ISSN: 1813 – 1662 (Print)
E-ISSN: 2415 – 1726 (On Line)

Fabrication and characterization of Ag-BaF_2/GaSb Schottky diode

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Abstract

The Ag-BaF_2/GaSb Schottky diode measurement has been investigated by using voltage versus current (I-V) at different temperatures, voltage versus capacitance (C-V) and hotoelectric measurements on n-type GaSb carrier per cm^{-3}, Current – voltage measurement were used to study the interface layer. Near ideal characteristics were observed for Ag-BaF_2/GaSb contact with ideality factor values (1.21-1.451). The Schottky barrier height and donor concentration (N_d) have been obtained from C-V characteristics. Barrier height results from these methods were the same approximately with the results obtained from current – voltage measurement and were in the same range which suggests that the Fermi level is pinned in the lower half of the band gap. Photoelectric measurements were used for barrier height measurements by applying the fowler method. The surfaces of sample was analyses using scanning electron microscopy (SEM) and also the x-ray is used to investigate the reasons for the non-ideal behavior of Ga contacts and to study the surface of Ag-BaF_2 layer on the air-cleaved n-GaSb surface.

Keyword: Schottky diode; electrical properties; x-ray differaction ; scanning electron microscopy

1. Introduction

"Schottky barrier-type devices are rectifying metal-semiconductor (M-S) structure. This device is used in microelectronics, in solar cell applications, and in chemical sensing" [1]. In the Schottky model the amount of band bending is equal to the difference between the work functions, ϕ_m and ϕ_s of the metal and semiconductor respectively. Thus

$$qV_i = \phi_m - \phi_s \quad .....(1)$$

Where (q) is the contact polenta of the junction and(V_i) is the potential barrier which an electron moving from semiconductor into the metal has to surmount. The barrier height, looking from the metal towards the semiconductor is given by

$$\phi_b = qV_i + (E_c - E_f) \quad .... (2)$$

$$\phi_b = \phi_m - \chi_s \quad .... (3)$$

Where (χ_s) is the electron affinity of the semiconductor. Most practical Schottky contacts do not appear to obey the above equation in that the barrier height is found to be independent of the difference between the work functions [2].In the past several authors remarked that the schottky barrier height determined from C-V measurements by assuming a simple model was different from the one obtained from I-V measurements. Crowell and Rideout [3], working on Si and GaAs contacts, attributed this difference to the influence of thermionic field emission on the charge transport through the interface. Later on, similar observations were made on GaAs Schottky barriers in which other contact metals were used [4-7]. Recently effects were reported for several metal / GaSb barriers [8]. The present paper reports the study of the I-V measurement, C-V measurement and photoresponse measurement at room temperature.

2: Experimental details

2.1 Samples preparation

Te-doped n-type GaSb semiconductor with carrier density of $2.1x10^{17}$ carriers per cm^3, obtained from M.C.P. Electronic Materials Ltd., was used for this study. Ohmic contacts were preformed by painting on an In-Ga alloy on both sides of the sample. Surface preparation was normally carried out by air cleaving. The GaSb crystal was cleaved by applying a sharp force to a blade placed parallel to the (110) plane which in the natural cleavage plane of this material. The cleaving was done immediately before transferring to a high vacuum system so that the air interacted with the faces for a period of only 5 to 10 minutes. When etching was also used, it was carried out after preparing an ohmic contact, as explained, on one side of the crystal only. The ohmic contact was covered with 'Lacomit ' a chemically resistant varnish which was allowed to dry then the other side was cleaned and polished to a fine finish with 0.25 m diamond paste. The surface was then cleaned ultrasonically in methanol for 5 minutes then chemically etched using a solution of 1% bromine in methanol. Finally the crystal was cleaned ultrasonically in methanol again for 5 minutes. A metal mask with 0.5 mm diameter circular holes was placed on the prepared surface to produce contacts in the form of small dotes. An Edward model E610 vacuum coater was used to prepare method and BaF_2 layers. This system is intended primarily for the production of thin film coatings which can be used in the microelectronics. This ideal was tested by four different techniques viz. I-V measurement, C-V measurements, photoreponse measurement, XRD and SEM image.

