Electron-beam Irradiation during Schottky Gate Metallization of GaAs FET

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ABSTRACT

The electron-beam irradiation damage during Schottky gate metallization of GaAs FET has been investigated. It has been found that the damage introduced within GaAs during the electron-beam deposition strongly related to the electron-beam irradiation dose, which depended on the evaporated metal species. For the Mo Schottky gate HEMT, the threshold voltage shifts towards the positive direction after the forward gate current test due to a large concentration of deep-traps under the gate induced by the electron-beam irradiation. In order to suppress such an instability of the device characteristics, it is effective to insert a Ti layer with a small electron-beam irradiation dose during the deposition.

INTRODUCTION

The electron-beam evaporation process is widely used for the Schottky gate metallization of GaAs FETs. However, it has been reported that defects are introduced into GaAs by the electron-beam evaporation of metals [1][2]. One of the causes of the defect formation is the electron-beam irradiation effect [3]-[5]. We found that the concentration of deep-traps introduced into GaAs during the evaporation strongly related to the electron-beam irradiation dose, which depends on the evaporated metal species. We also found that such an electron-beam irradiation damage seriously degraded a stability of GaAs HEMT.

ELECTRON-BEAM IRRADIATION DURING DEPOSITION

The electron-beam current irradiating GaAs surface during a Schottky gate metallization was measured using a Faraday cup set on a wafer holder in the electron-beam evaporation chamber. Figure 1 shows a change of the electron-beam current during the Mo evaporation. The acceleration energy of the electron gun was 8 keV. The electron-beam current increased as the output power of the electron gun increased although the shutter was closed, because the electron-beam from the gun was scattered on the source metal towards every angle. When the shutter was opened to start the deposition

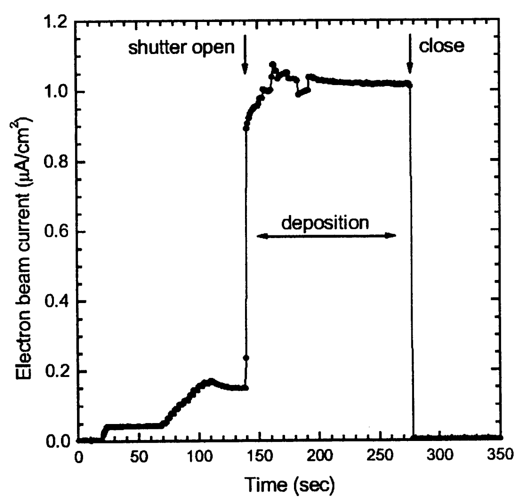

Fig. 1 Change of electron-beam current irradiating GaAs surface during Mo evaporation.

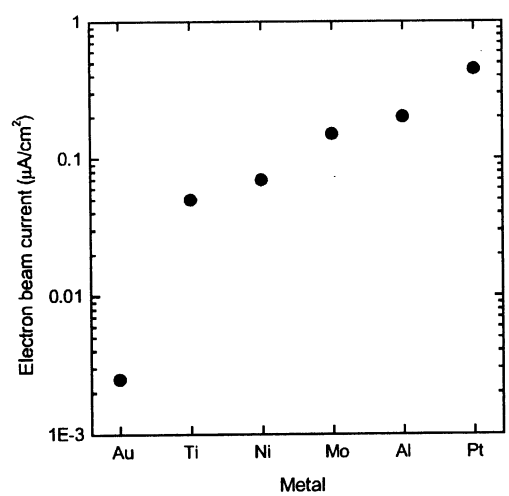

Fig. 2 Electron-beam current just before the deposition for various metals.

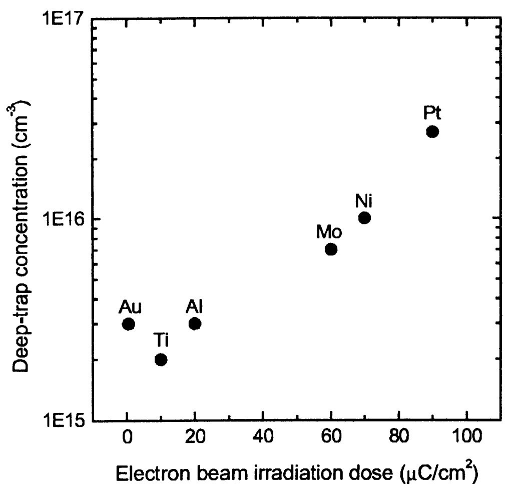

Fig. 3 Deep-trap concentration measured by DLTS for various Schottky metals.

