Study the Optical and Structural Properties for Thin Film Zinc Oxide (ZNO) Produced by Pulsed Laser Deposition

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Abstract

Zinc oxide (ZnO) was prepared by pulsed laser deposition(PLD) using Q-Switching Nd: YAG laser with $Wavelength$ (λ) = 1064 nm, Repetition rate (f)= 6 Hz , and Energy (E) = 500 mJ at room temperature under vacuum condition with 10^{-3}torr. The optical properties included the absorption coefficient, extinction coefficient, index of refractive for the films of ZnO was evaluated and the results are discussed. The energy band gap of thin film ZnO 3 (eV) at room temperature. The optical transition was found to be direct and allowed transition. Moreover, UV–visible spectra were used to evaluate the ZnO energy gap. FTIR spectra for ZnO used to presence of Zn-O bonding.

1. Introduction

Zinc oxide (ZnO) has received an amazing concern due to it contains an enormous ranging of large features that depending on doping, involving of a range of conductivity from metal to insulating involving n-type, piezoelectricity, high transparency and enormous energy band gap semi-conductivity. Zinc Oxide (ZnO) is an enormous band gap semiconductor with a large number of attractive more properties for electronics and optoelectronics devices. ZnO belongs to II-VI semiconductor group and the native doping of the ZnO is n-type. At normal temperature for room, the ZnO is a direct band gap of 3.3 (eV). Zinc Oxide (ZnO) has large excitons binding energy of 60 m (eV),due to that , the exciton in Zinc Oxide (ZnO) are thermally stable at the room temperature[1]. Zinc Oxide (ZnO) contains a very great potential of ionization (~8eV) and affinity of electron (~4.7eV) that incompletely clarifies the ease to gain n-doping . This semiconductor has many favorable properties like high mobility of electron, good translucence, strong luminescence at room temperature, etc. Those features are employed in electronic applications of Zinc Oxide (ZnO) as thin-film transistors and light-emitting diodes [2,3,4]. Some basic physical properties of Zinc Oxide(ZnO) at 300K are listed in the table 1. The structural configuration of Zn and O ions in 3- dimensional space also gives ZnO its optical and electrical properties.

Table (1). Basic physical properties of Zinc Oxide(ZnO) at R.T.[3,4,5,6,7,8].

Parameters	ZnO	Parameters	ZnO
Band gap energy (eV)	3.3	Melting point (^oC)	1975
Electron mobility (cm^2/Vs)	~210	Thermal conductivity	0.13, 1-1.2
Hole mobility (cm^2/Vs)	~10	Static dielectric constant	8.656
Exciton binding energy (meV)	60	Refractive index	2.008, 2.029
Lattice constant	a= 0.32495 nm, c=0.52069 nm	Bulk Young´s modulus, E (GPa)	111.2±4.7
Density (g cm^{-3})	5.606	Electron effective mass	$0.23m_0$

This paper aims to study of optical and structural about thin film Zinc Oxide (ZnO) produced by pulsed laser deposition (PLD) technique that used Q–Switching Nd:YAG laser $(\lambda = 1064nm\,, f = 6Hz\,, E = 500\,mJ)$ under vacuum condition with 10^{-3}torr at room temperature. The constants of Optical included the refractive index (n) and the extinction coefficient (k). The refractive of complex index (n_c) is introduced as[9] :

$$n_c = n - iK \quad ......(1)$$

And it is concerned with the propagation velocity (v), and velocity of light (c) by:

$$V = C/n_c \quad ......(2)$$

The index of refractive magnitude can be determined from the formula:

$$n = \left(\frac{4R}{(R-1)^2} - k^2\right)^{\frac{1}{2}} - \frac{(R+1)}{(R-1)} \quad ......(3)$$

