High Dose ^{60}Co γ-Ray Irradiation of W/GaN Schottky Diodes

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Abstract—**W/n-GaN Schottky diodes were irradiated with ^{60}Co γ-rays to doses up to 315Mrad. The barrier height obtained from current-voltage (I-V) measurements showed minimal change from its estimated initial value of ~0.4eV over this dose range, though both forward and reverse I-V characteristics show evidence of defect center introduction at doses as low as 150 Mrad. Post irradiation annealing at 500°C increased the reverse leakage current, suggesting migration and complexing of defects. The W/GaN interface is stable to high dose of γ-rays, but Au/Ti overlayers employed for reducing contact sheet resistance suffer from adhesion problems at the highest doses.**

Index Terms—**GaN, irradiation, contact stability, annealing, rectifiers**

I. INTRODUCTION

GaN power rectifiers show great potential for inverter units in traction motor control, hybrid electric vehicles and for utility power flow control[1-12]. There is also great interest in GaN electronics and sensors for use in the nuclear power industry and in satellite-based communication systems. For these latter applications it is necessary to establish the response of GaN rectifiers to ionizing radiation. GaN has a high bond strength (8.92eV/atom), which suggests it should have a high tolerance against creation of point defects by radiation damage. AlGaN/GaN high electron mobility transistors (HEMTs) showed little measurable change in their performance after irradiation with ^{60}Co γ-rays for doses ≤300 Mrad[13, 14]. At higher doses there was a significant decrease in forward gate current and increase in reverse breakdown voltage(V_B). SiC Schottky rectifiers showed a much degraded power figure-of-merit V_B^2/R_{on}, where R_{on} is the on-state resistance, after ^{60}Co γ-ray doses in the range of 300-600Mrad[15]. In that case, one of the major degradation mechanisms was deterioration of the Ni Schottky contacts[15].

In this letter we report on the effect of high dose(315Mrad) ^{60}Co γ-ray irradiation of n-GaN Schottky diode rectifiers with W contacts. The devices show increased reverse leakage current as a function of ^{60}Co γ-ray dose and decreased forward current. Low-temperature annealing at 500°C after the irradiation had no effect on the forward current-voltage(I-V) characteristics, but does further degrade the reverse current.

II. EXPERIMENTAL

The starting sample was ~6μm of n-type($10^{17}cm^{-3}$) GaN grown on sapphire substrates by hydride vapor phase epitaxy. Electron-beam deposited Ti/Al/Pt/Au ohmic contacts was patterned by lift-off and annealed at 700°C, 30 secs under a flowing N_2 ambient. The W Schottky contact layers were deposited to a thickness of

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700Å using Ar plasma-assisted sputtering at an acceleration voltage of 90V. Prior to sputtering, the GaN native oxide was removed by rinsing the samples in both a 20:1 H_2O : NH_4OH solution and buffered oxide etchant(BOE). After Ar sputtering of the W, the samples were rinsed again in BOE to remove tungsten oxide. To reduce the sheet resistance of the contacts, a bilayer of 200Å Ti/800Å Au was deposited on the W by e-beam evaporation. The contact diameter was 80μm. The devices were exposed to a 600Ci ^{60}Co source for accumulated doses up to 315Mrad. The calibration of dose was performed with radioactive films and ion chamber radiation meters. The forward and reverse I-V characteristics before and after irradiation were measured at 25°C using a HP4145 parameter analyzer.

III. Results And Discussion

Figure 1 shows the forward I-V characteristics of the rectifiers for two different γ-ray doses(150 and 315Mrad). For W on GaN the theoretical barrier height(ϕ_B) is ~0.4eV from the relation[16, 17]

$$\phi_B=\phi_m-\chi_S$$

where ϕ_m is the metal work function and χ_S the electron affinity of GaN. The forward I-V characteristics shown in Figure 1 could not be fit to a thermionic emission relation, suggesting the presence of additional current transport mechanism such as space-charge generation surface leakage and tunneling through deep levels[17]. The main effect of the γ-irradiation is a reduction in forward current density. As will be seen later, much of this change appears to come from an increase in sheet resistance of the contact metal through deterioration of the adhesion of the Au/Ti overlayer on the W.

The reverse I-V characteristics are shown as a function of dose in Figure 2. The reverse current density varies approximately as $(V_R)^{0.5}$, where V_R is the reverse bias. This suggests that space-charge generation current is the dominant transport mechanism both before and after γ-irradiation. The changes in reverse leakage and hence breakdown voltage(V_B) as a result of irradiation are small. Since V_B is related to the epi later doping N_D through the relationship [18].

