Carrier Transport in Dilute Nitrides

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Effect of N incorporation

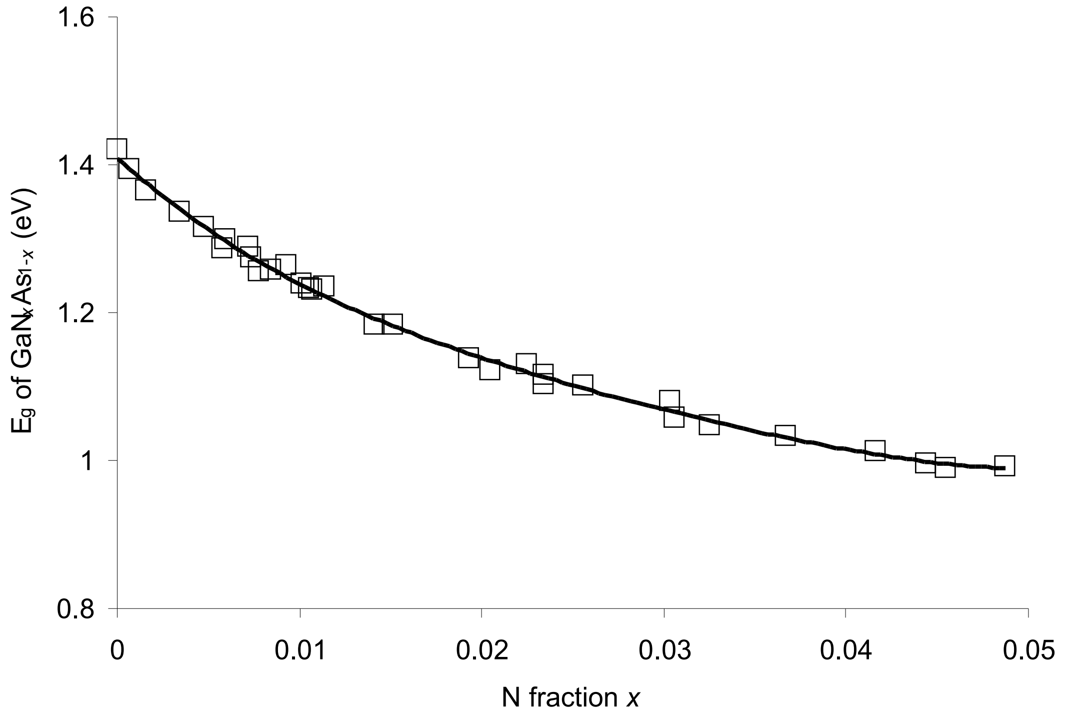
- Dilute N incorporation leads to a large red-shift in E_g
- Bowing parameter b giant and composition dependent

Optical bowing:

$$\Delta E_g(x) = bx(x-1)$$

b ~ 14 eV – 20 eV [1,2]

(x < 1.6%)



Energy gap of GaN_xAs_{1-x} [Tisch et al, 2002]

[1] M. Kondow, K. Uomi, K. Hosomi, T. Mozume, Jpn. J. Appl. Phys., 33, L1056 (1994)

[2] M. Weyers, M. Sato, H. Ando, Jpn. J. Appl. Phys. Pt. 2., 31, pp. L853, (1992)

[3] U. Tisch, E. Finkman, J. Salzman, Appl. Phys. Lett, 81 (3), pp. 463-465, (2002)

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Applications

- GaInNAs can be lattice-matched to GaAs

- Long wavelength VCSELs* for telecommunications[1]
- Efficient solar cells operating in infrared[2]
- Bipolar transistors

- Device performance will be affected by carrier mobility
- Little work done to date but...
- ...work that has been done suggests intrinsic limits to mobility[3]

*Vertical Cavity Surface Emitting Laser

[1] M. Kondow, K. Uomi, A. Niwa, T. Kitatani, S. Watahiki, Y. Yazawa, *Jpn. J. Appl. Phys.*, **35**, p. 1273 (1996)

