2020「中技社科技獎學金」

2020 CTCI Foundation Science and Technology Scholarship

境外生研究獎學金

Research Scholarship for International Graduate Students

Energy Band Engineering of III-Nitride High Electron Mobility Transistors for Power and RF Applications

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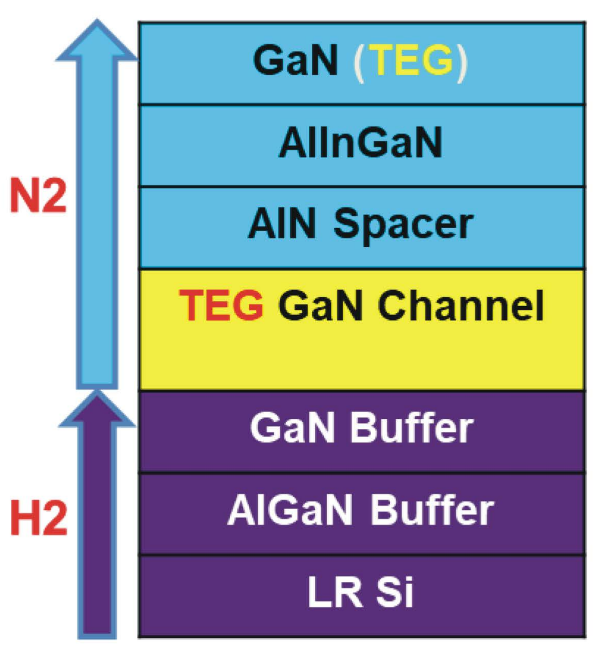
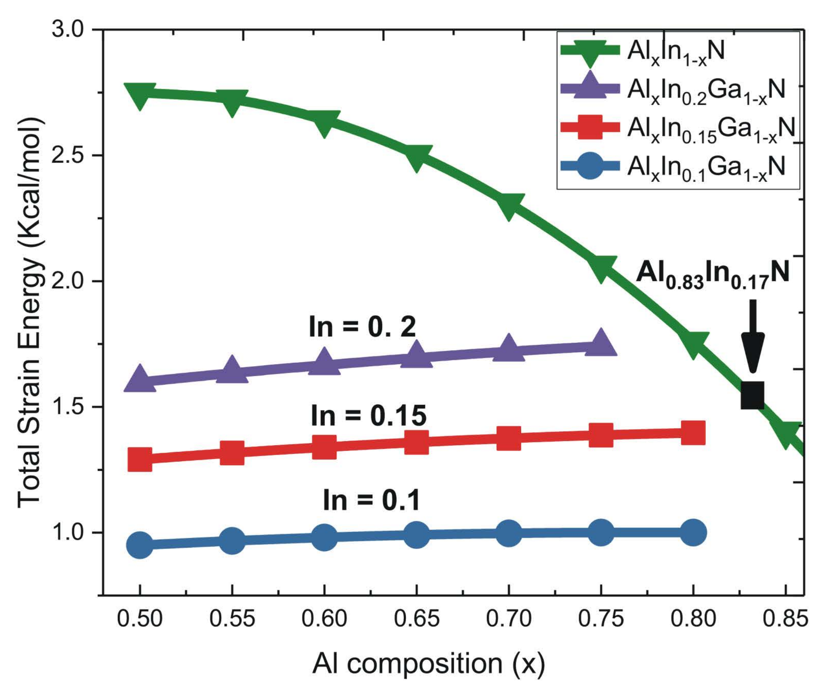
Aim and Scope

Our research is helpful in developing cost effective high power mm-wave GaN high electron mobility transistors (HEMTs) on low cost large diameter 150 mm low resistivity silicon substrates for 5G applications. The aim is to grow very high quality epitaxial layers and find a way to eliminate parasitic conduction at the substrate/buffer junction to minimize large signal power loss at high operating frequency. Furthermore, the research on emerging B(Al,Ga)N/(B)GaN heterostructures may open new opportunities in designing the next generation high current density and/or high power RF transistors due to the high two dimensional electron gas (2DEG) at the B(Al,Ga)N/(B)GaN heterointerface and lattice matched barrier/buffer with the SiC substrates.

