Preparation and Study I-V properties for Schottky Devices (Al-GaAs & Ni-GaAs) at forward bias

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تحضير ودراسة بعض خصائص تيار – فولتية لنبائط شوتكي (Al-GaAs & Ni-GaAs) في حالة الانحياز الأمامي

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Abstract

Four samples had been prepared by using two different metals (Al) with work function (4.13eV) and (Ni) with work function (5.01eV) as (Schottky contact) on (GaAs) semiconductor (n-Type) , first we made the Ohmic contact for the samples by using (Al) with two samples and (Ni) with the others after that we annealed the samples under a vacuum pressure of the order (10^{-4} Torr)and (450 K) for 30 min. in order to get a good contact resistance , then we made the Schottky contact with two samples (Al) and other two for (Ni) and (120 Å) thickness and we annealed the samples under (450 K) and (10^{-4} Torr) to avoid the interfacial layers ,the samples are:

{Al-GaAs (Al Ohmic) / Al-GaAs (Ni Ohmic) / Ni-GaAs (Al Ohmic) / Ni-GaAs (Ni Ohmic).}

Then the I-V characteristics had been measured for the samples and then the saturation current and the barrier height of Schottky contact and the ideality factor is found for the Schottky contact and the specific contact resistance for Ohmic contact is calculated , and then we study the work function and the interfacial layer effect on I-V characteristics .

الخلاصة

تم تحضير أربع نماذج باتصال معدن شبه موصل (مانح) على شكل تماس شوتكي (نقطي) حيث تم استخدام معدني الألمنيوم ذو دالة الشغل (4.13 eV) ومعدن النيكل ذو دالة الشغل (5.01 eV) وأرضية شبه موصل أرسنيد الكاليوم (مانح) حيث تم أولاً أجراء الاتصال الأومي باستخدام معدن الألمنيوم لنموذجين ومعدن النيكل لنموذجين فكانت المحصلة أربع نماذج وتمت عملية التلدين لهذه النماذج تحت درجة حرارة (450 K) وضغط (10^{-4} تور) لمدة نصف ساعة لتفادي حالات السطح البينية ومن ثم أجراء اتصال (شوتكي) باستخدام معدن الألمنيوم مرتين والنيكل مرتين وبسمك (120 Å) فكانت النماذج كالآتي :

(ألمنيوم – أرسنيد الكاليوم وبتماس أومي معدن الألمنيوم / ألمنيوم – أرسنيد الكاليوم وبتماس أومي معدن النيكل / نيكل – أرسنيد الكاليوم وبتماس أومي معدن الألمنيوم / نيكل – أرسنيد الكاليوم وبتماس أومي معدن النيكل) .

ومن ثم أجراء عملية التلدين الحراري للنماذج تحت درجة حرارة (450 K) وضغط (10^{-4} تور) وتم قياس خصائص تيار - فولتية عند درجة حرارة الغرفة ومنها حساب قيم تيار الإشباع وعامل المثالية وارتفاع حاجز شوتكي ومدى تأثره بدالة شغل المعدن المستخدم وقيمة مقاومة التماس للاتصال الأومي وتأثير نوع المعدن المستخدم والطبقات البينية على خصائص تيار فولتية المحتسبة من هذا البحث. .

Theoretical method

Due to scale down of feature sizes of semiconductor devices and recent increasing interest in quantum devices including quantum wire transistors and single electron transistors, nanometer sized Schottky contacts and Ohmic contacts are strongly required Especially the nanometer sized Schottky contacts with tight gate controllability becomes much important to realize reliable devices performances because the number of electron to be controlled decrease when the device size is reduce into nano sized region. Regarding the formation process of metal- semiconductor (MS) interface the size and position controllability of metal contact are required as well as the reduction of process induced damage .**(Taketomo 2001)**

With this background, we have recently reported an in situ electrochemical process can produce nanometer sized Schottky contacts in size and position controlled fashion and they behaved differently from macroscopic Schottky contacts. Namely Schottky barrier heights (SBH) approached to Schottky limit as the size of the contact is reduced in the nanometer range.**(Hasegawg 1999)**

