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Ir-Al BIMETALLIC SCHOTTKY CONTACT SYSTEMS ON GaAs

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We report on novel Ir-Al/GaAs Schottky contact systems based on sequentially evaporated Ir-Al bimetallic multilayers. Electrical and thermal stability of these contact systems are investigated by $I-V$ measurements and Auger depth profiling method. An increase of the barrier height with annealing temperature has been indicated for all Schottky contacts. A model of the barrier height enhancement based on a solid phase epitaxy of a graded $Al_xGa_{1-x}As$ layer at the interface at elevated temperatures was used to explain the electrical and the thermal stability of the contacts. A method of controlling of the barrier height and of the thermal stability of the Ir-Al/n-GaAs interface is proposed.

1. Introduction

Electrical and thermal stability of metal/n-GaAs Schottky gate contacts has motivated several groups of investigators to design novel contact systems and novel models of the interfaces. Schottky gate contacts on GaAs with an enhanced barrier height and high thermal stability are required for devices based on heterostructures (heterostructure field effect transistor – HFET) and self–aligned gate FET technology (SAG – FET). Attention is now directed toward aluminum based metallic compounds. M-Al/n-GaAs contact systems, where M stands for Ni [1], Co [2], Pt [3] and Mo [4,5] appear to be potential candidates for gate contacts in these devices. Some of these contact systems [2-5] are expected to replace contact systems based on refractory metal silicides and nitrides generally used in SAG-FET technology [6].

The M-Al/n-GaAs contact systems are interesting because of the effect of a significant barrier height enhancement that is observed after high temperature annealing [1,2,4,5,7]. The barrier height enhancement is attributed to the formation of a graded $Al_xGa_{1-x}As$ layer at the M-Al/GaAs interface as a consequence of an Al-Ga exchange reaction at elevated temperatures. It can be explained by the larger energy band gap of $Al_xGa_{1-x}As$ than that of GaAs and the same pinning positions of the Fermi level at the metal/semiconductor interface.

Another attractive property of M-Al/n-GaAs contact systems is the high thermal stability of the Schottky barriers which correlates with a metallurgically stable and laterally uniform interface. Based on thermodynamic considerations, the excellent thermal stability of the contact systems could be attributed to the metallurgical stability of M-Al alloys because of the higher heats of formation of M-Al compounds compared with those of M-Ga and M-As [5].

However, the thermal stability of M-Al/n-GaAs Schottky contacts considerably depends on the deposition technique [2], relative composition of M-Al metallization [3,5] and annealing conditions [2,5].

We have already reported on the advantages of an Ir-Al/n-GaAs bimetallic contact system as a stable high barrier Schottky contact [7], compared to that of a single Ir/n-GaAs.

In this paper, following our previous results [7], we report on a method of controlling of the barrier height and of the thermal stability of the Ir-Al/n-GaAs Schottky diodes by applying a novel Ir-Al bimetallic multilayer contact system. Electical and thermal stability of the Schottky diodes is investigated by the $I-V$ measurements and the Auger electron spectroscopy (AES). The model contributions to the formation of the high barrier and thermally stable Ir-Al/n-GaAs Schottky diodes are discussed.

2. *Experimental*

The GaAs wafers were (100) oriented, n-type, with Si dopant concentration of 7×10^{16} cm^{-3}. The samples were degreased in boiling trichloroethylene, acetone and isopropylalcohol for 5 min in each. Prior to deposition, the damaged surface layer was removed by etching in a sulphuric acid based solution. Nine circular Schottky contacts with various diameters (d = 40–80 μm) were patterned using the lift-off technique. Before loading into a cryopumped evaporation system with a dual electron gun, the samples were dipped into 1 NH_4OH:10 H_2O solution for

1 min in order to remove the surface native oxide. The multilayer films of iridium and aluminum were deposited by sequential electron beam evaporation.

Three different Ir-Al/nGaAs multilayer contact systems (S1, S2 and S3) were deposited with six periods of Ir/Al. The total thicknees of Ir-Al multilayers was about 60 nm. Next, a 10 nm thick Ir layer was deposited as a cap layer. The first Schottky layer in contact with GaAs was made in three ways. A 3 nm thick Ir layer was deposited as the first layer on the interface of the contact system S1, while for that of S2 the thickness of the first Ir interface layer was approximatelly 1 nm. The deposition for the contact system S3 was started with a 3 nm thick Al interface layer. The pressure in the vacuum chamber during electron beam evaporation of Ir and Al was lower than 10^{-5} Pa. The deposition rate was 10^{-8} cm/s. Capless RTA of Ir-Al/n-GaAs contact systems was carried out under local As overpressure in the tempereture range from 450 °C up to 950 °C for 10 s. Backside alloyed ohmic contacts were formed by a sequential evaporation of a Ni-AuGe-Ni metallization followed by RTA in a pure hydrogen atmosphere at 450 °C for 30 s.

