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CHARACTERISTICS OF ELECTRON-BEAM EVAPORATED GaAs FILMS

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Thin films of polycrystalline GaAs were prepared using electron-beam evaporation technique. The optical constants, determined from the measured transmittance and reflectance at normal incidence of light, have values in good agreement with those determined for GaAs prepared by other techniques. The film exhibit an interband direct optical transition with energy gap $E_q^d = 1.4$ eV. The high-frequency dielectric constant, calculated by two different methods was found 12.255 and 10.91 in close agreement with published data. The thermal activation energy determined from the temperature dependence of the electrical resistivity approximates the bulk value. Current-voltage measurements in the non-ohmic region showed that a space-charge limited conduction begins at 5 V and extends to high values of the applied voltage on increasing the temperature. Poole-Frenkel effect predominates the voltage range 26 V—100 V at 444 K.

1. Introduction

Polycrystalline semiconducting films have received much attention because of their possible applications to large area devices, such as solar cells and displays. A considerable amount of attention is being directed to GaAs, for its application in high-frequency devices. Many of these devices require epitaxial layer and considerable efforts have been expended in obtaining device quality films. The molecular beam epitaxy technique has received much attention because the film composition can be controlled and varied by vaiying the intensity of each individually controlled beam during the film growth[1-5]. Another vacuum deposition technique which may achieve similar control of the film composition is the co-sputtering of the two constituent elements[6-8].

In the present work, GaAs films were prepared by an electron-beam evaporation technique. The structural, optical and electrical characteristics of such films were studied.

2. *Experimental techniques*

The films of GaAs [99.999% supplied by Koch-Light, England] were prepared by electron-beam evaporation technique using an electron-gun (Metallux, ML-P 18) attached to a vacuum system (BAL 307, Balzar Co, FRG). The vacuum was kept at 10^{-3} Pa during deposition. The film thickness was monitored using a quartz crystal thickness monitor (model QSG 301), and also measured interferometrically. The structural properties of the deposited films were examined by a X-ray diffractometer (Philips, PW 1373) using CuK_{α} radiation and a transmission electron microscope (EM 10, Zeiss) operating at 60 KV.

Spectrophotometric measurements of the transmittance and reflectance at normal incidence in the wavelength range of 400 nm—2000 nm was undertaken using a double-beam spectrophotometer with a specular reflection attachment (Cary 2390). A computor program was used for determining the optical constant[9].

Electrical measurements were made using a high impedance electrometer (Keithley 617). The sample was mounted on a special holder in an evacuated chamber (10^{-3} Pa). The temperature of the sample was controlled using Cr-Alumel thermocouple and a special temperature regulator. Thick vapour-deposited films of Au-Ge were used as ohmic contacting electrodes.

3. *Results and discussions*

The X-ray diffraction patterns carried out for GaAs film thickness range of (51.1 nm—409.5 nm) deposited on glass substrates did not show any peak line even after annealing at temperature 523 K for 1-hour. However, transmission electron diffraction patterns showed ring patterns indicating polycrystalline structure. The analysis of the pattern indicated a good agreement with that of the standard JCPDS powder diffraction data of GaAs.

Fig. 1 shows the spectral behaviour of the transmittance and reflectance of GaAs films at normal incidence of light in the wavelength range from 400 nm to 2000 nm. The real and imaginary parts of the complex refractive index ($\tilde{n} = n - ik$) computed from the measured, $T(\lambda)$ and $R(\lambda)$ values are given in Fig. 2. The mean value of the refractive index approximates to 3.5 beyond the absorption edge at long wavelengths, but increases slowly at first and then abruptly at the absorption edge. The value of the refractive index at 540 nm (about 4.105) is in good agreement with published data[10].