2.2 Electrical properties

2.2.1 Current – voltage measurements

The current – voltage measurements were measured using a D. C. method in which the voltage was preset in steps and the corresponding current measured. Currents were measured with a Keithley while a Keithley electrometer (Model - 2000) programmable voltage supply provided the supply voltage. The current as a function of applied bias V is given by the relation [9-10].:

$$I = I_o\left[\exp\left(\frac{qV}{nKT}\right) - 1\right] \quad .... (4)$$

Where, the saturation current

$$I_o = S\,A^*\,T^2 \exp\left(\frac{-\phi_B}{KT}\right) \quad \text{……… (5)}$$

Here n is the diode ideality factor, A* is the modified Richardson constant for the semiconductor ($A^*= 5.08\times10^4\ Acm^{-2}K^{-2}$). For forward values of V in excess of $3KT/q$, a plot of log I against V gives a straight line. The value of I_o can be obtained by extrapolating the straight line to $V = 0$. Knowing Io, A*, S is the diode cross-sectional area, and T is the temperature, the barrier height ϕ_B can be determined. The ideality factor, n, can be calculated from the equation

$$n = \frac{q}{KT}\frac{\partial V}{\partial[\log(I)]} = \frac{q}{KT}\frac{1}{slope} \quad \text{… (6)}$$

2.2.1 Current – voltage measurements

C-V measurements for Ag-BaF_2/GaSb Schottky diode at frequency of 1 MHz were determined by using precision LCR Bridge (model HIOKI 3532-50 LCR Hi TESTER) at room temperature. The reverse bias applied was the range (0 to 1.6) volt. The capacitance C as a function of applied bais V is given by the relation [11]:

$$C = S\left[\frac{\varepsilon_s q N_d}{2\left(V_i + V_R - \frac{KT}{q}\right)}\right]^{1/2} \quad \text{……. (7)}$$

Where S is the diode cross-section area, ε_s is the permittivity of the semiconductor, V_R is applied reverse voltage, and all other symbols have their usual meaning. It is seen from the above equation that a plot of $1/C^2$ versus V_R gives a straight line with slope $2/S\varepsilon_s qN_d$ and an intercept on the voltage axis $V_O = (V_i\text{-}KT/q)$. The slope of the straight line can be used to determine the do pant concentration N_d and since $qV_i = (\phi_B - \phi_n)$ the barrier height ϕ_B is obtained as

$$\phi_B = (qV_i + \phi_n + KT) \quad \text{…… (8)}$$

The KT factor comes from the contribution of majority carriers to the space charge.

2.2.3 Photoelectric measurement

The photoelectric method is the most accurate band direct method of determined barrier height. When a monochromatic light is incident on a metal in contact with the semiconductor and the photon energy hν is large than the barrier height but smaller than the band gap of the semiconductor, the incident photons will excite some electrons from the metal over the barrier. The resulting photocurrent I_{ph} for $(h\nu - \phi_b)^2 >> 3KT$ is given by the Fowler theory [12]..

$$I_{ph} = B\,(h\nu - \phi_b)^2 \quad \text{………..(9)}$$

Where B is contact of proportionality. If $\sqrt{I_{ph}}$ is plotted as a function of hν, a straight line is obtained whose intercept on the hν axis directly given the barrier height ϕ_b.

2.2.4 Structural analysis

The x-ray diffraction patterns of the sample were recorded using x-ray diffactometer (model Bruker D8 Advance), with CuKα radiations (λ=1.5418 Å) at a scanning rate of 0.4 sec/step. The x-ray to investigate the reasons for the non-ideal behavior of Ga contacts and study the surface of Ag-BaF_2 layer on the air-cleaved n-GaSb surface.

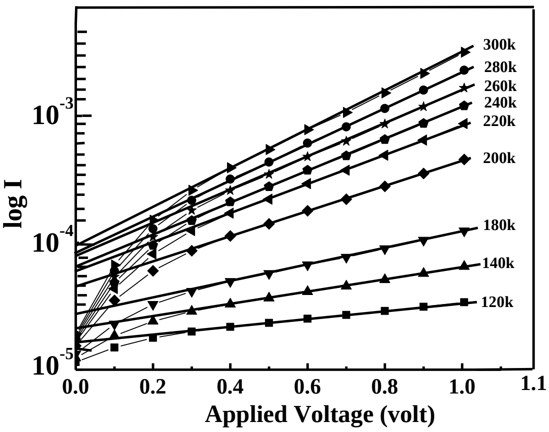
2.2.5 Surface morphological studies

Scanning electron microscope (SEM) (JEOL, Model JSM-6360A) was used to investigate the surface of the fabricated schottky devices. .