A (SBH) is a metal – semiconductor junction which has rectifying characteristics , suitable for use as a diode. The largest differences between a (SBH) and p-n junction are its typically lower junction voltage , and decreased (almost nonexistent) depletion width in the metal .**(Mc Graw 2005)** functioning of the metal–semiconductor contact (Fig. 1) **(Joachim piprek 2003)** and Simulation can be explained in the band model similarly to what has been done for the diode junction. Conductors differ from semiconductors by having a partially filled conduction band and therefore having the Fermi level – the level at which the occupation probability is one-half – inside the conduction band , furthermore, the amount of charge carriers available in the metal is so huge that for static situations in good approximation the electric field inside the metal is zero and the interaction with the surrounding material can be described by a surface charge on the outside boundary of the metal .**(Gerhard Lutz 1999)**

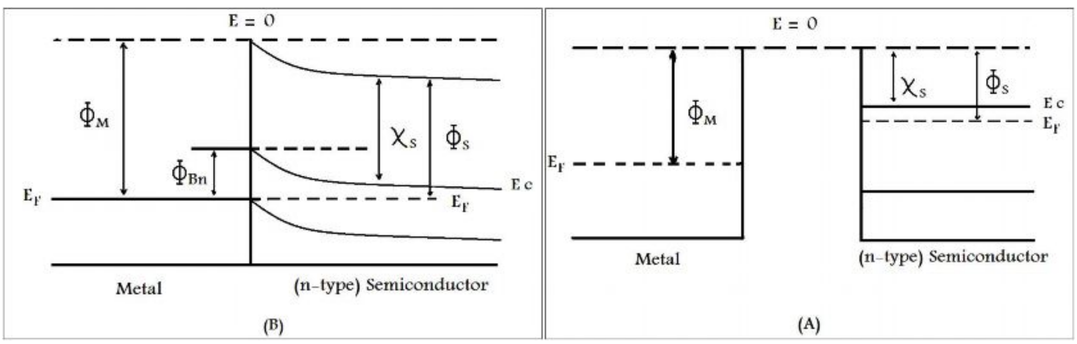


Fig. 1: Schottky contact between metal and n- semiconductor
A-before contact B- after contact

Not all metal-semiconductor junction are Schottky barriers metal-semiconductor junction that does not rectify current is called (Ohmic contact) . Rectifying properties depend on the metal´s work function, the band gab of the intrinsic semiconductor, and the type and concentration of dopants in the semiconductors. Design of semiconductor devices requires familiarity with the Schottky effect to ensure Schottky barrier are not created accidentally where an Ohmic connection is desired .**(Mc Graw 2005 , R. V. Ghita 2005)**

And we can calculate the specific contact resistance for Ohmic contact by using equation (1) : **(S. M. Sze 1981)**

$$Rc=(K/qA^*T) \exp[(q\Phi_{Bn} / KT)] \ldots\ldots(1)$$

The conventional Ohmic contact formation involves deposition of a contact metal on GaAs and subsequent annealing at elevated temperatures (which enhances the chemical reaction between the metals and GaAs) to reduce the electrical voltage drop at the contact metal and GaAs interface **.(Masanori Murakami 2002)**

The chemical reaction at interface involved the process parameters i.e. metal selection, annealing temperature, time and atmosphere, these parameters are related to an ideal interfacial microstructure, which could not be determined on the basis of existing thermodynamic and diffusion data **.(V. L. Rideout 1975)**

Thin interfacial layers also affect contact formation. Most metal-semiconductor contacts are annealed or alloyed after the initial deposition of the metal in an effort to further improve the contact resistivity**.(B. Van Zeghbroeck 2007)**

The I-V characteristics were analyzed using thermionic emission theory The relationship between the current and the applied forward voltage is given by the following equation (2): **(S. M. Sze 1981)**

$$I=SA^*T^2 \exp[- q\Phi_{Bn} / kT] \text{ x } \exp[(qV / nkT) – 1] \ldots\ldots(2)$$

in which S is the contact area A is the effective Richardson constant (8.64 $A/cm^2 K^2$)for n-GaAs , k is the Boltzmann constant, T is the temperature in K, and (n) is the ideality factor , the ideality factor must be close to 1 to assure that thermionic emission is the dominant transport mechanism and Φ_{Bn} is (SBH) and we can find it from the equation (3) and the ideality factor from equation (4) **(S. M. Sze 1981, C.P. Chen1994)**

$$\Phi_{Bn}= (KT/q) \ln (A^*T^2 /I) \ldots\ldots\ldots(3)$$

$$n=q / KT [dv/d(\ln I)] \ldots\ldots\ldots(4)$$

Experimental Result and discussion

The samples had been prepared by using GaAs (n-type) with Electron affinity (4.07eV) as a semiconductor substrate and we choose the (Ni) with work function (5.01 eV) and (Al) with (4.13 eV) .**(Gerhard Lutz 1999)** as Schottky contact and ohmic contact for different samples .

