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Thermally Stable Schottky Contact to n-GaAs Using W-Al Alloy and Al/W Two Layer Metal

Hazime Matsuura, Hiroshi Nakamura, Toshimasa Ishida and Katsuzo Kaminishi

Research Laboratory, OKI Electric Industry Co.,Ltd.

550-5, Higashiasakawa, Hachioji, Tokyo 193

Sputter-deposited W-Al alloy and Al/W two layer metal were found to be low resistive and suitable to the thermally stable refractory gate metal for GaAs MESFET. The resistivities of 1000 Å thick films were 42 and 18 μΩcm for W-Al alloy(1.7 at % Al) and Al/W film with 20 Å Al thickness, respectively. The barrier heights of Schottky contacts using the W-Al alloy and the Al/W film were 0.76 and 0.78 V, respectively, and were higher than that of W film (0.72 V).

§1. Introduction

To realize high speed GaAs LSI's, self-alignment device technologies, such as the refractory metal gate technology[1,2], the SAINT[3] and the closely spaced electrode technology[4], are indispensable and have been applied to the fabrication of memory or multiplier.

Among them, the self-alignment process with a refractory metal gate is very attractive for simplicity of FET structure and its process. In this process, the activation of implanted n^+ ions (source and drain regions) is done after the formation of metal gate. So the key point of this process is the choice of gate metal, which must maintain good Schottky contact to n-GaAs even after the annealing at above 800°C. Moreover, to reduce the gate resistance, the Schottky metal with low resistivity and high adhesion to GaAs is preferable.

Recently, many kinds of refractory Shottky metals, for example, TiW[2], TiWSi [2], WSi_x[5] and WN[6], have been reported. Among them, WSi_x seems to be the attractive metal as a thermally stable Shottky gate, however, it has fairly large resistivity. On the other hand, the thermal stability of sputter-deposited W film Schottky contact was said to be poor[7], whereas, EB-evaporated W film[8] was reported to have good thermal stability up to 950°C. However, the formatiom of Schottky contact using EB-W film is very difficult.

We reported previously that a sputter-deposited W film containing small amount of Al atoms showed high thermal stability as Schottky metal and low resistivity, and that it was successfully applied to the fabrication of self-aligned MESFET's[9].

In present study, it was found that a sputter-deposited W film formed under adequate conditions showed fairly good Schottky property after 800°C annealing and furthermore that the Schottky contact with more excellently thermal stability was able to be realized by using (thin Al)/W two layer metal.

In this paper, we show detailed results of the thermal stability of W, W-Al alloy and Al/W two layer metal Schottky contact to n-GaAs and discuss what is the best way to make the thermally stable Schottky contacts using W and Al metal.

§2. Experiment

(2-1). Measurements of Schottky contact

Thermal stabilities of Schottky contact were investigated by forward I-V measurements. The barrier heights $\phi_b(V)$ and the ideal factors n were estimated from the intercept I_0 and the slope, respectively, of the log I_f versus V_f plots : $\phi_b = (kT/q)\ \ln\ (7.34\times10^5\ S/I_0)$, $n = (q/kT)\ \partial V_f / \partial(\ln I_f)$, where S is the area of the Schottky contact and an effective Richardson constant of 8.16 A $cm^{-2}K^{-2}$ is used for n-GaAs.

(2-2). Fabrication of Schottky contact

Films of W, W-Al alloy and Al/W metals were deposited on n-GaAs ($2x10^{17}cm^{-3}$) substrates by using planar magnetron sputtering system. Clean vacuum (less than $5x10^{-7}$Torr) was achieved by cryo-pump. W-Al alloys were obtained from co-sputtering of W-plate (6-inch ϕ) and Al-wire (1mm ϕ). Al concentrations of W-Al alloys could be varied by using Al-wire of different length. Substrate temperature was 150°C and deposition rate was 500 Å/min. Al/W two layer metals were prepared by sequential sputter-deposition of Al and W metals. The deposition rate of Al was 400 Å/min. Metals on GaAs substrates were patterned to 80x100 μm^2 areas by plasma etching. The samples were annealed at various temperatures for 15 min in Ar atomosphere. P-CVD SiN_x films were used as passivation films for annealing.

