Supporting Information

Epitaxtial lift-off for flexible arrayed GaN-based HEMT and its performances optimization by the piezotronic effect

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Supplementary Notes:

The calculation of intrinsic polarization in AlGaN/AlN/GaN heterostructure membrane: The intensity of spontaneous polarization in GaN is -0.034 C/m^2, in AlN is -0.090 C/m^2 which the direction is opposite to the +c-axis. The intensity of spontaneous polarization in AlGaN can be calculated from the formula [1]:

$$p_{sp}(Al_xGa_{1-x}N) = [-0.09x - 0.034(1-x) + 0.019x(1-x)]\ C/m^2 \quad (1)$$

Where x represents Al component.

In our work, Al component is 0.3, thus the intensity of spontaneous polarization in AlGaN is -0.0468 C/m^2. The lattice constants of AlN and GaN are 0.3112 nm and 0.3189 nm, the former is about 2.4% smaller than the latter. Thus, when the $Al_xGa_{1-x}N$ epitaxially fabricated on the GaN crystal is less than the critical thickness, a strained heterojunction structure will be formed, the $Al_xGa_{1-x}N$ film undergoes tensile strain in the lateral direction and compressive strain in the longitudinal direction. Thus, the lattice-mismatch piezoelectric polarization in $Al_xGa_{1-x}N$ can be obtained from the formula [2]:

$$p_{pz}(Al_xGa_{1-x}N/GaN) = [-0.0525x + 0.0282x(1-x)]\, C/m^2 \quad (2)$$

Where x represents Al component.

The intensity of piezoelectric polarization in $Al_xGa_{1-x}N$ (x=0.3) is -0.0098 C/m^2. Consider the combined effect of spontaneous polarization and piezoelectric polarizationin in AlGaN/GaN heterojunction, the total polarization intensity in AlGaN can be given from:

$$p_{Al_xGa_{1-x}N} = p_{sp}(Al_xGa_{1-x}N) + p_{pz}(Al_xGa_{1-x}N/GaN)\, C/m^2 \quad (3)$$

And the calculation results is -0.0566 C/m^2. At the $Al_{0.3}Ga_{0.7}N$/GaN heterojunction interface (AlN ultrathin layer is not considered), the net fixed charges can be estimated from:

$$p^{Total}_{Al_{0.3}Ga_{0.7}N/GaN} = p_{Al_xGa_{1-x}N} + p^{sp}_{GaN} \tag{4}$$

The net fixed charges at interface are 0.0226 C/m^2, which are always positive regardless of the stress condition.

