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# Effect of Bias Sputtering on W and W-Al Schottky Contact Formation and Its Application to GaAs MESFETs

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We investigated the effect of DC bias on the sputter-deposition of W and W-Al on the GaAs substrates. By applying a negative bias to the substrate, we found that the concentration of impurities in the metal and at the interface were reduced, and the characteristics of the Schottky contact were improved with respect to the barrier height, the n-value and the uniformity, which was due to the reverse sputtering effect on the substrate.

This technique was applied to the gate formation of GaAs MESFETs, and the uniformity of the threshold voltage within a 2 inch wafer was much improved.

## 1. Introduction

The $n^+$ self-aligned GaAs MESFET with a refractory gate is suitable for the large scale integration, and W or its compound has been used for the gate metal. We previously reported that the Schottky contact of W-Al (0.8 atom% Al) on GaAs[1)2)] is thermally stable and that the barrier height is higher than that of W and the resistivity of W-Al is lower than that of $WSi_x$[3)] or $WN_x$[4)].

To obtain the good Schottky contact by such a refractory gate metal, it is quite important to reduce the surface oxide before sputtering, and various kinds of surface preparation, such as HCl treatment, have been reported.[5)]

In this paper, we applied the bias sputtering, which is known to reduce the impurity concentration of the film,[6)] for the formation of W and W-Al films on GaAs, for the first time, then observed that it was a very powerful technique to improve the Schottky characteristics.

## 2. Experimental

W or W-Al was deposited on n-GaAs substrates ($n \sim 3\times10^{17}cm^{-3}$) by a DC magnetron sputtering system. The system was evacuated to less than $4\times10^{-7}$Torr before the sputtering. Ar gas pressure was 5mTorr, the power was 230W, the size of the target was 6inches in diameter and the substrate temperature was 150℃. DC bias voltage in the range of -100V~+100V was applied to the substrate. Then the samples were annealed at 800℃ for 20min in $AsH_3$ atmosphere. The barrier height ($\phi_B$) and the value of ideality factor (n-value) were obtained from the Schottky I-V measurement before and after the annealing.

## 3. Results and Discussion

### 3.1 Bias sputtering of W and W-Al

We first studied the Schottky contact of W on n-GaAs substrate. Figure 1 shows the dependences of the barrier height and the n-value on the bias voltage before and after the annealing. As the positive bias increased, the barrier height increased, but the n-value did not change. On the contrary, as the negative bias increased, the barrier height increased and the n-value decreased. It is clear that the Schottky characteristics were improved by the negative bias. Figure 2 shows the dependence of the resistivity of W on the bias voltage. The resistivity decreased with the negative bias increased, and decreased by 20~30% at -100V. Sputtering rate of W was almost the same in the range of the bias voltage applied here. It means that the improvement of the Schottky characteristics was not related to the sputtering rate, but related to the effect of the bias voltage.

Similar results were obtained in the case of W-Al. As the negative bias increased, the barrier height increased and the n-value decreased as shown in Figure 3, and the resistivity of W-Al decreased. We investigated Al content of W-Al using Electron Probe X-ray Micro Analysis (EPMA), and found that the Al content was the same regardless of the negative bias. Therefore, it is clear that the improvement of the Schottky characteristics was caused only by the effect of the bias voltage.

To study the effect of the DC bias on the decrease of the resistivity of W and W-Al, we performed SIMS measurement of W-Al/GaAs for the bias voltages of 0, +100 and