§ 3. Results

The characteristics of Schottky contact to n-GaAs largely depend on a lot of factors, for example, sputtering conditions, surface treatments of GaAs substrate, annealing process and so on.

First, the Al concentration of W-Al alloy films deposited by co-sputtering of W-plate and Al-wire is shown in Fig. 1. The assays of W-Al alloys were investigated by EPMA. It is found in this figure that the concentration of Al in W-Al alloys can be determined arbitrarily by the length of Al-wire. The reproducibility and the uniformity of Al concentrations also depended on the Al concentration and for W-Al alloy with more than 1 at % Al, the deviation of them were less than 10%.

The I-V propeties of W, W-Al alloy (1.7 at % Al) and Al(20 Å)/W two layer metal Schottky contact after annealing at 800°C are shown in Fig. 2. In these cases, the Schottky contacts are well behaved with n close to 1.0 . The barrier heights of W, W-Al alloy and Al/W Schottky contact were 0.72, 0.76 and 0.78 V, respectively. The reverse I-V properties were also improved and it is seemed that the existence of Al atoms at the interface of GaAs makes the Schottky property better.

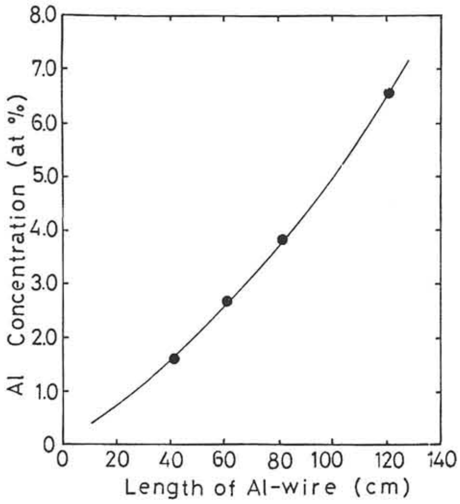

Fig.1 Al concentration of W-Al alloy versus length of Al-wire.

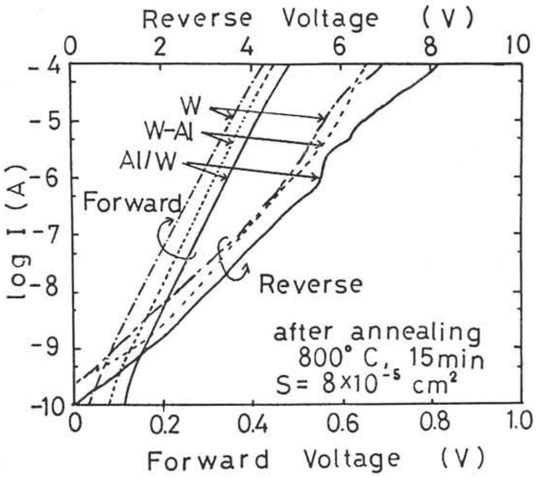

Fig.2 I-V property of W, W-Al alloy (1.7 at % Al) and Al(20 Å)/W Schottky contact to n-GaAs after 800°C annealing.