Basic electrical properties of the Ir-Al/n-GaAs Schottky diodes based on the contact systems S1, S2 and S3, before and after annealing, were derived from forward $I - V$ characteristics. The barier height, the ideality factor n, the series resistance R_S and the leakage resistance R_L were determined using a computer fitting method. Thermionic emission was assumed to be the dominant mechanism of current transport in our model.

AES in combination with Ar^+ ion sputtering was applied to analyse the composition depth profiles and the thermal stability of the interfaces.

3. Results

3.1. Electrical characterization

Excellent agreement of the $I-V$ curves of the Ir–Al/n–GaAs diodes with a computer simulation was observed in both directions after each annealing temperature. The derived barrier height and ideality factor values of the Schottky diodes after RTA are plotted in Fig. 1 as functions of the annealing temperature. Also plotted are the values which correspond to the alloying temperature of ohmic contacts (450 °C for 30 s).

A slight increase of the barrier height with annealing temperature for Schottky diode based on contact system S1 can be seen. The diode exhibits an excellent thermal stability with low ideality factors up to 950 °C. The diode annealled at 900 °C has an ideality factor approximatelly 1.08 and a barrier height of 0.88 V. The barrier height enhancement was determined to be 100 mV with respect to the diode annealed at 450 °C.

A steeper increase of the barrier height with the annealing temperature was observed for Schottky diode on the contact system S2. The Schottky diode is thermally stable up to 800 °C. The diode annealed at 800 °C achieved the barrier height as high as 0.95 V with an ideality factor value of 1.1. The barrier height enhancement was found to be 200 mV with respect to the diode annealed at temperature of the ohmic-contact alloying. A very sharp increase of the barrier height corresponding to the narrow range of annealing temperatures (450–600 °C) was achieved for annealed Schottky diode based on the system S3. The highest barrier height (0.95 V) with low ideality factor (1.11) of the diode annealed at 600 °C is comparable to that of S2 annealed at 800 °C. However, the diode deteriorated at annealing temperatures higher than 650 °C, when an ohmic-like current transport mechanism was observed.

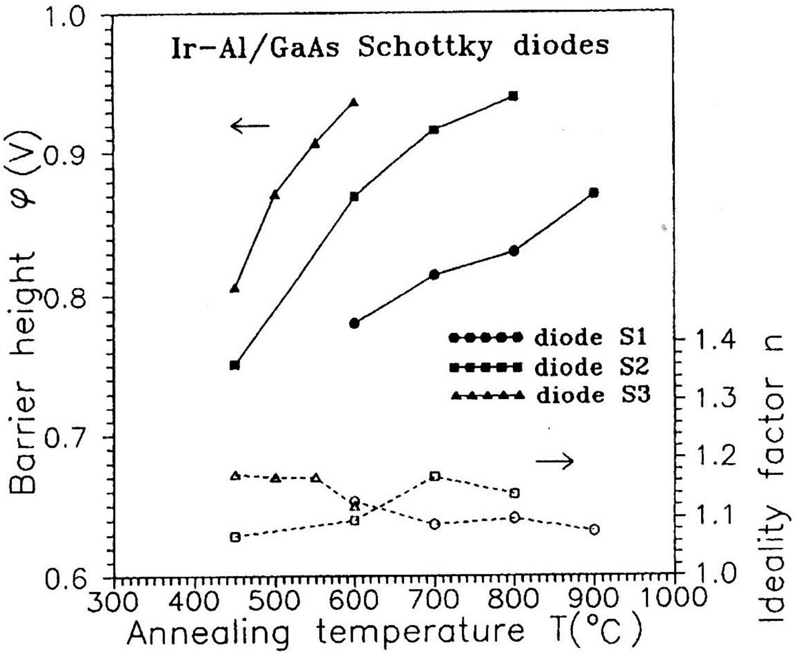

Fig. 1. Variations of barrier heights and ideality factors of the Ir-Al/n-GaAs *Schottky diodes as functions of annealing temperatures.*

3.2. Interface stability

The excellent electrical stability of the Schottky diode of type S1 has been confirmed by investigating the thermal stability of the Ir-Al/n-Ga As interface using the AES depth profiling. The AES depth profiles of the interfaces annealed at 450, 800 and 900 ° C are shown in Fig. 2. It can be seen that the interfaces between the contact system (S1) and GaAs substrate are quite sharp and no significant effect of in-diffusion or out-diffusion is indicated. The relative composition of the atomic ratio of Ir/Al is approximately 3:1 (25 at % of Al) and remains stable during high temperature annealing.

