Progress in Novel Oxides for Gate Dielectrics and Surface Passivation of GaN/AlGaN Heterostructure Field Effect Transistors

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Abstract —**Both MgO and Sc_2O_3 are shown to provide low interface state densities (in the 10^{11} eV^{-1} cm^{-2} range) on n-and p-GaN, making them useful for gate dielectrics for metal-oxide semiconductor(MOS) devices and also as surface passivation layers to mitigate current collapse in GaN/AlGaN high electron mobility transistors(HEMTs).Clear evidence of inversion has been demonstrated in gate-controlled MOS p-GaN diodes using both types of oxide. Charge pumping measurements on diodes undergoing a high temperature implant activation anneal show a total surface state density of ~3×10^{12} cm^{-2}. On HEMT structures, both oxides provide effective passivation of surface states and these devices show improved output power. The MgO/GaN structures are also found to be quite radiation-resistant, making them attractive for satellite and terrestrial communication systems requiring a high tolerance to high energy(40MeV) protons.**

Index Terms —**GaN, HEMTs, interface state densities and passivation.**

I. INTRODUCTION

AlGaN/GaN high electron mobility transistors (HEMTs) appear well-suited to high speed and high temperature applications including high frequency wireless base stations and broad-band links, commercial and military radar and satellite communications[1-34]. These devices appear capable of producing very high power densities (>12W/mm), along with high breakdown voltage and low noise figures. The use of metal-oxide-semiconductor (MOS) or metal-insulator-semiconductor (MIS) gates for HEMTs produces a number of advantages over the more conventional Schottky metal gates, including lower leakage current and greater voltage swing[2, 22, 26, 28-30].The materials reported for gate oxide/insulators include SiO_2[3, 22-27, 35], $Gd(Ga_2O_3)$[22, 23, 27, 33], AlN[34], SiN_X[14,31,32], MgO[24, 36] and Sc_2O_3[36]. These materials can also be employed as surface passivation layers on HEMTs. A commonly observed problem in these devices is the so-called "current collapse" in which the application of a high drain-source voltage leads to a decrease of the drain current and increase in the knee voltage[4, 6,12-17, 20]. This phenomenon can also be observed by a current dispersion between dc and pulsed test conditions or a degraded rf output power. The mechanisms include the presence of surface states on the cap layer or trapping centers in the resistive buffer underlying the active channel. The carriers in the 2-dimentional electron gas can be lost either to the surface

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Manuscript received February 5, 2003; revised March 4, 2003.

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Table 1 : Material properties for GaN and various dielectrics. W = Wurtzite, A = amorphous, B = Bixbyite, N = NaCl.

	GaN [a]	**SiO_2** [b-d]	**SiN_x** [d]	**AlN** [e-g]	**GGG** [h]	**Gd_2O_3** [i,j]	**Sc_2O_3** [k]	**MgO** [l,m]
Structure	W	A	A	W or A	A	B	B	N
Lattice Constant	3.186	-	-	3.113		10.813	9.845	4.2112
Atomic Spacing in the (111) plane		-	-	-	-	3.828	3.4807	2.978
Mismatch to GaN (%)	-	-	-	2.3	-	20.1	9.2	-6.5
T_{MP} (K)	2800	1900	2173	3500	2023	2668	2678	3073
Bandgap (eV)	3.4	9	5	6.2	4.7	5.3	6.3	8
Electron Affinity (eV)	3.4	0.9		0 – 2.9		0.63		0.7
Work Function (eV)				0.9 – 1.2		2.1 – 3.3	4	3.1 – 4.4
Dielectric Constant	9.5	3.9	7.5	8.5	14.2	11.4	14	9.8

a. *Properties of Group III Nitrides*, ed. J. H. Edgar, Inspec, the Institution of Electrical Engineers, London, UK, 1994.

