Effect of Oblique Illumination on Photoconductivity Phenomena

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Photoconductivity studies were carried out on Ga_2Se single crystals prepared from melt. The effect of light intensity, applied voltage and side illumination on the AC Photoconductivity was studied. Also the spectral distribution of the DC Photoconductivity was investigated. Lifetime relations of the charge carriers were discussed. The forbidden energy gap at room temperature, for this crystal, was also calculated and found to be 0.49 eV

1. Introduction:

The Ga_2Se subchalcogenide belongs to the binary semiconductors which have the formula A2B (A:Ga, In or Tl and B:S, Se or Te). The phase diagram of the Ga-Se system contains three stable compounds [1]. They are GaSe, Ga_2Se_3 and Ga_2Se Both GaSe and Ga_2Se_3 have been studied far much intensively than Ga_2Se as concluded from the literature survey. Chang et al. have investigated some optical properties of this compound [2]. It is established fact that Ga_2Se has a density equals 5.02 gm/cm^3 and a crystal parameter a = 8.918 Å[3]. The present authors have investigated the electrical conductivity, Hall effect and thermoelectric power of this semiconducting compound [4]. The lack of the data concerning the crystal structure of the compound makes it difficult to have a definite picture of the fundamental principles of the crystal properties. So, the present paper is an attempt to add some information about the photoconductivity (PC) behaviour of this crystalline compound. Also the aim of the present work is to investigate the effect of oblique illumination of the sample surface with direct white light of constant intensity, the called side illumination, in addition to the chopped light. It must be mentioned that one of the authors has noticed this effect earlier in InSe crystals investigation [5]. This effect was observed again in 1990 in TlSe crystals [6].

2. Experimental Detalis:

In this experiment we used the same crystal which was previously prepared by using the same electronic programmer to change the furnace (Vectstar VH-3 type) temperature. This method is successful because it avoided the possibility of the melt movement during the growth time. A quartz ampoule, contains 6.972 gm of Ga (63.85% of the compound) and 3.948 gm of Se (36.15% of the compound), was evacuated (~ 10^{-6} Torr) and sealed under vacuum. The ampoule with its contents was introduced in the furnace where the following programs were used:

1- The first program began from the set point (373 K) to 1373 K with a rate of 25K/h. Then the temperature was held constant for 6 hours.

2- The second one was from 1373 K to 1203 K, where the last temperature represents the crystallization point [1], via a rate of 10 K/h. Then the temperature was kept constant before turning to the last program.

3- The third program was suggested for solidification i.e. cooling the melt slowly down to room temperature. The obtained product was confirmed by X-ray diffraction carried out in the Central Metallurgical Research and Development Institute (CRMDI) (Cairo Egypt) to ensure the proper crystal structure and stoichiometry.

The cherry red Ga_2Se product crystal was layered. A razor blade was used to cleave the crystal normal to the c-axis. The used sample was rectangular parallelepiped of dimensions 6.68 mm x 4.1 mm x 0.41 mm. Silver paste was used to make a good ohmic contact on Ga_2Se sample. Ohmic contact properties were checked by measuring the current-voltage characteristcs.

For measuring the steady state PC ($\Delta\sigma_{st}$) and dark conductivity ($\Delta\sigma_d$), we used a load resistance of 14 x $10^4\Omega$ in series with a stable DC voltage. The chopper controller (type SR 450) used in AC PC measurements had a symmetric square pulse of monochromatic light. An optical system, consisting of two convex lenses, was employed to collimate the normal incident light on the specimen surface (a and b axes are in this plan). The variation of potential difference across the load resistance due to the modulated PC was observed on a double beam oscillograph (COS 5020) and measured by an AC valve microvoltmeter (Level Electronic). Side illumination of the sample was achieved by direct white light source of constant intensity making an angle 45^o with the sample surface. This angle was chosen because the effect of oblique (side) illumination has a maximum value at this angle [5]. As to the DC PC, it was considered when a beam of light was incident perpendicularly on the sample surface without a chopper. It was measured by a Keithley electrometer

(610C). The light source was a 1000W tungsten lamp and a monochromator (CARL-ZEISS. L I) and a luxmeter type X 101) for measuring the intensity of the incident light. In the measurement of the primary PC, the values of the dark conductivity were eliminated by subtraction from the total photo current.