Whereas R is the reflectance, and he relationship could be expressed by the following formula:

$$R = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \quad ......(4)$$

The extinction coefficient, which is correlated with the exponential decay of the wave as it passes via the medium, is introduced as :

$$k = \frac{\alpha\lambda}{4\pi} \quad ......(5)$$

Whereas λ is the incident radiating wavelength

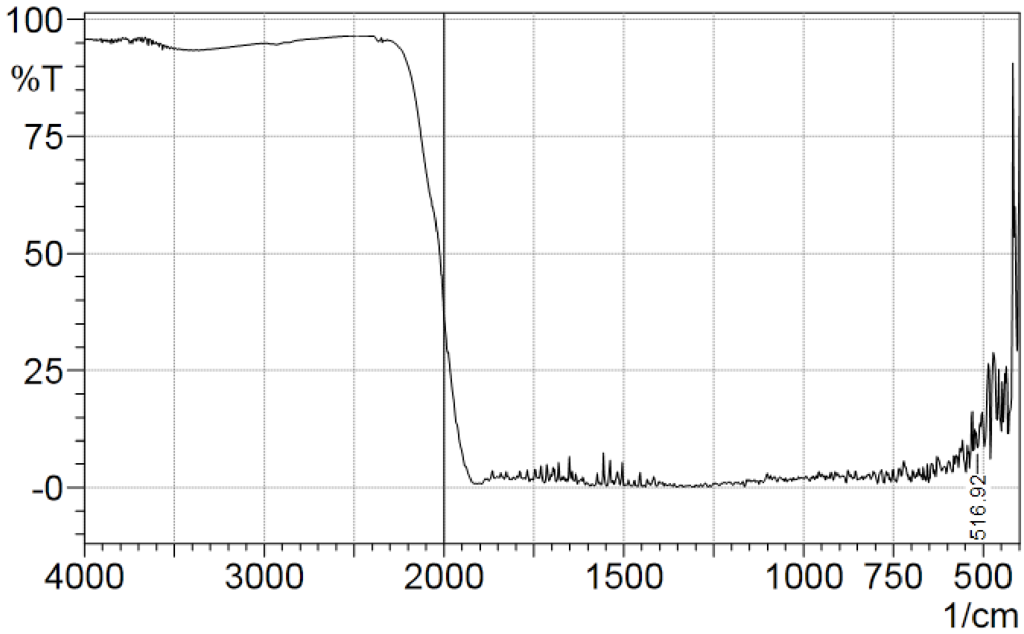
2.Materials and Methods

Zinc Oxide (ZnO) thin film was deposited by (PLD) technique using Q-Switching Nd:YAG laser ($\lambda = 1064nm\,,\ f = 6Hz\,,\ E = 500mJ$) under vacuum condition with 10^{-3}torr on glass substrate at a normal room temperature with thickness (200 nm). The slides (substrates) were cleaned by utilizing detergent and water for removing any attached dust on surface and gently rubbing gently for fifteen minutes . Slides were the placed in a clean beaker containing distilled water. The processing has been replaced by replacing the distilled water with pure alcohol solution and the slides wiped with soft paper . The substrate was located 3cm from the target. The target (diameter of 10 mm and thickness 2mm at weight of 0.5 gram) with press of 6tons. The optical features of thin film ZnO at room temperature were investigated in the wavelength ranging from (250 to 800 nm) by employing UV-VIS shimadzu 1800 spectrophotometer . The transmittance and absorption spectrum employed in the a computer software program to calculate the photovoltaic band gap, the wavelength of the optical absorption core, and all optical constants. Fourier Transformed Infrared Spectrum for ZnO powder was recorded by shimadzu double beam FTIR spectrometer. Thin Film thicknesses were measured by Interferometer fringes method. His method is an application of Fizeau fringes of equal spacing. It can be used Na light (5893 Å) or laser light He –Ne laser wavelength (632.8 nm).

3. Results and Discussion

3.1 FTIR Spectroscopy

Figure 1. shows (ZnO) spectrum at room temperature. In general (ZnO) is giving a ranges of absorption in the region of fingerprint i.e. less than 1000cm^{-1} at room temperature arising from inter-atomic vibration. The highest observation at 3354.21 $cm^{-1}$is might be because of O-H stretching. The peak at 516.92 cm^{-1}at room temperature is referring to Zn-O stretching.



