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The Change of Mo/GaAs Schottky Characteristics by the Forward Gate Current

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We found that the threshold voltage and the Schottky barrier height of Mo Schottky gate GaAsFET shift towards the positive direction after the high forward gate current test. The electron beam irradiation damage during the EB evaporation of Mo induces deep traps into GaAs and results in such a shift. To improve the reliability of Schottky gate by suppressing the electron beam irradiation damage, it is quite effective to insert a Ti layer with a thickness about 100Å between Mo and GaAs.

1. INTRODUCTION

The thermal stability of the characteristics is one of the most important issues in GaAsFETs. It is well known that due to the interdiffusion between GaAs and Au/Pt/Ti, which is widely used as a Schottky gate electrode, the threshold voltage shifts towards positive direction after a thermal stress test[1]. To improve the thermal stability, it is reported that Au/Pt/Ti/Mo Schottky gate, where the refractory metal Mo is used as a barrier layer to suppress the interdiffusion, is effective[2]. However, we found that the threshold voltage and the Schottky barrier height of such Au/Pt/Ti/Mo Schottky gate GaAsFETs shift towards the positive direction after the high forward gate current test. This paper describes details about the phenomenon and its mechanism.

2. THE CHANGE OF CHARACTERISTICS BY THE FORWARD GATE CURRENT

Figure 1 shows the cross-sectional structure of InGaAs/AlGaAs inverted HEMT (I-HEMT)[3]. The Schottky gate was Au(7000Å)/Pt(500Å)/Ti(100Å)/Mo(100Å) (Mo Schottky) or Au(7000Å)/Pt(500Å)/Ti(100Å)/Mo(500Å)/Ti(100Å) (Ti Schottky) formed by the lifted-off process using electron beam (EB) evaporation at the electron beam acceleration energy of 8keV. The channel layer is Si-doped ($n=8\times10^{17}cm^{-3}$) GaAs grown by MBE. The high forward gate current test was performed at the gate current density of $1\times10^5A/cm^2$ and the drain voltage of 1V at room temperature for 5 minutes. Figure 2 shows the change of the threshold voltage Vth before and after the test. In case of the Mo Schottky gate, Vth increased after the test. On the other hand, in case of the Ti Schottky gate with a 100Å-thick Ti layer between Mo and GaAs, the shift of Vth was almost suppressed. In order to consider this phenomenon more simply, Au(2000Å)/Pt(500Å)/Ti(100Å)/Mo(500Å)/Ti(0~500Å) Schottky diode was fabricated on Si-doped ($n=8\times10^{17}cm^{-3}$ as same as I-HEMT) GaAs grown by MBE and the test was performed at the forward current density of $1\times10^5A/cm^2$ at room temperature for 5 minutes. Figure 3 shows a dependence of the Schottky barrier height ϕb shift on the thickness of the inserted Ti layer. ϕb increased with the

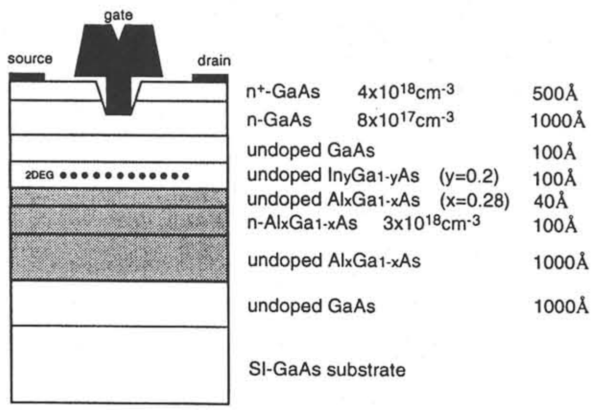

Fig. 1. Cross-sectional structure of InGaAs/AlGaAs inverted HEMT.

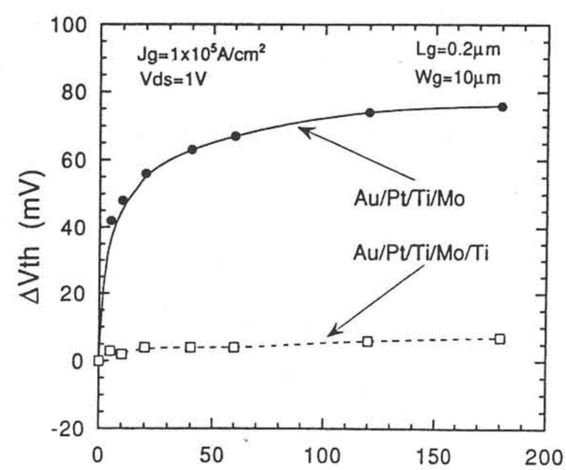

Fig. 2. Change of the Vth of Mo Schottky (closed circles) and Ti Schottky (open squares) I-HEMT before and after the test.

thickness for the Ti layer thinner than 50Å, but the shift was negligibly small for the thickness thicker than 100Å. From these results, it was concluded that the phenomenon of the shift after the high forward gate current test depends on the Schottky metal structure, but not on the device structure. The shifted Vth and ϕb due to the test were