b. G.W. Kaye, T.H. Laby, *Tables of Physical and Chemical Constants and some Mathematical Functions*, 11th ed, Longmans, New York, 1956

c. C. T. Sah, *Fundamentals of Solid-State Electronics*, World Scientific, New Jersey, 1991

d. S.M. Sze, *Physics of Semiconductor Devices*, 2nd edition, Wiley, New York, 1981

e. "Epitaxially grown AlN and its optical band gap," W.M. Yim, E.J. Stofko, P.J. Zanzucchi, J.I. Pankove, M. Ettenburg, S.L. Gilbert, J. of Appl. Phys., **44**, 292 (1973)

f. "Electron mobilities in gallium, indium, and aluminum nitrides," W.L. Chin, T.L. Tansley, T. Osotchan, J. of Appl. Phys., **75**, 7365 (1994)

g. "GaN/AlGaN heterostructure devices: photodetectors and field-effect transistors," M.S. Shur, M.A. Khan, Mat. Res. Bull., **22(2)**, 44 (1997)

h. S.S. Derbeneva, S.S. Batsano, Dokl. Chem., **175**, 710 (1967)

i. S.S. Batsono, E.V. Dulepov, Soviet Physics – Solid State, **7(4)**, 995 (1965)

j. K.A. Gschneider, *Rare Earth Alloys*, Izd. Mir., 1965

k. "Optical properties and electron energy structure of Y2O3 and Sc2O3," V. N. Abramov, A. N. Ermoshkin and A. I. Kuznetsov, Sov. Phys. Sol. State, **25**, 981 (1983).

l. "Electronic band structure of magnesium and calcium oxides," N. Daude, C. Jouanin and C. Gout, Phys. Rev. B, **15**, 2399 (1977).

m. G. V. Samsonov, *The Oxide Handbook*, Plenum, New York, 1973

or buffer traps[4, 6,37]. The former may be mitigated to a greater or lesser extent by use of appropriate surface passivation, most often SiN_X deposited by plasma-enhanced chemical vapor deposition (PECVD), while the latter is a function of the epitaxial growth conditions.

In this paper,we will describe progress on two alternative candidates for HEMT gate dielectrics and passivation, namely Sc_2O_3 and MgO[38]. Table I shows a comparison of the properties of these oxides with those of the other commonly used passivation materials on GaN. These novel oxides do not contain hydrogen and may have advantages over SiN_X in that respect because atomic hydrogen diffuses rapidly and could enter the GaN or gate metal over extended periods of device operation

II. EXPERIMENTAL

To fabricate gate-controlled diodes using the oxides as gate dielectrics, the starting sample was a 1μm thick p-GaN (hole concentration is ~ 2×10^{17} cm^{-3} at 25 °C) layer grown on a 2 μm undoped GaN buffer grown on a Al_2O_3 substrate by Metal Organic Chemical Vapor Deposition. The Sc_2O_3 was deposited by rf plasma-activated Molecular Beam Epitaxy (MBE) at 650°C

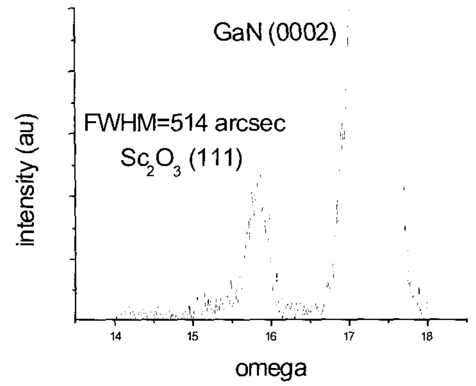


Fig. 1 HXRD scans of Sc_2O_3 on h-GaN.

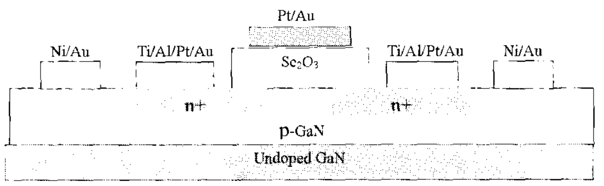


Fig. 2 Schematic of Sc_2O_3/p-GaN gate-controlled diodes.