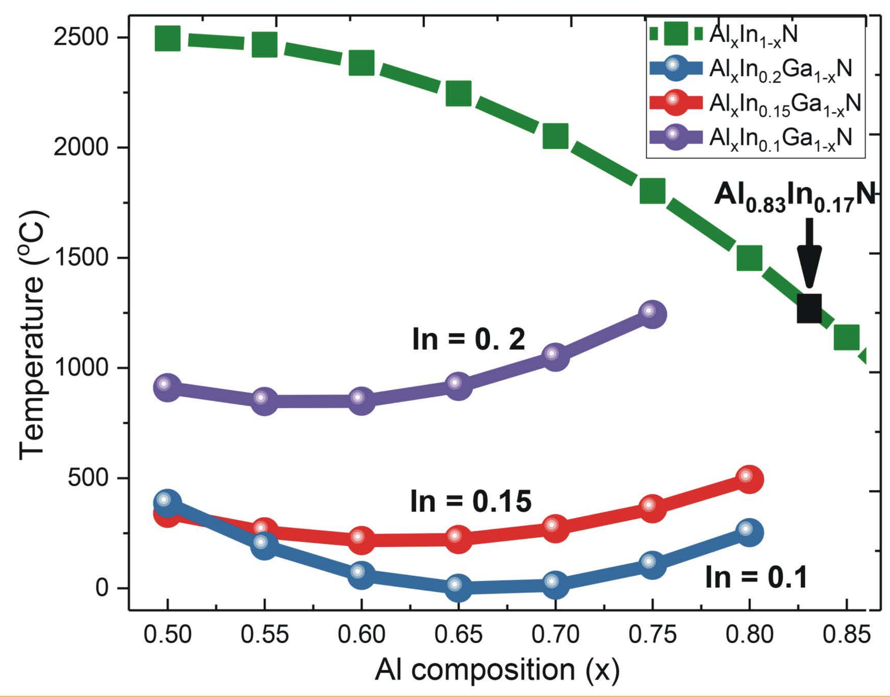
AlInGaN Heterostructure and its Thermodynamic Stability

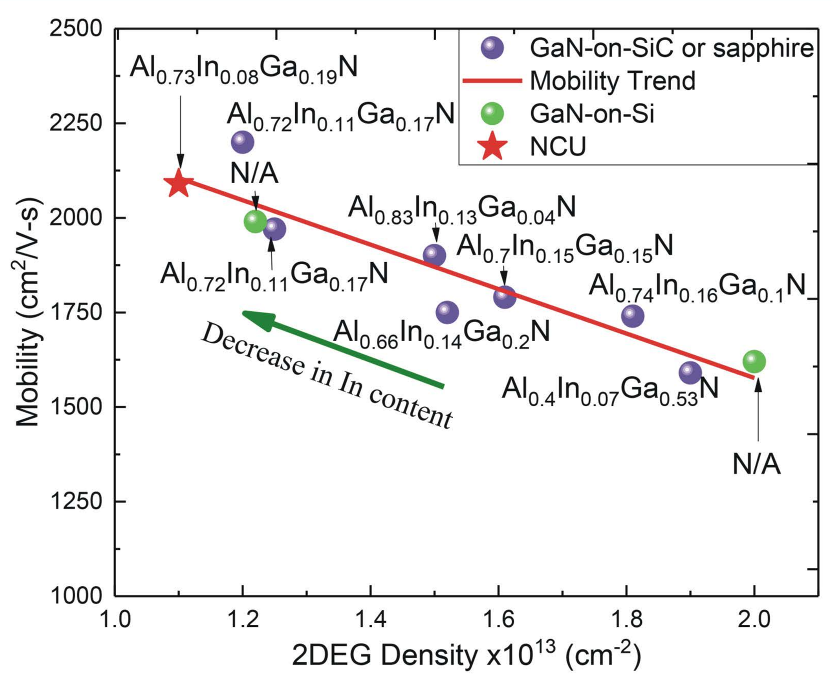




- ✓ TEG grown GaN channel in N_2 ambient significantly reduces C-incorporation up to an order of magnitude as compared to TMG grown GaN in H_2 ambient
- ✓ A slow change in stability when the Ga atoms replace Al atoms
- ✓ Significant improvement in stability when indium atoms are replaced by Ga atoms owing to significant reduction in total elastic strain in the barrier

