Non-contact Characterization of Bias Stress-Induced Instability of 2DEG in SiN/AlGaN/GaN Structures

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Abstract

We report a novel application of corona-charge-Kelvin probe metrology that enables quantitative characterization of bias-stress induced charge transfer involving interface states, dielectric traps and 2DEG in SiN/AlGaN/GaN structures. The measurements are performed without fabrication of MIS-HEMTs, MIS capacitors or ohmic contacts. Instead, incremental corona charging of the SiN surface provides a bias sweep for non-contact corona-kelvin measurements, while larger dose charging creates bias-stress. The capacitance-voltage, C-V, and capacitance-charge, C-Q, characteristics are used for determination of the interfacial and 2DEG parameters before and after bias-stress application. The results identify different behavior in low and high bias-stress fields. For fields below the tunneling range, the charge transfer involves the interfacial traps and the 2DEG, including photo-assisted processes. The C-V shift is a simple translation analogous to threshold voltage instability. For large positive stress fields, the charging of traps in SiN takes place, increasing the C-V shift. In addition, stress-induced interface traps are created and manifested by stretch-out in C-V. Negative corona biasing can also be used to quickly investigate negative bias-stress (NBI) phenomena in passivated HEMT structures.

Experimental Results and Discussion

We have recently demonstrated application of the charge-based corona-Kelvin metrology for noncontact electrical characterization of wide energy gap semiconductors including AlGaN/GaN structures [1]. This technique does not require fabrication of electrical test devices or electrical contact thereby reducing cost and providing fast data feedback that can benefit development, pilot lines, and manufacturing lines. The present work demonstrates characterization of bias stress-induced instability effects taking place in SiN/AlGaN/GaN structures [2].

The measured structures were Ga-face MOCVD grown layers on Si-substrates. The structure from top to bottom was: 18nm LPCVD SiN, 20nm $Al_{0.26}Ga_{0.74}N$ and 3.5µm GaN on a n-Si substrate.

Figures 1A and 1B show the pre-stress non-contact corona-Kelvin capacitance characteristics. The C-V results in Figure 1A are similar to results of MIS or Hg-probe measurements on similar structures [2,3]. The two capacitance ledges correspond to the SiN capacitance at V > +6V and the total capacitance from +4V to -7V. The sharp drop below -7V is due to depletion of two-dimensional gas at the AlGaN/GaN interface. The pinch-off voltage V_P corresponds to half of the capacitance drop. The C-Q characteristic in Fig. 1B was measured simultaneously with the C-V. It provides a means for direct parameter-free determination of the 2DEG charge i.e., the corona charge density required for full depletion of the 2DEG.

Figure 2 demonstrates the positive bias-stress induced instability that causes a positive shift of C-V. For a low dielectric stress field of +2MV/cm (i.e., below tunneling range), the C-V shift is a simple translation by $\Delta V=+1.6V$. As seen in Fig. 3 the ΔV is independent of stress time even for a 15h stress. This is unlike interfacial instability in SiO_2/SiC caused by electron tunneling to near-interfacial dielectric traps [1]. Increasing of the positive bias-stress (PBS) field to a tunneling range has two effects seen in Fig. 2: 1) it increases the magnitude of ΔV to +4.9V, perhaps due to charging of traps in the SiN and 2) it increases the interface trap density at SiN/AlGaN interface. The latter effect is manifested by the stretch-out in the C-V characteristic observed in Fig 2.

Negative corona bias-stress in the dark beyond the full depletion of the 2DEG causes a drop of capacitance to a low value that cannot be reserved by simply using positive bias. In order to populate the 2DEG and recover the pre-stress capacitance range, photo-assisted positive bias is needed as illustrated by the results in Fig.4. By analogy to the current collapse effect, such behaviors can be explained considering photo-assisted charge transfer between interface traps and 2DEG discussed in ref [2,3]. After the photo-assisted recovery of the 2DEG, a negative C-V sweep reveals a ΔV shift of -2.7V which is an indication of the negative bias instability (NBI) for this SiN/AlGaN/GaN structure.

