

**NANO EXPRESS**

**Open Access**

# The role of dislocation-induced scattering in electronic transport in $\text{Ga}_x\text{In}_{1-x}\text{N}$ alloys

Omer Donmez<sup>1</sup>, Mustafa Gunes<sup>1</sup>, Ayse Erol<sup>1</sup>, Cetin M Arikan<sup>1\*</sup>, Naci Balkan<sup>2</sup> and William J Schaff<sup>3</sup>

## Abstract

Electronic transport in unintentionally doped  $\text{Ga}_x\text{In}_{1-x}\text{N}$  alloys with various Ga concentrations ( $x=0.06, 0.32$  and  $0.52$ ) is studied. Hall effect measurements are performed at temperatures between 77 and 300 K. Temperature dependence of carrier mobility is analysed by an analytical formula based on two-dimensional degenerate statistics by taking into account all major scattering mechanisms for a two-dimensional electron gas confined in a triangular quantum well between  $\text{Ga}_x\text{In}_{1-x}\text{N}$  epilayer and GaN buffer. Experimental results show that as the Ga concentration increases, mobility not only decreases drastically but also becomes less temperature dependent. Carrier density is almost temperature independent and tends to increase with increasing Ga concentration. The weak temperature dependence of the mobility may be attributed to screening of polar optical phonon scattering at high temperatures by the high free carrier concentration, which is at the order of  $10^{14} \text{ cm}^{-2}$ . In our analytical model, the dislocation density is used as an adjustable parameter for the best fit to the experimental results. Our results reveal that in the samples with lower Ga compositions and carrier concentrations, alloy and interface roughness scattering are the dominant scattering mechanisms at low temperatures, while at high temperatures, optical phonon scattering is the dominant mechanism. In the samples with higher Ga compositions and carrier concentrations, however, dislocation scattering becomes more significant and suppresses the effect of longitudinal optical phonon scattering at high temperatures, leading to an almost temperature-independent behaviour.

**Keywords:**  $\text{Ga}_x\text{In}_{1-x}\text{N}$ , In-rich  $\text{Ga}_x\text{In}_{1-x}\text{N}$ , Mobility, Electronic transport

**PACS:** 72.10.Fk, 72.20.Fr

## Background

In the last decade, after the revision of the band gap energy from 1.9 to approximately 0.7 eV [1], intensive research has been carried out on InN and In-rich  $\text{Ga}_x\text{In}_{1-x}\text{N}$  alloys in order to re-determine the fundamental properties [2-4]. Despite much interest on the optical properties of InN and  $\text{Ga}_x\text{In}_{1-x}\text{N}$  [5,6], there has been a relatively small number of investigations to explain temperature-dependent electronic transport properties in  $\text{Ga}_x\text{In}_{1-x}\text{N}$  alloys [7,8].

In this article, we report the electronic transport properties of nominally undoped  $\text{Ga}_x\text{In}_{1-x}\text{N}$  alloys with different Ga concentrations ( $x=0.06, 0.32$  and  $0.52$ ). Hall effect results show that all the alloys are highly n-type,

and the free carrier concentrations are independent of temperature.

## Methods

### Experimental details

The samples with different Ga concentrations ( $x=0.06, 0.32$  and  $0.52$ ) were grown by a Varian GEN-II gas source molecular beam epitaxy chamber on (0001) c-sapphire substrates with a 200-nm-thick GaN buffer layer. The growth temperature was varied from low to high with increasing Ga composition [9,10]. The thickness of the  $\text{Ga}_x\text{In}_{1-x}\text{N}$  layer was determined from the growth parameters and verified by backscattering spectrometry at nearly 500 nm. The  $\text{Ga}_x\text{In}_{1-x}\text{N}$  samples were fabricated in Hall-bar geometry, and ohmic contacts were formed by diffusing Au/Ni alloy. Hall effect measurements were carried out at temperatures between 77 and 300 K.

