Chalcogenide Letters Vol. 20, No. 2, February 2023, p. 145 - 152

Fabrication and evaluation of $CuAlSe_2$/Si photodetector

H. K. Hassun[a], B. K.H. Al-Maiyaly[a]. A. H. Shaban[b,*]
[a]*Department of physics, college of Education for pure sciences Ibn Al-Haitham, University of Baghdad, Iraq*
[b]*College of Science, University of Baghdad, Baghdad, Iraq*

In this work, we have examined the spectral response of (p-$CuAlSe_2$/n-Si) detector, (CAS) thin films deposited by thermal evaporation at RT with a thickness (450) nm, and annealing temperature at (473K) for 2 h. Optical transmission measurements displayed reasonably slight transmission besides higher absorbance trendy the visible region, energy gaps were observed by annealing, were found to be direct, and decreased with the effect of annealing. The extreme responsivity value arises at wavelength 459 nm, with improvement value of specific detectivity and quantum efficiency the annealing films be situated originate as greatest suitable aimed at numerous device application.

(Received November 19, 2022; Accepted February 14, 2023)

Keywords: Photodetector, $CuAlSe_2$/Si, Thin films, Thermal evaporation, Annealing

1. Introduction

Ternary wide-gap chalcogenide semiconductors(abridged by way of (I-III-Ch_2)here in), collection IB transition metallic cation is (Cu^{1+} or Ag^{1+}), set III metal cation stands (Al^{3+} ,Ga^3 ,or In^3 [1-4]. $CuAlS_2$ through tetragonal $I\bar{4}2d$ space assembly, entailing of tetrahedral management of anions and cations. Chalcopyrite construction was an iso electronic ternary similarity zinc blende (MCh) arrangement, designated formerly, through a unit cell twice by means of great and per metal species I and III irregular amid locations [5]. The band gap greatness is completely associated thru the electronegative for (Ch) anion, by means of the electronegativity modification among the two cations [6]. $CuAlS_2$ requires the broadest band gap (~3.4–3.5 eV) midst entirely (I-III-Ch2) chalcopyrite complexes, then later is the greatest transparent [7]. It remained initial explored by means of blue (UV LED) material [8, 9], AsS, ZnAl, and MgAl be located exceptional p-type dopant designed for $CuAlS_2$ [10]. The band gap droplets immediately p-doping the Al site, probable by reason of the augmented VBM energy plus attendance of unnoticed CuxS impurities, nevertheless organizes not below Cu-poor and S-rich situations [11,12]. $CuAlSe_2$ be necessary testified investigational band gap at near-stoichiometry of ~2.6–2.7 eV, besides explored meant on behalf of several requests, optical filters, blueLEDs, and solar cells [13], Interest embraces submissions in nonlinear optics, photovoltaic detectors [14], experiment effort on the electronical assembly of $CuAlSe_2$ has practically imperfect to the region everywhere the essential absorption edge, crystal models deliberate were generally platelet developed through chemically iodine vapor transport besides band gap energy require inspected utilizing optical absorption [15-19] polarization inflection of reflectance [20], phase-shift-alteration reflectance [21], then photo reflectance [22]. In this work, fabricate (p-$CuAlSe_2$/n-Si) heterojunctions photo detector, the optical properties and photodetector parameters like responsivity and specific detectivity of the (p-$CuAlSe_2$/n-Si) visible light photodetector are reported for the first time using thermal evaporation technique.

* Corresponding author: auday.h@sc.uobaghdad.edu.iq
https://doi.org/10.15251/CL.2023.202.145

