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Supplementary Information

Strong interfacial coupling effect of ferroelectric polarization with two-dimensional electron gas in $BaTiO_3$/MgO/AlGaN/GaN/Si heterostructure†

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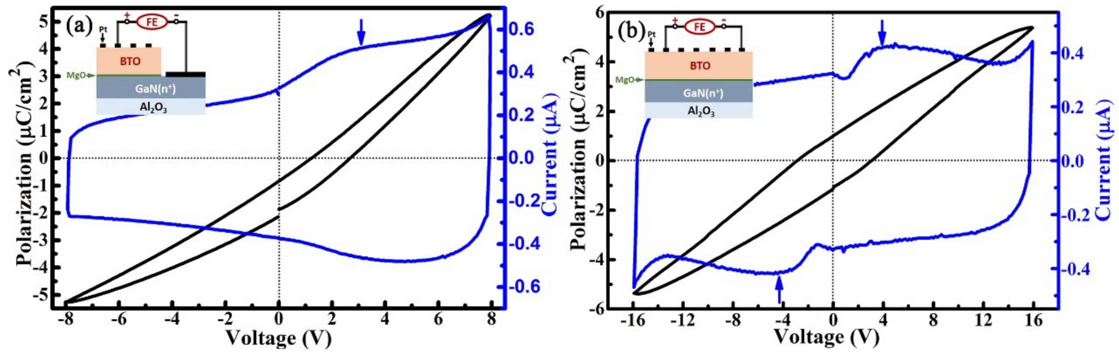

Fig. S1. P-V loop and corresponding I-E curve with (a) top-bottom electrode test mode and (b) top-top electrode test mode in BTO/MgO/GaN (n^+).

Fig. S1 shows the P-E loop and corresponding I-E curve of BTO thin films on GaN (n^+) with top-bottom and top-top electrode test mode, which indicate relatively weak ferroelectric domain switching property in BTO. The relatively weak switching current peaks in I-E curve with top-top electrode test mode prove the ferroelectric properties in BTO, and the relatively low Pr value could be originated from the pinning effect by formation of depletion layer in GaN, large depolarization field for incomplete screening of charges at BTO/MgO interface and relatively large leakage current in BTO.

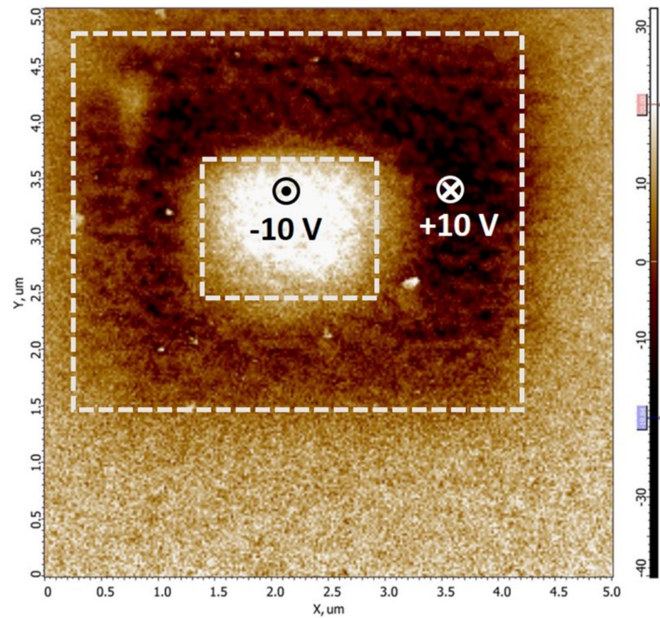

Fig. S2. PFM phase image of BTO in BTO/GaN (n+) after poling treatment.

As shown in **Fig. S2**, the ferroelectric domain switching property is confirmed by PFM phase image. Ferroelectric domain could be partly switched to upward and downward directions with -10 V and + 10 V external voltage, respectively. Weak upward self-polarization could be also confirmed for the positive phase angle without poling treatment, which is consistent with pervious PFM results.

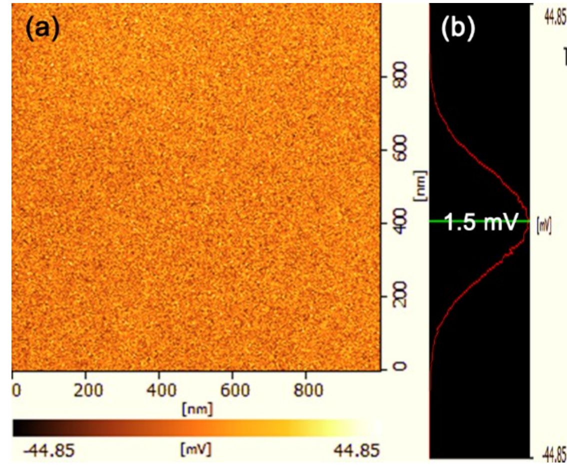

Fig. S3. (a) OPP PFM piezoresponse signal image and (b) Histogram for PFM piezoresponse signal of GaN/Al_2O_3 substrates without poling.

Under consideration the piezoelectric property of (0002) GaN, the PFM test was conducted on GaN/Al_2O_3 substrates. The piezoresponse signal is weak and the median statistical distribution is only 1.5 mV, which confirms that the large median statistical distribution of 36.9 mV in BTO/MgO/GaN/Al_2O_3 is originated from the self-polarization of BTO.