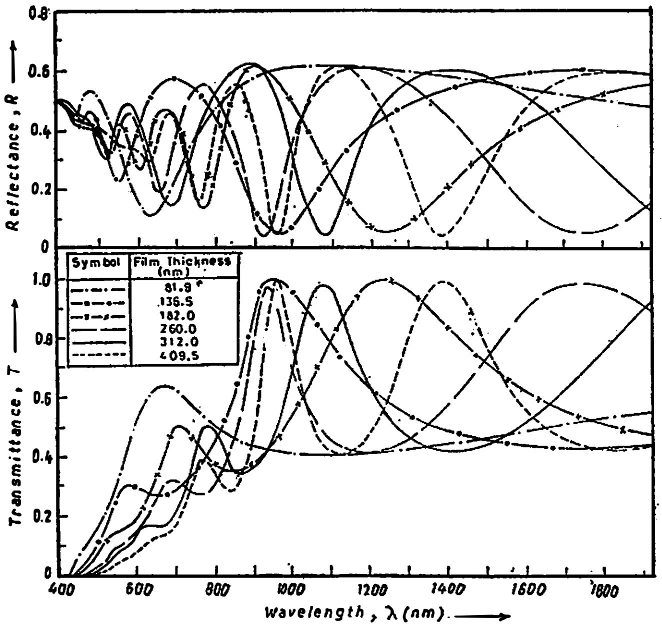

Fig. 1. Spectral behaviour of the reflectance and transmittance of thin GaAs films at normal incidence light.

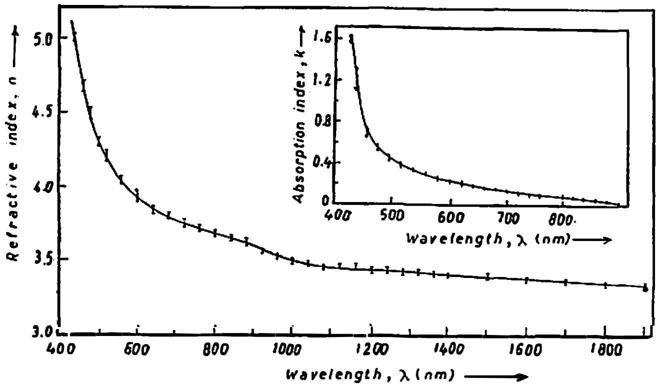

Fig. 2. Spectral behaviour of the calculated real and imaginary parts of the refractive index of GaAs films.

Plotting $\alpha^2 = F(h\nu)$ as shown in Fig. 3, yields a straight line indicating an allowed direct transition following the relation[11]

$$\alpha = \frac{A}{h\nu}(h\nu - E_g)^{1/2}. \tag{1}$$

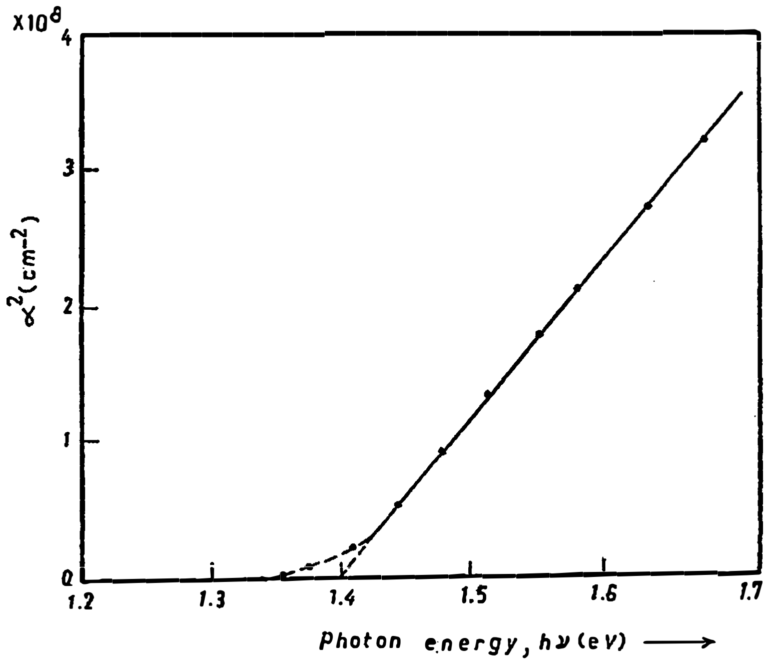

Fig. 3. Square of the absorption coefficient α^2, of GaAs films versus photon energy, $h\nu$.