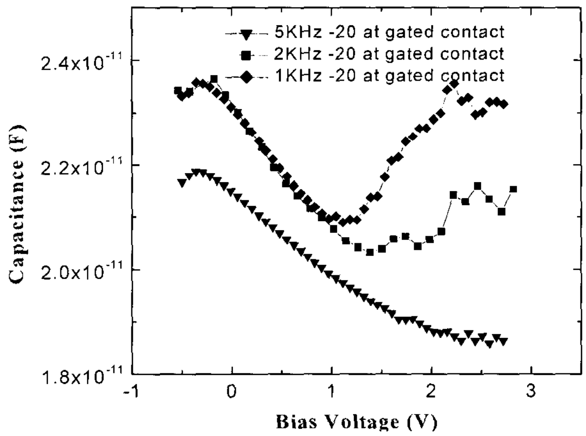


Fig. 3 C-V characteristics of GaN MOS gate-controlled diodes at 25 °C as a function of measurement frequency(+15V bias in gated contact in each case).

using elemental Sc evaporated from a standard effusion cell at 1130 °C and O_2 derived from an electron cyclotron plasma source operating at 200W forward power (2.45GHz) and 10^{-4} Torr. The Sc_2O_3 layers were ~400Å thick. The smaller mismatch between the Sc_2O_3 and the GaN (0001) should lead to a lower defect density and in fact the FWHM in the x-ray diffraction scan is substantially reduced at 514 arcseconds as compared to the 883 arcseconds found for comparable Gd_2O_3 layers, as shown in Figure 1.

The MgO was deposited by MBE at 100°C. The MgO precursors were elemental Mg and radio-frequency plasma-activated oxygen. The GaN samples were cleaned initially with a 3 min chemical etch in HCl/H_2O(1:1), H_2O rinse, UV-ozone exposure for 25 min, rinse in buffered oxide etch solution(6:1, NH_4F/HF) and rinsed in H_2O. The samples were then loaded into the MBE system and heated at 650 °C to ensure oxide removal. A standard effusion cell operating at 380 °C was used for evaporation of the Mg, while the O_2 source was operated at 300W forward power(13.56MHz) and 2.5×10^{-5} Torr. The MgO layers were ~800Å thick. In separate measurements, we obtained interface state densities of $2\text{-}3\text{x}10^{11}$ cm^2eV^{-1} from the AC Conductance and Terman methods(39-42).

N^+ regions were created by selective implantation of Si^+ at multiple energies and doses (70keV, $2 \times 10^{13}cm^2$, 195 keV, $6 \times 10^{13}cm^{-2}$ and 380 keV, $1.8 \times 10^{14}cm^{-2}$). The junction depth was ~0.4 μm from ion range simulations. The samples were then annealed at 950°C under N_2 to activate the Si-implanted regions. Windows were etched into the oxide and e-beam deposited p-ohmic(Ni/Au), n-ohmic(Ti/Al/Pt/Au) and gate metal(Pt/Au) were patterned by lithography. The separation of the n^+ regions was ~ 60μm. A schematic of the completed gate-controlled diode is shown in Figure 2.

III. RESULTS AND DISCUSSION

A. *Gate-controlled diodes*

Figure 3 shows C-V characteristics of the MgO/GaN MOS-controlled diodes at 25°C in the dark as a function of the measurement frequency. In each case, -20V was applied at the gated contact to provide a source of minority carriers. The frequency dispersion observed in inversion is due to the resistance of the inversion channel. At 5 KHz measurement frequency, we observe only deep depletion since the characteristics are dominated by majority carriers. As the frequency is decreased, a clear inversion behavior is observed due to charge flow into and from the n^+ regions external to the gate. In diodes without the n^+ regions to act as an external supply of minority carriers, we could not observe inversion, even up to measurement temperatures of 300C.Similar results were obtained for Sc_2O_3/GaN diodes.