2. Experimental

Ternary composite alloy ($CuAlSe_2$) alloy was prepared, where meticulous magnitudes in height purity (99.999%) elements copper (Cu) aluminum (Al) and selenium (Se_2) proportions through weightiness (1:1:2) individually, in accord thru their atomic fractions, are balanced utilized in electronical balance per the slightest amount of (10-4 gm). as a result of mixed three elements then placed them trendy a quartz cylinder lower than pressure of (10-4 mbar), the tube located slantwise in an electric oven (1600 K) besides occupancy at this temperature for 5 hours. Thin films the prepared with thickness (450) nm and annealing with 473 K for 2 hour, by thermal evaporation technique on glass substrate to study optical properties, and on silicon substrate to fabricate photovoltaic detector. The optical properties measurements were found using UV/Visible 1800 spectrophotometer from 400nm to1100nm. The energy gap Eg (eV) calculated from Tauc's relation [23-26]. Suitable arrangement was equipped to regulate the detector parameters, the illuminated I-V characteristics done under light with different illumination power densities by Halogen lamp 180W. Spectral responsivity of fabricated detectors was measured via monochrometer with series (200-900) nm, electrometer and power meter for determining the radiation power aimed at individually wavelength in addition DC power supply (0-15V, 0-2 A).

3. Results and discussion

Fig.1 demonstration the optical absorption, transmittance and reflection of the ($CuAlSe_2$) film deposited with (450) nm and annealing temperature at (473K), sharp fall in absorption was observed at the fundamental absorption edge for film in visible region. From these curves we show the transmittance of the thin film approximately have (36.18% - 29.06%), absorption rang value (56.76% - 67.91.76%) with a wavelength of (435- 459) ºA, the transmittance and reflection spectra of the films decrease which subsequently increase absorption, we can observe change in absorption with effect of annealing temperature which means. The shifts spectrum to the wavelength compared to that of the annealed film might be accredited to the decreased in the band gap with annealed.

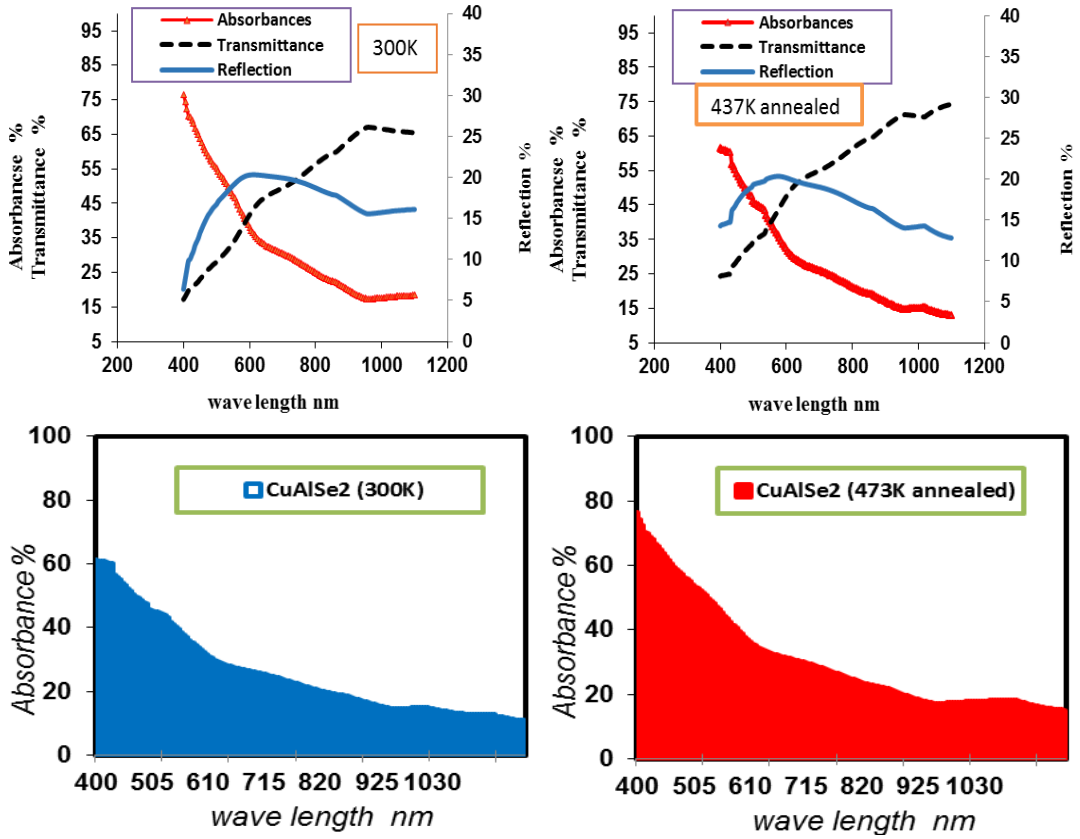

Fig. 1. Optical absorption, transmittance and reflection spectra for $CuAlSe_2$ thin film.