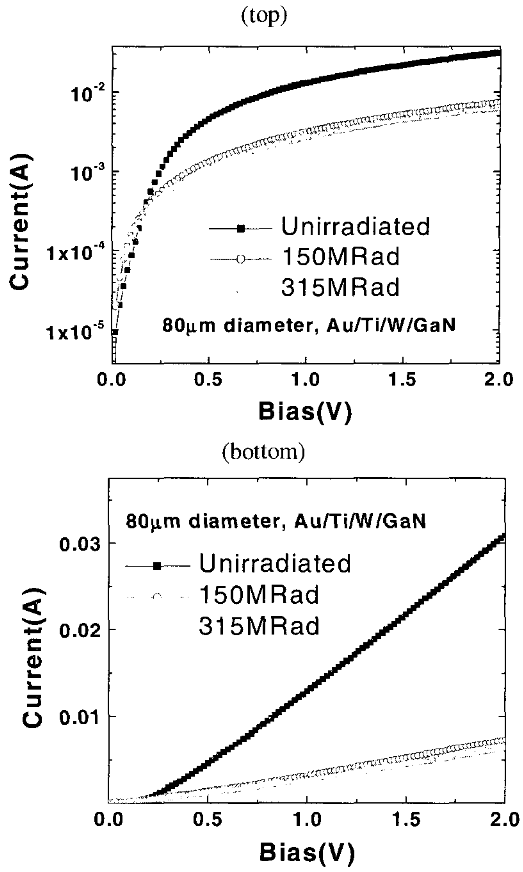

Fig. 1. Forward I-V characteristics from GaN rectifiers before and after γ-irradiation at dose of 150 or 315Mrad. The data is shown is both log(top) and linear(bottom) form.

$$V_B=\frac{\varepsilon E_C^2}{2eN_D}$$

where ε is the dielectric constant of GaN, E_C the critical field for breakdown and e the electronic charge, then the result in Figure 2 indicates that epi layer doping is affected only slightly by γ-doses up to 315Mrad. However, post irradiation annealing at 500°C for 1 min produced more significant increase in reverse current while still retaining the $V_R^{0.5}$ dependence. Clearly, this annealing temperature is insufficient to remove the point defects created by the irradiation and serves only to cause their migration and complexing which degrades the diode reverse current.

Figure 3 shows optical micrographs of the rectifying contact stack before(left) and after(right) γ-irradiation to a dose of 315Mrad. The irradiation causes a lift-off and peeling of the Ti/Al overlayer on the W, which leads to an increase in effective sheet resistance of the contact. Similar degradation of metal contacts have been reported previously for Ni/SiC rectifiers(15) and while the mechanism is not clear, it is not thermally induced. Therefore, to improve the lifetime of GaN rectifiers in ionizing ambients it is necessary to develop metallization schemes that are stable to high radiation doses.

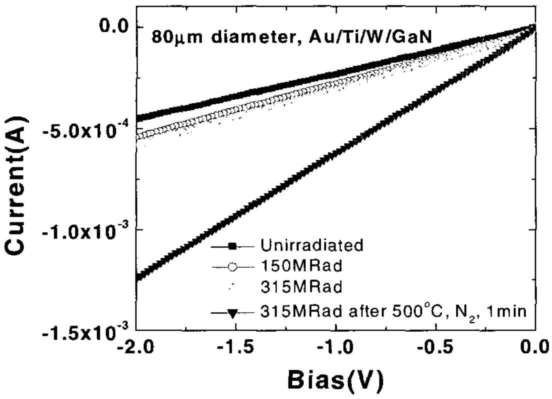

Fig. 2. Replace I-V characteristics from GaN rectifiers before and after γ-irradiation at dose of 150 or 315Mrad and after annealing of the latter sample at 500°C.

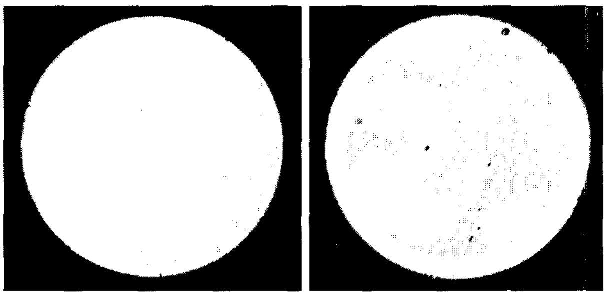
Fig. 3. Optical micrographs of 80μm diameter W/Ti/Au contacts before(left) and after(right) 315Mrad γ-ray irradiation.

IV. Summary and Conclusions

W/GaN rectifiers show modest changes in forward and reverse current characteristics even after ^{60}Co γ-ray doses up to 315Mrad. The changes in forward current are mostly due to peeling of the Ti/Au overlayers on the W rectifying contact. More stable metal contact schemes are needed to ensure adequate relaibility of the GaN rectifiers in ionizing radiation environments.

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