Figure S1

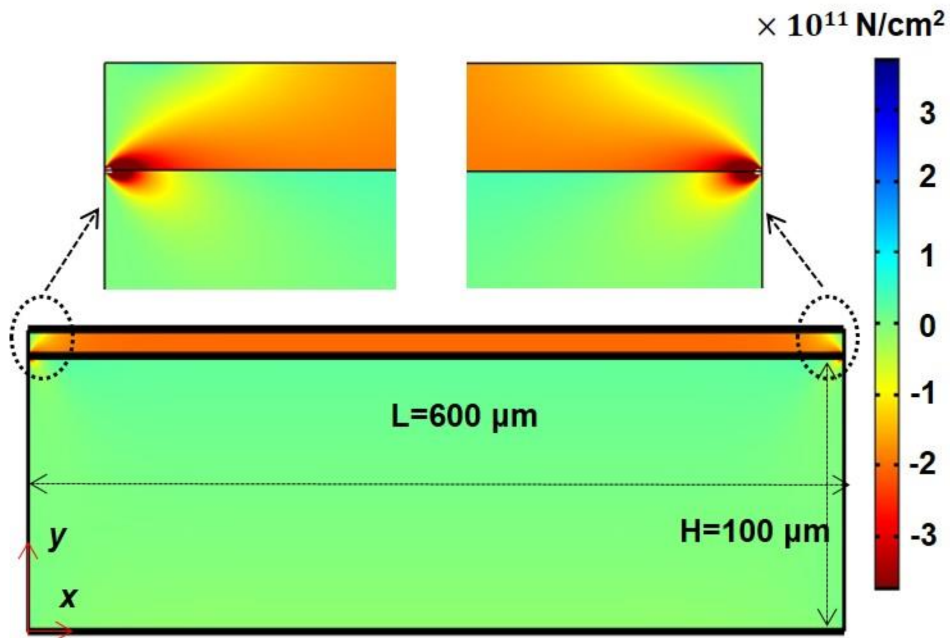

Figure S1. The simulated stress distribution of AlGaN/AlN/GaN heterostructure membrane. The model is the as-grown AlGaN/AlN/GaN heterostructure membrane. The partial enlarged detail is selected in the range y=100 to y=110 μm and x=600 μm.

Figure S2

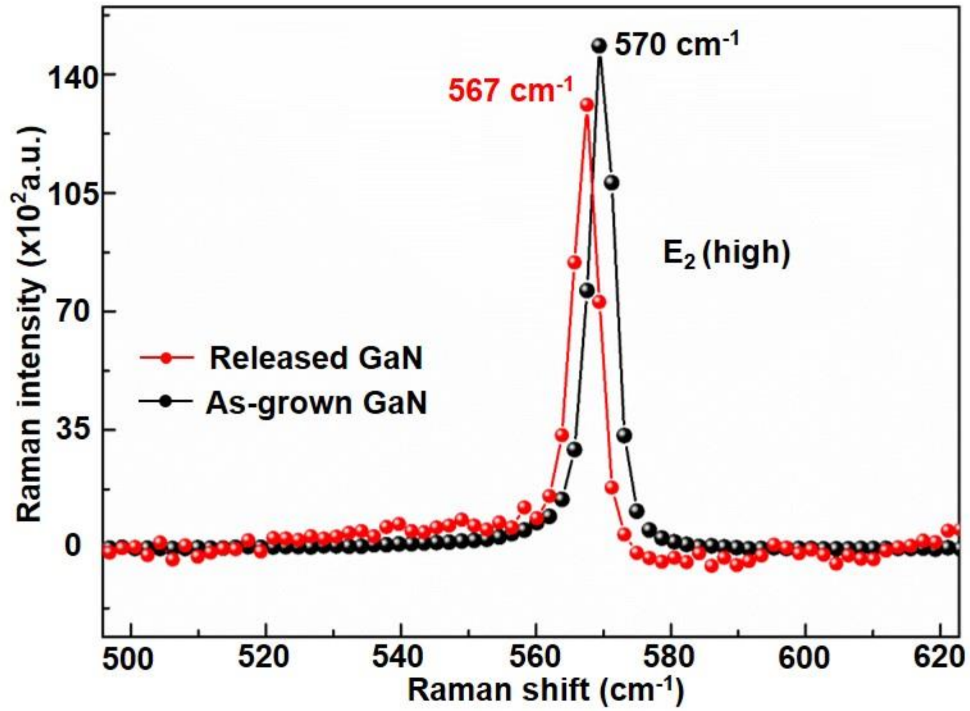

Figure S2. Roman scattering measured from as grown as-grown AlGaN/AlN/GaN heterostructure membrane on sapphire (black line) and after (red line) releasing.