The deepest band gap energy in semiconducting materials is mentioned to by means of the central absorption edge of inter band transition. Fig. 2a demonstrations the band gap spectra of (300K and 473K annealed) CAS thin films. The value of optical band gap energy have originate toward reduced as of (2.85 to 2.7) eV. Furthermore, annealing film recovers the band gap rate to 2.7 eV , dropping in the band gap besides perfecting of the band edge at the band gap district obviously expressions the development in the film regularity once annealing. With consequence annealing along with the lessening of strain energy as a result of the reordering of the atoms. As follows, the grain boundaries remain tranquil and eradicated and under the influence of annealing the optical properties of the film change extremely [27] [28]. The absorption coefficient has considered by equation [29], Fig. 2 b illustration allowable direct band gap transition, the absorption coefficient correlated to the photon energy, It can be seen separate variation in the slope of the absorption coefficient curve nearby 2.69 eV, in addition intensification in the absorption coefficient at photon energy due to the effect of annealing. Table 1.show values of energy gap and some optical parameters for films in (300K) and (473k annealed).

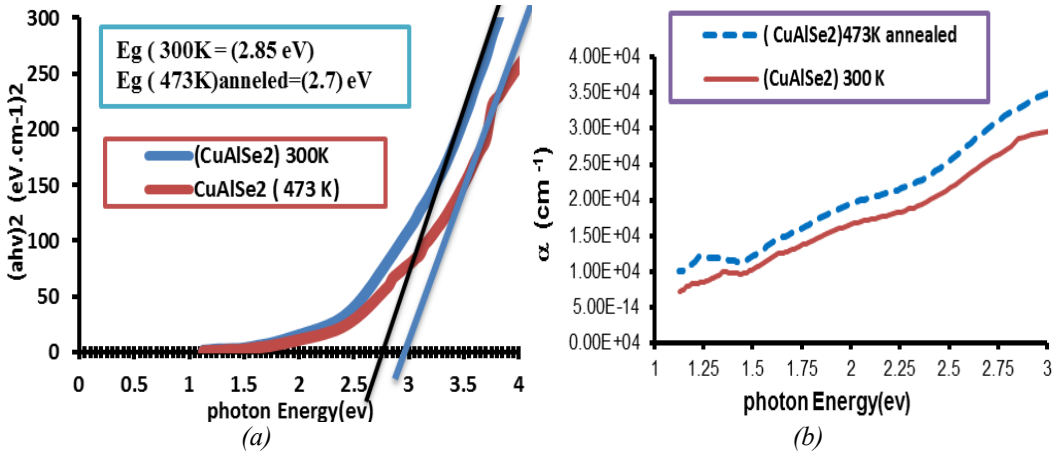

Fig. 2. The energy band gap, the absorption coefficient a variation annealed $CuAlSe_2$ thin films.

Table 1. Parameters of the optical properties for $CuAlSe_2$ thin film at $\lambda \approx 459$ nm.

band gap and optical continual near $\lambda \approx 459$ nm	300K	437K annealed
Eg (eV)	2.85	2.7
refractive index	2.63875302	2.576592352
dielectric constant (real part)	6.095631806	5.438294316
of dielectric constant (imaginary part	4.915128384	4.646286492
extinction coefficient	0.931335435	1.095688747

Measurement of current – voltage (IV) characteristic explained the performance of the subsequent current through the practical forward besides reverse bias voltages. Indications figure (3) to the typical current-voltage (I–V) curves of (p-$CuAlSe_2$/n-Si) heterojunction stately per diverse with annealing temperature under a dark state.