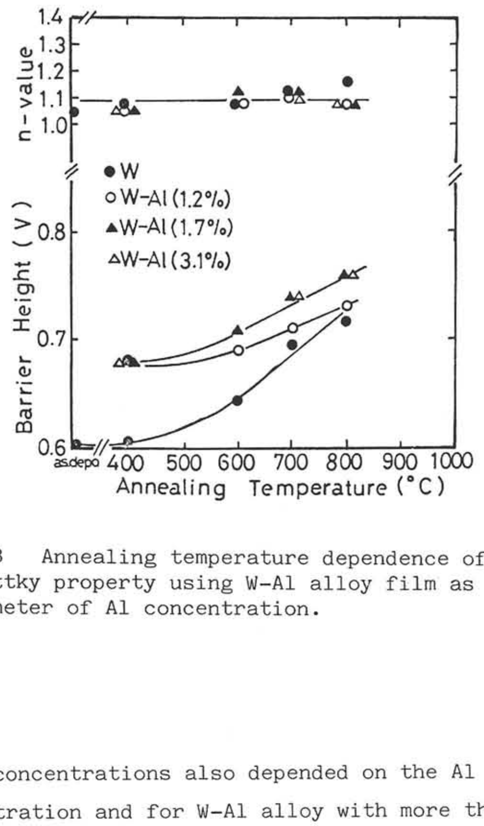

Fig.3 Annealing temperature dependence of the Schottky property using W-Al alloy film as the parameter of Al concentration.

Figure 3 shows the annealing temperature dependence of W-Al alloy Schottky properties as the parameter of Al concentration. In this figure, the barrier height slightly increases with Al concentration but n-values are almost constant and remain as small as 1.07± 0.04 .

Figure 4 shows the annealing temperature dependence of Al/W Schottky properties with 20 and 40 Å Al thickness. The n-values are as small as 1.10±0.05 up to 900°C. The barrier heights of Al/W film with 20 Å Al thickness are 0.73 and 0.78 V for the as-depo and 800°C annealed film, respectively. Its difference is 0.05 V and is much smaller than that of W (0.12 V) and W-Al (1.7 at % Al : 0.09 V). The barrier height of Al/W film with 40 Å Al thickness is lower than that with 20 Å Al thickness, and so it is found that the thin Al film with the thickness of about 20 Å is neccessary to get more thermally stable Schottky contact.

Figure 5 shows the resistivity of W-Al alloy films with about 1000 Å thickness. The resistivity of alloys linearly increases with Al concentration. That of W-Al alloy with 1.7 at % Al is only 42 μΩcm which is far lower than that of WSi_x film (200 μΩcm The resistivity of Al/W films is 15~20 μΩcm and is close to that of pure W film (12±2 μΩcm). The difference in resistivity between Al/W and W film is thought to be related to the alloying of W and Al metal near the GaAs surface. The temperature dependences of the resistivity of these metals were very weak and the small reduction of 10 % was observed after 800°C annealing.

Table 1 shows the comparison of the barrier height, n-value and resistivity among W, W-Al alloy and Al/W Schottky metals. As for the n-value, these metals are quite thermally stable and almost independent on annealing temperature up to 800°C.

	Schottky property[a]		resistivity[b]
	ϕ_b (V)	n-value	(μΩ·cm)
W	0.72±0.02	1.16±0.03	12±2
W-Al (1.7 %)	0.76±0.02	1.08±0.03	42±3
Al/W (Al 20Å)	0.78±0.03	1.09±0.05	18±3

a: after 800°C annealing
b: as-depo.

Table 1 Schottky properties and resistivities of W, W-Al alloy (1.7 at % Al) and Al(20 Å)/W film with about 1000 Å thickness.

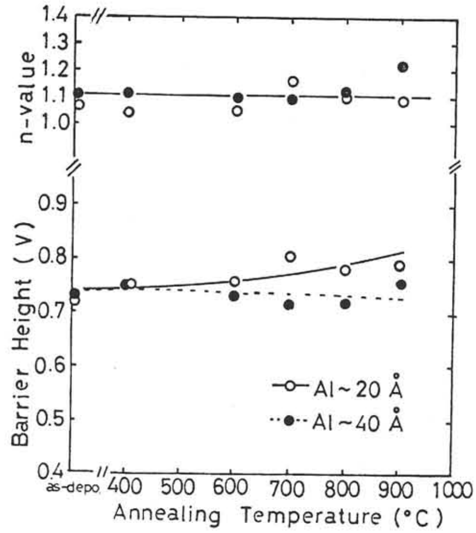

Fig.4 Annealing temperature dependence of the Schottky property using Al/W two layer metal as the parameter of Al thickness.

