MRS Internet Journal Nitride Semiconductor Research

Schottky Diodes on MOCVD Grown AlGaN Films.

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(Received Monday, June 22, 1998; accepted Friday, October 16, 1998)

Au Schottky diodes were prepared by vacuum evaporation or by plasma sputtering on n-AlGaN(Si) films with Al mole fractions of 0, 0.11 or 0.23. The barrier heights were deduced from C-V and I-T measurements. The difference between the C-V and I-T results was less than 0.1 eV for the barriers deposited at 300 °C on HF etched samles with prior in situ heating at 450 °C. For low deposition temperatures (about 150°C) C-V and I-T methods give results differing by some tenths of an eV. For deposition temperatures exceeding 450°C the diodes were very leaky. The barrier heights were 0.8 eV, 0. 9 eV and 1.1 eV for AlGaN with compositions of 0, 0.11 and 0.23. For plasma sputtered diodes on GaN and AlGaN (x=0.11) samples, the difference in C-V and I-T results was quite considerable and admittance spectroscopy indicated the presence of deep electron traps at 0.12-0.14 eV that were absent in vacuum evaporated diodes. For similar diodes on AlGaN(x=0.23) samples the results of C-V and I-T measurements were very close and no traps at 0.12-0.14 eV could be detected. This difference is most likely due to damage caused by low energy ions. More Al-rich films are less susceptible to such damage. Persistent photocapacitance was observed in n-AlGaN Schottky diodes after illumination at 85K.

1 Introduction

Ternary solid solutions of AlGaN are currently under intense study for applications in solar-blind photodetectors and in high-power/high-frequency/high-temperature field effect transistors (see e.g. [1]). Schottky diodes are important building blocks for both types of devices. However, experimental work on Schottky diodes until now has been mainly focused on GaN (see e.g. [2] [3] [4]) with very little known about the properties of Schottky diodes on $Al_xGa_{1-x}N$ with x>0. For GaN, it has been suggested that the Fermi level pinning at the surface is but of minor importance, with the major contribution to the Schottky barrier height coming from the difference in electron affinities (see e.g. [2]). Nevertheless, several groups (see e.g. [5] [6]) have reported that nonoptimized surface preparation conditions can lead to considerable surface pinning and other nonidealities.The impact of such effects on AlGaN-based Schottky diodes has not been really studied and such studies are to be reported below.

2 Experimental

N-type $Al_xGa_{1-x}N$ layers studied in this work were grown by low-pressure metallorganic chemical vapor deposition (MOCVD) on basal plane sapphire substrates as described in detail in [7]. The composition of the two films that were used was x=0.11 and x=0.23 as established by energy dispersive x-ray analysis. The thickness of the films was close to 2.5 μm for both samples. The layers were doped with silicon to electron concentration of about 10^{17} cm^{-3} at room temperature. For comparison we also made measurements on a GaN film grown by MOCVD on SiC using a thin AlN buffer layer [8]. The film was doped with Si to electron concentration of about 10^{17} cm^{-3} and was about 1 μm thick. Schottky diodes were prepared by vacuum evaporation of Au using a shadow mask (the diode diameter of about 1 mm). Prior to charging the samples into the deposition chamber they were degreased in organic solvents (trichlorethane, aceton, methanol), etched in aqua regia and, immediately before charging into the deposition chamber, rinsed in buffered HF. The background vacuum during deposition was better than 10^{-6} Torr. The parameters that were varied were the temperature of pre-deposition bake-out (the time of this treatment was set at 0.5 h) and the temperature at which the barriers were deposited. For comparison we also carried out Au Schottky diodes deposition using Ar plasma sputtering of Au. The diodes area was defined by shadow mask (diameter of about 1 mm). No deliberate heating of the samples was used in this process.

The characterization involved current-voltage (I-V) measurements at various temperatures (77-400K), forward current versus temperature (I-T) measurements at several forward biases, capacitance-voltage (C-V) measurements at various frequencies in the 10^2-10^6 Hz range and capacitance/conductivity versus temperature measurements at various temperatures (so called admittance spectroscopy [9]). We also briefly studied effects of persistent photoconductivity observed in our Schottky diodes after exposure to UV light at low temperature (a deuterium lamp equipped with mechanical shutter was used as a light source). The computer-controlled experimental set-up for all these measurements was fairly standard and is described in more detail e.g. in [7]. The Schottky barrier heights were deduced by three different methods: a) from the temperature dependence of the saturation current I_0 obtained by fitting the forward I-V curves by the usual expression $I= I_0\exp(qU/nkT)$, where q is the electronic charge, U is the forward bias, n is the ideality factor, k is the Boltzmann constant, T is the absolute temperature and $I_0=I_{00}\exp(-q\phi_{I-V}/kT)$ (ϕ_{I-V} is the barrier height derived by such measurements); b) from the temperature dependence of forward current measured at several forward biases (this value is denoted ϕ_{I-T} below; from the expression above it follows that $\phi_{I-T}= (q/kT)(d\ln(I)/dT)-U/n$); c) from the cut-off value of the $1/C^2$ versus voltage plots at 300K at frequencies where the effects of series resistance on measured capacitance are negligible (ϕ_{C-V} below).