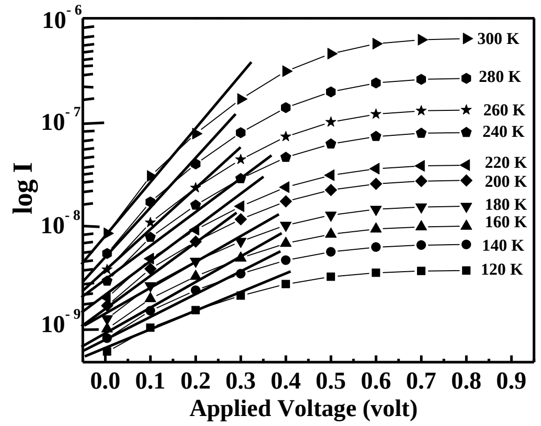
3. Results and discussion

3.1 Current-voltage measurement

The I-V characteristics (forward bias and reverse bias) of Ag contact on air-cleaved GaSb, presented in Fig. 1(a-b), show a good rectification factor (Rec = 475) with good saturated reverse current. The values of both parameters ϕ_b and n for Ag-BaF_2-GaSb Schottky diode tested are (0.49 eV and 1.15). In the forward bias characteristics below 0.2 V, more than one component was visible. These characteristics suggest an additional electron transport mechanism is present, possibly associated with recombination in the depletion region. Results from recent studies of Ag contact on . Non-saturation of the reverse bias current was observed for Ag-BaF_2-GaSb Schottky diode and their non-ideality was attributed to the release of Sb immediately after the Ag deposition and the possibility of chemical interaction in the interface [13-14].



(a)



(b)

Fig. 1 I-V characterization of Ag-BaF_2-GaSb Schottky diode into two types (a) forward bias and (b) Reverse bias at different tempersure

3.2 Capacitance-voltage measurement

From Fig. 2, it is clear that when increase reverses bias voltage, the depletion region width decreases because the electrons move out of this region leaving behind the uncompensated donors [15].

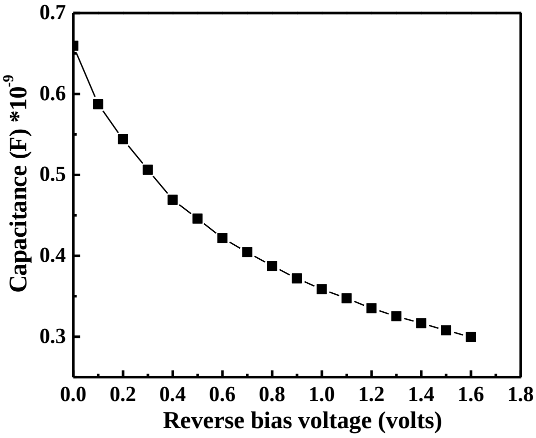


Fig. 2 C-V plot for Ag-BaF$_2$/GaSb Schottky diode

The plot of $\frac{1}{C^2}$ against applied reverse voltage in Fig. 3 shows straight line behavior up to -1.7 V. giving barrier height in the range These are thus in very good agreement with values from I-V method. Carrier concentration obtained from the slope was in the range. C-V characteristics of Ag contact on air-cleaved GaSb, presented in Fig. 3.