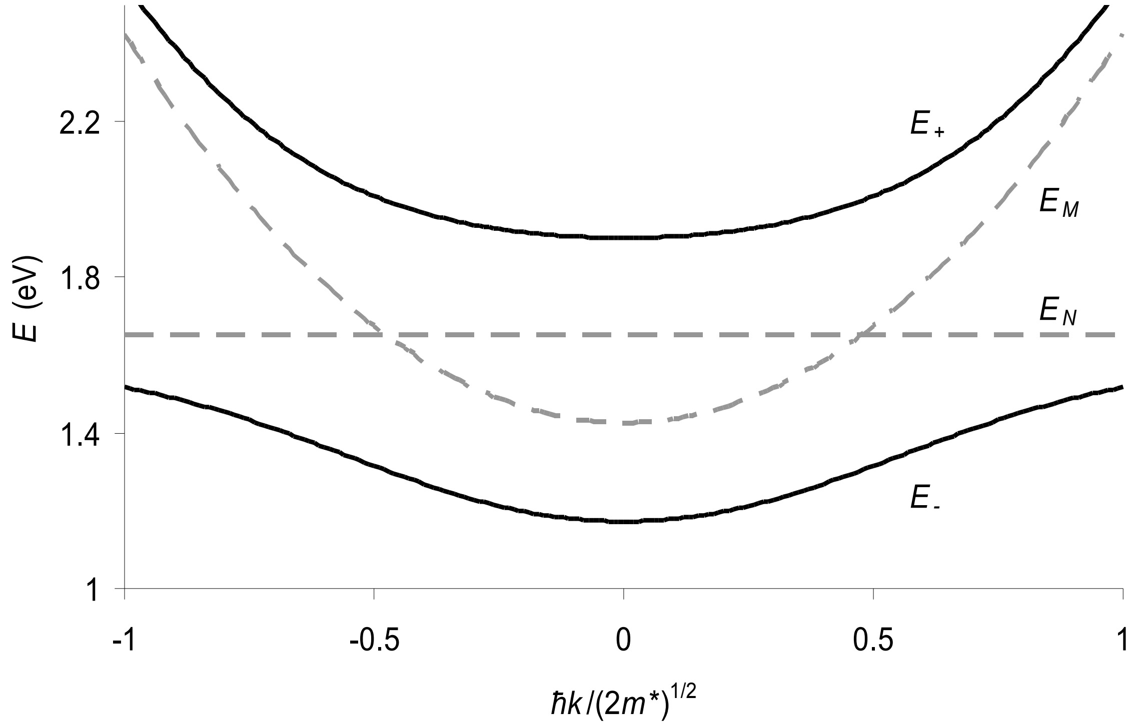
[2] S.R. Kurtz, A. A. Allerman, E. D. Jones, J. M. Gee, J. J. Banas, B. E. Hammons, *Appl. Phys. Lett*, **74** (5), pp. 729, (1999)

[3] S. Fahy and E.P. O'Reilly, *Appl. Phys. Lett*, **83** (18), pp. 3731-3733, (2003)

The Band Anti-crossing model[1,2]

$$\begin{vmatrix} E - E_M & \beta x^{1/2} \\ \beta x^{1/2} & E - E_N \end{vmatrix} = 0$$

$$E_M = E_c(y) - \alpha x$$



Splitting of the conduction band according to the BAC model for GaN_xAs_{1-x} using α = -1.45 eV, β = 2.45 eV and E_N = 1.65 eV.

[1] W. Shan, W. Walukiewicz, J.W. Ager III, E.E. Haller, J.F. Geisz, D.J. Friedman, J.M. Olson, S.R. Kurtz, Phys. Rev. Lett., 82 (6), pp. 1221, (1999)

[2] A. Lindsay, E.P. O'Reilly, Solid State Commun., 112 (8), pp. 443, (1999)

Scattering by nitrogen impurities

Momentum relaxation cross-section [Fahy and O’Reilly, 2003]

$$\sigma_m = \frac{\pi}{4}\left(\frac{m^*}{2\pi\hbar^2}\right)^2\left[\frac{dE_c}{dx}\right]^2 a_0^6$$

E_c is the energy of the conduction band edge

a_0 is the lattice constant

Approximations suggest Nitrogen scattering is the dominant mechanism limiting the mobility[1].

[1] S. Fahy and E.P. O'Reilly, *Appl. Phys. Lett*, **83** (18), pp. 3731-3733, (2003)