3 Results and discussion

Four different Schottky diodes preparation conditions were used. In the first process (process I below) the temperatures of pre-deposition annealing and the deposition temperature were both 150°C. Corresponding I-V characteristics for the x=0.11 sample are shown in Figure 1. The results of the measurements for all three AlGaN samples studied were qualitatively very similar. The measured ideality factors and Schottky barrier heights are summarized in Table 1. The reverse current for process I was the lowest among studied. However, the ideality factors were measurably higher than unity and the values of ϕ_{C-V} were significantly higher than those derived from forward current measurements (see Table 1) indicating that a thin interfacial layer between the metal and the AlGaN was present and the current flow was strongly affected by tunneling through this layer. In process II the baking temperature and the deposition temperature were increased to 250 °C, but the results were similar to those for process I. In process III the baking temperature was elevated to 450°C while the deposition temperature was kept at 300°C. Under these conditions the ideality factors became fairly close to unity and the discreapancies between the Schottky barrier heights measured by different methods did not exceed 0.1 eV indicating an almost complete removal of the interfacial insulating layer. Further increasing of the deposition temperature to 450°C in process IV resulted in practically ohmic behavior of the Schottky diodes, probably because of the onset of interfacial reactions between Au and AlGaN.

In plasma sputtered diodes the ideality factors were very close to unity for all three samples, even though the samples were not heated during deposition. Most likely the result is due to an efficient removal of the dielectric (native oxide?) layer by low energy ions bombardment. It has to be noted, however, that for the GaN and the AlGaN (x=0.11) samples the values of the Schottky barrier heights deduced from forward current and capacitance measurements differ quite considerably (Table 1). C-T measurements on plasma deposited samples show a step corresponding to an electron trap with activation energy of 0.12 eV (x=0) and 0.14 eV (x=0.11) as deduced from the measurements of the shift in the step temperature with the measurement frequency (the theory is given in [9]) (see Figure 3 for the x=0.11 sample).These steps are markedly absent in the Schottky diodes prepared on the same samples by thermal evaporation of Au (see Figure 2).

For the x=0.23 sample the Schottky barriers measured by different methods are very reasonably close to each other, the C-T curves for the plasma sputtered and the thermal-evaporation methods were qualitatively similar and no additional steps for the plasma sputtered sample were observed .

It seems reasonable to assume that the difference between the thermal evaporation and the plasma sputtering results is due to the surface damage caused by low energy ions bombardment in the latter case and that the ~0.1 eV electron traps in the x=0 and x=0.11 samples are due to this surface damage. Apparently, the radiation hardness of the more Al-rich x=0.23 sample is higher, hence no appreciable difference between the two Schottky diodes preparation techniques.

It could be noted that the data in Table 1 do indicate some increase of the Au Schottky barrier height from about 0.8 eV for x=0 to 0.9 eV (x=0.11) and 1.1 eV for x=0.23, but one would expect a steeper rise in the barrier height as a function of composition if only the change in electron affinity is at play.

Finally, Figure 3 and Figure 4 illustrate the persistent changes in capacitance for the x=0.11 and x=0.23 samples after illumination at 85K. The changes persist up to temperatures higher than the room temperature in good agreement with the earlier published results on persistent photoconductivity [7]. Figure 5 and Figure 6 illustrate the changes in capacitance versus frequency curves for the two AlGaN samples at 300K, at 85K and at 85K after illumination. The roll-off in the measured capacitance is due to the effects of series resistance. These resistances considerably increase with the decrease in temperature causing the shift in the roll-off frequency toward lower frequencies. Illumination persistently increases electron concentration and reduces the series resistance resulting in C-f curves to shift toward the 300K curve. It can be seen that the magnitude of persistent photoconductivity is very considerably higher in the AlGaN (x=0.23) sample.