3. Results and Discussions :

Figure (1) depicts the relation between the photovoltage (V_{ph}) and the incident photons wave lengths, in the range from 1.22 up to 2.7 μm. A family of curves are presented at different bias voltages (15, 20, 25 and 30 volts). The same work was repeated in Fig. 2 whilst changing the illumination intensity in order to establish its effect on the PC behaviour of the Ga_2Se crystals. Four curves, corresponding to four light intensities(2350, 4450, 9850 and 12500 Lux), were obtained in Fig. (2). From Figures 1 and 2 we concluded the following points:

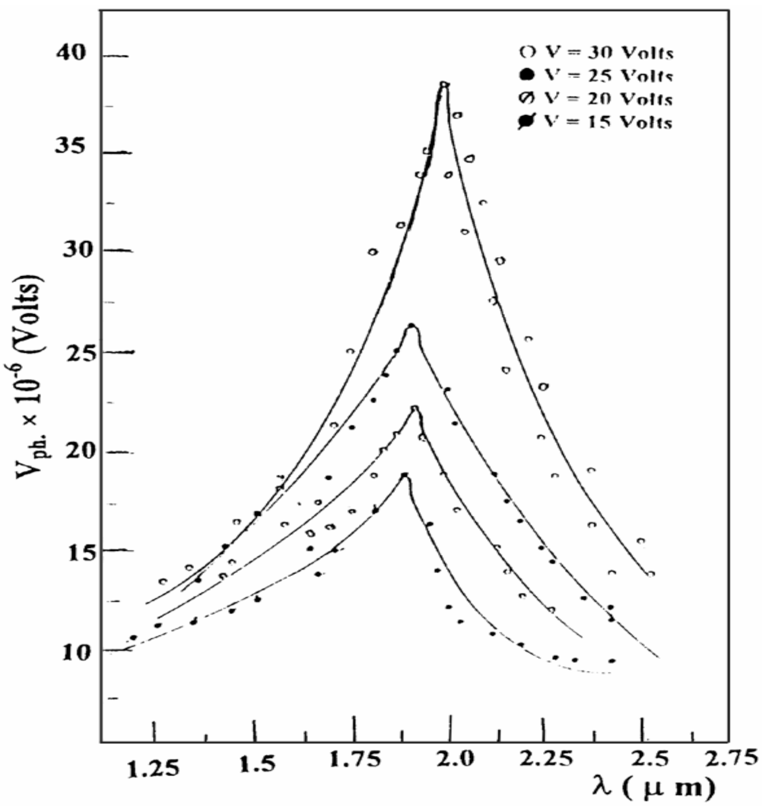

Fig. (1): Variation of the photovoltage with the incident photon wavelengths at different bias voltages.

1- The photovoltage rises continuously with photon energy, and reaches a certain maximum value at 1.94 mm, then steep fall is observed at high photon energy.

2- The shape of the spectral distribution characteristics was practically independent of the light intensity and applied bias voltage. Only the peak position shifted toward higher values of the photovoltage with increasing light intensity and applied bias voltage.