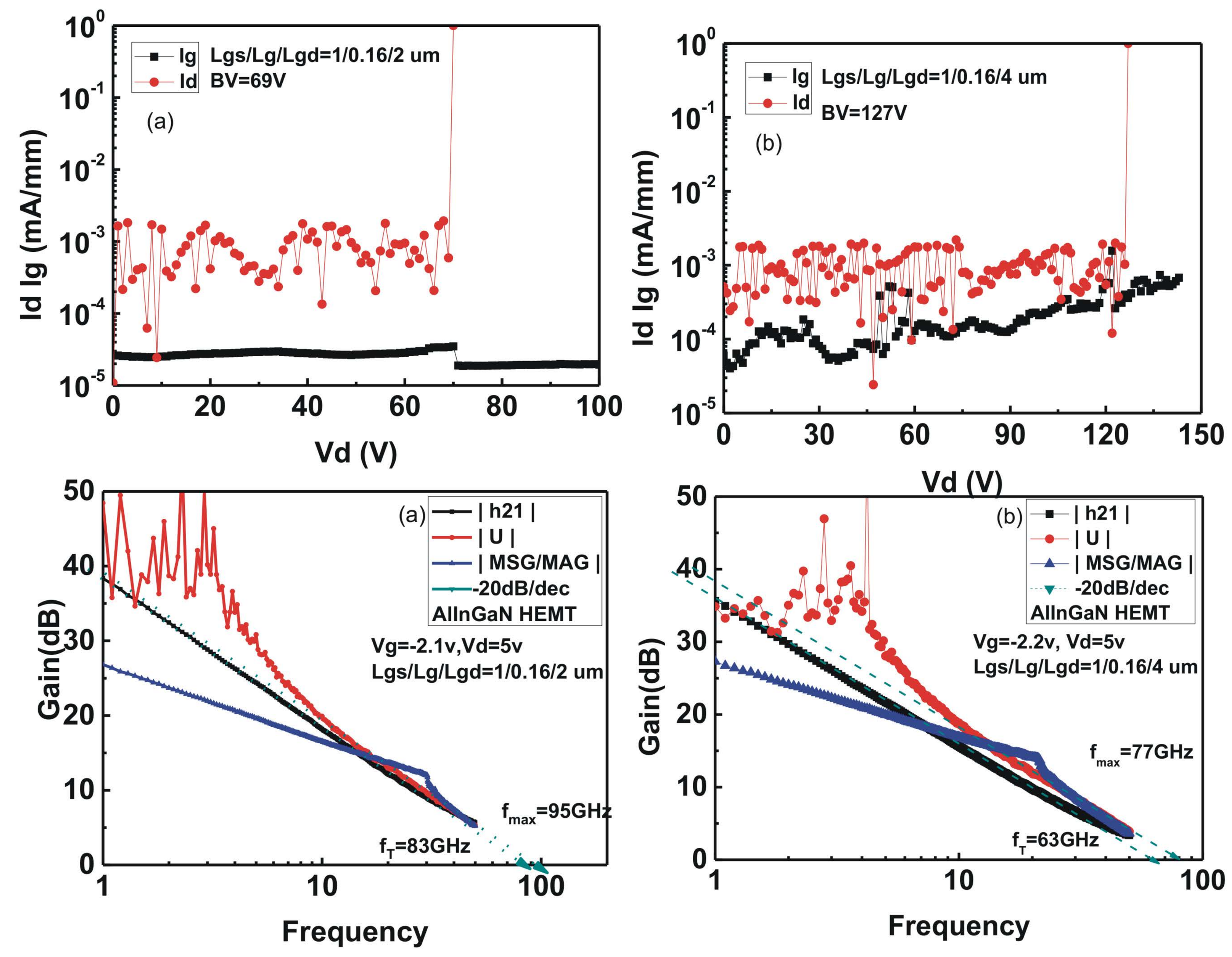
Thermodynamic Stability and Transport Properties Benchmark





- ➢Al content in the range of 65% to 70% with 10% In leads to the highest thermodynamic stability
- ➢Results in lower compositional inhomogeneity
- ➢The electron transport properties achieved on low resistivity silicon substrate are comparable to those grown on SiC and sapphire substrates