4 Conclusions

We have shown that nearly ideal Au Schottky diodes can be prepared by thermal evaporation of Au on n-AlGaN if the samples are annealed in situ prior to deposition at 450°C and the deposition is carried out at 300-350°C. For lower annealing temperatures the thin insulating interfacial layer could not be totally removed causing nonideality of the Schottky diodes behavior.

The barrier heights for Au in n-$Al_xGa_{1-x}N$ increase from 0.8 eV for x=0 to 1.1 eV for x=0.23 which correlates with increased difference in electron affinity between Au and AlGaN.

Preparation of Schottky diodes by plasma sputtering is quite efficient in removal of insulating interfacial layers, but, for low Al compositions, can cause considerable surface damage and produce electron traps with activation energies close to 0.1 eV. These effects are very much less pronounced for Al-rich n-AlGaN films.

Illumination at low temperature leads to serious changes in measured capacitances. These changes persist up to temperatures above room temperature. The effect is stronger in the more Al-rich sample with x=0.23.

ACKNOWLEDGMENTS

The work at IRM was supported in part by a grant from the U.S. Civilian Research and Development Foundation (Grant RP1-211) and by a grant from the Russian Foundation for Basic Research (Grant 97-02-17076). The authors would like to thank G.A. Petrovicheva and E.F. Astakhova for experimental assistance.

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FIGURES

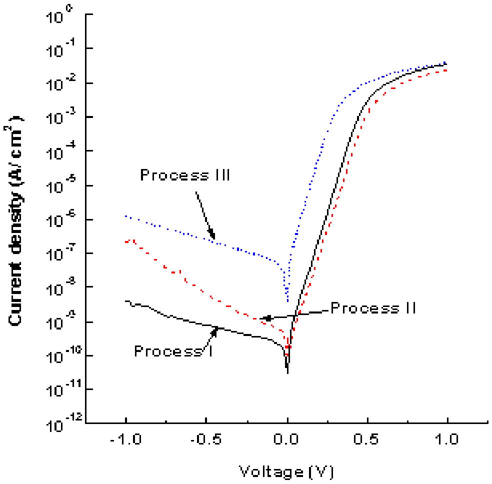

Figure 1. I-V curves for Au Schottky diodes prepared on the n-AlGaN (x=0.11) sample in three different processes (see text).

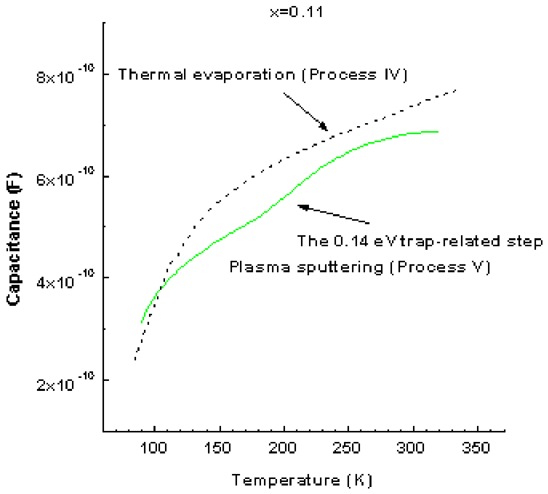

Figure 2. The 20 KHz capacitance measured as a function of temperature on the n-AlGaN (x=0.11) sample with a Schottky diode deposited by thermal evaporation (Process III) and by plasma sputtering; mind the appearance of the step in capacitance related to the electron trap with activation energy of 0.14 eV.

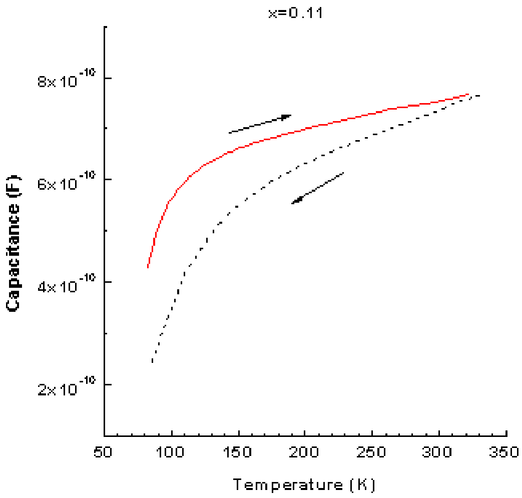

Figure 3. The temperature dependence of the 20 kHz capacitance for the AlGaN (x=0.11) sample measured in the dark during cooling and after exposure to UV light at 85K.