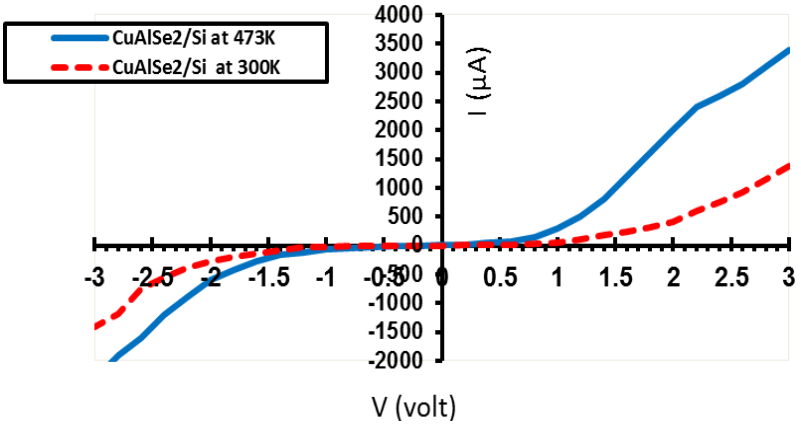

Fig. 3. Dark I-V physiognomies for variation annealed $CuAlSe_2$ heterojunction.

We see the reverse currents are identical weak then the forward dark current is produced as a consequence of the movement of majority carriers and the practical voltage. At that point, we

notice the exponential upsurge at low voltage for the forward bias condition thru cause of the lessening in the distance across of the depletion region at the junction on account of growth carriers inoculated thru the practically voltage where reason the reduction in the built-in potential. Likewise within the variety of voltage (0.0-3.2) V the forward current intensifications with annealing since the upsurge of carrier concentration which pretentious the energy band bending, therefore, consequence in a reduction in depletion region width. Saturation current in addition ideality factor standards might remain restrained utilized about equalities [30] and registered in Table 2.

Table 2. Some parameters variation with annealed $CuAlSe_2$ heterojunction.

temperature	**ideality factor**	**saturation current (J_s) A**
300K	2.154818541	9.86E-07
473K	1.844810484	1.74E-06

Fig 4. Expressions the semi–log relative amid dark forward current density against practical voltage, the ideality factor reduction with annealing, by means of increased temperature, additional electrons would obtain substantial energy to irritated high barrier. Therefore, the effective barrier height determination rise thru the temperature besides bias voltage concluding in lower ideality factor on higher temperature.

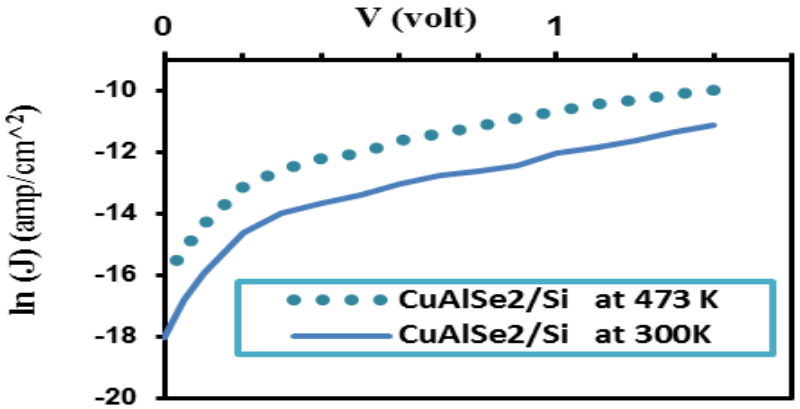

Fig. 4. In (J) compared to V for variation annealed $CuAlSe_2$ hetero junction.

For dissimilar incident power density (100, 160, 250 mw/cm^2) , the I-V characteristic of $CuAlSe_2$/ Si illustrations be situated deliberate below dark as well as illumination condition. Fig (5), totally prepared photodetectors, the photocurrent upsurges through intensifying of the reverse voltage, cause of expansion the depletion region by means of growing bias voltage, generated electron-hole pairs on central depletion width at that time confidential diffusion length exterior of the depletion width be situated quickly uninvolved attributable to the robust electric field. Also we notice that the photocurrent increasing per effect of annealing owing to the escalation of the mobility besides growth the photocurrent along with increase the depletion width which centrals to rise of the absorption through it and the creation of electron hole pairs.