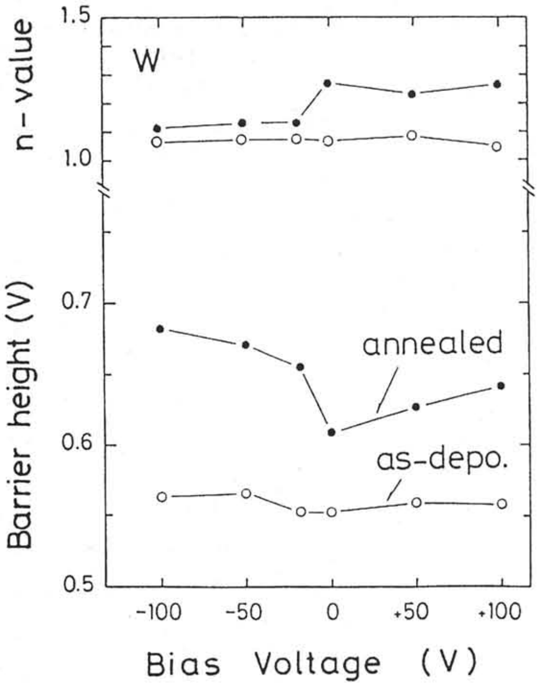


Fig.1 The dependences of the barrier height and the n-value of W on the bias voltage before and after the annealing.

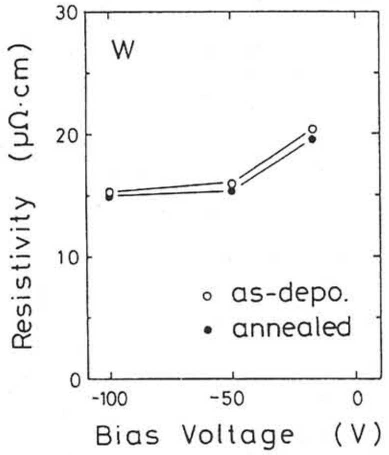


Fig.2 The dependence of the resistivity of W on the bias voltage before and after the annealing.

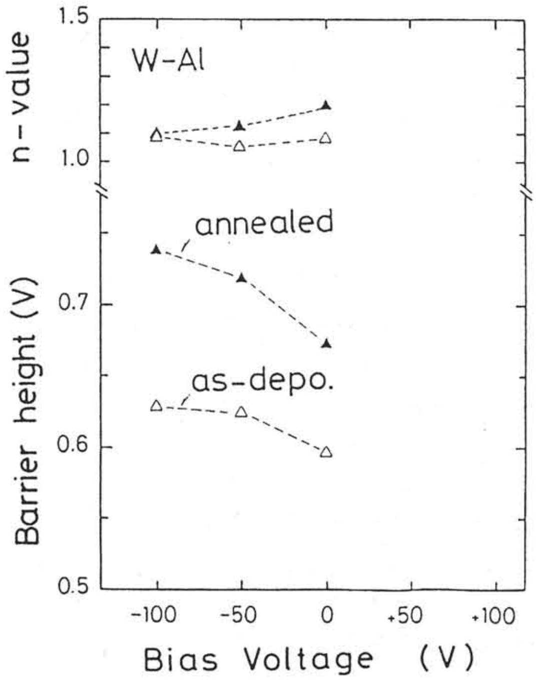


Fig.3 The dependences of the barrier height and the n-value of W-Al on the bias voltage before and after the annealing.

-100V as shown in Figure 4. It was confirmed that the oxygen concentration, as shown by AlO, was reduced only in the case of -100V. The reduction of the concentration of other impurities, such as carbon, was also observed.

The reduction of the impurity concentration can be explained as schematically shown in Figure 5. By the negative bias voltage applied to the substrate, a part of $Ar^+$ strikes the substrate ("reverse sputtering effect") and sputters out the impurities adsorbed on the substrate, which results in the reduction of the impurity concentration. Besides the "reverse sputtering effect", the electro static effect has to be taken into account. Namely the negative bias voltage forces the negative impurity ion ($Y^-$) to be moved from the substrate.