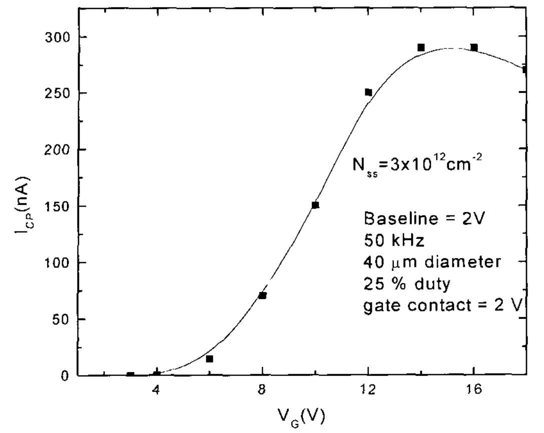
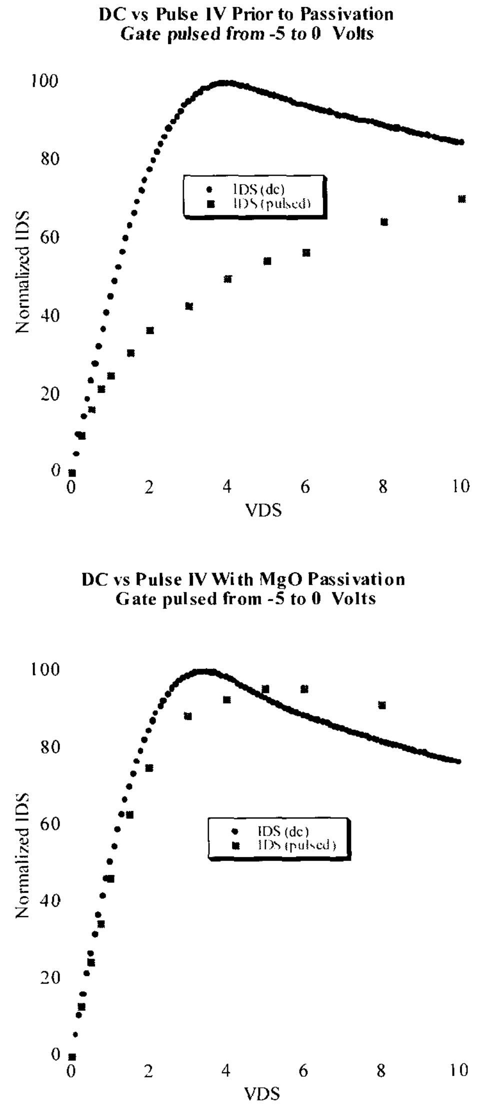


Fig. 4 Charge-pumping current as a function of pulsed gate voltage.


DC vs Pulse IV Prior to Passivation
Gate pulsed from -5 to 0 Volts

DC vs Pulse IV With MgO Passivation
Gate pulsed from -5 to 0 Volts

Fig. 5 (top)Gate lag measurements on unpassivated AlGaN/GaN HEMTs. V_G is switched from -5V to 0V.(bottom)similar measurements after MgO passivation.

We also used charge pumping experiments to measure the surface state density. This density, N_{SS}, can be related to the pulse frequency υ and charge-pumping current I_{CP} through the relation

$$N_{SS}=\frac{I_{CP}}{\upsilon A_C e}$$

where A_C is the diode channel area and e is the electronic charge. Figure 4 shows typical data measured at υ = 50kHz. From this data, we obtain $N_{SS}= 3 \times 10^{12}$ cm^{-2} at the Sc_2O_3/p-GaN interface Note that no effort has been made in our structures to passivate surface states through forming gas anneals or plasma hydrogenation. This is the first measurement of surface state density in GaN-based MOS structures that more fully approximate a transistor, i.e. the structures show inversion and have gone through an extensive device processing sequence.

B. *Surface Passivation*

We have employed gate lag measurements on the HEMTs as a metric for establishing the effectiveness of the oxide passivation[38]. In this method, the drain current (I_{DS}) response to a pulsed gate-source voltage (V_G) is measured. Figure 5(top) shows the normalized I_{DS} as a function of drain-source voltage (V_{DS}) for both dc and pulsed measurements on unpassivated HEMTs. In the data, V_G was pulsed from –5V to 0 at 0.1MHz and 10% duty cycle. The bottom of Figure 5 shows the normalized I_{DS} for the same device after MgO deposition. Note the much reduced current collapse. Figure 6 shows the normalized I_{DS} as a function of gate -source voltage, V_G, switched from –5V to 0V with V_{DS} held constant at a low value (3V) to avoid the complications of device heating, for both unpassivated(top) and MgO-passivated HEMTs. The large differences between dc and pulsed drain currents in the case of the unpassivated devices is consistent with the presence of surface traps that deplete the channel in the access regions between the gate and drain contacts. However, after MgO deposition, the HEMTs showed an increase in drain-source current of 20% in the dc mode which is consistent with passivation of surface state. This is clear evidence for the assumption that surface states are the cause of the gate-lag phenomena and also that MgO passivation mitigates this problem. Once again, similar results were obtained with