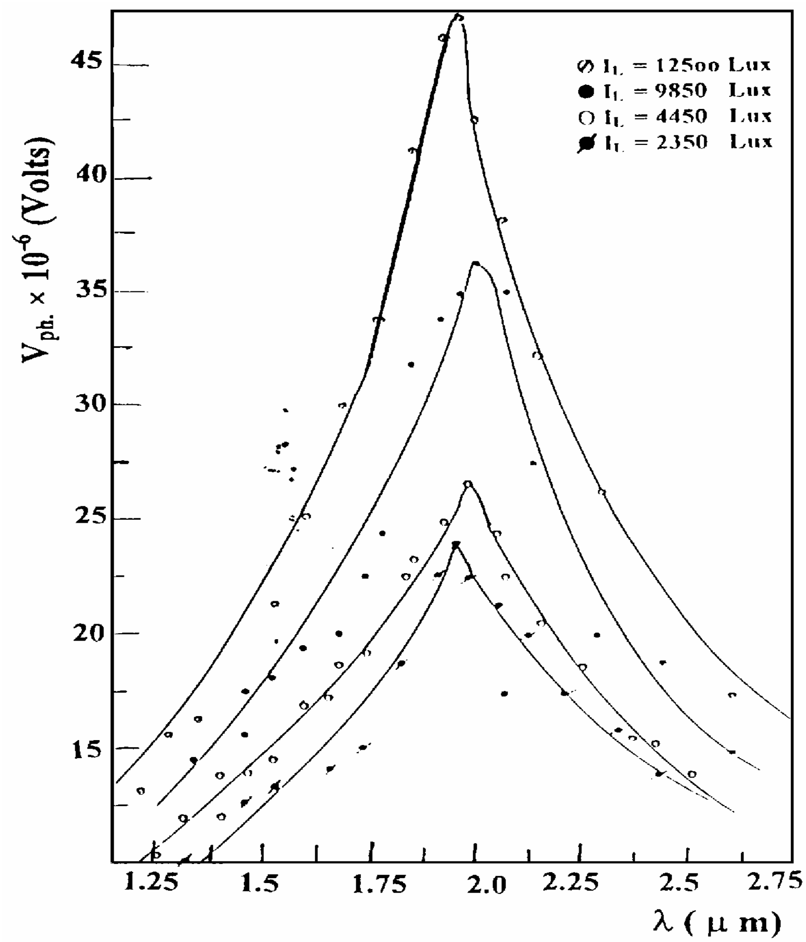

Fig. (2): Variation of the photovoltage with the incident photon wavelengths at different illumination intensities.

The kinetics of the phtoconductivity PC was studied from the frequency-dependence of the PC (Ds ~ / Dsst vs F), where Ds ~ is the AC component of the PC, st represents the steady state PC and F is we concluded from Figurer 1. Figure (3) illustrates the (Ds~ / Dsst) vs F dependence at different light intensities (540, 2350 and 10580 Lux). The effect of chopping frequency is noticeable in the low-frequency range up to 60 Hz, where Ds~ / Dsst decreases as the frequency increases The behaviour of these curves obeys the relation [7]:-

$$Ds\sim /Dsst = \tanh [1/(4 F t)]$$

According to this relation, and making use of such curves, we can derive the lifetime of the carriers at different light intensities.

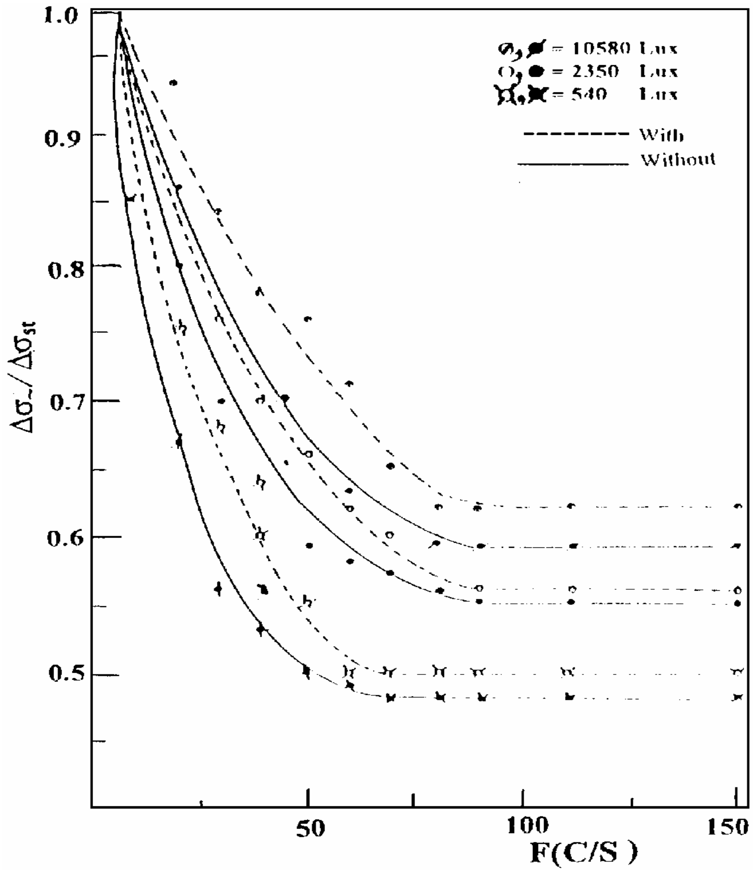

Fig. (3): Relation between the photoconductivity and the chopping frequency at different light intensities with and without side illumination (bias voltage = 30 V).

The graphic representation of the relation between the carrier lifetime and light intensity is illustrated in Fig. (4). From this graph we conclude the following:

1- Both solid curve (without side illumination effect) and dashed on (with side illumination) are similar and have the same behaviour.