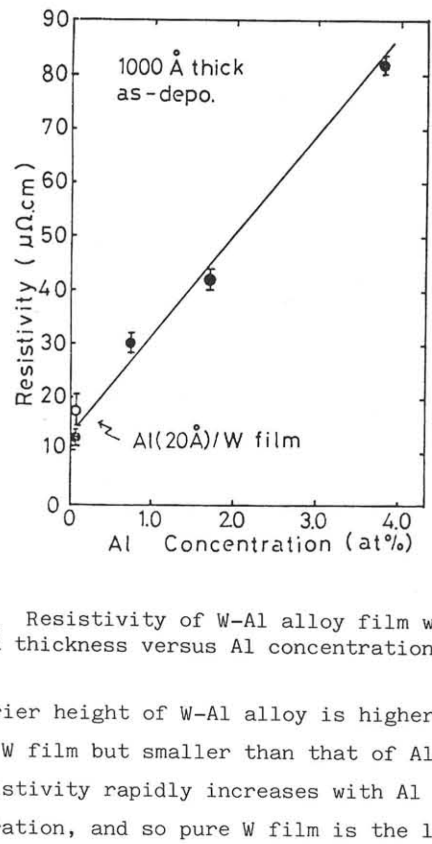

Fig.5 Resistivity of W-Al alloy film with 1000 Å thickness versus Al concentration.

The barrier height of W-Al alloy is higher than that of W film but smaller than that of Al/W film. The resistivity rapidly increases with Al concentration, and so pure W film is the lowest resistive.

Alloying W with Al metal was seemed to be effective to improve the adhesion to GaAs substrate. Although peeling-off of W film with more than 4000 Å thickness occured by boiling in HCl solution, it was not found in case of W-Al alloy with the same thickness. In case of Al/W films, peeling-off or shrinking of the metal film was found to depend on Al film thickness. These problems did not occur at all for Al/W film less than 40 Å Al thickness but was found for that with more than 80 Å Al thickness.

§ 4. Discussion

The barrier height of Al/W-GaAs Schottky contact (0.78 V) is higher than that of EB-deposited W film (0.73 V) and close to that of Al-GaAs Schottky contact reported in elsewhere(0.80~0.82 V)[10]. It is thought that the increase of barrier height is due to the partial formation of Al-GaAs Schottky contact.

From above experimental results, the following characteristics are concluded in W-GaAs Schottky contacts.

1). The n-values are almost independent on annealing temperature and remain the value of 1.07~1.10 .

2). The barrier heights slightly increase with annealing temperature.

3). Al atoms at the interface of GaAs increase the barrier heights.

In general, the barrier heights of metal-semiconductor Schottky contact are determined by the metal work function and the surface states. The influence of the surface states is seemed to be very significant especially for as-depo W films. However, the increase of annealing temperature or the introduction of Al at the interface of GaAs raise the barrier height of W-GaAs Schottky contacts, and it is thought to be very effective to reduce the influence of the surface states.

In view of Schottky barrier height and resistivity, Al/W film is thought to be the most excellent among them. However, the thickness controllability of thin Al film (20 Å) by sputter-deposition is fairly difficult and the problems of the reproducibility and the uniformity have been remained. The Schottky property of Al/W film was very sensitive to the Al deposition rate and the thermal stability of Schottky contact fabricated under low deposition rate degraded with increasing annealing temperature. So these problems can not be resolved by only lowering Al deposition rate. As for the W-Al alloy and pure W films, such problems do not occur but have disadvantage of relatively high resistivity or low barrier height. Although the W-Al alloy, which we usually use as refractory Schottky metal, is the most reproducible now, it is believed that Al/W two layer metal would be hopeful for the fabrication of GaAs MESFET's, if the deposition technique is improved.

§ 5. Conclusion

W-GaAs Schottky contacts with small amount of Al atoms at the interface of GaAs are more excellent than that of pure W film and show ideal properties even after annealing at above 800°C. By using sputter-deposited W-Al alloy and Al/W film with highly thermal stability and low resistivity, the simple and reproducible fabrication process of GaAs MESFET's will be improved.

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