Fig(1) : FTIR for Zinc Oxide (ZnO).

3.2. The absorbance spectra

The absorbance spectrum ZnO thin films with thickness (200nm) at room temperature as demonstrated in fig(2). Figure (2) illustrates that the membrane has a high absorption in the region of ultraviolet and the absorption of UV reduced significantly with increasing the wavelength, which illustrate that ZnO has a good response in ultraviolet region. This behavior is typically for several semiconductors because of the internal electric field within the flexible and non-flexible photon transport dispersion.

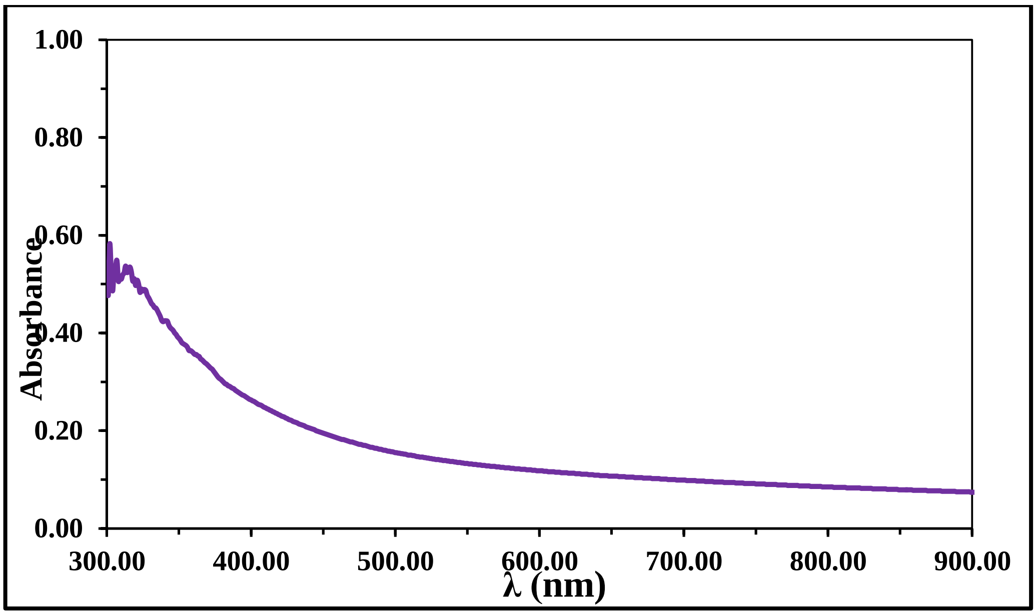


Fig (2):The absorbance spectra for ZnO with 200nm thickness.

3.3.The absorption coefficient

The absorption coefficient ∝ is determined by employing of the equation [10]:

$$\alpha = 2.303\frac{A}{t} \quad \text{......................................(6)}$$

Whereas (A & t) are the absorbance and the thickness respectively. The absorbance (A) represents the logarithm of the reciprocal of the transmittance (T) according to Beer-Lambert:

A=Log(1/T)……………………………………(7)

The energy (E) of the incident photon can be calculated from the equation :

$$\lambda(nm) = \frac{hc}{E_g} = \frac{1240}{E_g(eV)} \quad \text{..............................(8)}$$

Whereas (h & ν) are presenting the plank constant and the light incident frequency respectively. The dependence of the absorption coefficient on the wavelength for 200nm thickness of the deposited ZnO is show in fig(3).