2- The dependence shows that the lifetime t is inversely proportional to the illumination of the chopped light intensity.

3- The value of t was found to be of the order of 10-3 s and such long lifetime suggests that the PC mechanism, in our case, was controlled by transition trapping processes.

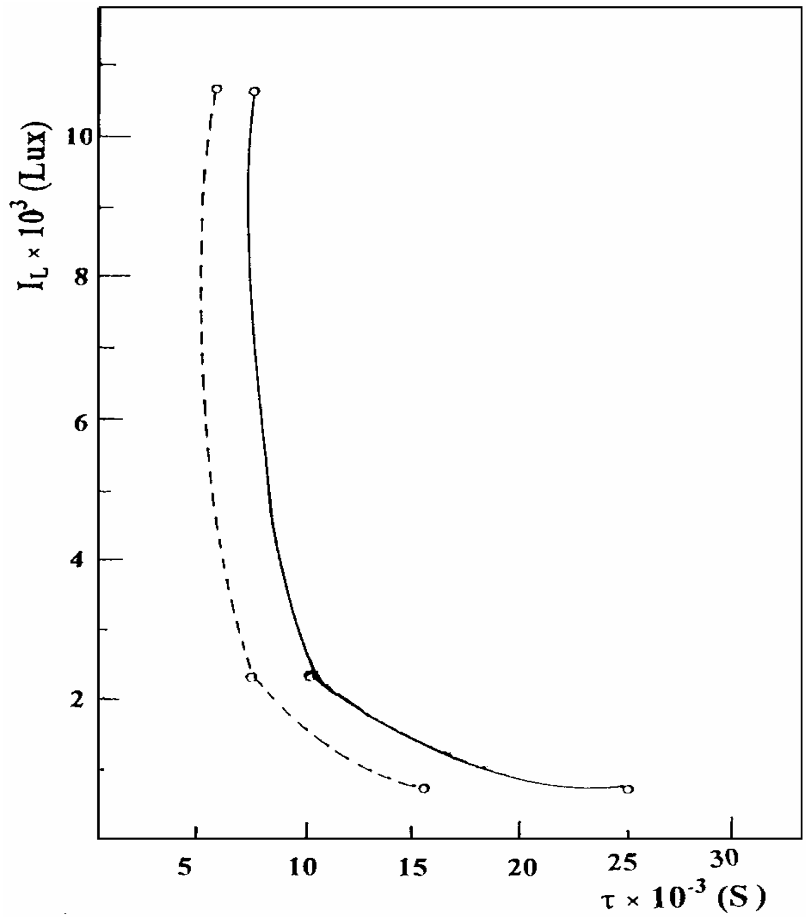

Fig. (4): Dependence of carrier lifetime on light intensity at a bias voltage of 30 (with and without side illumination).

The PC mechanism, when the trapping process predominated, can be explained as follows : the traps which capture free carriers for a time release them back to the free state by thermal re-excitation. This process could continue after the light had been removed. This slow emptying of the traps can maintain the PC decay after the light has been switched off for a time long compared with the decay time when only the recombination process was considered. The decrease in τ with increasing light intensity indicates of the exciting light. A similar argument was used in the interpretation of Ga_2Se_3 work [8].