Figure S3

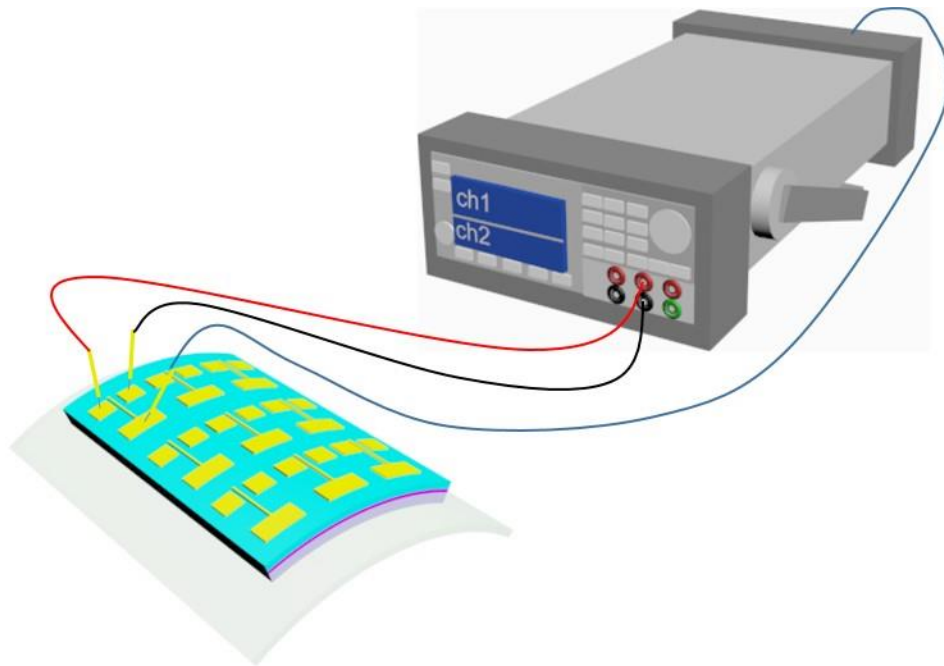

Figure S3. The schematic diagram of Keysight B2902A Precision Source/Measure Unit combined with a probe station to measure DC I_{ds}-V_{ds}.

Figure S4

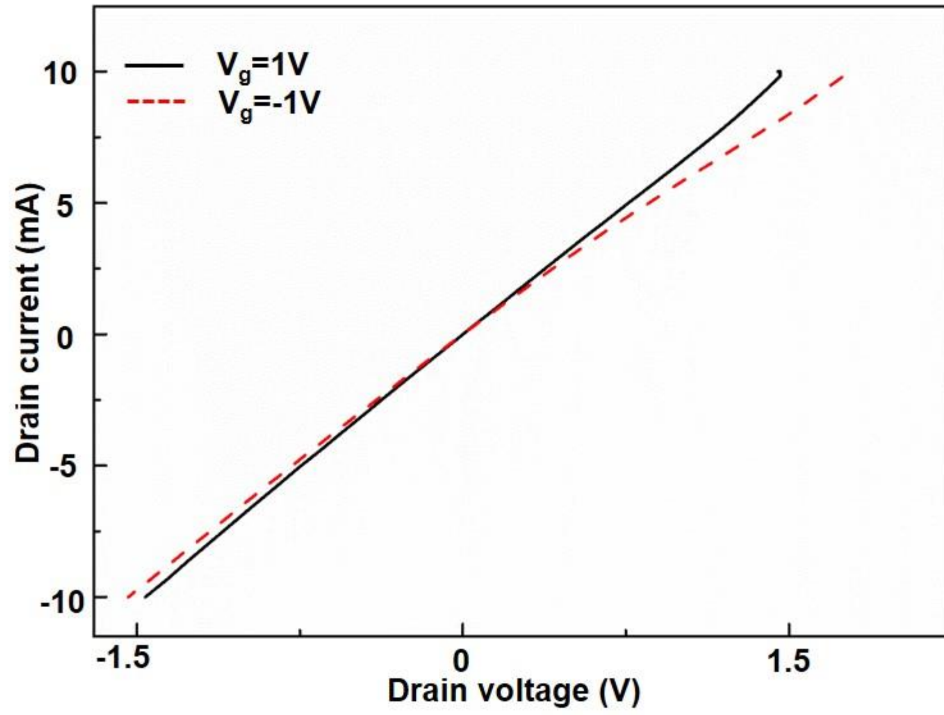

Figure S4. The electrical characteristics measure of HEMTs on sapphire, with sacrificial layers.