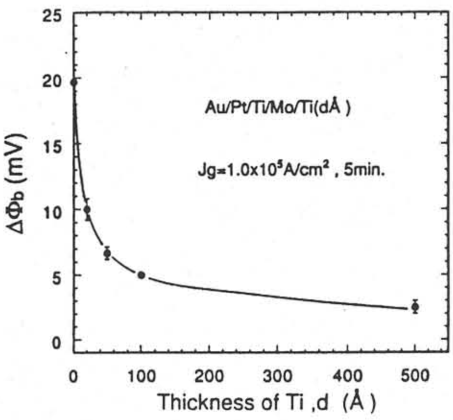

Fig. 3. Dependence of the ϕb shift on the thickness of the inserted Ti layer.

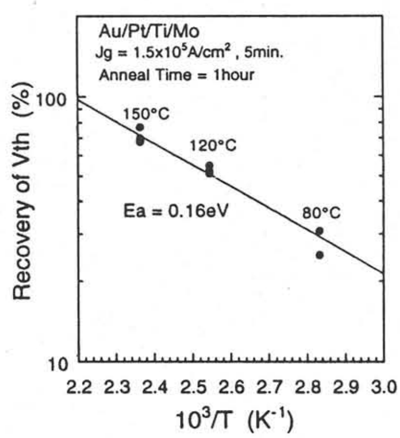

Fig. 4. Dependence of Vth recovery of I-HEMT on the annealing temperature.

recovered by the annealing. Figure 4 shows the dependence of Vth recovery of I-HEMT on the annealing temperature after the test at the gate current density of 1.5×10^5A/cm^2 and the drain voltage of 1V at room temperature for 5 minutes. As shown in figure 4, the shifted Vth was recovered to almost 80% at 150°C in 1 hour. This result indicates the phenomenon is not related to a metallurgical diffusion of the Schottky metal, but related to deep traps.

As for the origin of such deep traps, we assumed that the electron beam irradiation effect induces the damage within the GaAs surface during the Mo evaporation process. Nel and Auret reported[4] that defects are introduced in GaAs by the EB evaporation of metals. They shown that the low-energy (<3.6keV) electrons in the EB evaporation induce deep traps which are similar to that created by high-energy (1MeV) electrons[5), 6)]. Wada *et al.*, also reported[7)] that low-energy (3.5~7.5keV) electron beam irradiation causes degradation of the electronic properties of the two-dimensional electron gases in AlGaAs/GaAs heterostructures. In case of EB evaporation of Mo, low-energy (8keV) electron beam from Mo source with high electron density, because of its high melting point, is thought to induce such damage to GaAs.

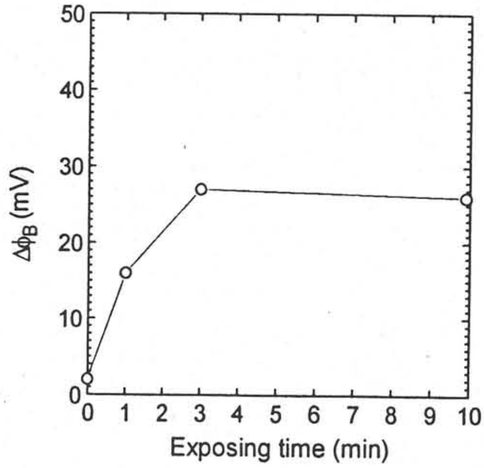

Fig. 5. Dependence of exposure time on the ϕb shift after the test.

To confirm the electron beam irradiation effect, the Au(2000Å)/Pt(300Å)/Ti(300Å) Schottky diode was fabricated on Si-doped ($n=8\times10^{17}$cm^{-3}) GaAs grown by MBE after exposing the surface to the electron beam during Mo evaporation process, where the beam intensity was intentionally controlled not to start evaporation. The electron beam current density irradiating GaAs surface measured by Faraday cup was about 0.41~0.42μA/cm^2. Then the high gate current test was performed at the forward current density of 1×10^5A/cm^2 at room temperature for 5 minutes. Figure 5 shows the dependence of exposure time on the ϕb shift after the test. In this figure, it was found that even in case of the Au/Pt/Ti Schottky, ϕb shifted similar to that of the Mo Schottky. This result suggests that electron beam irradiation resulted in the shift of characteristics after the high forward gate current test.

3. INVESTIGATION OF ELECTRON BEAM IRRADIATION DAMAGE

To determine the depth affected by the irradiation during evaporation, PL (photoluminescence) spectrums were measured for the sample with GaAs/AlGaAs quantum wells with different widths at different depths, shown in figure 6, before and after electron beam irradiation. As shown in figure 7, PL intensities of the quantum wells located near the surface were drastically decreased by the electron beam irradiation. Figure 8 shows the ratio of PL intensities at each depth before and after the irradiation. It was found that the damage was introduced within the depth of about 1000Å.