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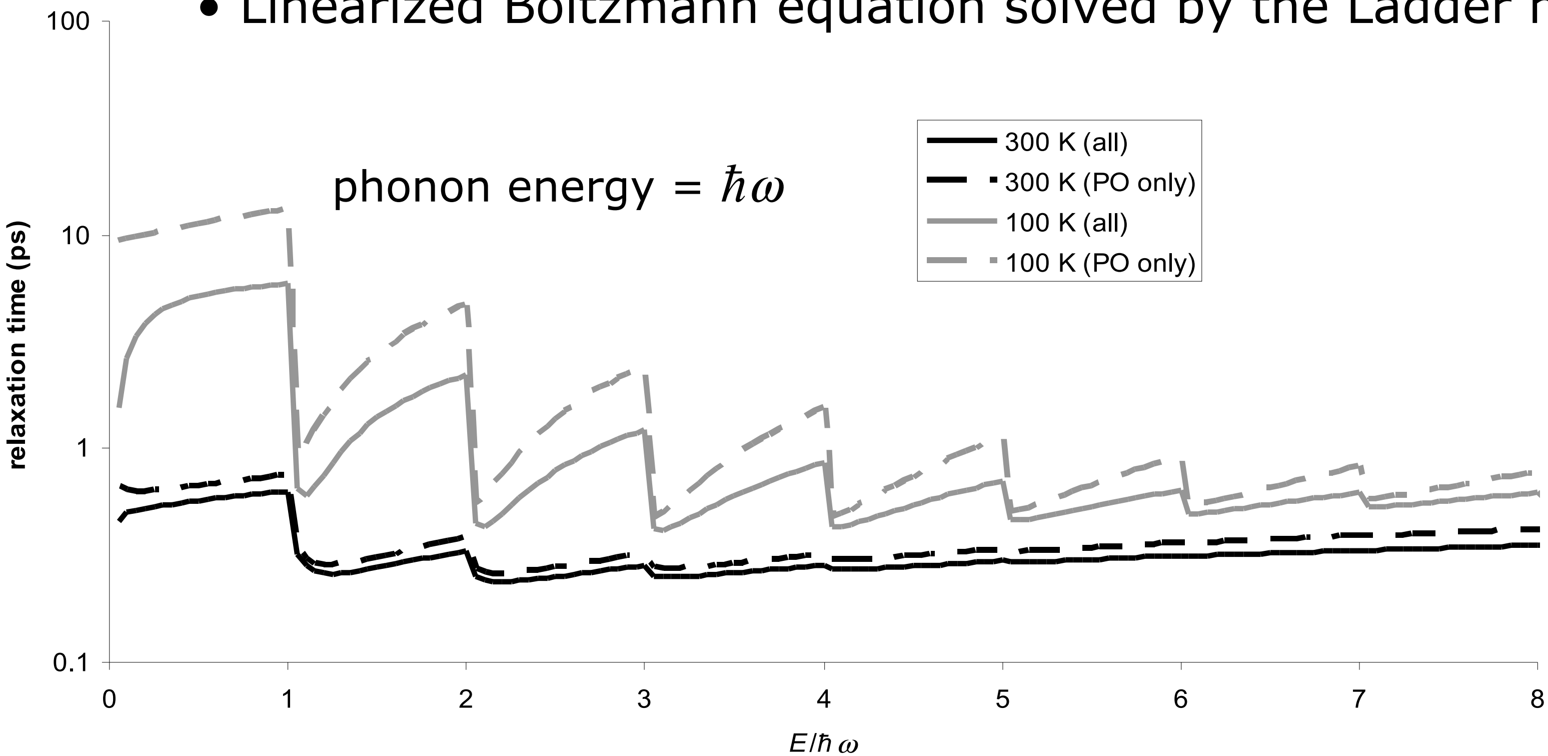
Solving the Boltzmann equation: The Ladder Method

- Energy relaxation by polar optical scattering
- No unique momentum relaxation time
- Linearized Boltzmann equation solved by the Ladder method[1,2]

