# Resonant Tunneling Spectroscopy of High-Energy States in Non-centrosymmetric GaN/AlN Resonant Tunneling Diodes


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The recent demonstration of resonant tunneling injection in GaN/AlN double-barrier heterostructures has revived interest in harnessing this quantum transport regime for ultrafast electronic and photonic devices. Unlike non-polar semiconductors, the electronic spectrum in non-centrosymmetric heterostructures is strongly influenced by the spontaneous and piezoelectric polarization fields emerging from the geometric Berry phase [1,2]. In these structures, quantum confinement results not only in a discrete electronic spectrum, but also induces built-in polarization charges, which lack inversion symmetry along the transport direction. Therefore, electrons traversing the active region exhibit highly asymmetric quantum interference effects, giving rise to nonreciprocal electronic transport [3]. In this report, we experimentally study quantization effects in the presence of the strong internal electric fields by systematically varying the thickness of the polar resonant tunneling cavity. Multi-subband resonant tunneling injection up to the second excited state is reported for the first in GaN/AlN resonant tunneling diodes (RTDs), attesting to their highly coherent tunneling injection.

A series of GaN/AlN RTDs with different quantum well thickness ($t_w = \{3,4,5\}$ nm) were grown using molecular beam epitaxy on single-crystal GaN substrates. Conventional fabrication steps are employed to process the heterostructures into vertical diodes. After fabrication, room temperature electronic transport reveals highly repeatable negative differential conductance (NDC) in each sample. Moreover, an increasing number of resonances is measured as the thickness of the resonant cavity increases. Cryogenic resonant tunneling spectroscopy, combined with a theoretical quantum transport model, is employed to elucidate the origin of each resonance. A good agreement was obtained between the experimentally measured resonant tunneling voltages and theoretical calculations. These results indicate that the narrowest cavity supports tunneling transport only through the ground state. In contrast, RTDs with wider wells exhibit injection into the higher-energy states, up to the second-excited state. These results shed light on the quantum interference properties of polar resonant tunneling cavities with multiple subbands, raising hopes for the demonstration of nitride-based intersubband electronic and photonic devices.

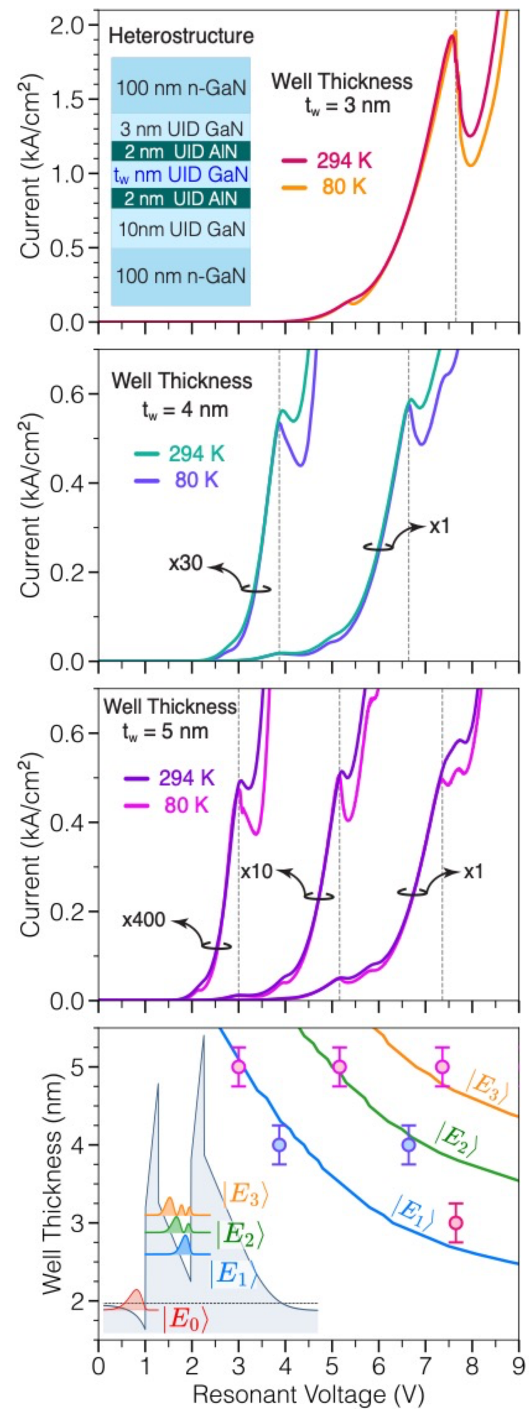


Fig.1. Current-voltage characteristics of GaN/AlN RTDs with different quantum well thickness: a) $t_w$=3 nm, b) $t_w$= 4 nm, and c) $t_w$= 5 nm. d) Resonant voltages as a function of quantum well thickness.


References:

[1] Encomendero et al., Phys. Rev. X 7, 041017 (2017)

[2] Encomendero et al., Phys. Rev. Applied 11, 034032 (2019)

[3] Encomendero et al., Phys. Rev. B 107, 125301 (2023)