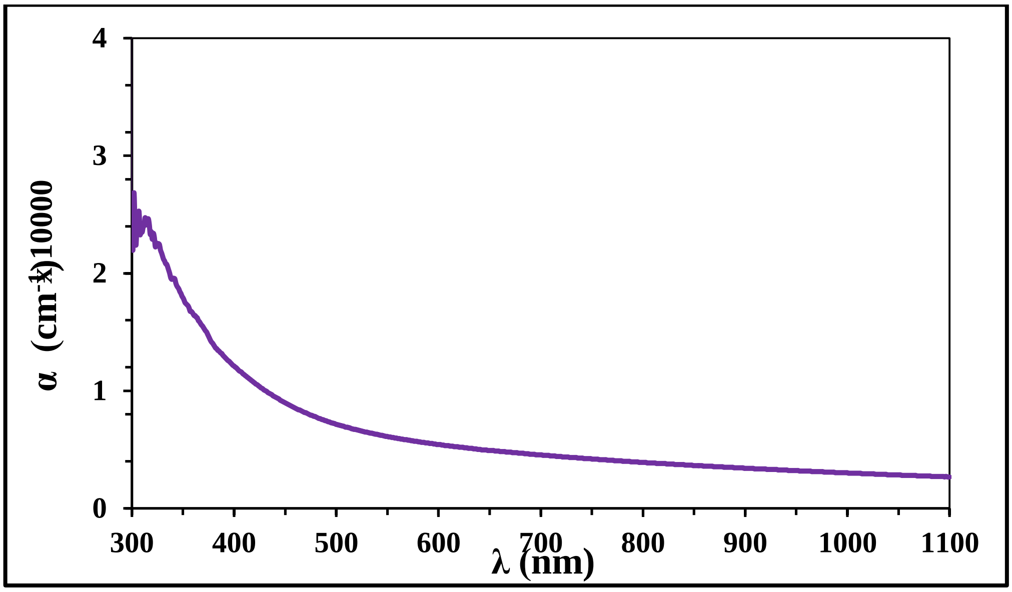


Fig (3): Coefficient of absorption as a role of wavelength for thin Film ZnO with 200nm thickness.

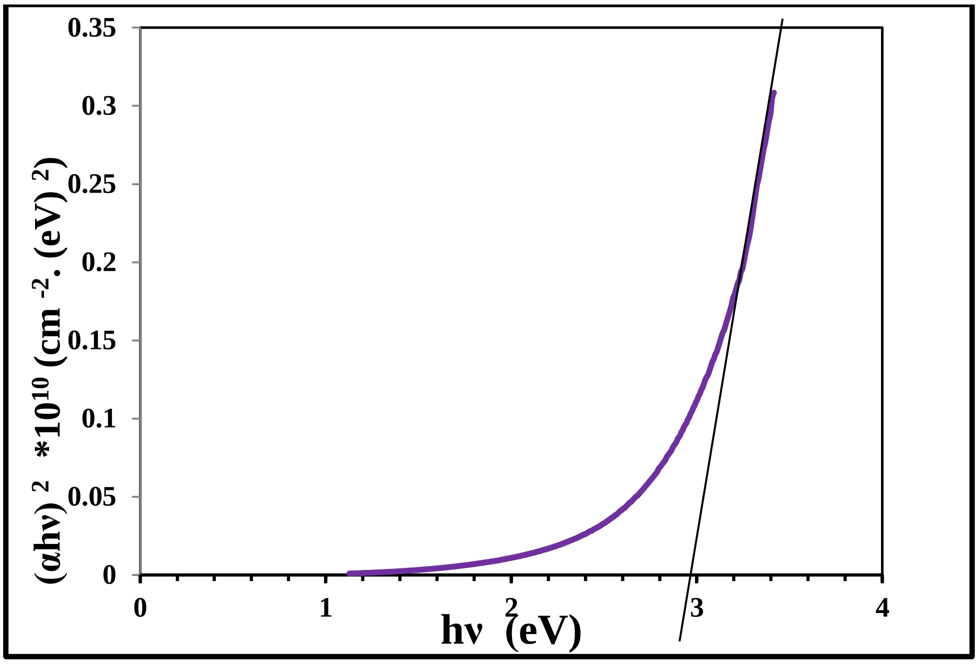
One can see from this figure that the coefficient of absorption for the thin film ZnO is described by a strong absorption at the shorter wavelength region between (300-320nm). The absorption coefficient displays maximum magnitudes of α (α=2.x10^4) cm^{-1} at the wavelength 300nm, which refers to a great probability of direct transmission allowed. The absorption coefficient decreases with wavelength increasing for ZnO thin film at room temperature.

