Supporting Information

Quantitative heat dissipation characteristics in current-carrying GaN nanowires probed by combining scanning thermal microscopy and spatially resolved Raman spectroscopy

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Fitting of A_1 LO phonon frequency (ω_{LO}) as a function of temperature

The decrease of the lattice phonon frequency in semiconductors is the result of decreased harmonic frequency due to thermal expansion and anharmonic coupling to other phonon modes.[S1] Particularly, taking into account the three-phonon and four-phonon anharmonic interactions, ω_{LO} can be written as

$$\omega_{LO}(T) = \omega_{LO,0} + \Delta^{(1)}(T) + \Delta^{(2)}(T) \quad \text{(S1)}$$

with $\Delta^{(1)}(T) = \omega_{LO,0}\,\{\exp\,[-3\gamma \int_0^T \alpha(T')dT] - 1\}$, (S2)

and $\Delta^{(2)}(T) = -C[1 + \sum_{i=1}^{2} \frac{1}{(e^{x_i}-1)}] - D\{1 + \sum_{i=1}^{3}[\frac{1}{(e^{y_i}-1)} + \frac{1}{(e^{y_i}-1)^2}]\}$ (S3)

$\omega_{LO,0}$ is the harmonic frequency, γ (=0.74) is the Gruneisen parameter of the LO phonon for GaN,[S2] α (= 5.6 × 10^{-6} /K) is the linear thermal expansion coefficient of GaN[S3] and is approximated as a constant.[S4] x_i and y_i are given by $\hbar\omega_i/k_BT$, with $\sum_{i=1}^{2} x_i = \hbar\omega_{LO,0}$ and $\sum_{i=1}^{3} y_i = \hbar\omega_{LO,0}$. C and D are the three-phonon and four-phonon interaction constants, respectively, with the first (second) term in the expression of $\Delta^{(2)}(T)$ representing the three (four)-phonon anharmonic interactions.

The fitting in Figure 2 (c) leads to $\omega_{LO,0}$ ~ 740 cm^{-1}, with ω_1 ~ 636 cm^{-1}, ω_2 ~ 104 cm^{-1} for the three-phonon anharmonic interaction, and with ω_1 ~ 580 cm^{-1}, ω_2 ~ 97 cm^{-1}, and ω_2 ~ 63 cm^{-1} for the four-phonon anharmonic interaction. C (~ 4.11 cm^{-1}) was found to be much larger than D (~ 0.06 cm^{-1}), indicating the three-phonon interaction is the dominant phonon anharmonic coupling process. This is consistent with a previous study on an ensemble of GaN nanowires.[S4]

Supplementary references:

[S1] H. Tang and I. P. Herman, Phys. Rev. B **43**, 2299 (1991).

[S2] A. Witek, Diamond Relat. Mater. **7**, 962 (1998).

[S3] H. P. Maruska and J. J. Tietjen, Appl. Phys. Lett. **15**, 327 (1969).

[S4] X. B. Chen, J. Huso, J. L. Morrison, L. Bergman, and A. P. Purdy, J. Appl. Phys. **98**, 026106 (2005).