RF-MBE growth of AlN/GaN/AlN resonant tunneling diodes on freestanding GaN and GaN templates

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AlN/GaN/AlN resonant tunneling diodes (RTD) grown by RF plasma-assisted MBE on low dislocation-density, freestanding (FS) GaN substrates exhibit repeatable, stable, and hysteresis-free negative differential resistance at room temperature [1], extremely high current density [2], and near-UV cross-gap light emission [3]. In order to investigate the effects of growth conditions and dislocation density on the materials and electronic properties, we have grown AlN/GaN/AlN RTD structures by RF-MBE on hydride vapor-phase epitaxy (HVPE) grown FS GaN substrates and on metal organic chemical-vapor deposition (MOCVD)-grown GaN templates on sapphire. Nominally identical sets of structures were grown in the Ga-rich and Ga-stable growth regimes on each substrate type. The as-grown samples were characterized by optical microscopy, atomic force microscopy (AFM), and high-resolution x-ray diffractometry (HRXRD). Ga droplets were observed on the as-grown surfaces of the samples grown below 800 °C, and no droplets were observed on samples grown at or above 800 °C. AFM reveals surface morphologies of samples grown Ga-rich to be smoother, as expected; however, previous investigations indicate that smoother surface morphology does not correlate with improved device properties [4]. Dynamical simulations of the HRXRD data suggest trends toward thinner AlN barriers and thicker GaN wells in samples grown on freestanding GaN, potentially indicative of greater interfacial roughness, as growth temperature increases and the growth mode transitions from Ga-rich to Ga-stable. RTDs have been fabricated on all samples and devices tested. Electronic device results will be presented.

[1] T.A. Growden *et al.*, Appl. Phys. Lett. **109**, 083504 (2016)
[2] T.A. Growden *et al.*, Appl. Phys. Lett. **112**, 033508 (2018)
[3] T.A. Growden *et al.*, Light: Science & Applications **7**, 17150 (2018)
[4] D.F. Storm *et al.*, J. Vac. Sci. Technol. B **35**, 02B110 (2017)

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Table I. AlN barrier and GaN well thicknesses in structures grown at the indicated growth temperatures on freestanding HVPE-grown GaN substrates and MOCVD GaN templates on sapphire. Layer thicknesses were determined from dynamical simulations of ω-2θ high resolution x-ray diffractometry about the (000.2) diffraction peak. Root-mean-square roughness (R_q) of the sample surface as measured by AFM is also indicated.

	GaN Substrate					
T_S (°C)	Freestanding GaN			GaN Template		
	AlN (nm)	GaN (nm)	R_q (nm)	AlN (nm)	GaN (nm)	R_q (nm)
750	1.4	3.1	0.37	1.3	3.5	0.7
780	1.6	2.7	0.38	--	--	--
800	1.3	3.4	0.8	1.3	3.5	4.4
850	1.2	3.6	4	1.1	3.4	15.4