Mobility Modeling of Split-gate GaN Nanowires

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This work aims to develop a low-field electron mobility model for GaN nanowires. Nanowires being quasi-1D systems exhibit transport properties significantly differing from their bulk counterparts. Investigation of electron – phonon scattering mechanisms in confined systems is necessary to provide insight into transport dynamics. The split-gate nanowire considered in this work consists of an AlGaN/AlN/GaN heterostructure and two gates as shown in Figure 1. Application of a negative potential at the split-gates creates a 2D potential well at the AlN/GaN heterointerface. A self-consistent 2D Schrödinger-Poisson solver is implemented which determines the subband energies and the corresponding wavefunctions of the confined system. Figures 2 and 3 show the confining potential superimposed over electron density profiles in the nanowire. Figure 4 shows the lowest 15 subband energies with their corresponding line densities. Three scattering mechanisms: acoustic phonon scattering, polar optical phonon scattering and piezoelectric scattering are considered to account for the electron phonon interactions in the system. Overlap integrals and 1D scattering rate expressions are derived for all the mechanisms listed. A generic one-dimensional Monte Carlo solver is also developed. Due to the high optical phonon energy in GaN, piezoelectric scattering is the only electron-phonon scattering mechanism found to be dominant at low fields. Steady state results for subband velocity and subband energies from the 1D Monte Carlo solver are extracted to determine the low field mobility of the GaN nanowires. The results for phonon limited electron mobility predicted by the model (3140 cm^2/V.s) are consistent with experimental results for a similar highly intrinsic, pure AlGaN/GaN radial nanowire [1]. Figure 5 compares the electron mobility determined from the model for various temperatures versus the experimental results of a similar highly intrinsic AlGaN/GaN nanowire. Since this structure uses split-gates to achieve electrostatic confinement in the x-direction, interface-roughness scattering is a factor only along the y-direction. The interface roughness scattering, combined with the quantum confined stark effect due to the presence of high electric field at the AlN/GaN interface, will play a role at lower temperatures [2]. The contribution of total interface roughness scattering to the electron mobility at lower temperatures is currently being studied and will be presented at the conference.

[1] Y. Li, J. Xiang, F. Qian, S. Gradecak, Y. Wu, H. Yan, D. A. Blom and C. M. Lieber, "Dopant-free GaN/AlN/AlGaN radial nanowire heterostructures as high electron mobility transistors," *Nano letters,* vol. 6, no. 7, pp. 1468-1473, 2006.

[2] R. K. Jana and D. Jena, Stark-effect scattering in rough quantum wells," Applied Physics Letters 99, 012104 (2011), https://doi.org/10.1063/1.3607485.

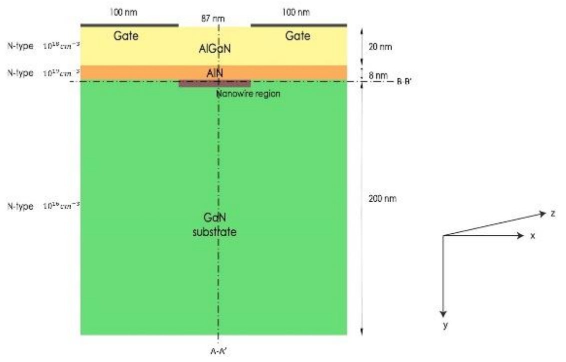

Fig.1: The split-gate nanowire structure used in this work.

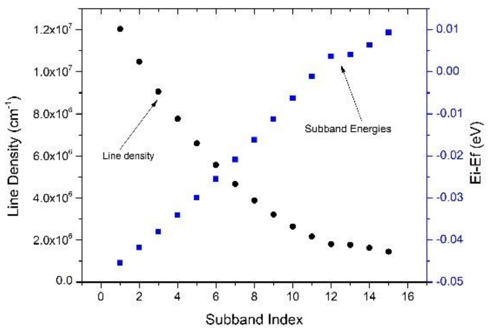

Fig 4: Subband energies and line densities of the lowest 15 subbands in the nanowire.

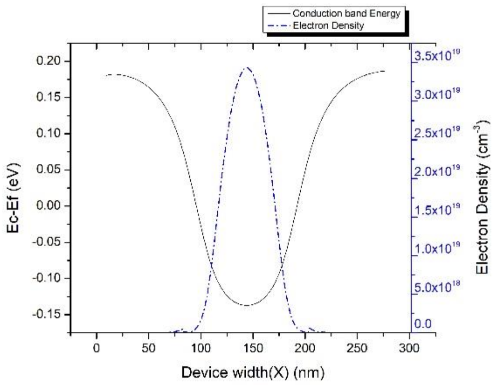

Fig.2: Conduction band profile and Electron density along x axis (Cutline A-A').

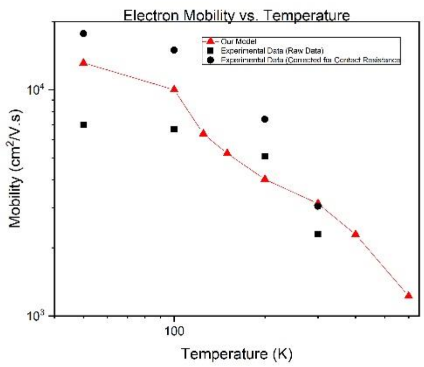

Fig 5. Comparison of electron mobility obtained by this model with the experimental results taken from Ref. [1].

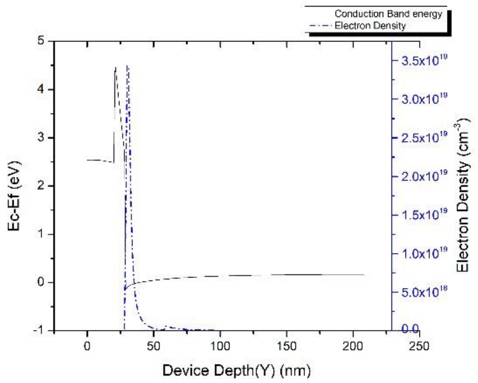

Fig 3. Conduction band profile and Electron density along y axis (Cutline B-B')