Supporting Information: Room-temperature ballistic transport in III-Nitride heterostructures

Elison Matioli[1,2,*] and Tomás Palacios[1,†]

[1] *Department of Electrical Engineering and Computer Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts, 02139, United States*

[2] *Institute of Electrical Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 11, 1015, Lausanne, Switzerland*

A. Ballistic measurements performed in 5 μm-long crosses

Longer nanoscale crosses, with length of 5 μm (as show in the SEM image in Figure 1a) and widths of 315 nm, 205 nm, 94 nm and 59 nm, were also fabricated on $In_{0.17}Al_{0.83}N$ on GaN heterostructure grown on SiC substrate to evaluate the effect of the cross geometry on the electronic transport. A transition from drift to ballistic transport is also observed for these longer crosses, indicated by the negative slope of V_{34}, however, the negative slope as well as the amplitude of V_{34} are much less pronounced than in shorter crosses. In addition, a much larger V_{knee} is observed, close to 500 mV. These results show that V_{knee} extracted from such measurements is largely dependent on device geometry and cannot be directly assigned to $\hbar w_{\mathrm{op}}$, as often found in the literature. This is because the energy of electrons crossing the center portion of the crosses, where ballistic transport is probed, is smaller than the energy qV_{knee} applied at the leads since electrons scatter and lose part of their energy during their propagation to the center of the crosses. The difference between $\hbar w_{\mathrm{op}}$ and qV_{knee} increases as the length of the crosses is increased.

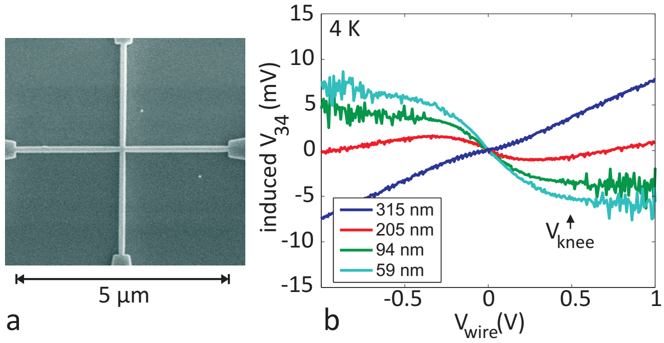

FIG. 1. Induced voltage V_{34} versus applied voltage V_{wire} for 5 μm-long crosses on InAlN/GaN heterostructure. (a) SEM images of 5 μm-long nanoscale crosses. (b) Measurement at 4 K showing again a change from drift (positive slope) to ballistic transport (negative slope) as the cross width is reduced. However, a much less pronounced ballistic effect is observed for these longer crosses as well as a much larger V_{knee}, close to 500 mV.

B. Current density to describe ballistic effects

The current density $J_2 = I_2/w$ is a more consistent variable to look at these effects since, unlike V_{knee}, is not dependent on the cross geometry. This can be observed in the plot of V_{34} versus J_2 for both 1 μm and 5 μm-long crosses, shown in Figure 2, where a similar behavior is observed for both cross lengths, differently from V_{34} versus V_{wire}. This motivated us to make a model to extract the optical phonon energy from the current density rather than voltage drop at the crosses.

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* elison.matioli@epfl.ch
† tpalacios@mit.edu

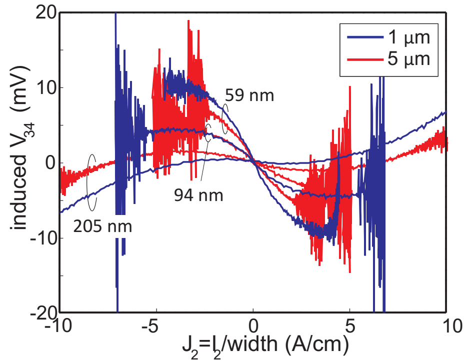

FIG. 2. Induced voltage V_{34} versus current density J_2 for 1 μm (blue) and 5 μm-long (red) crosses on InAlN/GaN heterostructure at 4 K.

C. Ballistic measurements in AlGaN/GaN heterostructures

Similar nanoscale crosses were also fabricated in another III-Nitride heterostructure, consisting of $Al_{0.25}Ga_{0.75}N$ (25 nm)/ AlN (8 nm) /GaN on Silicon substrate. The 2DEG formed at the heterostructure interface presented $n =$ 1.10x10^{13} cm^{-2}, $\mu = 5151$ cm^2/Vs at 4 K and an estimated L_m of 281 nm. The longer L_m is due to the higher electron mobility in this heterostructure. For this structure, $J_2^* = 2.40$ A/cm, resulting in $\hbar\omega_{op} = 93$ meV, which is again in agreement with $\hbar\omega_{\mathrm{op}}$ of III-Nitrides despite the different heterostructure, electron mobility and carrier density. For completeness, we show the behavior of V_{34} versus J_2 for all temperatures. Here again we observe a linear dependence of V_{34} versus J_2, with a positive slope, indicating drift transport as $V_{34} = wR_{\mathrm{cross}}\, J_2$. As the temperature is reduced, even at 150 K and below, $V_{34} = wR_b\, J_2$ where R_b is negative.

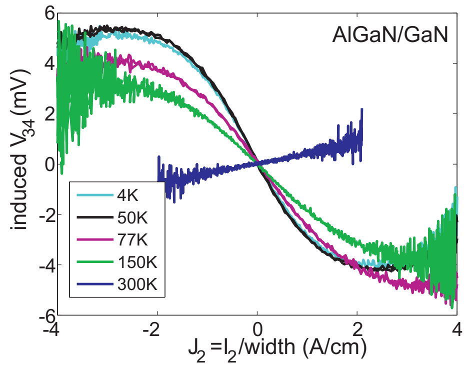

FIG. 3. Induced voltage V_{34} versus J_2, for a 1 μm-long and 98 nm-wide cross on AlGaN/GaN heterostructures for temperatures varying from 300 K to 4 K.

D. Summary of parameters for different heterostructures investigated

The summary of the parameters of both heterostructures used in this work is presented in Table I.

	AlGaN/GaN		InAlN/GaN	
	4 K	300 K	4 K	300 K
n_s (cm^{-2})	1.10x10^{13}	1.16x10^{13}	1.51x10^{13}	1.24x10^{13}
μ (cm^2/Vs)	5151.0	1579.8	3476.2	1285.4
L_m (nm)	281	89	223	75

TABLE I. Parameters of AlGaN/GaN and InAlN/GaN heterostructures