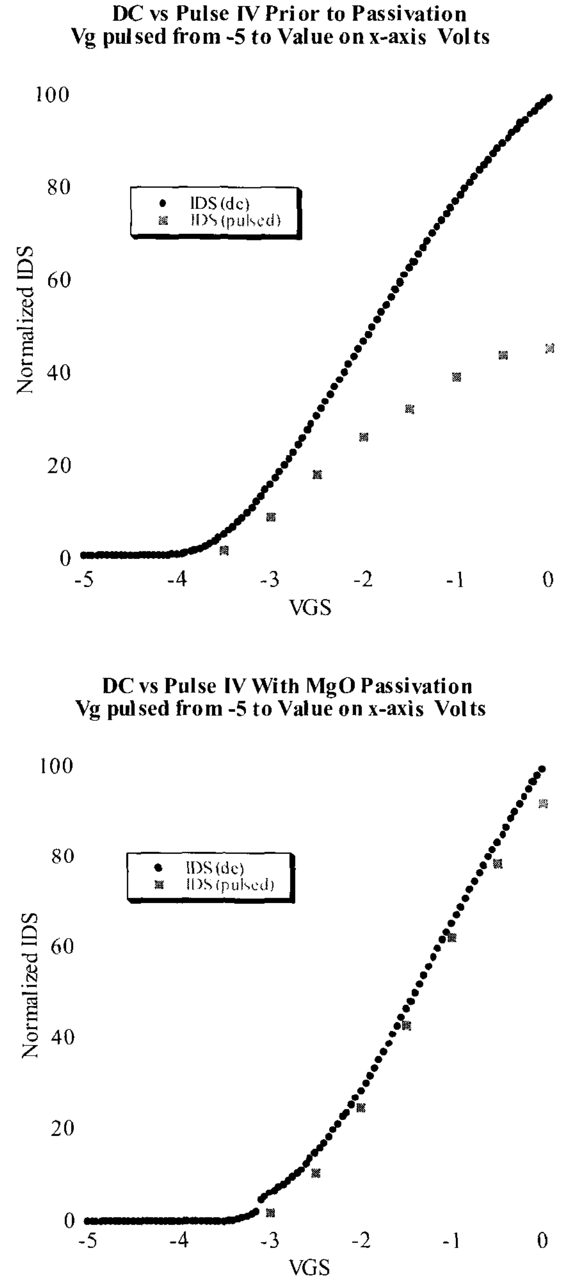


Fig. 6 (top)Gate lag measurements on unpassivated AlGaN/GaN HEMTs. V_G is switched from −5V to the value shown on the X-axis.(bottom)similar measurements after MgO passivation.

Sc_2O_3 passivation.

Typical load-pull data for HEMTs before and after Sc_2O_3 passivation are shown in Figure 7 for a measurement frequency of 4GHz. In all cases, the drain voltage, V_D, was held at 10V, while the gate voltage V_G was −2V. The wafer measurements employed mechanical tuners for matching and there was no harmonic termination under class A operation. The devices were matched for the power testing prior to passivation and were tested under these same conditions after oxide deposition. Note the increased power output. By contrast, the difference in output power before and after SiN_X passivation was < 2dB in all cases. This is consistent with the higher percentage recovery of I_{DS} during the gate lag measurements with Sc_2O_3 passivation. The Sc_2O_3 passivation has shown excellent aging characteristics when measured under dc test conditions, with no change in HEMT performance over a period of > 5 months.

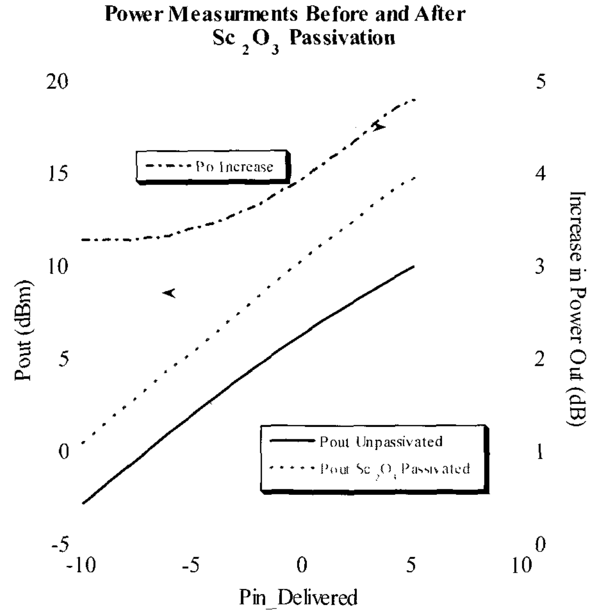


Fig. 7 Output power characteristics before and after Sc_2O_3 passivation of 0.5 × 100μm^2 devices measured at 4GHz and a bias point of V_D = 10V, V_G = -2V.