3.4. **Optical energy band gap**

The optical energy gap (E_g) for Zinc Oxide (ZnO) thin film have been identified by using tauc formulas [11]:

$$\alpha h\nu = B(h\nu - E_g)^{1/2} \quad \text{................................(9)}$$

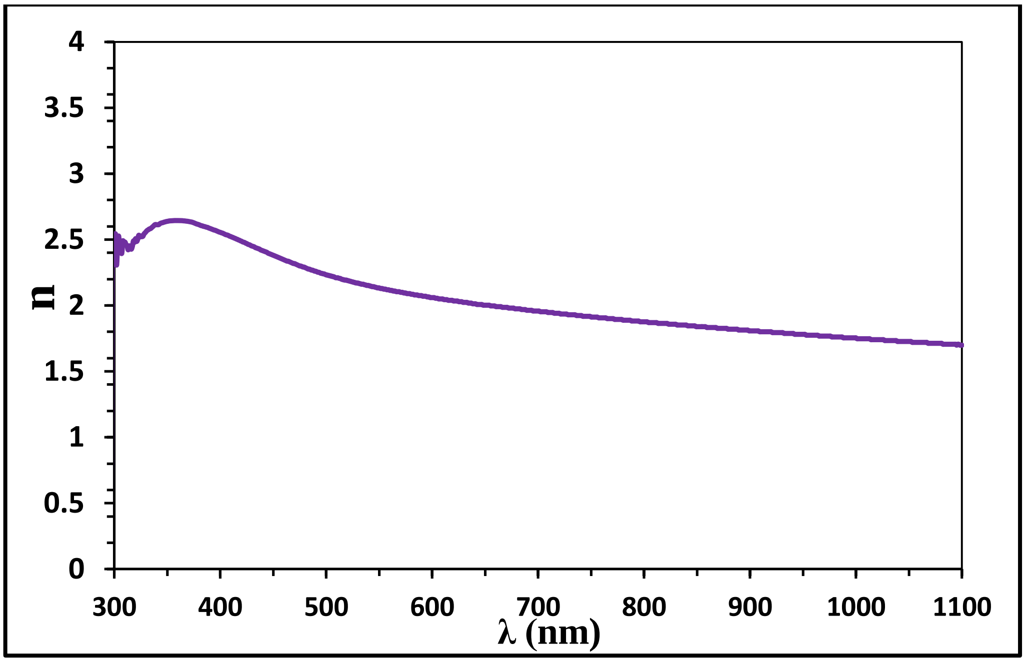
Whereas B is an inversely constant proportionate to a morphousity, h□ is the energy of photon (eV), E_g is the optical energy gap (eV) , r is constant and many take magnitudes (0.5, 1.5, 2 and 3) based on the material and the optical transition type .Figure (4) show the variables of $(\alpha h□)^2$ as a role of energy of photon (h□) for thin film ZnO at room temperature .From the extrapolation of linear portion of the curve to $(\alpha h□)^2$ equal to zero we can deduce the energy gap of prepared film . The direct range gap of thin film ZnO was estimated in 3 (eV) , this means that the value of wavelength is around 415nm i.e. that the visible portion of sunlight is allowed to pass through for ZnO thin film only. and the magnitude of the optical energy gap E_g decreases with increasing in wavelength according the equation (3), this behavior is resulting from the increasing of the grain size and increasing of the defect states near the bands .