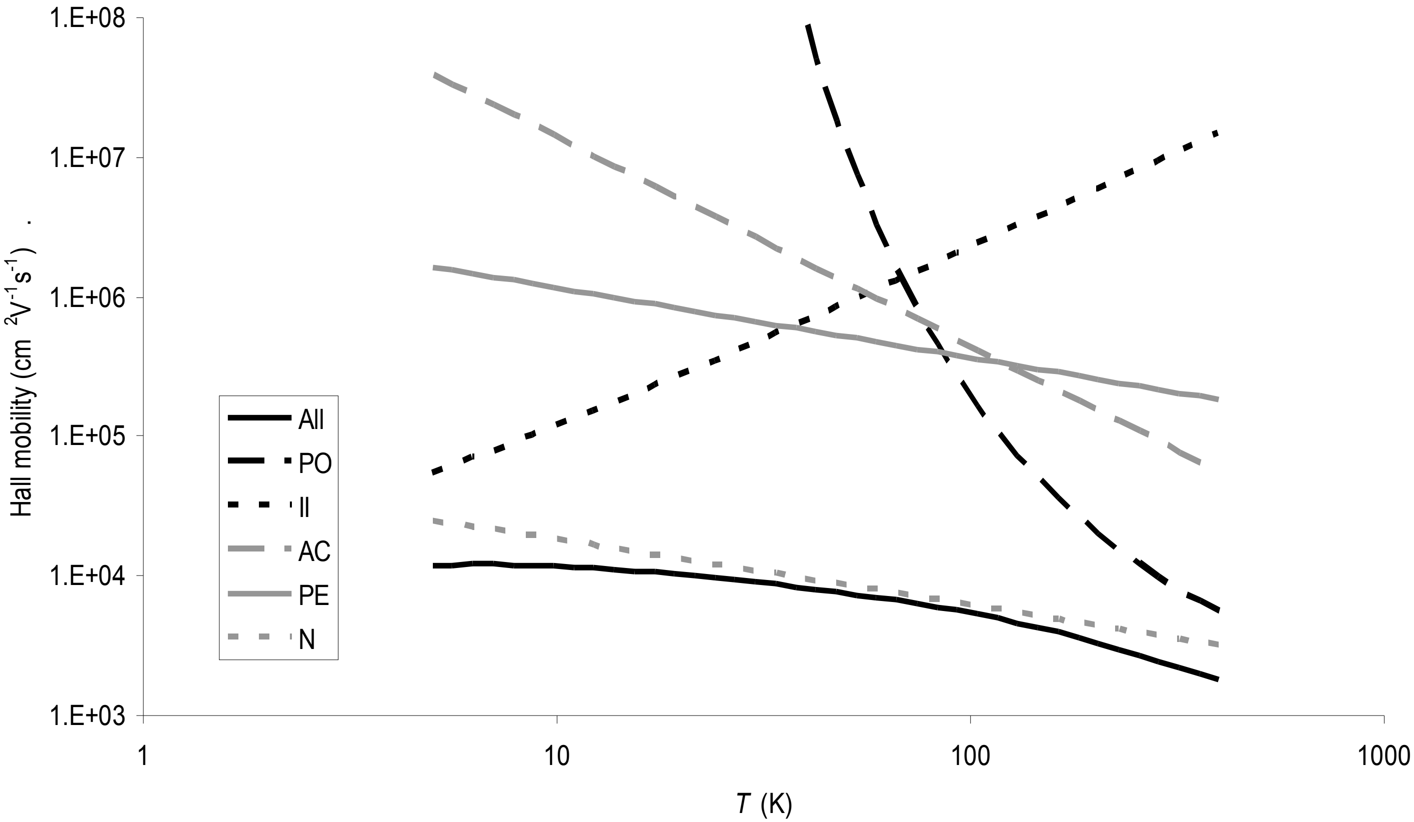


Momentum relaxation time for GaAs calculated via the ladder method using the formula for scattering mechanisms from ref [2].

[1] R.T. Delves, *Proc, Phys. Soc.* **73**, pp. 572, (1959)

[2] K. Fletcher and P.N. Butcher, *J. Phys. C: Solid State Phys.*, **5**, pp. 212-224, (1972)