First we cleaned the GaAs substrate by using $NH_4OH:H_2O$ (1:2) for (2 min) **(C.P. Chen* 1994)** and then by water for (5 min) then we made the ohmic contact with (Al) for two samples and(Ni) for other two samples with (5000 Å) and the specific contact resistance is calculated by equation (1) and it depends on (SBH) and temperature for both Ohmic and Schottky contact, then we annealed the samples under a vacuum pressure of the order (10^{-4} Torr) and (450 K) for 30 min. to get good Ohmic contact and small contact resistance ,(12) after that we made the Schottky contact with (Ni) for two samples and (Al) for other two samples with (120 Å) thickness **(C.P. Chen* 1994)** after that we annealed the samples under (450 K) and (10^{-4} Torr) pressure in vacuum for (30 min) to avoid the interfacial layer effect for the (SBH) because we presumed that oxygen play an important role in forming Schottky barrier and the Ohmic contacts **. (Otsubo M 2004)**

Table (1) show the I-V properties we calculated for the samples

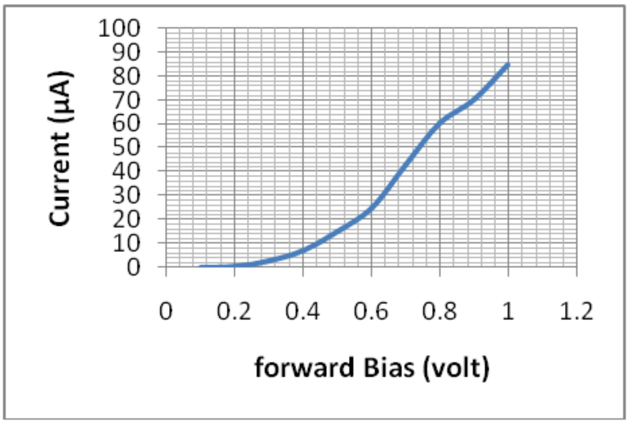
samples	I_o (Ampere)	Φ_{Bn} (eV)	Ideality factor(n)	Rc (Ohm.cm^2)
Al-GaAs(Al Ohmic)	7×10^{-7}	0.72	1.08	3.54×10^{-5}
Al-GaAs(Ni Ohmic)	3×10^{-7}	0.74	1.30	3.64×10^{-5}
Ni-GaAs(Al Ohmic)	1.5×10^{-7}	0.76	1.47	3.74×10^{-5}
Ni-GaAs(Ni Ohmic)	3×10^{-8}	0.80	1.63	3.94×10^{-5}

From Figs.(2,3,4,5) the current - voltage (I-V) method were investigated and the saturation current for the samples calculated as shown in table (1) and we found that the (SBH) for(1st & 2nd) samples fig(2,3) the Schottky contact with (Al) was attributed to deep levels existing in the GaAs substrate the (Ga,Al)As phase formed at the interface and the enhancement of the (SBH) was due to the formation of this phase **(C. P. Chen 1994)** and no effect for the work function and for the (3rd and 4th) samples fig(4,5) the Schottky contact with (Ni) is effected with metal work function and a little effect founded for interfacial layers , the I-V characteristics at dark are important parameter to identify the significance of the various components under reveres and forward bias , the forward bias current can be divided into two distinct regions:

1- The low voltage region :
 The recombination current dominate at low bias voltage this current is developed the number of product of generated majority ,minority charge carriers are greater than that of the square intrinsic carrier ,to reach the equilibrium there is recombination.
2- The high voltage region :
 The diffusion current in the forward bias dominates for bias value.