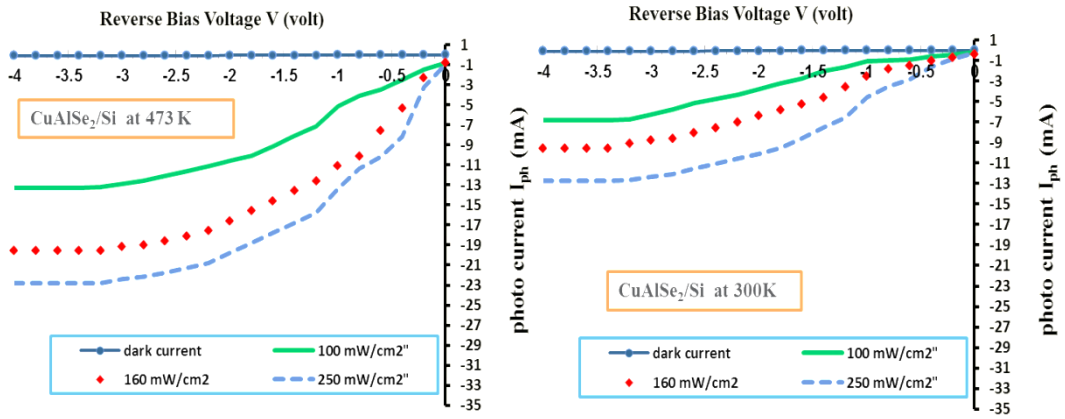

Fig. 5. I-V for variation annealed $CuAlSe_2$ photodetectors.

Fig 6 show the disparity of spectral responsivity (R_λ) by way of the wavelength for effect of annealing, the maximum photo responsivity peaked (biased at 4 V) at about (400-459) nm. In this case the fabricated detectors are sensitive to visible radiation, accredited to enhanced optical (reduction Eg by annealing), radical augmentation of light absorption then augmentation carrier's concentration completed advanced spectral response for p-$CuAlSe_2$/n-Si. Similarly the quantum efficiency is related with adjustment of the spectral responsivity which is strongminded for heterojunction sample with 473K where improved to 77.928.

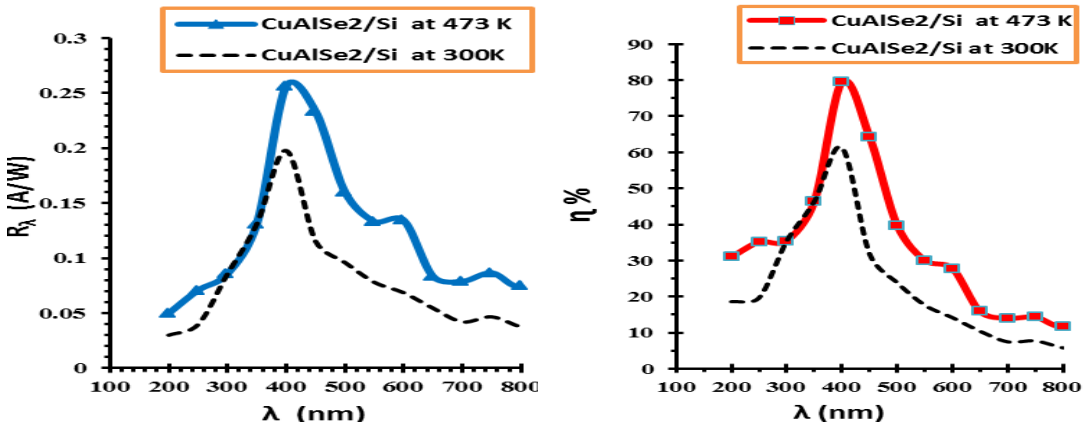

Fig. 6. Inequality of spectral responsivity and quantum efficiency aimed at variation annealed $CuAlSe_2$/ Si photodetectors.