Results – parabolic approximation

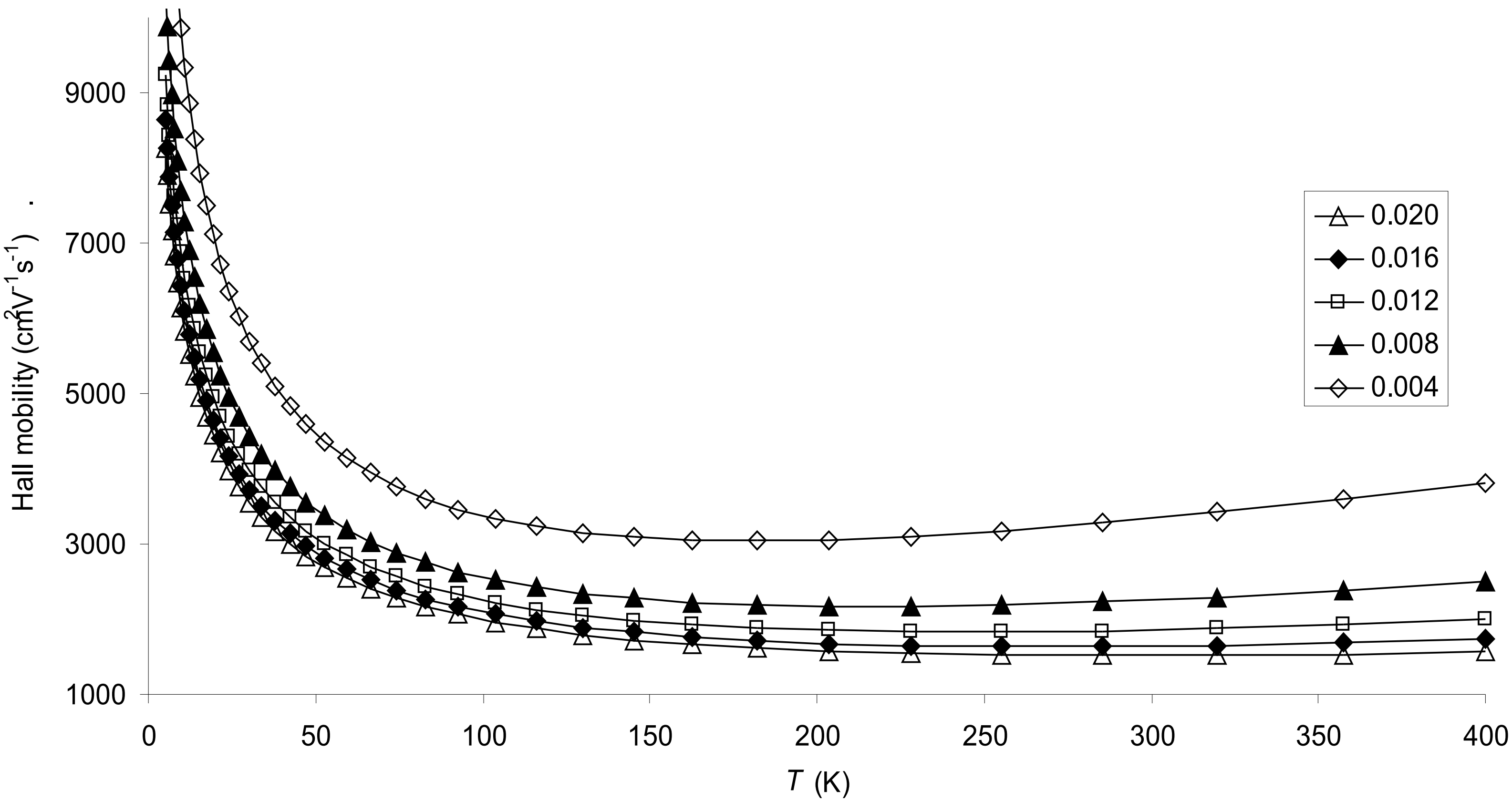


Hall mobility calculated using the Fahy/O'Reilly model for N scattering, other scattering mechanisms from ref [1] and GaAs material parameters in ref [2]. The BAC parameters were E_N = 1.65 eV, α = -1.45 eV and β = 2.45 eV [Fahy & O'Reilly 2003].

[1] K. Fletcher and P.N. Butcher, *J. Phys. C: Solid State Phys.*, **5**, pp. 212-224, (1972)

[2] G.E. Stillman, C.M. Wolfe and J.O. Dimmock, *J. Phys. Chem. Solids*, **31**, pp. 1199-1204 (1970)

Results – non-parabolic (N scattering only)



Hall mobility calculated using the Fahy/O'Reilly model for N scattering, and the non-parabolicity due to the BAC model (the matrix semiconductor is taken to have a parabolic energy band).

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Conclusions

- Mobility limited by nitrogen scattering ($\sim 10^3$ $cm^2V^{-1}s^{-1}$)
- Non-parabolicity reduces the calculated mobility by about 10% (around 200 K – 300 K)
- Calculated Hall mobilities an order of magnitude less than GaAs
- Most experimental results[1,2] (GaInNAs) of order 10^2 $cm^2V^{-1}s^{-1}$...
- ...but best experimental results[3] of order 10^3 $cm^2V^{-1}s^{-1}$

[1] S.R. Kurtz, A.A. Allerman, C.H. Seager, R.M. Sieg,, *Appl. Phys. Lett*, **77** (3), pp. 400-403, (2000)
[2] W. Li, M. Pessa, J. Toivonen, H. Lipsanen, *Phys. Rev. B*, **64**, pp. 113308, (2001)
[3] K. Volz, J. Koch, B. Kunert, W. Stolz, J. Cryst. Growth, 248, pp. 451-456, (2003)