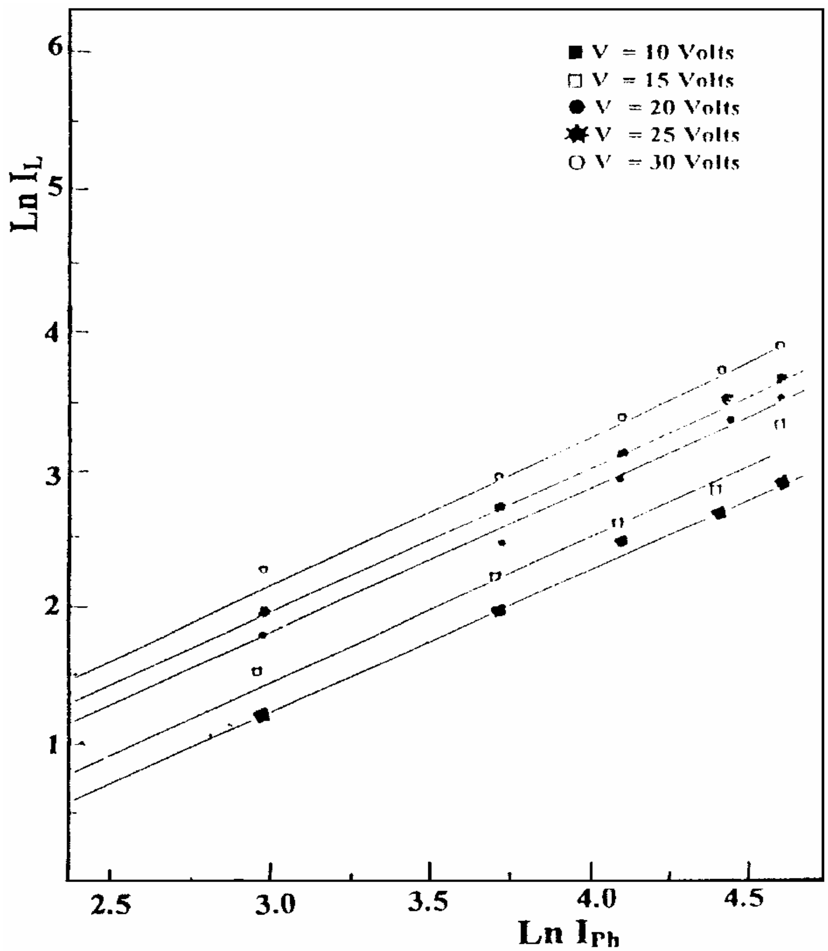

Fig. (5): Dependence of the photocurrent on the light intensity at different bias voltages.

As for the DC PC measurements, the effect of light intensity and applied voltage on the photocurrent is depicted in Fig. (5) (where the photocurrent (I_{ph}) is obtained by subtracting the dark current from the total current). It is seen that the relation betweeen the photocurrent (I_{ph}) and the light intensity. (I_L) is linear at the different bias voltage and justifies Rose equation[9].

$$I_{ph} \alpha \quad I_L^n$$

The increment of the photocurrent under the influence of light intensity is due to the fact that increasing the light intensity leads, in turn, to an increase of the number of the excited carriers. Also it is evident from the figure that at a certain value of light intensity, as the bias voltage increases the photocurrent increases too. This is regarded as a result of the increment of the carrier velocities.

Rose [9] has showed that the exponent n, in the last equation should satisfies the following $0.5 < n < 1$. In our case n nearly equals 1 in accordance with Rose predictions.

Another spectral distribution relation, but constructed between the DC photocourrent and the incident photon wave lengths, is illustrated in Fig. (6). The spectral dependence of the photocurrent agrees with other measurement of the DC PC in semiconductor compounds of $A^{III} B^{VI}$ group [10,11]. At low wavelengths (high photon energy), the photocurrent rises and reaches its maximum value at λ corresponds 1.94 μm. It falls again on the long-wavelength side from the peak position due o the carriers produced by defects and impurities. It must be mentioned that the fall in the photocurrent on the high energy side (short wavelengths) arises from bimolecular recombination at high carrier densities and surface recombination. Also Veith [12] explained the relation between the impurities and PC. It is found that the intrinsic excitation is converted to impurity excitation with increasing impurity concentration. When the acceptor impurities are incorporated into the crystal, the sensitivity is reduced because of the presence of uncompensated impurities, which act as recombination centres.