Figure S5

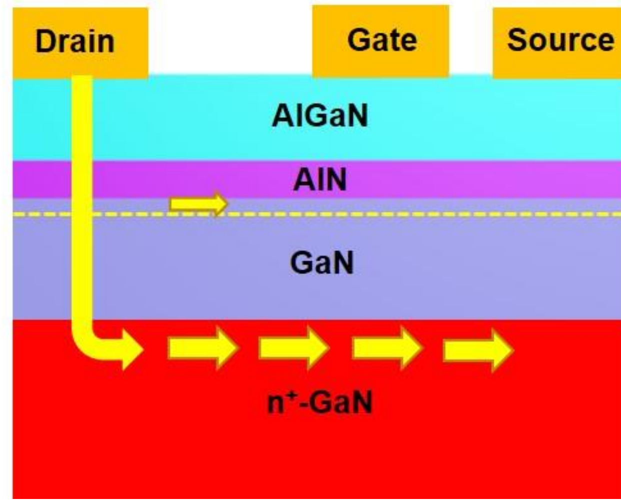

Figure S5. The schematic diagram of electron transmission path with the existence of n^+-GaN layer.

Figure S6

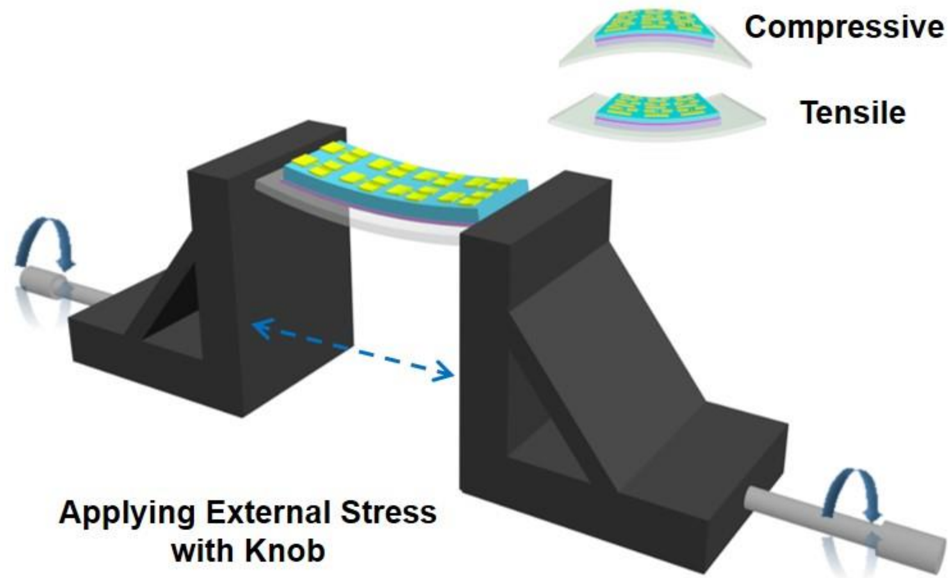

Figure S6. The schematic diagram of experimental device and membrane for inducing external strain.

Table S1. The relative change of saturation drain current value and the corresponding peak position under different strain state.

$(I_{stress}-I_{0.00})/I_{0.00}$	Compression strain	Tensile strain
Vg=1V	-13.56%	8.63%
Vg=0V	-43.53%	3.15%
Vg=-1V	-51.08%	5.38%
Vg=-1.5V	-50.68%	6.39%

Supplemental References:

1. O. Ambacher, J. Smart, J. R. Shealy, N. G. Weimann, K. Chu, M. Murphy, W. J. Schaff, L.F. Eastman, R. Dimitrov, L. Wittmer, M. Stutzmann, W. Rieger, J. Hilsenbeck, Two-dimensional electron gases induced by spontaneous and piezoelectric polarization charges in N- and Ga-face AlGaN/GaN heterostructures. J. Appl. Phys. **85**, 3222-3233 (1999). **https://doi.org/10.1063/1.369664**
2. V. Fiorentini, F. Bernardini, O. Ambacher, Evidence for nonlinear macroscopic polarization in III–V nitride alloy heterostructures. Appl. Phys. Lett. **80**, 1204-1206 (2002). **https://doi.org/10.1063/1.1448668**