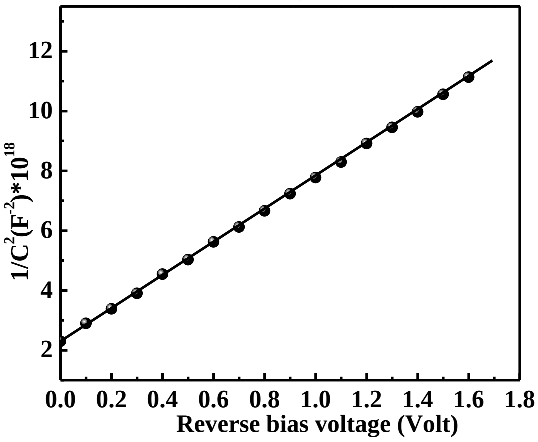


Fig. 3 The relationship between 1/C^2 with reveries bias voltage Ag-BaF$_2$ -GaSb Schottky diode

3.3 Photoelectric measurement

The barrier height of a Schottky contact can be determined from the spectral dependence of photovoltaic. Photo-threshold measurements have long been accepted as the single most reliable method of determining Schottky barrier heights [2]. Fig. 4 shows a typical photoresponse plot for Ag-BaF$_2$ –GaSb contact which gives a barrier height of 0.553 eV from Fowler method. In general, the result from this method lower value for the barrier height without correction than those barrier height values observed from the I –V and C – V methods.

The general photoresponse equation due to Fowler can be written as [16]:

$$R = C\left[\frac{\pi^2}{6}+\frac{\pi^2}{2}-\left[e^{-\mu}-\frac{e^{-2\mu}}{2^2}+\frac{e^{-3\mu}}{3^2}\dots\dots\dots\dots\right]\right] \quad .. (10)$$

Where R is the response of the diode per light quantum, C = $C_1 + C_2$, $C_1 = \mu = \frac{h\nu-\phi_b}{kT}$, and $C_2 = \frac{E_f}{kT}-C_1$. Equation 10 suggests that, for large μ , R α μ^2 or $\sqrt{R}$ α μ which is applied in the classic Fowler method used in this study. The third term, $\left[e^{-\mu}-\frac{e^{-2\mu}}{2^2}+\frac{e^{-3\mu}}{3^2}-\dots\dots\right]$, is negligible for μ>>3. However the term, $\frac{\pi^2}{6}$, which is constant, remains important for small μ..

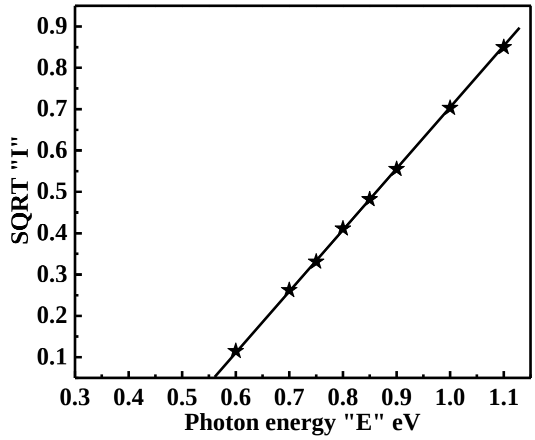


Fig.4 SQRT of "I" versus photon energy for Ag-BaF$_2$-GaSb Schottky diode.

De Sousa Pires [17] has put forward a correction method involving a correction diagram for the photoelectric measurement of metal – semiconductor barrier heights. Fig. 5 shows the correction produce on Ag-BaF$_2$ –GaSb where the least squares fit was made from 4Kt (lower limit) to 9.5Kt (upper limit). For this range the diagram gives a correction of about 0.6Kt which is 0.015 Ev. The corrected barrier height is thus 0.553 + 0.015 = 0.568 Ev which is more reasonable and comparable to the values obtained from the I-V and C – V methods [13-15].

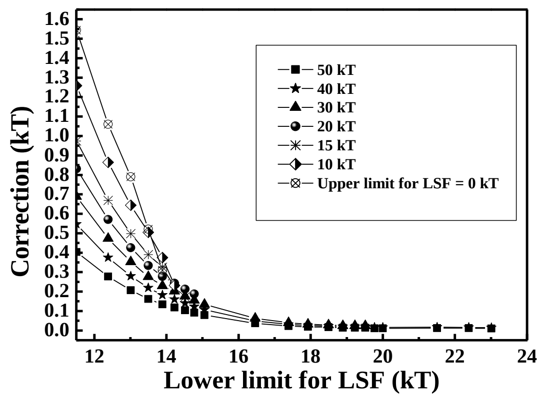


Fig.5 A correction diagram for the experimental Fowler plot.