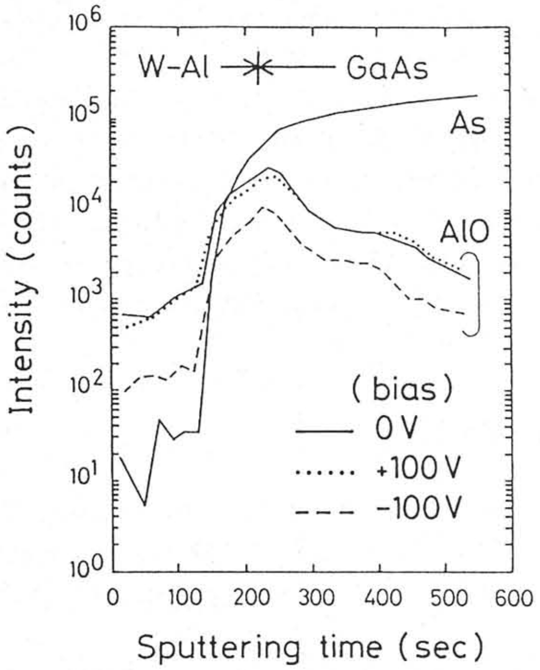


Fig.4 SIMS profiles of W-Al/GaAs for the bias voltages of 0, +100 and -100V.

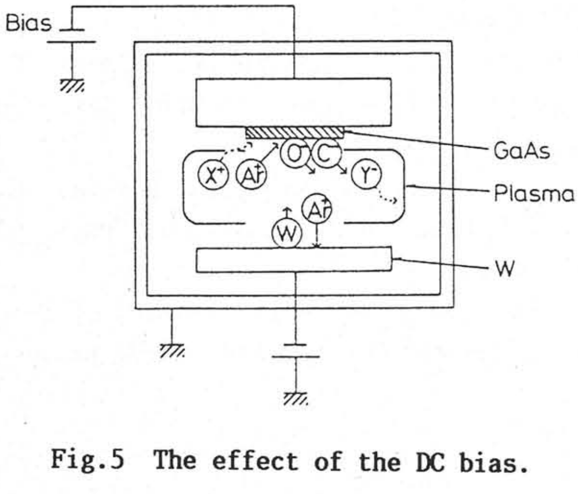


Fig.5 The effect of the DC bias.

## 3.2 Sputtering effect and improvement of Schottky characteristics

To prove the effect of the DC bias on the reduction of the impurity concentration, we performed the bias sputtering for the n-GaAs substrate with the surface oxidized intentionally.

We formed an oxide layer of about 50Å on the n-GaAs substrate by dipping in sulphuric acid. Tungsten was then sputtered on it using (a) conventional (bias=0V) or (b) bias sputtering (bias=-100V). The relation between the barrier height and the n-value after the annealing for the bias=0V and -100V is shown in Figure 6. In the case

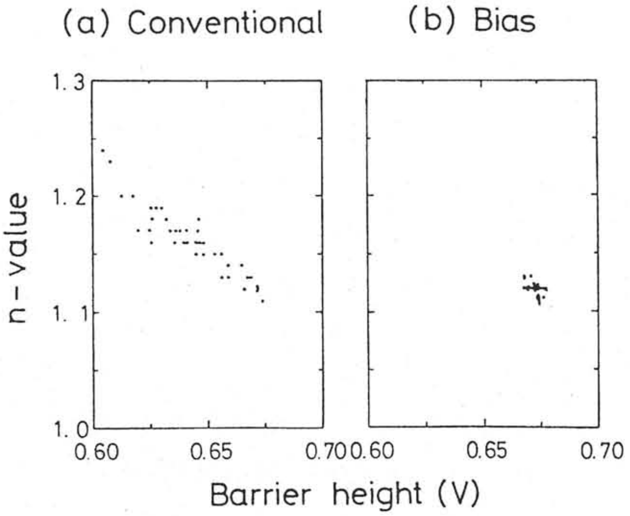


Fig.6 The relation between the barrier height and the n-value of W deposited on the oxidized substrate using (a) conventional sputtering (bias=0V) or (b) bias sputtering (bias=-100V).

of (a), the data were scattered, but in the case of (b), the uniformity was much improved and the average of the barrier height was higher and that of the n-value was closer to 1. Because the existence of the oxide at the GaAs surface degrades the characteristics of the Schottky contact as discussed in the previous reports,[2] this result proved that the oxide layer at the GaAs surface was removed effectively by the negative bias.