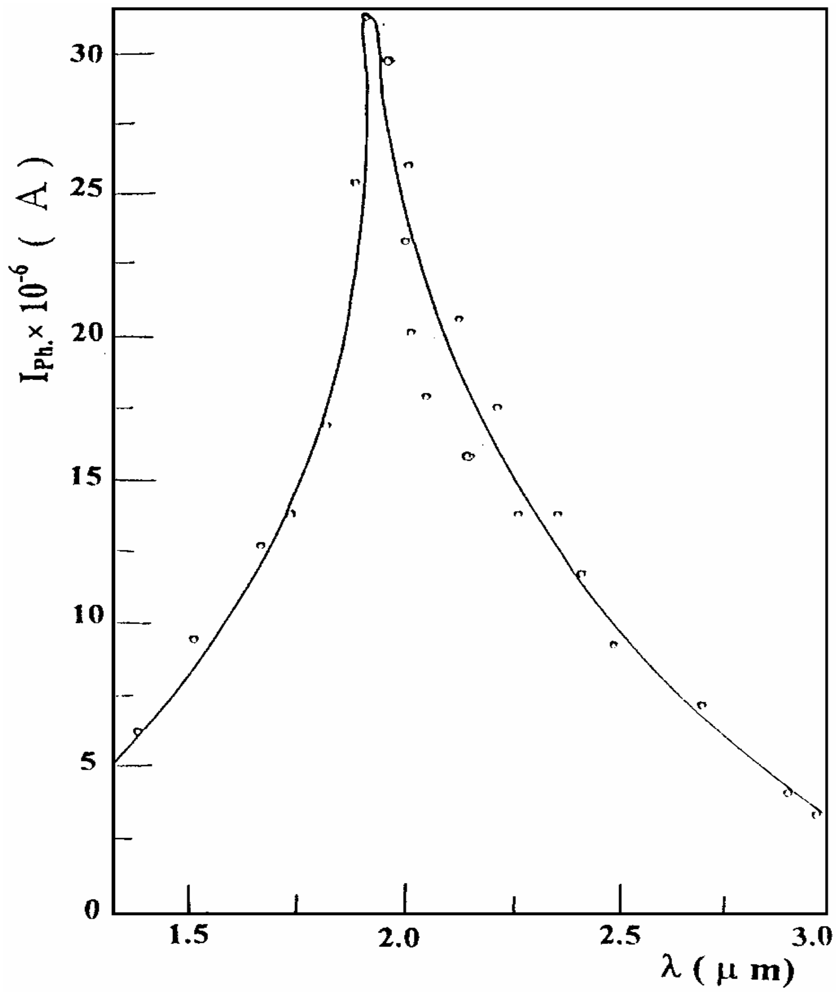

Fig. (6): Spectral distribution of the photocurrent for Ga_2Se single crystal at bias voltage = 30 V.

By applying the $\lambda_{½}$ method, the energy gap ΔE_g was calculated to be 0.49 eV at room temperature. This value is in a good agreement with that obtained from the electrical conductivity work done by the present authors [4].
Conclusion:

During investigating of the semiconductor Ga_2Se crystal, the following points were concluded:-

1- The carrier lifetime is inversely proportional to the illumination intensity and trapping processes govern PC as concluded from the lifetime curve.

2- Practically the spectral distribution characteristics were independent of the light intensity or the applied bias voltage except for making an upward shift to the peak accompanied by an increase in the value of the photocurrent or the photovoltage.

3- The energy gap of the Ga_2Se single crystal is 0.49 eV which agrees with that obtained previously by the present authors [4].

4- Oblique illumination governs PC and carriers lifetime.

References:

1. Lengaii N.B., Babayeva, B.K, and Rostamov, B.G. in: Novye pluprovad Mater., New semicond. Mater., Baku., *ELM*, P. 27 (1972).

2. Chang, Sum Yoon, Soon and Kyu Park : New Phys. (Korea Phys. Soc.) (South Korea) 29 (4) P. 32 (1989).

3. Rostamov, B.G., Babayeva, B.K. And Gamidov, R.S.: In : Novye pluprovad Mater., New Semicond. Mater., Baku, ELM P. 65 (1972).

4. Gamal, G.A., Nagat, A. T., Nassary, M.M., and Abou-Alwafa, A. M. Cryst. Res. Technol, 31 (3) 359 (1996).

5. Belal, A.E., Hussien, S.A., Madkour, H. and El Shaikh, H. Ind. J. Pure Appl. Phys. 31 464 (1993).

6. Elshikh, H.A., Abdal-Rahman, M., Belal, A.E. and Ashraf, I.M. J. Phys. D: Appl. Phys. 29 466 (1995).

7. Rose, A. ACA Rev. 12 362 (1951).

8. Kurbatov, L.N., Dircochka, A.I. and Sosin, V.A Sov. Phys. Semicond. 17 113. (1983).

9. Kuznich; Z.T., Maschke, K. and Schnid, P.H.J. Phys. C: Solid state Phys. 12 3749 (1970).

10. Veith, W., Physik 7 96 (1955).

11. Gamal,G.A.: Ph.D. Thesis (Physics), Assiut University (Qena) (1987).

12. Nagat, A.T., Gamal, G.A., Gameel, Y.H. and Mohamed, N. M.Phys. Stat. Sol. (a) 119 K 47 (1990).