The transport properties, while of interest in themselves, require theoretical modeling in order for them to be linked to the measurement of the wave length of excitation and to the electronic yield as a function of the metal. Vasoya1 et al [18] have derived a modified expression in the absence of scattering to explain the enhanced photoemission observed with thin films. The modified equation can be written as

$$Y = \frac{[h\,\nu - \Phi_b]^2}{8\,E_f\;h\,\nu} \quad \text{.................} \quad (11)$$

The photoresponse measurements were also corrected using the cohen modified equation. Fig. 6 show plotted against the photo energy, hυ, for Ag-BaF_2-GaSb schottky contacts respectively. The barrier height result for Ag-BaF_2-GaSb diode was measured as 0.460 eV. Barrier height results obtains from the Cohen modified equation were in good agreement with those obtained using the de Sousa Pires correction method and both sets of corrected results show reasonable and comparable agreement with barrier height values obtained from I-V and C-V methods for same diode[19].

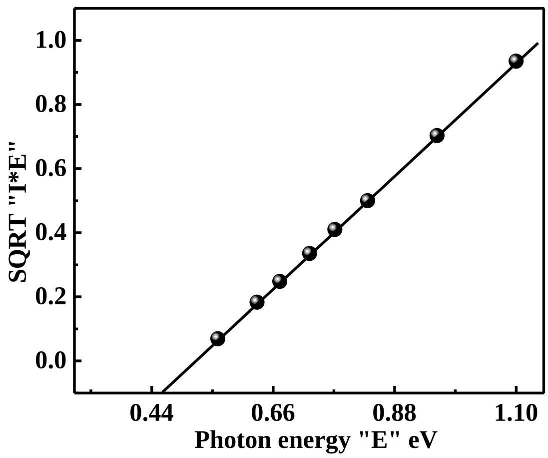


Fig.6 Barrier height of Ag-BaF_2-GaSb Schottky diode as determined from modified Fowler method.

3.4 X-ray analysis

X-ray analysis, represented in Fig.7 (a-b), Fig. 7(a) shows the X-ray energy dispersive spectrometer (EDS) analysis, focused within the Schottky contact region, of a studied MS-type device. X-ray analysis shown in Fig. 7(a) , did not show any oxygen or carbon at the surface, using a BaF_2 layer between the Ag and GaSb causes clustering to disappear from the surface , thus showing the important of BaF_2 in preventing chemical and physical interacting between metal and semiconductor. The X-ray analysis, shown in Fig. 7(b). Obviously, the important elements, e.g., Ag, Ba, F, Ga, and Sb, are found due to contamination of the surface. Based on the work reported by Hashizume *et al.*, the chemical composition of this thermally grown oxide layer is possibly the InPO –like component [20].

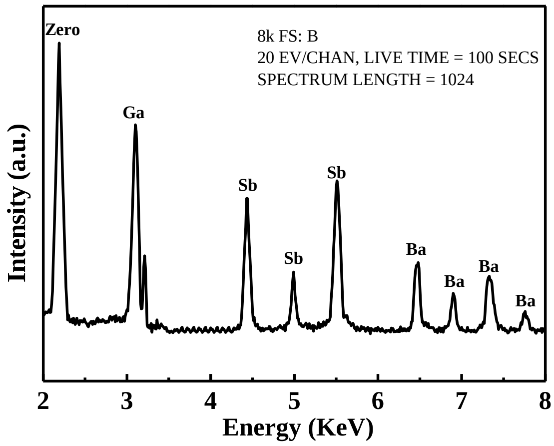


Fig. 7(a). X-ray energy dispersive spectrometer (EDS) analysis on the Schottky contact area of the studied for BaF_2-GaSb Schottky diode

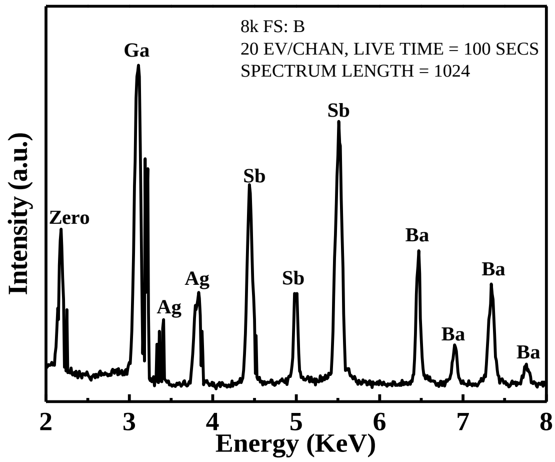


Fig. 7(b). X-ray energy dispersive spectrometer (EDS) analysis on the Schottky contact area of the studied for Ag-BaF_2-GaSb Schottky diode.