C. *Radiation damage experiments*

MgO/GaN metal oxide semiconductor diodes were irradiated with 40MeV protons at a fluence of 5×10^9 cm^{-2}, simulating long-term (10 years) exposure in space-borne applications. The result of the proton irradiation was a decrease in device capacitance, consistent with the creation of deep electron traps that reduce the effective channel doping and also a decrease in breakdown field from ~10^6 V·cm^{-1} in control devices to 0.76×10^6 V·cm^{-1} in devices irradiated with the gate metal in place. The capacitance of the device irradiated with the contacts in place recovers to the same value as the contact diodes.

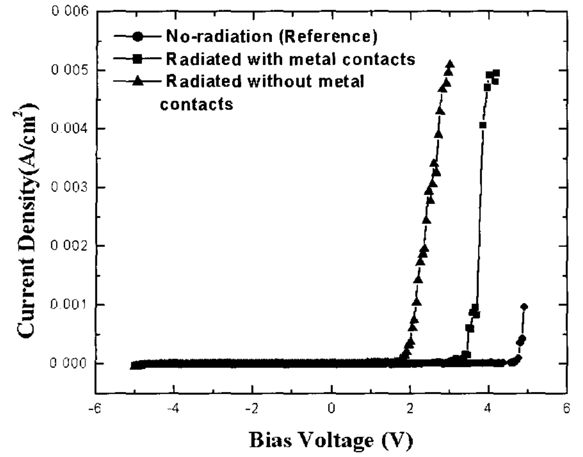


Fig. 8 Current density-voltage (top) and capacitance-voltage characteristics (bottom) from MgO/GaN MOS devices before and after irradiation.

The D_{it} values are decreased by the H_2 anneal in both the unirradiated and irradiated devices.

Figure 8 shows the current density(J)-voltage(top) and capacitance-voltage(C-V) characteristics(bottom) from the MgO/GaN devices with 500Å oxide thickness before and after proton irradiation. We also irradiated devices both before and after deposition of their gate contacts in order to investigate the effect of the presence of the metal over the MgO. While we could not measure any significant change in reverse breakdown voltage as a result of the proton irradiation, the V_F values were decreased in both types of devices(i.e. those irradiated before or after deposition of the gate metal). The D_{it} values extracted from the C-V characteristics using the Terman method(which is generally found to under-estimated the trap density), were also essentially unchanged in the devices from which we could extract accurate date. Note that the forward breakdown field decreases from $\sim 10^6$ V·cm^{-1} in the control samples to $\sim 0.76 \times 10^6$ V·cm^{-1} for the devices irradiated with contacts in place and for 0.46×10^6 V·cm^{-1} for the structures irradiated prior to deposition of the contacts. This result indicates that the protons make displacement-damage in the MgO which degrade its breakdown capabilities.

IV. CONCLUSIONS

Rapid recent progress in the development of gate dielectrics and surface passivation films for GaN electronic devices has been reported. This research shows the promise of MOS-HEMTs with appropriate passivation for applications in low noise amplifiers with high dynamic range and also in high efficiency power amplifiers.

ACKNOWLEDGEMENTS

The work at UF was partially supported by ONR under contract N00014-98-1-02-04 (H. B. Dietrich) and NSF (DMR0101438 and CTS 9901173)

REFERENCES

[1] N. X. Nguyen, M. Micovic, W.-S. Wong, P. Hashimoto, L.-M. McCray, P. Janke, C. Nguyen, *Electron. Lett.* 36, 468(2000).

[2] Y. -F. Wu, B. P. Keller, S. Keller, D. Kapolnek, P. Kozodoy, S. P. DenBaars and U. K. Mishra, *Solid-State Electron.*, 41, 1569(1997).

[3] M. A. Khan, X. Hu, G. Simin, A. Lunev, J. Yang, R. Gaska, and M.S. Shur, *IEEE Electron. Dev. Lett.* 21, 63(2000).