References

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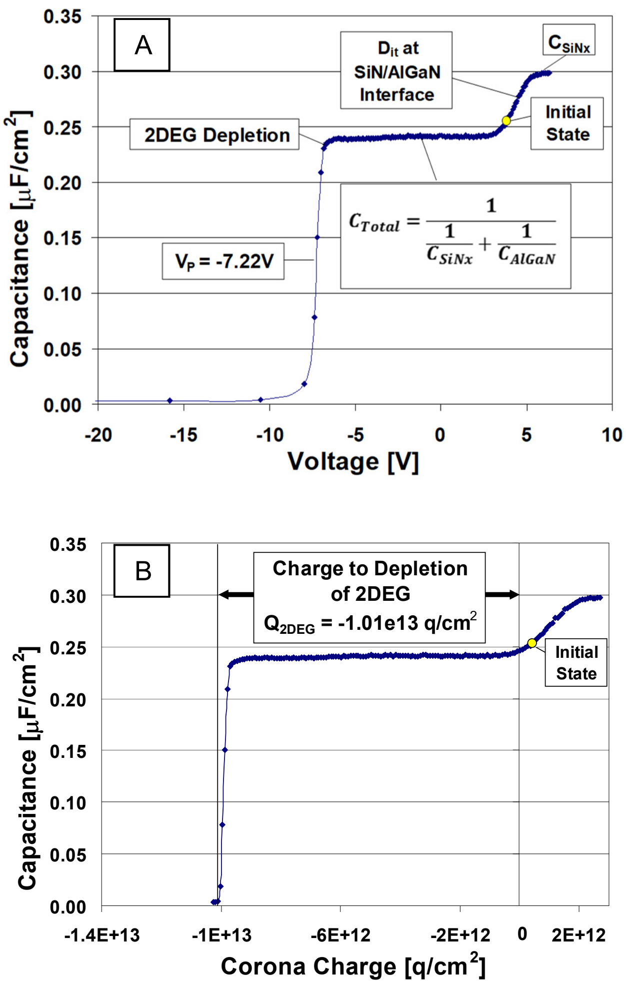

Figure 1. Example non-contact corona-Kelvin C-V (A) and C-Q (B) characteristics for HEMT structure passivated with 18nm SiN_x.

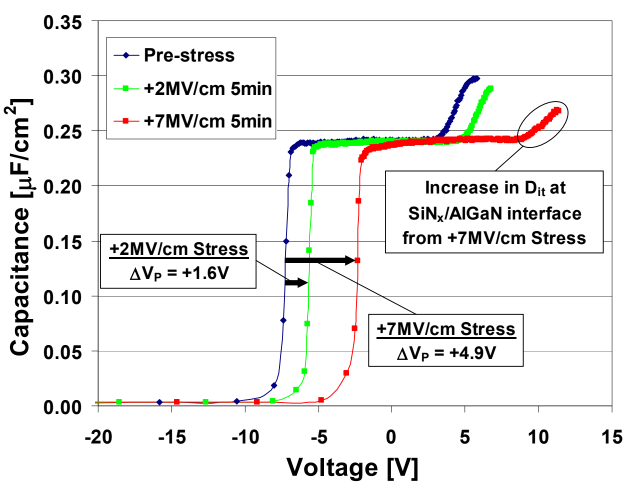

Figure 2. V_P shifts in 18nm SiN_x passivated AlGaN/GaN HEMT structure induced by positive corona stress in low and high field ranges of +2MV/cm and +7MV/cm.

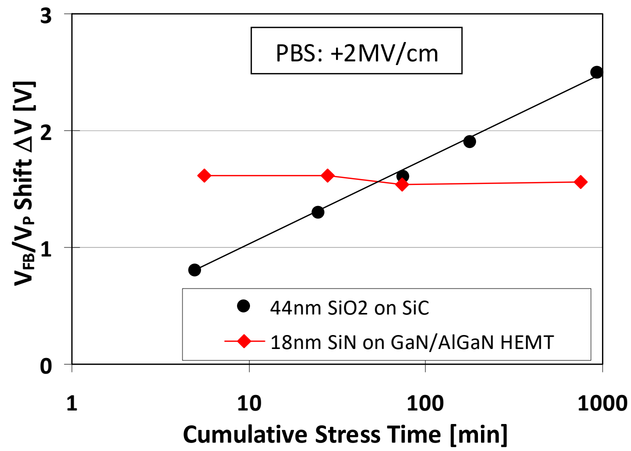

Figure 3. Logarithmic stress time dependence of +2MV/cm corona bias stress-induced flatband shift of 44nm SiO_2 on SiC and 18nm SiN_x on AlGaN/GaN HEMT.

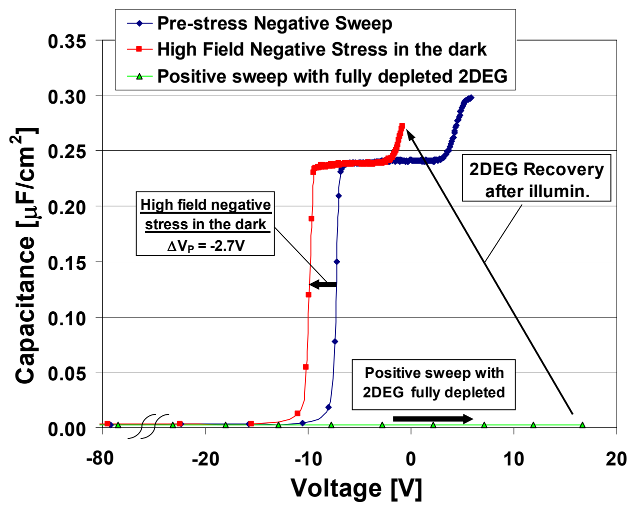

Figure 4. V_P shift in 18nm SiN_x passivated AlGaN/GaN HEMT structure induced by high negative field stress corona stress in the dark.