The direct energy gap E_g^d was found to be 1.4 eV, in good agreement with the published values[12–14].

Plotting $n^2 = F(\lambda^2)$ as shown in Fig. 4, yields a linear part at longer wavelengths. Extrapolating this linear parts to the zero-wavelength, the part of intersection will then ordinate yield $\varepsilon_\infty = n_0^2 = 12.255$. Assuming that the high frequency properties of GaAs films could be treated as a single oscillator at infinite wavelength, the value of $\varepsilon_\infty = n_0^2$ could be determined from a plot of $(n^2 - 1)^{-1}$ versus λ^{-2} (Fig. 5). It was found that $\varepsilon_\infty = n_0^2 = 10.9$; which is in agreement with the values 10.9[15], 10.75[16] and 11.004[17].

The temperature dependence of the electrical conductivity of GaAs films is shown in Fig. 6. The value of the resistance was calcualted as $R = \frac{\Delta V}{\Delta I}$ by taking the current reading corresponding to a voltage value in the ohmic region. The behaviour follows the semiconducting relation

$$\sigma = \sigma_0 \, e^{-\Delta E/kT} \tag{2}$$

giving $\Delta E = 0.82$ eV which is the thermal activation energy of mobile charge carriers in agreement with the published data[18–19].

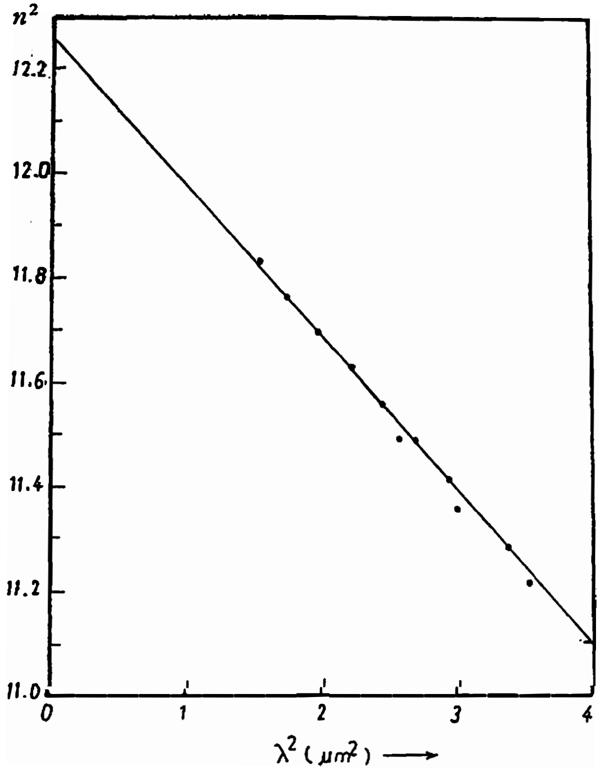

Fig. 4. Square of the real part of the refractive index, n^2 of GaAs films versus square of the wavelength, λ^2.

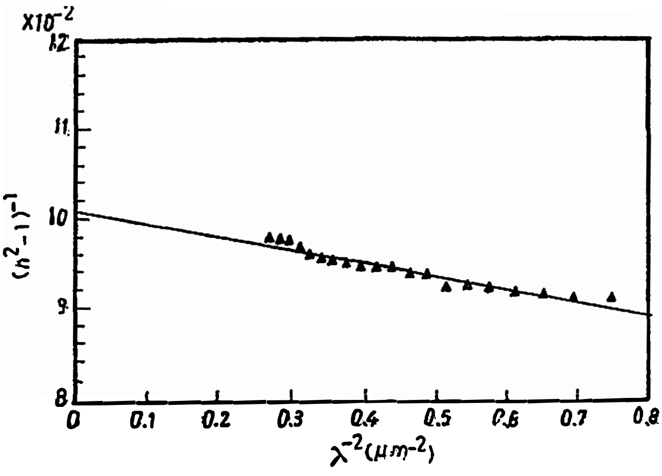

Fig. 5. $(n^2 - 1)^{-1}$ versus λ^{-2} of GaAs films.