The contact resistance for all the samples shows that the clean process is good enough to make an almost equal contact resistance to ensure that Schottky barrier are not created accidentally. .**(Mc Graw 2005 , R. V. Ghita 2005)**

From fig. (6) we can see the relation between the (SBH) and (n) , when the (SBH) is low (0.72 eV) for the 1st sample the ideality factor is close to 1 this assure that thermionic emission is the dominant transport mechanism and for the 2nd sample almost the same thing happen , but for the 3rd and 4th sample the ideality factor is between the (1-2) this means that both generation and thermionic emission are close to be the dominant transport mechanism **(S. M. Sze 1981)**



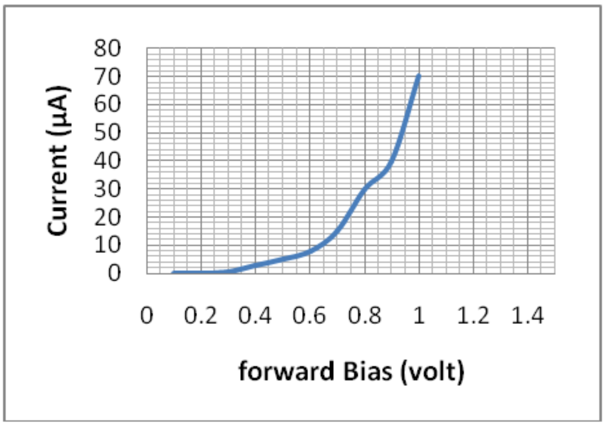
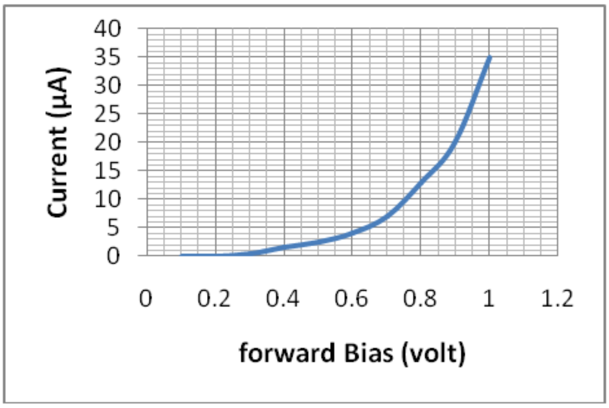


Fig (2)Al-GaAs (Al Ohmic) ***Fig (3)Al-GaAs (Ni Ohmic)***



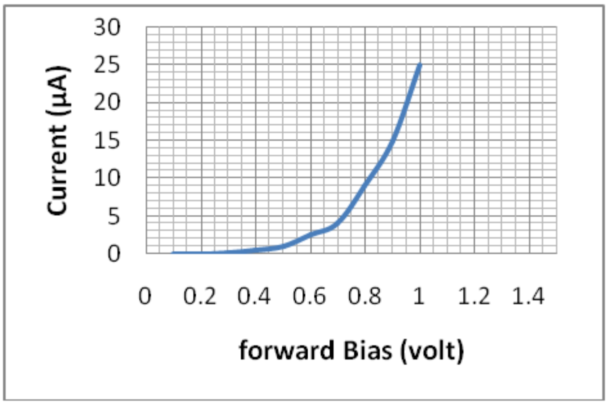
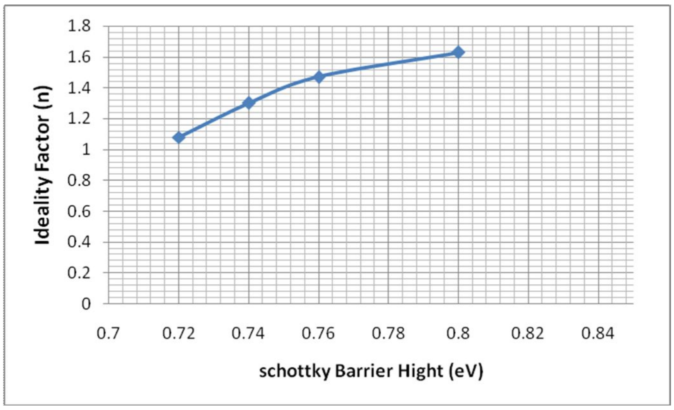


Fig (4)Ni-GaAs (Al Ohmic) ***Fig (5)Ni-GaAs (Ni Ohmic)***



Fig(6) shows the relation between (SBH) and (n) at room temperature

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