## 4. Application to the GaAs MESFETs

The bias sputtering was applied to the fabrication process of W-Al gate GaAs MESFETs. The gate length and width were 1μm and 10μm, respectively. Figure 7 shows the relation between the threshold voltage ($V_{th}$) and the barrier height for 50 MESFETs fabricated on a 2 inch wafer for the bias=0V and -100V. By the bias sputtering, the average of the barrier height became higher and the uniformity was improved. The uniformity of $V_{th}$ was better than that expected from the data of the barrier height. The uniformity of Schottky breakdown voltage was also observed to be improved. It is concluded that the impurity concentration at the interface was reduced by the negative bias, and it yielded the ideal Schottky I-V characteristics.

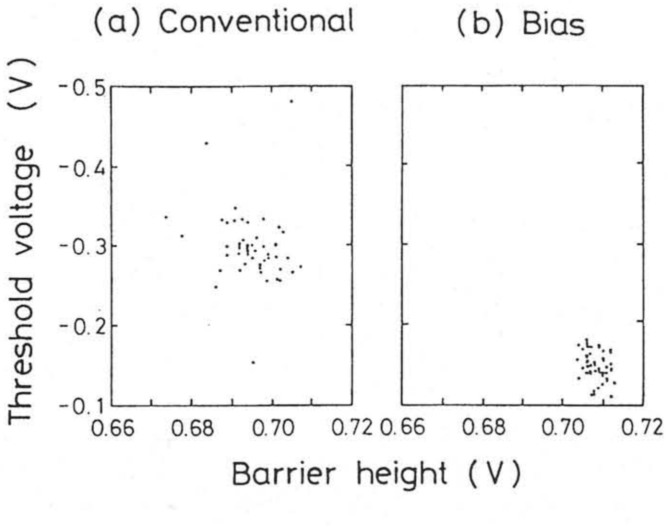


Fig.7 The relation between the threshold voltage ($V_{th}$) and the barrier height of W-Al gate GaAs MESFETs fabricated on a 2 inch wafer using (a) conventional sputtering (bias=0V) or (b) bias sputtering (bias=-100V).

## 5. Conclusion

The bias sputtering was proved to be very effective to reduce the concentration of oxygen and other impurities in the deposited film and at the interface between the film and the substrate, which resulted in good Schottky characteristics. This technique was applied to the fabrication process of the W-Al gate GaAs MESFETs and the good uniformity of the threshold voltage was obtained. From these results, it is confirmed that the bias sputtering is very useful for a gate formation process of GaAs LSIs.

## 6. References

1) H. Nakamura, Y. Sano, T. Nonaka, T. Ishida and K. Kaminishi : IEEE GaAs IC Symp. Tech. Digest, 1983 (IEEE, New Jersey, 1983) p134.

2) H. Matsuura, H. Nakamura, T. Ishida and K. Kaminishi : Extended Abstracts of the 16th Conf. on SSDM, (1984) p379.

3) T. Ohnishi, N. Yokoyama, H. Onodera, S. Suzuki and A. Shibatomi : Appl. Phys. Lett. 43 (1983) 600.

4) N. Uchitomi, M. Nagaoka, K. Shimada, T. Mizoguchi and N. Toyoda : J. Vac. Sci. and Technol. B4 (1986) 1392.

5) A. Callegari, D. Ralph, N. Braslau, E. Latta and G. D. Spiers : J. Appl. Phys. 62 (1987) 4812.

6) G. Hass and R. E. Thun : Physics of Thin Films, (Academic Press, 1966) vol.3, p80.