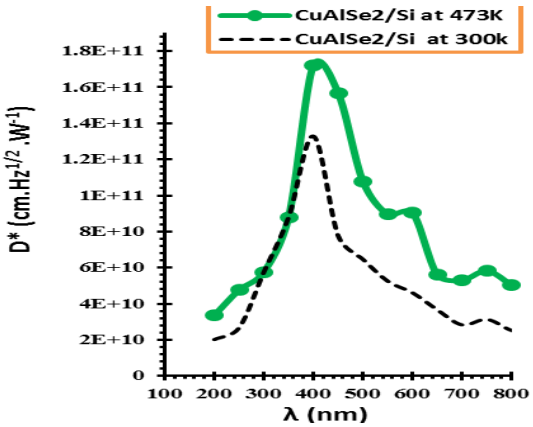

Fig. 7. Variation of specific detectivity in place of variation annealed $CuAlSe_2$/ Si photodetectors.

Table 3. Noise Equivalent Power (NEP).

temperature	NEP (Watt)	R_λ (Amp/W)
300K	8.21631E-12	0.115384615
473K	3.28653E-12	0.288461538

The variation of specific detectivity (D*) by way of function of wavelength for p-$CuAlSe_2$/n-Si at annealing is obtainable in fig 7 and table 3. It is observable that the D* upsurges per effect of annealing reached (1.939×10^{11} cm.$Hz1^{/2}$.W^{-1}) for 473 K annealed due to the growing in the absorption of incident radiation in thin film which is generating electron-hole pairs. Moreover Noise Equivalent Power (NEP) was a notion repeatedly utilized to enumerate the sensitivity of a detector or the power produced as a result of source of noise on a detector, the disparity of NEP for thin films under conclusion of annealed was revealed in same figure where the lowest NEP befalls when R_λ has the extreme, NEP decreases with effect annealed this attribute to the annealing process reduced the recombination process.

4. Conclusions

In summary, $CuAlSe_2$ thin films have been acquired by thermal evaporation process with effect of annealing, traditional higher responsivity designed p-$CuAlSe_2$/n-Si photodetectors. Annealing temperature plays essential character on the films optical and spectral measurements, the film characterizations indicate that value of optical band gap energy reduction with effect of annealing. Likewise, I-V measurements description rise the photocurrent for various occurrence power density, besides decent response in the visible region in addition the significant parameters for photodetectors devices were edited.

References

[1] Siebentritt, S., In Thin Solid Films; 2002; Vol. 403-404, pp 1-8; https://doi.org/10.1016/S0040-6090(01)01525-5

[2] Siebentritt, S.; Rau, U. Wide-Gap Chalcopyrites; Berlin, 2006; https://doi.org/10.1007/b105644

[3] Shay, J. L.; Wernick, J. H., Science of the Solid State, Vol. 7. Elsevier, 2017.

[4] Pamplin, B. R.; Kiyosawa, T.; Masumoto, K., Prog. Cryst. Growth Charact. 1979, 1, 331-387; https://doi.org/10.1016/0146-3535(79)90002-9

[5] Jaffe, J. E.; Zunger, A., Phys. Rev. B 1984, 29, 1882-1906; https://doi.org/10.1103/PhysRevB.29.1882

[6] Zhang, Y.; Xi, L.; Wang, Y.; Zhang, J.; Zhang, P.; Zhang, W., Comput. Mater. Sci. 2015, 108, 239-249; https://doi.org/10.1016/j.commatsci.2015.05.028

[7] Madelung, O., Semiconductors: Data Handbook 3rd Ed.; 2004; pp 220-235; https://doi.org/10.1007/978-3-642-18865-7_27

[8] Notes, S.; Physics, S.; Aksenov, I. A.; Makuvetskaya, L. A., Electrical Properties of Cadmium and Zinc Doped CuAlS2. 1988, 63, 63-65; https://doi.org/10.1002/pssa.2211080164

[9] Morita, Y.; Narusawa, T.; Crystals, H. A. S.; Majima, M.; Otogawa, T.; Kitagawara, Y.; Bhandari, R. K.; Ito, K.; Ghosh, B.; Pradhan, S. K.; et al., Jpn. J. Appl. Phys. 1992, 31, L1396; https://doi.org/10.1143/JJAP.31.L1396

[10] Liu, M.; Huang, F.; Chen, L.; Wang, Y.; Wang, Y.; Li, G.; Zhang, Q.; Liu, M.; Huang, F.; Chen, L.; et al., P -Type Transparent Conductor : Zn-Doped CuAlS 2. 2009, 072109, 7-10; https://doi.org/10.1063/1.2591415