[4] B. M. Green, K. K. Chu, E. M. Chumbes, J. A. Smart, J. R. Shealy, and L. F. Eastman, *IEEE Electron. Dev. Lett.*, 21, 268(2000).

[5] S. C. Binari, W. Kruppa, H. B. Dietrich, G. Kelner, A. E. Wickenden and J. A. Freitas Jr, *Solid-State Electron.*, 41, 1549(1997).

[6] L. F. Eastman, V. Tilak, J. Smart, B. M. Green, E. M. Chumbes, R. Dimitrov, H. Kim; O. S. Ambacher, N. Weimann, T. Prunty, M. Murphy, W. J. Schaff, and J. R. Shealy, *IEEE Trans. Electron Dev.*, 48, 479(2001).

[7] Y. -F. Wu, B. P. Keller, S. Keller, D. Kapolnek, P. Kozodoy, S. P. DenBaars and U. K. Mishra, *Solid-State Electron.*, 41, 1569(1997).

[8] J. W. Johnson, A.G. Baca, R. D. Briggs, R. J. Shul, C. Monier, F. Ren, S. J. Pearton, A. M. Dabiran, A. M. Wowchack, C. J. Polley and P. P. Chow, *Solid-State Electron.*, 45, 1979(2001).

[9] W. Lu, J. Yang, M. A. Khan and I. Adesida, *IEEE Trans. Electron Dev.*, ED48, 581(2001).

[10] S. J. Pearton, J. C. Zolper. R. J. Shul and F. Ren, *J. Appl. Phys.*, 86, 1(1999).

[11] G.Simin, X. Hu, N. Ilinskaya, A. Kumar, A. Koudymov, J. Zhang, M. Asif Khan, R. Gaska, M. S. Shur, *Electron. Lett.* 36, 2043(2000).

[12] E. Kohn, I. Daumiller, P. Schmid, N. X. Nguyen, C. N. Nguyen, *Electron. Lett.* 35, 1022(1999).

[13] J.-S. Lee; A. Vescan, A. Wieszt, R. Dietrich, H. Leier, Y.-S. Kwon, *Electron. Lett.* 37, 130(2001).

[14] X. Hu, A. Koudymov, G. Simin, J. Yang, M. Asif Khan, A. Tarakji, M. S. Shur, and R. Gaska, *Appl. Phys. Lett.* 79, 2832(2001).

[15] I. Daumiller, C. Kirchner, M. Kamp, K. J. Ebeling, and E. Kohn, *IEEE Electron. Dev. Lett.* 20, 448(1999).

[16] A. Tarakji, G. Simin, N. Ilinskaya, X. Hu, A. Kumar, A. Koudymov, J. Yang, M. Asif Khan, M. S. Shur, and R. Gaska, *Appl. Phys. Lett.* 78, 2169(2001).

[17] E. M. Chumbes, J. A. Smart, T. Prunty and J. M. Shealy, *IEEE Trans. Electron Dev.*, 48, 416(2001).

[18] B. Luo, J. W. Johnson, F. Ren, K. K. Allums, C. R. Abernathy, S. J. Pearton, R. Dwivedi, T. N. Fogarty, R. Wilkins, A. M. Dabiran, A. M. Wowchack, C. J. Polley, P. P. Chow and A. G. Baca, *Appl. Phys. Lett.*, 79, 2196 (2001).

[19] S. J. Pearton, F. Ren, A. P. Zhang and K. P. Lee, *Mat. Sci. Eng. Rep. R30*, 55(2000).

[20] S. C. Binari, K. Ikossi, J. A. Roussos, W. Kruppa, D. Park; H. B. Dietrich, D. D. Koleske, A. E. Wickenden, and R. L. Henry, *IEEE Trans. Electron Dev.*, 48, 465(2001).

[21] G. Simin, A. Koudymov, A. Tarakji, X. Hu, J. Yang, M. Asif Khan, M. S. Shur, and R. Gaska, *Appl. Phys. Lett.* 79, 2651(2001).

[22] F. Ren, M. Hong, S. N. G. Chu, M. A. Marcus, M. J. Schurman, A. Baca, S. J. Pearton, and C. R. Abernathy, *Appl. Phys. Lett.*, 73, 3893(1998).