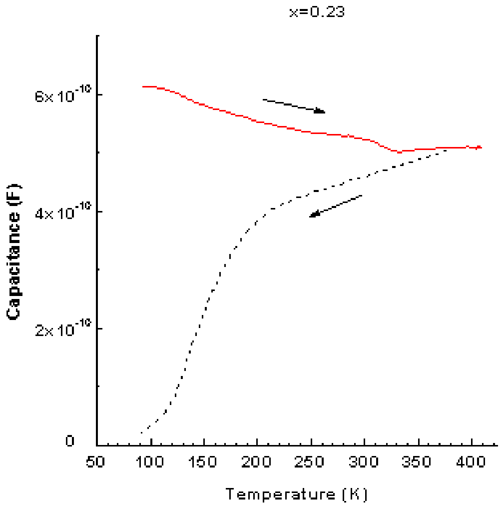

Figure 4. The temperature dependence of the 1 kHz capacitance for the AlGaN (x=0.23) sample measured in the dark during cooling and after exposure to UV light at 85K.

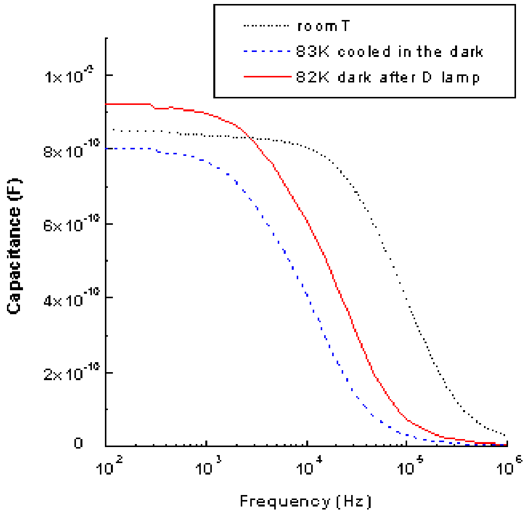

Figure 5. Capacitance versus frequency measurements on the AlGaN (x=0.11) sample made at 300K, at 85K in the dark and at 85K in the dark after illumination.

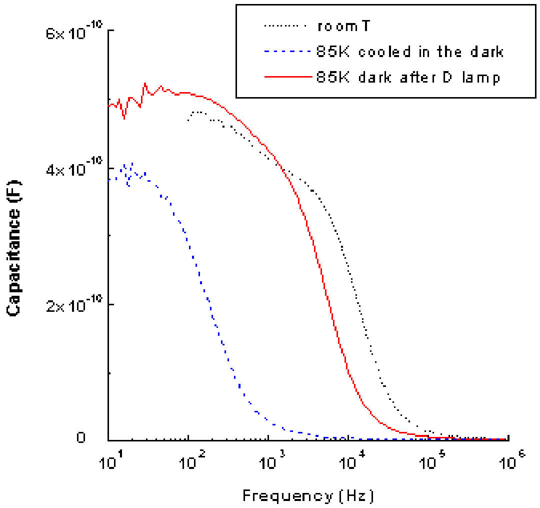

Figure 6. Capacitance versus frequency measurements on the AlGaN (x=0.23) sample made at 300K, at 85K in the dark and at 85K in the dark after illumination.

TABLES

Table 1. Ideality factors (n) and Schottky barrier heights measured for various Au Schottky diodes preparation processes; mind a significant difference between the barrier height deduced from C-V (ϕ_{C-V}) and I-T (ϕ_{I-V} and ϕ_{I-T}) for Processes I-III for all samples and for Process V (plasma sputtering) for the x=0 and x=0.11 samples, but not for the x=0.23 sample

Process	**x**	**n**	**ϕ_{C-V}, eV**	**ϕ_{I-T}, eV**	**ϕ_{I-V}, eV**
I	0	1.18	1.0	0.6	0.6
	0.11	1.1	1.08	0.56	0.7
	0.23	1.15	1.3	0.8	0.85
II	0	1.22	1.0	0.65	0.6
	0.11	1.16	1.02	0.68	0.6
	0.23	1.17	1.25	0.95	0.9
III	0	1.02	0.8	0.7	0.75
	0.11	1.0	0.9	0.83	0.85
	0.23	1.06	1.1	1.0	1.05
IV	0	nearly ohmic behavior			
	0.11	nearly ohmic behavior			
	0.23	nearly ohmic behavior			
V	0	1.02	0.8	0.56	0.6
	0.11	1.06	0.85	0.6	0.6
	0.23	1.02	1.05	0.95	1.0