11. Min Ling Liu, Fu Qiang Huang, L. D. C., PKey Eng. Mater. 2008, 368-372, 666-668;

https://doi.org/10.4028/www.scientific.net/KEM.368-372.666

[12] Liu, M.; Wang, Y.; Huang, F., Optical and Electrical Properties Study on P-Type Conducting CuAlS2+x with Wide Band Gap. 2007, 57, 1133-1136; https://doi.org/10.1016/j.scriptamat.2007.08.015

[13] M. Bettini, Solid State Commun. 1973, 13, 599-602; https://doi.org/10.1016/S0038-1098(73)80021-3

[14] J. L. Shay and J. H. Wernick, Ternary Chalcopyrite Semiconductors: Growth, Electronic Properties, and Applications ~Pergamon, Oxford, 1975.

[15] W. N. Honeyman, J. Phys. Chem. Solids 30, 1935 ~1969; https://doi.org/10.1016/0022-3697(69)90169-3

[16] G. D. Boyd, H. M. Kasper, J. H. McFee, and F. G. Storz, IEEE J. Quantum Electron. QE-8, 900 ~1972; https://doi.org/10.1109/JQE.1972.1076900

[17] V. Matveev, V. E. Grachev, V. V. Sobolev, and V. E. Tazlavan, Phys. Status Solidi B 194, K7 ~1996; https://doi.org/10.1002/pssb.2221940235

[18] N. Yamamoto, Y. Kikuno, M. Yamaguchi, and K. Wakita, Inst. Phys. Conf. Ser. A152, 71 ~1998.

[19] Hanan K. Hassun, Bushra H. Hussein, Ebtisam M.T. Salman, Auday H. Shaban, Energy Report, 2020, Vol.6, pp:46-54; https://doi.org/10.1016/j.egyr.2019.10.017

[20] Abbas K. Saadon, Auday H. Shaban, Kareem A. Jasim, Baghdad Science Journal, 19(1), (2022): 208-2016; https://doi.org/10.21123/bsj.2022.19.1.0208

[21] Abbas K.Saadon, Mustafa Mohammed Ali, Kareem A.Jasim & Duraid H. Younis, Ibn Al-Haitham Jour. for Pure & Appl. Sci, 86, (2014): 91-96.

[22] V. Bondar, Inorg. Mater. ~Transl. of Neorg. Mater. 18, 934 ~1982.

[23] M. Bettini, Solid State Commun. 13, 599 ~1973; https://doi.org/10.1016/S0038-1098(73)80021-3

[24] N. Yamamoto, H. Horinaka, K. Okada, and T. Miyauchi, Jpn. J. Appl. Phys. 16, 1817 ~1977; https://doi.org/10.1143/JJAP.16.1817

[25] S. Shirakata, S. Chichibu, and S. Isomura, Jpn. J. Appl. Phys., Part 1 36, 7160 ~1997; https://doi.org/10.1143/JJAP.36.7160

[26 J.W. Lekse, A.M. Pischera, J.A. Aitken, (2007), Mater. Res. Bull. 42. PP 395-403; https://doi.org/10.1016/j.materresbull.2006.09.025

[27] U. Parihar, N. Padha, J.R. Ray, M.S. Desai, C.J. Panchal , P.K. Mehta, I.V. Cheshko, I.Yu. Protsenko, Proceedings Of The International Conference Nanomaterials: Applications And Properties Vol. 2 No 1, 01PCSI29(6pp) (2013).

[28] S. Marsillac, K. Benchouk, C. El Moctar, J. Bernède, J. Pouzet, A. Khellil, M. Jamali, , J. Phys. III £Yance 7 (19971 2165-2169; https://doi.org/10.1051/jp3:1997249

[29] Yamada, N. Hoshino, T. Nakada, (2006), Science and Technology of Advanced Materials 7, 42-45; https://doi.org/10.1016/j.stam.2005.11.016

[30] Hanan K. Hassun, AIP Conf Proc 2018; 1968. 020017; https://doi.org/10.1063/1.5039176