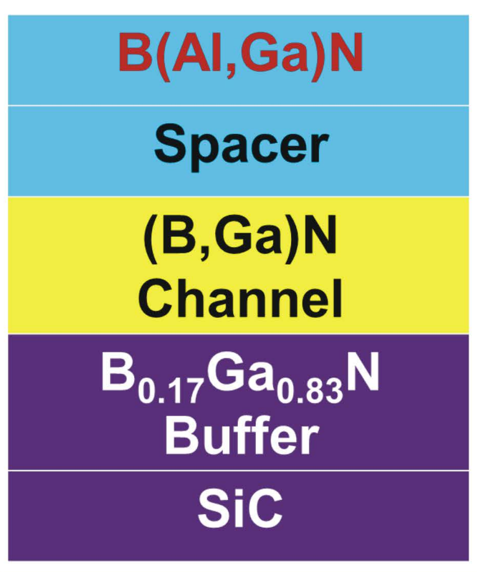
DC and RF Device Performance

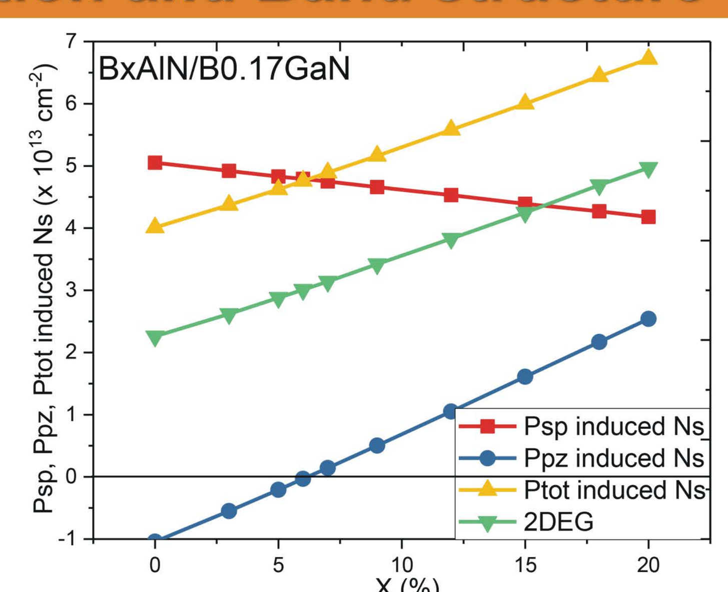


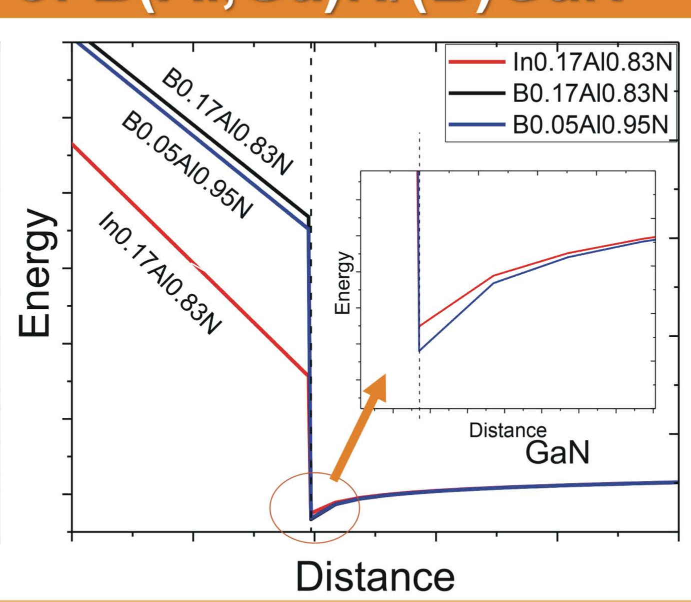
Sample Lgs/Lg/Lgd (μm)	BV (v)	ft/fmax (GHz)	JFOM (THz-V)
1/0.16/2	69	83/95	5.7
1/0.16/4	127	63/77	8.1

- ✓ The current gain cut-off frequency of 83 GHz and 63 GHz and the power gain cut-off frequency of 95 GHz and 77 GHz respectively are obtained, result in Johnson's figure of merit of 5.7 THz-V and as high as 8.1 THz-V respectively.
- ✓ The f_T and J-FOM are comparable with the reported values obtained on high resistive silicon for devices with similar gate length.

2DEG formation and Band structure of B(Al,Ga)N/(B)GaN







- ✓ Spontaneous polarization (Psp) induced carrier concentration (Ns) decreases from 5.05x10^{13} cm^{-2} to 4.18 x10^{13} cm^{-2} with increasing B incorporation from 0 to 20% in barrier
- ✓ Piezoelectric polarization (Ppz) induced carrier concentration increases from -1.04 x10^{13} cm^{-2} to 2.54 x10^{13} cm^{-2} with same increase in B composition
- ✓ 2DEG formed at heterointerface increases almost linearly from 2.26 x10^{13} cm^{-2} to 4.97 x10^{13} cm^{-2} as B incorporation varies from 0 to 20% in barrier
- ✓ Ppz induced Ns becomes zero at around 6% boron incorporation in barrier, indicating no strain due to lattice matched barrier and buffer
- ✓ $B_{0.05}Al_{0.95}N$ exhibits much higher Schottky barrier height as compared $Al_{0.83}In_{0.17}N$ barrier
- ✓ Schottky barrier height increases with increasing B incorporation in the barrier

Summary

AlInGaN/GaN heterostructures on 150 mm low resistivity silicon substrates have been grown with state of the art transport properties for mm wave transistor applications. A new model is proposed, correlating thermodynamic stability and electron scattering mechanisms. Electron mobility around 2100 cm^2/V-s with 2DEG density over 1x10^{13} cm^{-2} is achieved. Fabricated devices exhibit Johnson's figure of merit over 8 THz-V, comparable or better than GaN HEMT on high resistivity Si substrate. Further, proposed a B(Al,Ga)N heterostructure with both lattice matched barrier and buffer to SiC for high power/high frequency transistors. It is analytically shown that these novel heterostructures not only exhibit higher schottky barrier height to the injecting electron from the gate but also exhibit much higher 2DEG than the lattice matched AlInN/GaN HEMT and therefore, could be a promising alternative for next generation power/RF HEMTs

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