\* Correspondence: arikan@istanbul.edu.tr

<sup>1</sup>Science Faculty, Department of Physics, Istanbul University, Vezneciler, Istanbul 34134, Turkey

Full list of author information is available at the end of the article

### Modelling of carrier mobility

The temperature dependence of carrier mobility is analysed using an analytic model where all possible scattering mechanisms are individually calculated using the material parameters given in Table 1. Experimental mobility curves are fitted with the theoretical mobility curves that are obtained using the analytical expressions for the major scattering mechanisms given in Table 2. Although  $\text{Ga}_x\text{In}_{1-x}\text{N}$  layer is thick enough (500 nm) not to be two-dimensional (2D), the analytic model considers transport in a 2D electron gas (2DEG). This is because the electronic transport takes place at the interface of  $\text{Ga}_x\text{In}_{1-x}\text{N}/\text{GaN}$  [11] and on 2D  $\text{Ga}_x\text{In}_{1-x}\text{N}$  surface layer [12].

## Results and discussions

### Experimental results

Figure 1 shows the temperature dependence of the carrier concentration and the electron mobility between 77 and 300 K for all the samples investigated. Although the samples are not intentionally doped, the Hall effect results show that all the samples have n-type conductivity, and the free carrier densities are independent of the temperature; therefore, samples can be regarded as metallic-like over the whole temperature range as commonly reported by us and by other research groups [7,8,24-28]. It is clear from Figure 1a that the free carrier concentration increases by about a factor of 3 when the Ga composition increases from  $x = 0.06$  to 0.52. Also, as seen in Figure 1b, when Ga concentration increases from  $x = 0.06$  to 0.52, electron mobility has a sharp decrease from 1,035  $\text{cm}^2/\text{Vs}$  for  $\text{Ga}_{0.06}\text{In}_{0.94}\text{N}$  to 30  $\text{cm}^2/\text{Vs}$  for  $\text{Ga}_{0.52}\text{In}_{0.48}\text{N}$  at 77 K that may be associated with the contribution of both dislocations and point defects in the structure, which are acting as a source of donor-like defects, inducing high electron concentration. In the

low-temperature region ( $\leq 100$  K), the mobility is almost independent of temperature for all the samples. However, for the sample with the lowest Ga concentration,  $\text{Ga}_{0.06}\text{In}_{0.94}\text{N}$ , it decreases from 1,035 to 890  $\text{cm}^2/\text{Vs}$  with increasing temperature from 100 to 300 K but does not show any significant change in the other two samples, which is a characteristic feature of metallic-like semiconductors [7,26,27]. The insensitivity of carrier mobility to temperature is commonly observed in polar materials with elevated carrier densities where the polar interactions are screened [19,25,29-33].

### Modelling of temperature dependence of mobility

In order to understand fully the temperature dependence of electron mobility, we compared the experimental mobility results with analytical theoretical models by taking into account all the possible scattering mechanisms. At low temperatures, the dominant scattering mechanism in bulk semiconductors is ionized impurity scattering that changes with temperature as  $T^{3/2}$ . However, this kind of temperature dependence has not been observed in our samples. The samples have metallic-like characteristics, confirming the formation of a high-density 2DEG at both the  $\text{GaN}/\text{Ga}_x\text{In}_{1-x}\text{N}$  interface and on the  $\text{Ga}_x\text{In}_{1-x}\text{N}$  surface [26,27]. The dominant momentum relaxation mechanism is the electron-optical phonon scattering in  $\text{Ga}_x\text{In}_{1-x}\text{N}$  since it is a highly polar material above  $T > 150$  K [34-36].

In the theoretical calculation, interface roughness, alloy, dislocation, optical and acoustic phonon scattering mechanisms with the appropriate expressions given in Table 2 were considered. The lateral size of the interface roughness  $\Delta$ , correlation length  $\Lambda$  between interface fluctuations and the dislocation density are used as adjustable fitting parameters, and the values for the best fit