Fig(4): $(\alpha h\nu)^2$versus photon energy for ZnO thin film having 200nm thicken

3.5. Refractive Index

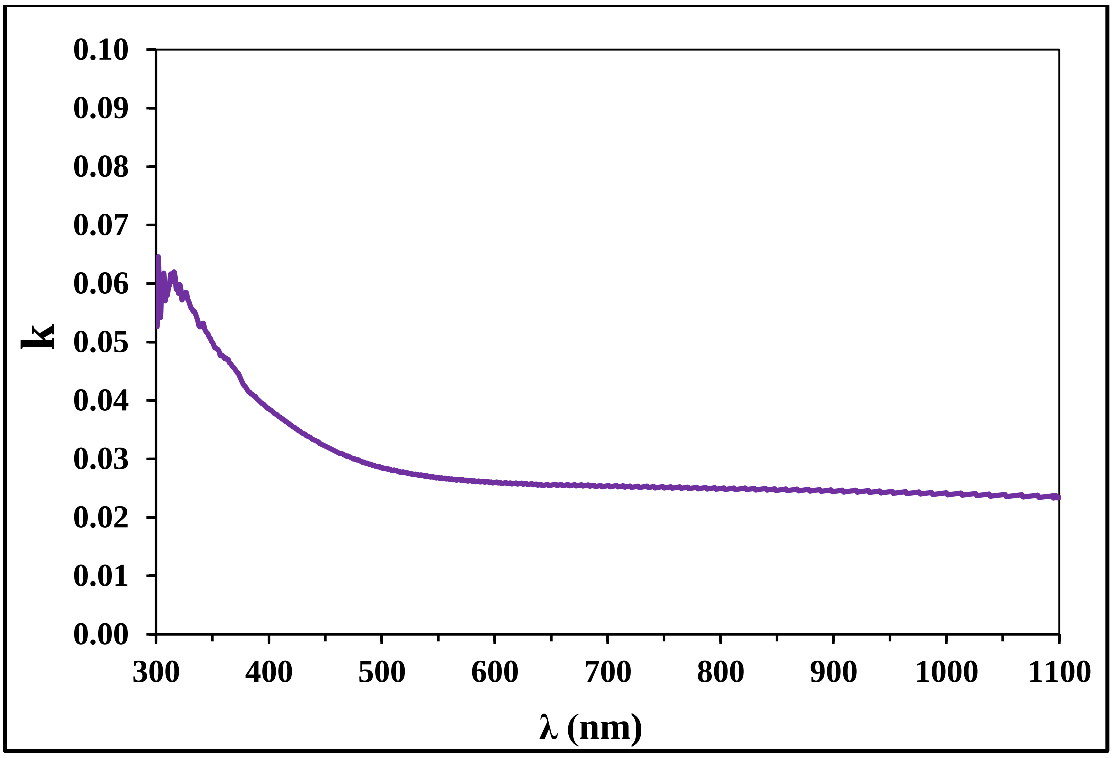
The magnitude of refractive index (n) for Zinc Oxide (ZnO) thin film as role of wavelength at room temperature is demonstrated in Figure (5). It could be observed that the value of refractive index (n) decrease with the increase wavelength. The maximum magnitude of refractive index equal (n=2.5) which could be gained at wavelength 350nm.



Fig(5): Refractive Index of thin film ZnO at normal temperature for room.

3.6.Extinction Coefficient

The extinction coefficient (K) behavior is approximately comparable with the corresponding absorbance and absorption coefficient for thin film ZnO at room temperature as shown in figure (6). It can see that the magnitude of extinction coefficient (K) decreasing with increasing the wavelength. The maximum magnitude of extinction coefficient (K=0.05) which could be gained at wavelength 320 nm.



Fig(6): Extinction Coefficient for ZnO at room temperature.

4.Conclusions

Zinc Oxide (ZnO) thin film was successfully prepared by PLD using Q-Switching Nd:YAG laser(λ=1064 nm , f=6 Hz , E=500mJ) under vacuum condition with 10^{-3}torr. The UV-Visible research indicates the maximum absorbenc at wavelength 320 nm within the area of UV. The permissible direct range gap energy transition of ZnO was noticed, about 3(eV) and it decreasing with increasing wavelength. The extinction coefficient (K) behavior is roughly comparable with the corresponding absorbance and absorption coefficient for thin film ZnO at room temperature.