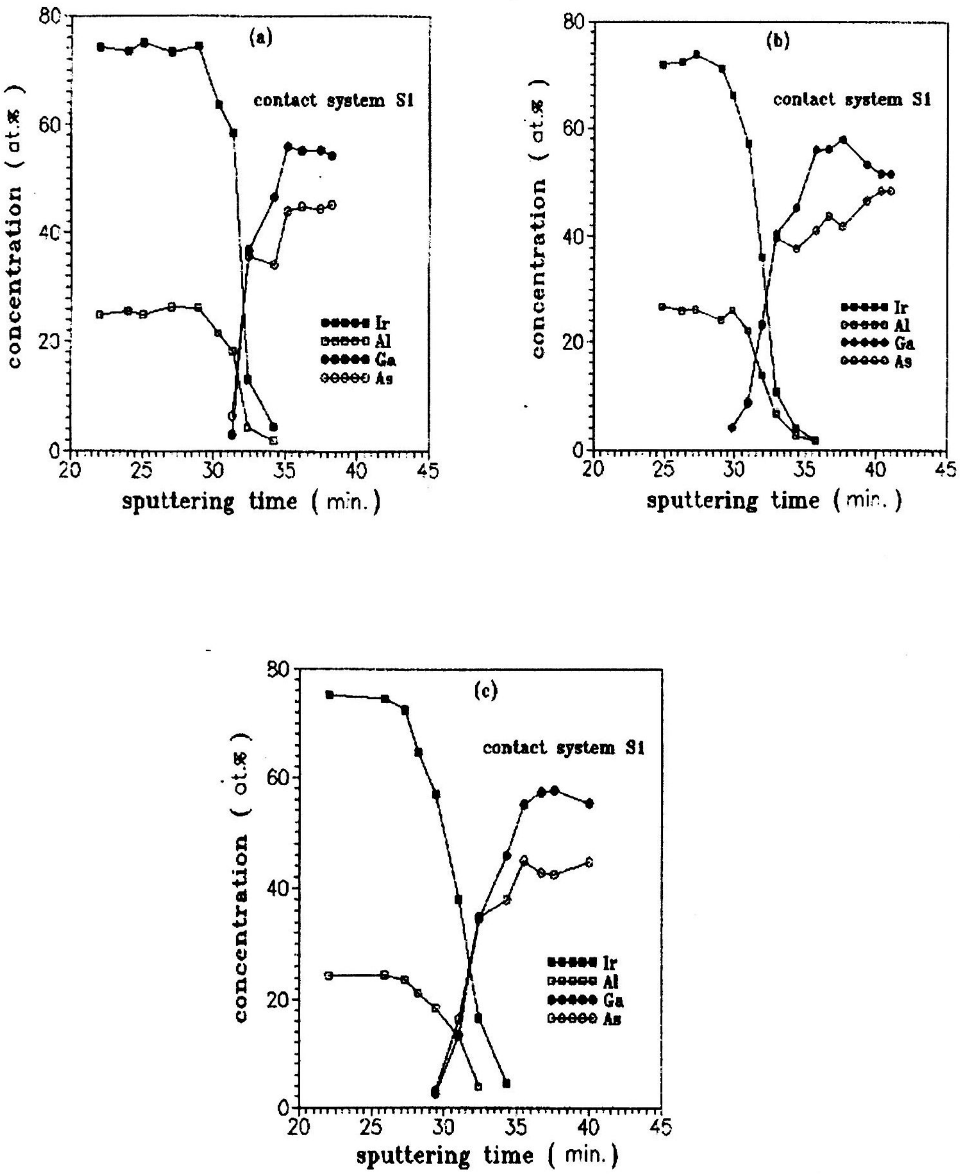

Fig. 2. The Auger depth profiles of Ir-Al/n-GaAs interface after annealing for 10 s (a) at 450 °C, *(b) at 800* °C *and (c) at 950* °C.