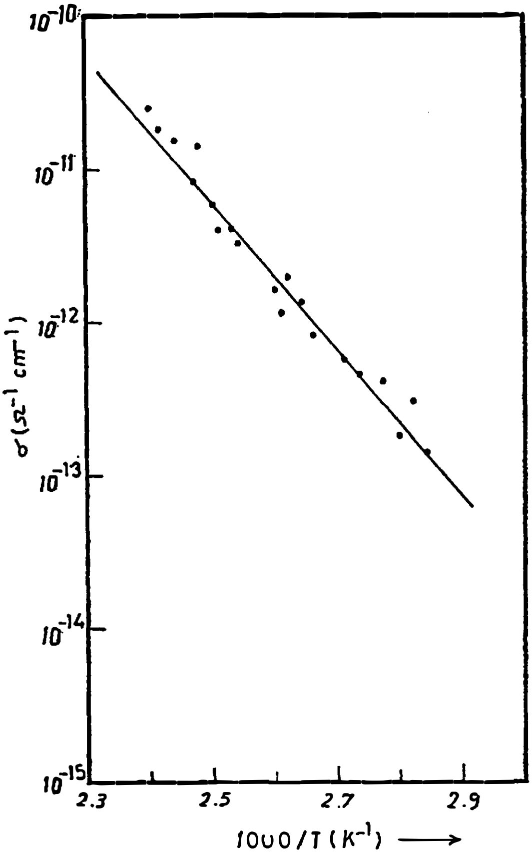

Fig. 6. Temperature dependence of the electrical conductivity of GaAs films.

Fig. 7 shows a plot of log I versus log V in the non-ohmic region at different temperatures for a sandwiched GaAs film. At low voltages above 400 K, the voltage dependence of the current follows the relation $I \sim V^2$. This could be attributed to the space-charge limited current (SCLS) in which the current density is given by[20]

$$J = \frac{9}{8} \varepsilon \mu \Theta \frac{V^2}{d^3} \tag{3}$$

where d is the film thickness, ε is the dielectric constant of the material, μ is the electronic mobility of the charge carriers and Θ is the ratio of the free to trapped carriers. At moderate values of the voltage and at temperatures below 430 K, the current depends on V as $I \sim V^{1.4}$, in the range from 32 V to 100 V, while the voltage dependence of the current at temperatures above 340 K follows the relation $I \sim V^3$. At 444 K a semilogarithmic plot of the current density versus the square-root of the applied electric field (Fig. 8), yields a straight line in the voltage range

