ara, Z. Dehghani, R. Sahraei, A. Daneshfar, Z. Javadi, F. Divsar, J. Quant. Spectrosc. Radiat. Transf. 113 (2012) 366