**Table 1 The material parameters used in scattering calculations (adopted from [10,13-15])**

Parameter	InN	GaN	$\text{Ga}_x\text{In}_{1-x}\text{N}$
High-frequency dielectric constant	$\epsilon_\infty = 8.4$	$\epsilon_\infty = 5.5$	$\epsilon_\infty = 8.4 - 2.9x$
Static dielectric constant	$\epsilon_s = 15.3$	$\epsilon_s = 8.9$	$\epsilon_s = 15.3 - 6.4x$
Electron effective mass	$m^* = 0.11m_0$	$m^* = 0.22m_0$	$m^* = (0.1 + 0.12x)m_0$
LO-phonon energy	73 meV	92 meV	$(73 + 11.3x + 12x^2)\text{meV}$
LA-phonon velocity	$v_s = 5.17 \cdot 10^3 \text{ ms}^{-1}$	$v_s = 6.59 \cdot 10^3 \text{ ms}^{-1}$	$v_s = (5.17 + 1.42x) \cdot 10^3 \text{ ms}^{-1}$
Density of crystal	$\rho = 6.81 \cdot 10^3 \text{ kgm}^{-3}$	$\rho = 6.15 \cdot 10^3 \text{ kgm}^{-3}$	$\rho = (6.81 - 0.7x) \cdot 10^3 \text{ kgm}^{-3}$
Electron wave vector at Fermi level	$k_F = 4.61 \cdot 10^8 \text{ m}^{-1}$	$k_F = 7.3 \cdot 10^8 \text{ m}^{-1}$	$k_F = (7.3 + 2.69x) \cdot 10^8 \text{ m}^{-1}$
The electromechanical coupling coefficient	$K^2 = 0.028$	$K^2 = 0.038$	$K^2 = (0.028 + 0.01x)$
Lattice constants	$a = 3.53310^{-10} \text{ m}$ $c = 5.69310^{-10} \text{ m}$	$a = 3.189 \cdot 10^{-10} \text{ m}$ $c = 5.185 \cdot 10^{-10} \text{ m}$	$a = (3.533 - 0.344x) \cdot 10^{-10} \text{ m}$ $c = (5.693 - 0.508x) \cdot 10^{-10} \text{ m}$
Occupied volume by an atom	$\Omega_0 = \left(\frac{\sqrt{3}}{4}\right)a^2c$	$\Omega_0 = \left(\frac{\sqrt{3}}{4}\right)a^2c$	$\Omega_0 = \left(\frac{\sqrt{3}}{4}\right)a^2c$
Deformation potential	$\Xi = 7.1 \text{ eV}$	$\Xi = 8.3 \text{ eV}$	$\Xi = (7.1 - 1.2x) \text{ eV}$
Alloy potential	-	-	$U_A = 2.72x10^{-19} \text{ V}$

LA-phonon, longitudinal acoustic phonon; LO-phonon, longitudinal optical phonon.

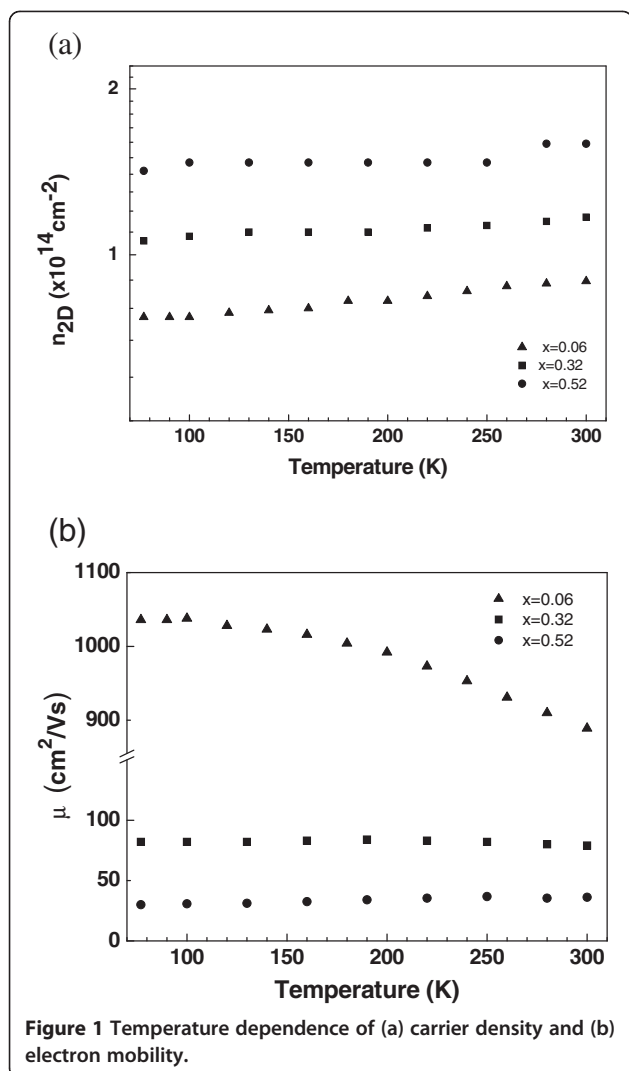
**Table 2 The formulas of major scattering mechanisms used in 2DEG mobility calculations**