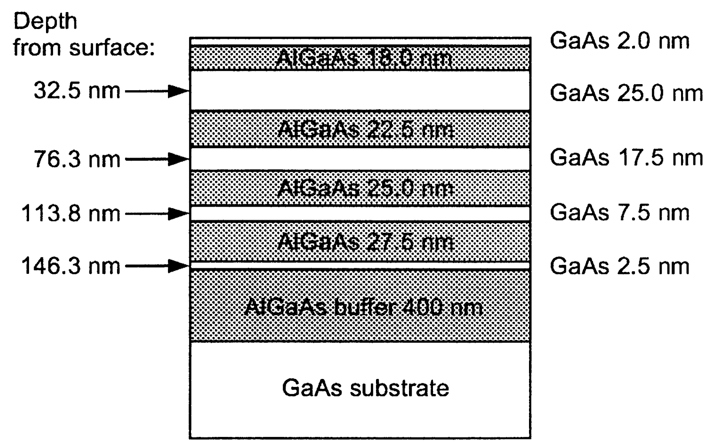

Fig. 4 Cross-sectional structure of GaAs/AlGaAs multi quantum well for PL measurement.

of Mo, the magnitude of the electron-beam current rapidly increased to 5-6 times. The similar measurements were performed for various metals using in GaAs FET process. The electron gun power was varied and optimized for each metal to obtain a stable deposition rate of 0.1-1.0 nm/sec. Figure 2 shows the dependence of the electron-beam current on the metal species. The electron-beam current was measured just before the shutter was opened, in order to neglect an influence of positively ionized metals during the deposition. As shown in fig. 2, it was found that the electron-beam current strongly depended on the evaporated metal species.

CARACTERIZATION OF ELECTRON-BEAM IRRADIATION DAMAGE

In order to confirm the relationship between the irradiated electron-beam during the deposition and the damage introduced into GaAs, deep-level transient spectroscopy (DLTS) measurements were performed. The samples were MBE-grown n-type GaAs (8×10^{17} cm^{-3}) and any thermal treatment was not performed after the deposition of Schottky metal of 100 nm-thick. Figure 3 shows the dependence of the detected deep-trap concentration for various Schottky metals on the electron-beam irradiation dose. The electron-beam irradiation dose was calculated from the deposition time and the electron-beam current as shown in fig. 2. It was found that the deep-trap concentration introduced into GaAs and the electron-beam irradiation dose was closely correlated,

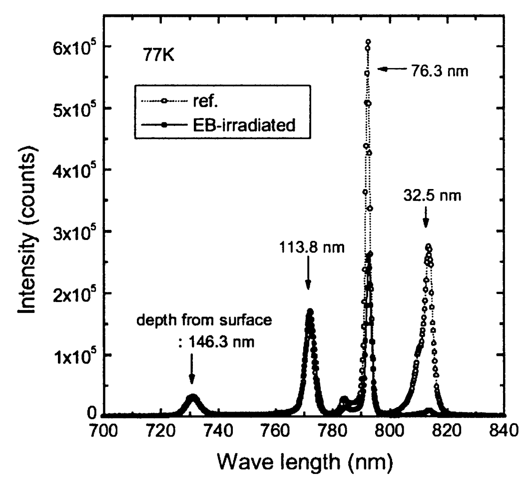

Fig. 5 PL spectrum of GaAs/AlGaAs multi quantum well before (doted line) and after (solid line) the electron beam irradiation.

in spite of the difference of the chemical structure of the interface between the metals and GaAs.

To determine the depth of such an electron-beam irradiation damage, photoluminescence (PL) measurements were performed for the sample of GaAs/AlGaAs quantum wells with different widths at different depths, as shown in fig. 4. Figure 5 shows the PL spectrums before and after exposing the sample to the electron-beam during the

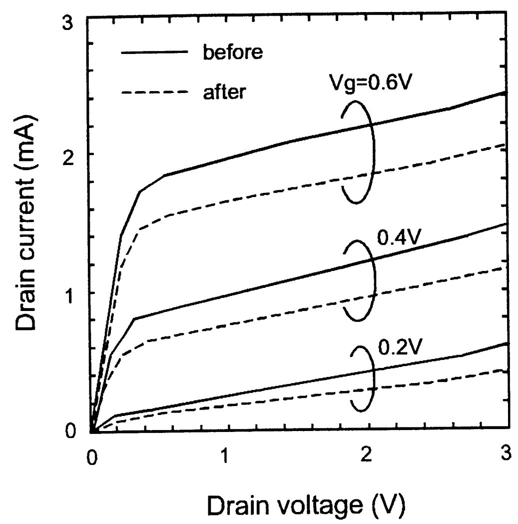

Fig. 6 I-V characteristics of Mo gate GaAs HEMT before and after the forward gate current test.