4. *Discussion*

It is worth noting that for all Ir-Al/n-GaAs Schottky diodes the barrier height increased with the annealing temperature in agreement with those of NiAl/n-GaAs [1] and MoAl/n-GaAs [4,5]. Therefore, it is possible to consider a generally accepted model of the barrier height enhancement based on the formation of a graded $Al_xGa_{1-x}As$ layer at M-Al/GaAs interfaces [1,2,4,5,7]. Since the formation of an interfacial $Al_xGa_{1-x}As$ layer should be a result of exchange reaction of Al and Ga by interdiffusion between Ir-Al multilayers and GaAs substrate, the barrier height enhancement should depend on the annealing time and the temperature, as well as on primary metallurgical microstructure of the interface.

It is shown that in the Schottky diodes based on sequentially evaporated Ir/Al multilayers, the process of exchange reactions is controlled by the first interfacial layer in contact with GaAs.

If at the interface in contact with GaAs a relatively thick Ir layer is deposited first (diode S1), the exchange reactions are slowed down, and, as a consequence, very slight increase of the barrier height with annealing temperature is indicated. That is why the maximum value of the barrier height (0.88 V) is limited by the lower Al content of the interfacial $Al_xGa_{1-x}As$ layer.

If the first Ir interfacial layer is sufficiently thin, the Al-Ga exchange reactions at the interface are accelerated and the formation of the $Al_xGa_{1-x}As$ layer should occur at lower annealing temperatures. That is the case of the Schottky diode S2 (Fig. 1). The temperature of approximately 800 °C is sufficiently high for a formation of a highly Al-rich compound semiconductor at the interface which seems to cause the Schottky barrier enhancement (0.95 V).

The extent of the exchange reactions at the interface is expected to be more extensive when Al is in an intimate contact with GaAs (diode S3). A graded $Al_xGa_{1-x}As$ interfacial layer with the same high Al-content as for the diode S2 can be formed, but already at relatively low annealing temperature (600 °C). This optimal annealing temperature is 100 °C higher than for sputtered Al/GaAs Schottky diodes [8], so Schottky diode S3 should be more stable. It should be noted that the temperature (600 °C) is close to the melting point of aluminium (660 °C). That is why the Schottky diode S3 degrades at annealing temperatures higher than 600 °C, i.e. probably due to a generation of point and extended defects either at the interface or within the bulk of GaAs [8].

5. *Conclusion*

We have proposed novel Ir-Al/n-GaAs bimetallic contact systems which allow control both of the barrier height and the thermal stability of the interfaces by controlling the interdiffusion exchange reactions between GaAs and Ir-Al bimetallic multilayers during the high temperature annealing. The Schottky diodes based on these contact systems exhibited an increase of the barrer height with annealing temperature. The barrier heights as high as 0.95 V were measured for the Schottky diodes with the first interfacial layer in contact with GaAs of aluminum or very thin iridium. The model of the barrier height enhancement based on a solid phase epitaxy of a graded $Al_xGa_{1-x}As$ layer at the interface at elevated temperatures was considered to explain the electrical properties and the thermal stability of the diodes. The excellent electrical stability up to 950 °C of the diode S1 was confirmed by investigating the thermal stability of the Ir-Al/n-GaAs interface using the AES depth profiling method.

The proposed method of controlling the Al-Ga exchange reactions at the Ir-Al/n-GaAs interface is of great technological importance since the reactions can, in principle, be used to fabricate $M/Al_xGa_{1-x}As/GaAs$ heterojunction Schottky diodes with the required barrier height and thermal stability of interface. Besides, the heterojunction Schottky barriers are favourable for high temperature operation of GaAs based FETs [9].

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BIMETALNI Ir-Al SCHOTTKYJEVI SPOJEVI NA GaAs

Opisuju se novi Ir-Al/GaAs Schottkyjevi spojevi dobiveni uzastopnim naparavanjem Ir-Al bimetalnih slojeva. Električna i toplinska stabilnost spojeva ispituje se $I - V$ mjerenjima i Augerovim dubinskim profiliranjem. Opaženo je povećanje barijere s povećanjem temperature otpuštanja. Za objašnjenje električne i toplinske stabilnosti spojeva, primijenjen je model povećanja barijere zasnovan na čvrstofaznoj epitaksiji $Al_xGa_{1-x}As$ sloja na granici spoja. Predložen je model upravljanja visinom barijere i toplinske stabilnosti granice Ir-Al/n-GaAs.