Scattering mechanism	Formula	Definition of variables
Acoustic phonon: piezoelectric [15-17]	$\mu_{PE} = \frac{\pi \epsilon_s \hbar^3 k}{e k^2 k_B T m^* J_{PE}(k)}$ $J_{PE}(k) = \int_0^{2k} \frac{F_{11}(q)}{4k^2 (q + q_s)^2 \sqrt{1 - (q/2k)^2}} q^3 dq$ $K^2 = \frac{\epsilon_{LA}^2}{\epsilon_s \epsilon_{LA}} + \frac{\epsilon_{TA}^2}{\epsilon_s \epsilon_{TA}}$	$K$ , electromagnetic coupling coefficient; $J_{PE}(k)$ , electron wave vector dependent integral.
Acoustic phonon: deformation [11,18] potential	$\mu_{DP} = \frac{16 \rho v_s^2 \hbar^3}{3 \Xi^2 k_B T m^* J_{DP}(k)}$ $J_{DP}(k) = \int_0^{2k} \frac{1}{2k \pi^3 (q + q_s)^2 \sqrt{1 - (q/2k)^2}} q^4 dq$ $q_s = \frac{e^2 m^*}{2 \pi \hbar^2 \epsilon_s} F_{11}(q) f(0)$ $b = \left( \frac{33 e^2 m^* n_{2D}}{8 \epsilon_s \hbar^2} \right)^{1/3}$ $F(q) = b(8b^2 + 9qb + 3q^2)/8(b + q)^3$	$\rho$ , crystal density; $v_s$ , longitudinal acoustic phonon velocity; $\Xi$ , deformation potential constant; $m^*$ , electron effective mass; $J_{DP}(k)$ , electron wave vector dependent integral. $b$ , Fang-Howard expression; $q_s$ , reciprocal screening length; $f(0)$ , occupation probability; $F_{11}(q)$ , ground-state Fang-Howard wave function.
Polar optical phonon [17-19]	$\mu_{PO} = \frac{4 \pi \epsilon_s \hbar^2}{e \omega m^* Z_0} [e^{\hbar \omega_{LO}/k_B T} - 1]$ $\frac{1}{\epsilon_p} = \frac{1}{\epsilon_\infty} - \frac{1}{\epsilon_s}$ $Z_0 = \frac{2\pi}{k_F} = \sqrt{\frac{2\pi}{n_{2D}}}$	$\hbar \omega_{LO}$ , polar optical phonon energy; $\epsilon_\infty$ and $\epsilon_s$ , high- and low-frequency dielectric constant; $Z_0$ , effective width of triangular well formed at the $\text{Ga}_x\text{In}_{1-x}\text{N}/\text{GaN}$ interface and is given in terms of Fermi wave vector.
Interface roughness [11,15,20]	$\mu_{IFR} = \left( \frac{2 \epsilon_s}{n_{2D} \Delta \Lambda} \right)^2 \frac{\hbar^3}{e^2 m^* J_{IFR}(k)}$ $J_{IFR}(k) = \int_0^{2k} \frac{\exp(-q^2 \Lambda^2/4)}{2k^3 (q + q_s)^2 \sqrt{1 - (q/2k)^2}} q^4 dq$ $q = 2k \sin(\theta/2)$ $q_s = \frac{e^2 m^*}{2 \pi \epsilon_s \hbar^2} F(q)$	$\Delta$ , lateral size of the roughness; $\Lambda$ , correlation length between fluctuations; $J_{IFR}(k)$ , correlation length and the lateral size-dependent integral; $n_{2D}$ , 2D electron density.
Alloy disorder [20]	$\mu_{Alloy} = \frac{16 e \hbar^3}{3 b x (1-x) m^* \Omega_0 U_A^2}$	$x$ , Ga fraction; $\Omega_0$ , the volume occupied by one atom; $U_A$ , alloy potential.
Dislocation [21-23]	$\mu_{Dis} = \frac{30 \sqrt{2\pi} e^2 c^2 (k_B T)^{3/2}}{e^3 N_{Dis} f^2 \lambda_D \sqrt{m^*}}$ $\lambda_D = (\epsilon_s k_B T / e^2 n_{2D})^{1/2}$	$N_{Dis}$ , dislocation density per unit area which is taken as a fitting parameter; $\lambda_D$ , Debye screening length; $c$ , lattice constant of $\text{Ga}_x\text{In}_{1-x}\text{N}$ . $f$ , the fraction of filled traps that are assumed fully occupied.