[23] J. W. Johnson, B. Luo, F. Ren, B. P. Gila, V. Krishnamoorthy, C. R. Abernathy, S. J. Pearton, J. I. Chyi, T. E. Nee, C. M. Lee, and C. C. Chuo, *Appl. Phys. Lett.*, 77, 3230(2000).

[24] B. P. Gila, J. W. Johnson, K. N. Lee, V. Krishnamoorthy, C. R. Abernathy, F. Ren, and S. J. Pearton, *ECS Proc. Vol.*, 2001-1, 71(2001).

[25] M. Asif Khan, X. Hu, A. Tarakji, G. Simin, J. Yang, R. Gaska, and M. S. Shur, *Appl. Phys. Lett.* 77, 1339(2001).

[26] G. Simin, X. Hu, N. Ilinskaya, J. Zhang, A. Tarakji, A. Kumar, J. Yang, M. Asif Khan, R. Gaska, M. S. Shur, *IEEE Electron. Dev. Lett.* 22, 53(2001).

[27] J. W. Johnson, B. P. Gila, B. Luo, K. P. Lee, C. R. Abernathy, S. J. Pearton, J. I. Chyi, T. E. Nee, C. M. Lee, C. Chou and F. Ren, *J. Electrochem. Soc.* G303(2001).

[28] Hadis Morkoç, Aldo Di Carlo and Roberto Cingolani, *Solid-State Electron.* 46, 157(2002).

[29] Y. Ohno, M. Kuzuhara, *IEEE Trans. Electron Dev.* ED48, 517(2001).

[30] Y.-F. Wu; D. Kapolnek, J. P. Ibbetson, P. Parikh, B. P. Keller, U. K. Mishra, *IEEE Trans. Electron Dev.* ED48, 586(2001).

[31] S. Arulkumaran, T. Egawa, H. Ishikawa, T. Jimbo, and M. Umeno, *Appl. Phys. Lett.* 73, 809(1998).

[32] I. Irokawa and Y. Nakano, Solid-State Electron. (In press).

[33] T. S. Lay, M. Hong, J. Kwo, J. P. Mannaerts, W. H. Hung and D. J. Huang, *Solid-State Electron.* 45, 1679(2001).

[34] T. Hashizume, E. Alekseev, D. Pavlidis, K. S. Boutros, and J. Redwing, *J. Appl. Phys.* 88, 1983(2000).

[35] N.-Q. Zhang, S. Keller, G. Parish, S. Heikman, S. P. DenBaars, U. K. Mishra, *IEEE Electron. Dev. Lett.* 21, 421(2000).

[36] B. P. Gila, J. Johnson, R. Mehandra, B. Luo, A. H. Onstine, K. K. Allums, V. Krishamoorthy, S. Bates, C. R. Abernathy, F. Ren, and S. J. Pearton, *Phys. Stat. Solidi* A188, 239(2001).

[37] P. B. Klein, S. C. Binari, K. Ikossi, A. E. Wickenden, D. D. Koleske, and R. L. Henry, *Appl. Phys. Lett.* 79, 3527 (2001).

[38] B. Luo, J. W. Johnson, J. Kim, R. M. Mehandru, F. Ren, B. P. Gila, A. H. Onstine, C. R. Abernathy, S. J. Pearton, A. G. Baca, R. D. Briggs, R. J. Shul, C. Monier, and J. Han, *Appl. Phys. Lett.* 80, 1661(2002).

[39] 39.R.Mehandru,B.P.Gila,J.Kim,J.W.Johnson,K.P.Lee,B. Luo,A.H.Onstine,C.R.Abernathy,S.J.Pearton and F.Ren, Electrochem.Solid-State Lett.5 G51(2002).

[40] J.Kim,R.Mehandru,B.Luo,F.Ren,B.P.Gila,A.H.Onstine,C .R.Abernathy,S.J.Pearton and Y.Irokawa,Appl.Phys.Lett. 81 373(2002).

[41] J.Kim,R.Mehandru,B.Luo,F.Ren,B.P.Gila,A.H.Onstine,C .R.Abernathy,S.J.Pearton and Y.Irokawa,Appl.Phys.Lett. 80 4555 (2002).

[42] 42.J.Kim,B.Gila,R.Mehandru,J.W.Johnson,J.H.Shin,K.P. Lee,B.Luo,A.Onstine,C.R.Abernathy,S.J.Pearton and F. Ren,J.Electrochem.Soc.149 G482(2002).

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