Next DLTS (deep level transient spectroscopy) measurement was performed to investigate deep traps induced by electron beam irradiation. Three samples with Au(2000Å)/Pt(500Å)/Ti(100Å)/Mo(500Å) Schottky (sampleA), Au(2000Å)/Pt(300Å)/Ti(300Å) Schottky (sampleB) and electron beam irradiated (as described above) Au(2000Å)/Pt(300Å)/Ti(300Å) Schottky (sampleC)

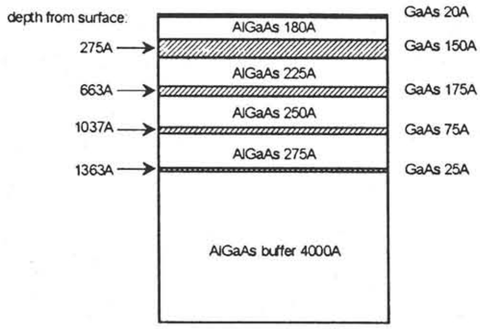

Fig. 6. Cross-sectional structure of GaAs/AlGaAs quantum well for PL measurement.

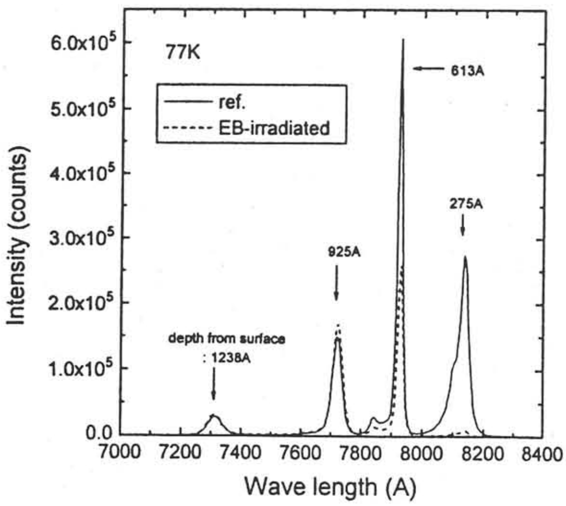

Fig. 7. PL spectrum of GaAs/AlGaAs quantum well before (solid line) and after (doted line) electron beam irradiation.

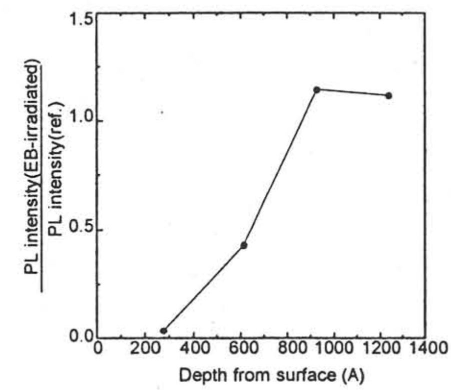

Fig. 8. Ratio of PL intensities of GaAs/AlGaAs quantum well at each depth before and after electron beam irradiation.

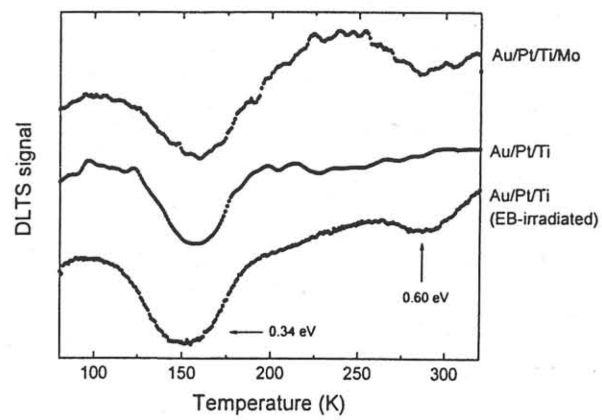

Fig. 9. DLTS signal of Au/Pt/Ti/Mo Schottky, Au/Pt/Ti Schottky and electron beam irradiated Au/Pt/Ti Schottky.

were prepared. Two electron traps with activation energies of 0.34eV and 0.60eV were observed in sampleA and C, while the only one trap of 0.34eV was observed in sampleB as shown in figure 9. This result indicates that EB evaporation of Mo induced the equivalent damage into GaAs as the electron beam irradiation, and insertion of Ti layer is thought to be effective to block such damage induced during Mo evaporation. However, Ti layer thicker than 100Å yields to degradation of thermal stability of the device. Therefore it should be important to optimize the thickness of the Ti layer to suppress the change of characteristics after the high forward gate current test without sacrificing thermal stability.

4. CONCLUSION

As a conclusion, it has been found that electron beam irradiation during Mo evaporation induces damage within GaAs to the depth of 1000Å and it creates deep traps. The change of the charge state of these traps near the surface and inside the channel of GaAs after the high forward gate current test results in the shifts of ϕb and Vth. we found that it is quite effective to insert a Ti layer between Mo and GaAs with the thickness about 100Å to improve thermal stability and reliability of the Schottky gate.

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