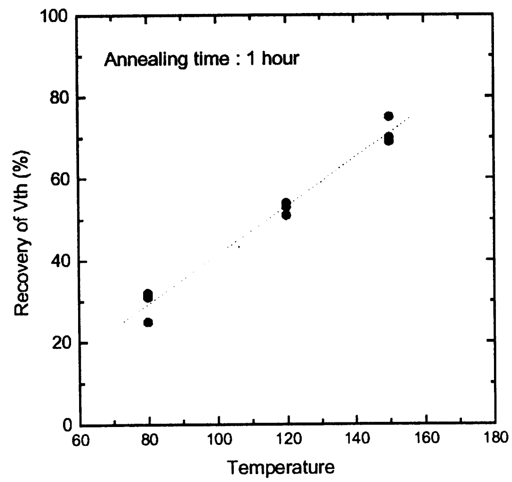

Fig. 7 Dependence of Vth recovery on annealing temperature.

evaporation process, where the electron gun power was intentionally controlled not to start evaporation. The electron-beam irradiation dose was about 70 $\mu C/cm^2$. PL intensities of the quantum wells located near the surface drastically decreased after the electron-beam irradiation. From fig. 5, it was found that the damage was introduced within the depth of about 100 nm.

INFLUENCE OF ELECTRON-BEAM IRRADIATION DAMAGE ON FET CHARACTERISTICS

To investigate the influence of the electron-beam irradiation damage on a stability of device characteristics, the forward gate current test was performed for the Au/Pt/Ti/Mo (Mo Schottky) gate GaAs HEMT [6], which involved a large concentration of deep-traps as shown in fig. 3. Figure 6 shows the I-V characteristics of the HEMT before and after the test at the forward gate current of 1×10^5 A/cm^2 and the drain voltage of 1 V for 10 minutes. The test was performed at room temperature. It was found that the drain current drastically decreased after the test because of threshold voltage (Vth) shift. The shifted Vth due to the test was recovered by the annealing. Figure 7 shows the dependence of Vth recovery of HEMT on the annealing temperature after the test at the gate current density of 1.5×10^5 A/cm^2 and the drain voltage of 1 V for 5 minutes. As shown in fig. 7, the shifted Vth was recovered to almost 80 % at 150°C. This result clearly indicates that the phenomenon is due to the change of the charged state of the deep-traps under the gate

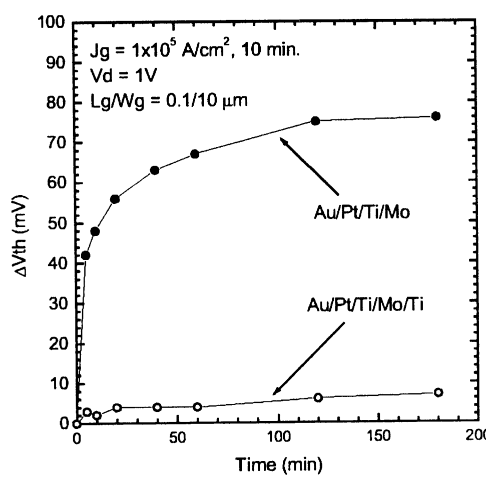

Fig. 8 Dependence of Vth shift on testing time for Mo and Ti gate HEMTs.

induced by the electron-beam irradiation during the Mo evaporation [7]-[9].

In order to suppress such an instability of the device characteristics, it is effective to use the metal with a small electron-beam irradiation dose during the deposition. We have fabricated the Au/Pt/Ti/Mo/Ti (Ti Schottky) gate GaAs HEMT, where a 10 nm-thick Ti was inserted between Mo and

GaAs. Figure 8 shows the dependence of the Vth shift on the testing time at the gate current density of 1×10^5 A/cm^2 and the drain voltage of 1 V. In case of the Mo Schottky gate HEMT, Vth increased as the testing time increased. On the other hand, in case of the Ti Schottky gate HEMT, the shift of Vth was successfully suppressed. This result clearly indicates that the Ti inserted between Mo and GaAs is effective to block the electron-beam irradiation damage during Mo evaporation.

CONCLUSIONS

The electron-beam irradiation damage during Schottky gate metallization of GaAs FET has been investigated. It was found that the deep-trap introduced within GaAs during the electron-beam deposition strongly related to the electron-beam irradiation dose, which depended on the evaporated metal species. For the Mo Schottky gate HEMT, the shift of the threshold voltage towards a positive direction by the forward gate current test was observed. This phenomenon can be understood by a change of the charged state of deep-traps under the gate induced by the electron-beam irradiation. In order to suppress such an instability of the device characteristics, it was effective to insert a Ti layer to block the electron-beam irradiation during Mo evaporation.

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