3.5 Surface morphological studies

Fig. 8 represent scan of the surface of a Ag-BaF_2-GaSb diode which show clustering of the Ag over layer on the surface of the BaF_2-GaSb.

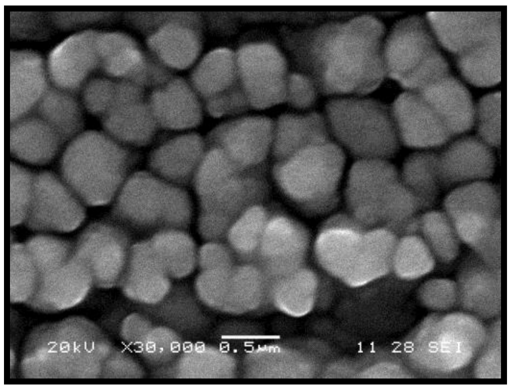


Fig. 8 SEM photo of the surface of Ag-BaF_2-GaSb.

Acknowledgements

The author thanks Dr. V. L. Mathe, for the C-V measurement by LCR meter, Mr. Jagtap, for the XRD analysis. The author thanks the Ministry of Higher Education and Scientific Research in Iraq for the financial support to carry out this work.

4. Conclusions

The Fabrication and characterization of Ag-BaF_2-GaSb Schottky diode is discussed in this paper. Barrier height results were measured using I–V and C–V methods and were comparable and in general were less than 0.5 eV. The I–V method at low temperatures was used to measure barrier hights and to establish the current transport mechanisms. The results suggest the more than one mechanism was responsible for current transport. Photoresponse measurements were used for barrier height measurements by applying the Fowler and modified Fowler methods. The scanning electron micrograph and x-ray of the Ag-BaF_2-GaSb Schottky diode to investigate the reasons for the non-ideal behaviour of Ag contacts and to study the surfaces of BaF_2 , and Ag-BaF_2 layers on the air-cleaved n-GaSb surface.

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" تصنيع ودراسة خصائص ثنائي شوتكي Ag–BaF_2-GaSb"

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الملخص

فحصت قياسات ثنائي شوتكي باستخدام التيار – الفولتية، السعة– الفولتية وقياسات الكهروضوئية على انتيمون الكاليوم من النوع المانح (n-GaSb) عند درجات الحرارة المختلفة. استخدمت قياسات التيار – الفولتية في دراسة الطبقة البينية حيث لوحظت خصائص شبه مثالية لتماس شوتكيAg-BaF_2-GaSb مع قيم عامل المثالية (1.451 –1.21). تم الحصول على ارتفاع حاجز شوتكي وتركيز الحاملات (N_d) من خصائص السعة–الفولتية (C-V). ارتفاع الحاجز (ϕ_b) باستخدام هذه الطرق يشبه تقريبا النتائج الملحوظة من قياسات التيار–الفولتية وعند نفس المدى المقترح لمستوى فيرمي لأقل من نصف فجوة الطاقة. استخدمت قياسات الكهربائية الضوئية لقياس ارتفاع الحاجز بواسطة تطبيق نظرية فولير Fowler theory. أما مجهر الماسح الالكتروني والأشعة السينية (X-ray) فقد استخدمت لفحص السلوك غير المثالي لتماسات الكاليوم Ga ودراسة سطوح طبقات Ag-BaF_2 على سطح انتيمون الكاليوم من النوع المانح (n-GaSb).

الكلمات الافتتاحية: ثنائي شوتكي، الخواص الكهربائية، حيود الاشعة السينية، ماسح المجهر الالكتروني.