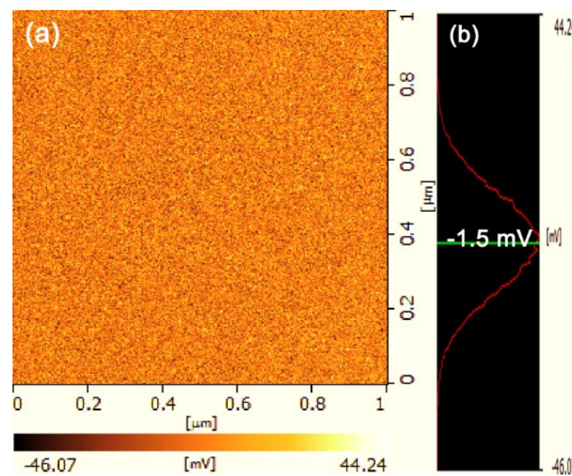

Fig. S4. (a) OPP PFM piezoresponse signal image and (b) Histogram for PFM piezoresponse signal of AlGaN/GaN/Buffer/Si substrates without poling.

Piezoresponse signal is weak and the median statistical distribution is only -1.5 mV, which confirms that the large median statistical distribution of 41.8 mV in BTO/MgO/AlGaN/GaN/Si is originated from the self-polarization of BTO.

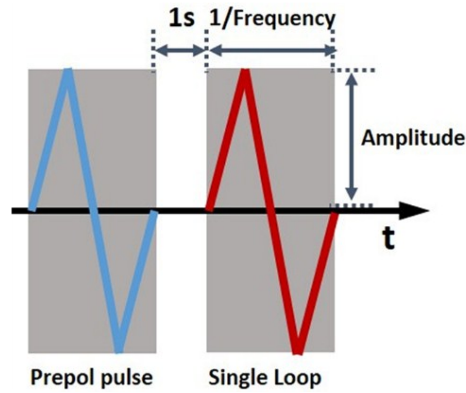

Fig. S5. Electrical signal in ferroelectric single loop test mode.

As shown in **Fig. S5**, the electrical signal in ferroelectric single loop test mode is constituted by prepol pulse and single loop test pulse with periodic time of 0.01 s (100 Hz) and interval time of 1 s. 2DEG at AlGaN/GaN interface would be depleted by upward polarization of BTO after poling with negative voltage signal in prepol pulse. Thus, the voltage signal would be loaded both on BTO and thick AlGaN/GaN in single loop test pulse. Owing to the low capacitance of AlGaN/GaN, the actual voltage loaded on BTO is small. The ferroelectric domain is hard to be switched by the single loop test pulse voltage. Hence, upward polarization of BTO would be pinned after FE tests, and upward polarization intensity could be regulated with different FE test voltage.

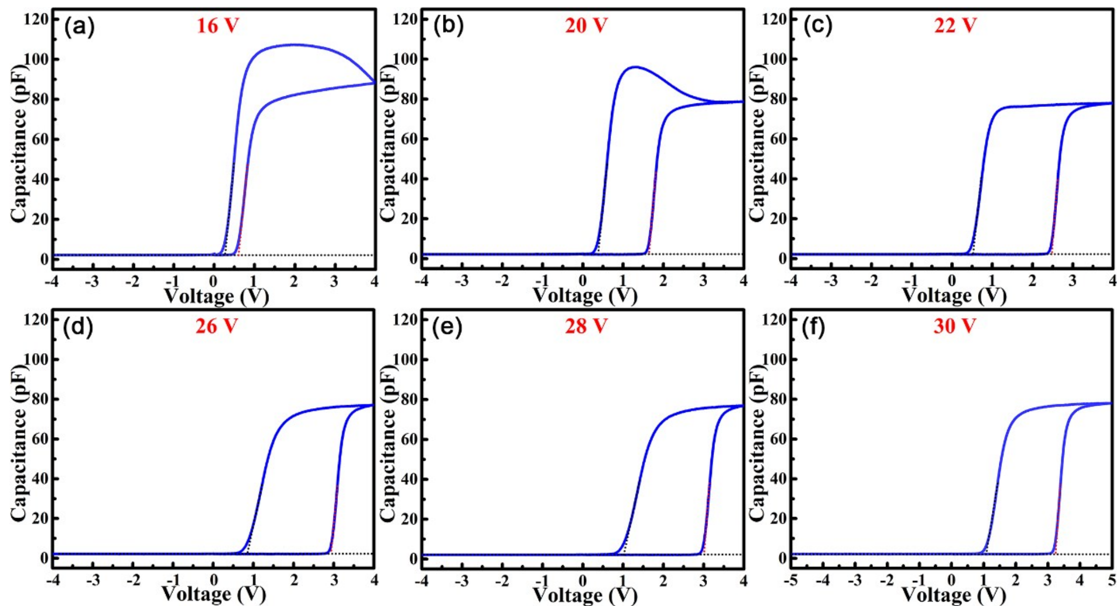

Fig. S6. C-V curves of BTO gate HEMT after poling with external ferroelectric test voltage of (a) 16 V, (b) 20V, (c) 22 V, (d) 26V, (e) 28V, (f) 30V.

Fig. S6 shows the C-V curves of BTO gate HEMT after poling with different FE test voltage. Threshold voltage of BTO/MgO/AlGaN/GaN is gradually raised with the enhancement of FE test voltage.