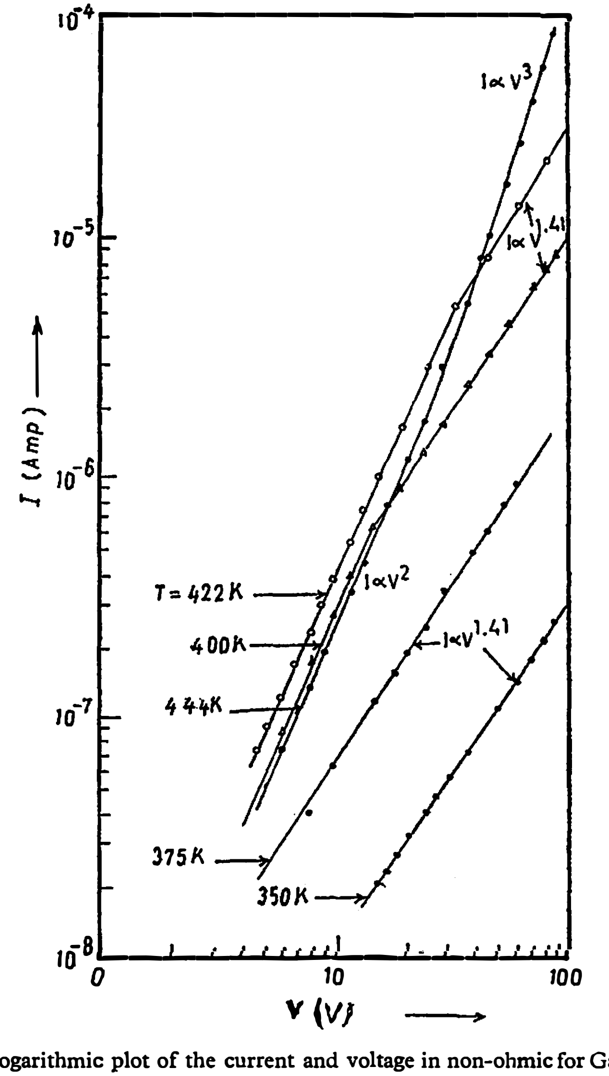

Fig. 7. Doubly logarithmic plot of the current and voltage in non-ohmic for GaAs film at different temperatures.

26—100 V. This indicates that the operating conduction mechanism may follow either Schottky effect or Poole-Frenkel effect. Since the contact resistance of (Au-Ge), GaAs is about 40 Ω[21], so the predominant effect is that of Poole-Frenkel.

Plots of log (V/I) against the applied voltage gave straight lines at 351, 375, 400 and 420 K (Fig. 9) indicating a uniform trap distribution following the relation[22]

$$J \infty 2en_0\mu \, (V/I) \exp \, (2\varepsilon V/NnkeL^2). \qquad (4)$$

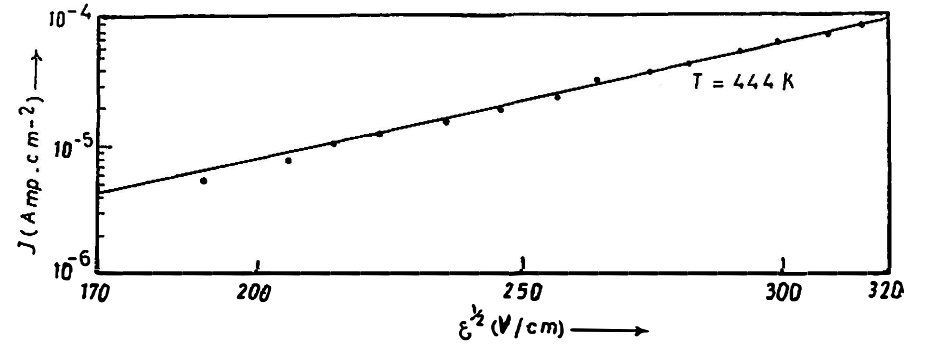

Fig. 8. Semilogarithmic plot of the current density versus the square-root of the applied electric field at 444 K.

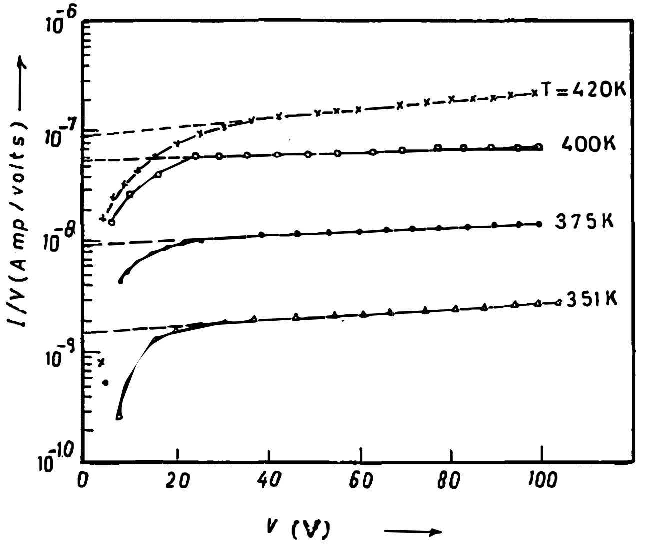

Fig. 9. Semilogarithmic plot of the ratio, (I/V) versus the applied voltage at different temperatures.