CONFLICT OF INTERESTS

There are no conflicts of interest.

5. References

[1] Zainelabdin, A., Zaman, S., Amin, G., Nur, O. and Willander, M., Stable white light electroluminescence from highly flexible polymer/ZnO nanorods hybrid heterojunction grown at 50 C. *Nanoscale research letters*, *5*(9), p.1442.2010.
[2] Bano, N. *Fabrication and Characterization of ZnO Nanorods Based Intrinsic White Light Emitting Diodes (LEDs)* (Doctoral dissertation, Linköping University Electronic Press) 2011.
[3] Lin, K.F., Cheng, H.M., Hsu, H.C., Lin, L.J. and Hsieh, W.F., Band gap variation of size-controlled ZnO quantum dots synthesized by sol–gel method. *Chemical Physics Letters*, *409*(4-6), pp.208-211.2005.
[4] Jiang, C., Electroluminescence from ZnO Nanostructure Synthesizes between Nanogap. thesis, Faculty of the Graduate School - Marquette University in USA, 2012.
[5] Lee, C.Y., Hui, Y.Y., Su, W.F. and Lin, C.F., Electroluminescence from monolayer ZnO nanoparticles using dry coating technique. *Applied Physics Letters*, *92*(26), p.261107.2008.
[6] He, Y., Wang, J.A., Zhang, W.F., Chen, X.B., Huang, Z.H. and Gu, Q.W., Colour electroluminescence with end light-emitting from ZnO nanowire/polymer film. In *Journal of Physics: Conference Series* (Vol. 152, No. 1, p. 012054). IOP Publishing.2009.
[7] Akhavan, O., Mehrabian, M., Mirabbaszadeh, K. and Azimirad, R., Hydrothermal synthesis of ZnO nanorod arrays for photocatalytic inactivation of bacteria. *Journal of Physics D: Applied Physics*, *42*(22), p.225305.2009.
[8] ZąBkowska- Wacławek, M., Talik, P. and Wacławek, W., On the Compensation Behaviour of Copper Phthalocyanine Films in NOx Ambient. *physica status solidi (a)*, *121*(2), pp.489-494.1990.
[9] D. Nithyaprakasha, M. Ramamurthya, P.Thirunavukarasub, T. Balasubramaniamc. J. Chandrasekarana ,& P. Maadeswarana," Journal of Optoelectronic and Biomedical Materials", Vol. 1, Issue 1, pp. 42-51 , (2009) .

[10] Newman, D.,*Semiconductor Physics and Devices*. Basis Principles, Richard, University of New Mexico, Printed in USA.1992.
[11] Taus, J., Amorphous and liquid semiconductor. Plenums Press, New York and London.1974.

دراسة الخصائص البصرية والتركيبية لأغشيه اوكسيد الزنك المحضرة بالترسيب بالليزر النبضي

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الخلاصة

اغشيه اوكسيد الزنك المحضرة بتقنيه الترسيب بالليزر النبضي باستخدام ليزر النديميوم ياك Q-Switching ذو الطول الموجي(1.06µm) ومعدل تكرار(6Hz) ولطاقه ليزر (500 mJ) بتقنيه الفراغ ولضغط 10^{-3} تورر في درجه حراره الغرفة . الخواص البصرية التي تتضمن معامل الامتصاصية ومعامل الخمود ومعامل الانكسار لأغشيه اوكسيد الزنك تم ايجادها ومناقشه النتائج . من طيف الامتصاصية لا وكسيد الزنك اظهرت النتائج بانه يمتلك فجوه طاقه مباشره مقدارها(3eV) . استخدم طيف تحويل فورير للأشعة تحت الحمراء لبيان وجود الأصرة بين الزنك والاوكسجين.

الكلمات الدالة: اوكسيد الزنك, تقنيه الترسيب بالليزر النديميوم ياك، فجوه الطاقه.