In conclusion, thin films of polycrystalline GaAs were prepared using electron-beam evaporation technique. The optical constants determined from the measured transmittance and reflectance at normal incidence of light, have values in good agreement with those determined for GaAs film prepared by other techniques. The films exhibit an interband direct optical transition with energy gap $E_g^a = 1.4$ eV. The high-frequency dielectric constant was calculated by two methods to be 12.255 and 10.91 which is very close to that given by other authors.

The thermal activation energy obtained from the electrical resistivity is found to be very close to that of the bulk GaAs. The measurement of I-V in the non-ohmic-region shows that a space-charge limit conduction begins from 5 V and extends to high values of the applied voltage on increasing the temperature. The Poole-Frenkel effect is predominant in the voltage range 26 V—100 V at 444 K.

References

1) R. Arthur, J. Appl. Phys. **39** (1968) 4032;
2) A. Y. Cho, J. Vac. Sci. Technol. **8** (1971) 831;
3) L. L. Chang, Armin Segmiiler and L. Esaki, Appl. Phys. Lett. **28** (1976) 39;
4) Paule Lusher, Solid State Technol. **20** (1977) 43;
5) A. Y. Cho and I. Hayashi, J. Appl. Phys. **42** (1971) 4422;
6) T. Evans and A. J. Noreika, Phil. Mag. **13** (1966) 717;
7) B. Molnar, J. J. Flood and M. H. Francambe, J. Appl. Phys. **35** (1964) 3554;
8) G. V. Bunton and S. C. M. Doy, Thin Solid Films **10** (1972) 11;
9) M. M. El-Nahass, H. S. Soliman, N. El-Kadry, A. Y. Morsy and S. Yaghmor, J. Material Sci. Lett. **7** (1988) 1050;
10) H. R. Philip and H. Ehrenreich, Phys. Rev. Lett. **8** (1962) 92;
11) J. I. Pankove, *Optical Processes in Semiconductors*, Dover Publ., Inc. New York (1971);
12) O. D. Castano Gonzatez, M. DE Dios Leyva and R. Perez Alvarez, Phys. Stat. Sol. (b) **71** (1975) 111;
13) S. A. Geidur, A. N. Pikhtin, V. T. Prokopenko and A. D. Yaskov, Opt. Spektrosk. **46** (1979) 177;
14) Sadao Adachi, Phys. Rev. B. **35** (1987) 7454;
15) J. B. Mckitterick, Phys. Rev. B. (USA) **28** (1983) 7384;
16) S. Jones and S. Mao, Appl. Phys. Lett. **11** (1967) 351;
17) T. Inoue and M. Ohyama, Sol. Stat. Comm. **8** (1970) 1309;
18) D. C. Look, J. Phys. Chem. Solids **36** (1975) 1311;
19) D. C. Look, J. Appl. Phys. **48** (1977) 5141;
20) M. A. Lamperi and P. Mark, *Current Injection in Solids*, Academic Press, New York (1970);
21) G. Hamamdjian, Thesis Doctor d'Etat, USTL, France (1987);
22) A. G. Milnes, *Deep Impurities in Semiconductors*, John Wiley and Sons, New York (1973).

KARAKTERISTIKE GaAs SLOJEVA EVAPORIRANIH ELEKTRONSKIM SNOPOM

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Tanki filmovi GaAs pripremljeni su tehnikom evaporacije elektronskim snopom. Optičke konstante, određene mjerenjem propusnosti i refleksivnosti svjetla pri normalnom upadu dobro se slažu s onima mjerenim za GaAs pripremljenog drugim tehnikama. Nađen je procijep za direktan optički interband prijelaz od 1,4 eV, kao i visokofrekventna dielektrična konstanta.