are given in Table 3. The values that we used for the dislocation densities are in good agreement with the transmission electron microscopy (TEM) results taken from  $\text{Ga}_{0.34}\text{In}_{0.66}\text{N}$  [9,25]. Look et al. [25] determined the dislocation density for both InN and  $\text{Ga}_{0.34}\text{In}_{0.66}\text{N}$  using TEM and found that dislocation density in  $\text{Ga}_{0.34}\text{In}_{0.66}\text{N}$  is actually higher than that of InN. It can be seen that

the trend of the dislocation density depending on Ga concentration follows the carrier concentration, which means that there is a correlation between dislocation density and the corresponding carrier concentration.

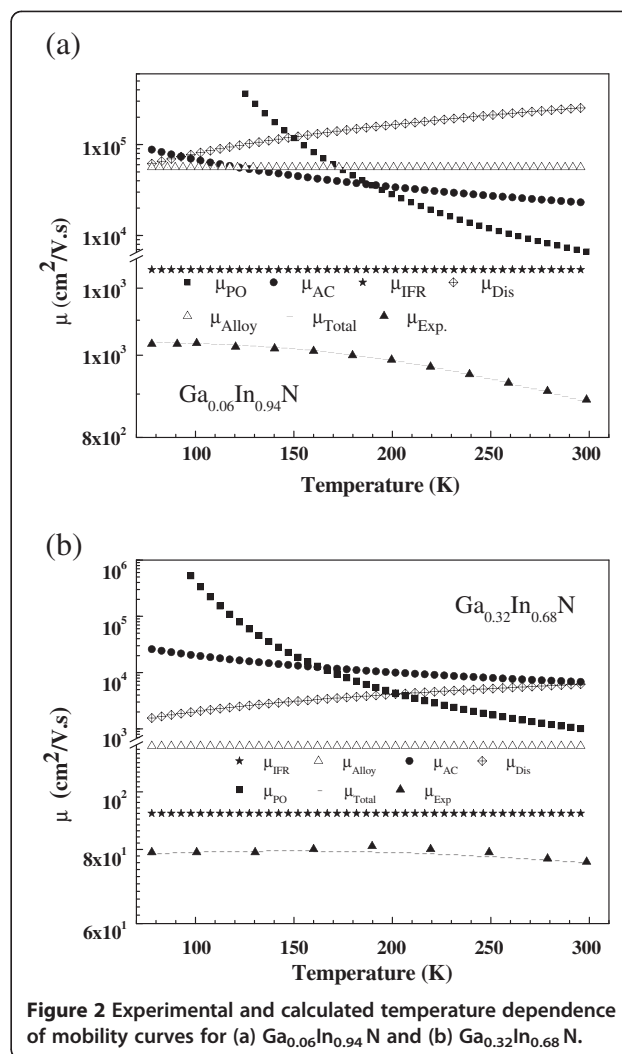
It is clear from Figure 2 that at low temperatures, electron mobilities in  $\text{Ga}_{0.06}\text{In}_{0.94}\text{N}$  and  $\text{Ga}_{0.32}\text{In}_{0.68}\text{N}$  are determined by alloy potential-induced scattering, interface



roughness scattering and dislocation scattering mechanisms. Optical phonon scatterings become significant at high temperatures, as described above. Figure 3 shows experimental and calculated temperature-dependent mobility of the  $\text{Ga}_{0.52}\text{In}_{0.48}\text{N}$ . The dislocation density increases with Ga concentration; therefore, its effect on the mobility becomes more pronounced in this sample. At low temperatures, mobility is limited by the same scattering mechanisms as in the other samples. At high temperatures, however, interface roughness and alloy potential restrict the mobility, but effect of the dislocation scattering

**Table 3** The values of the parameters used in the calculations

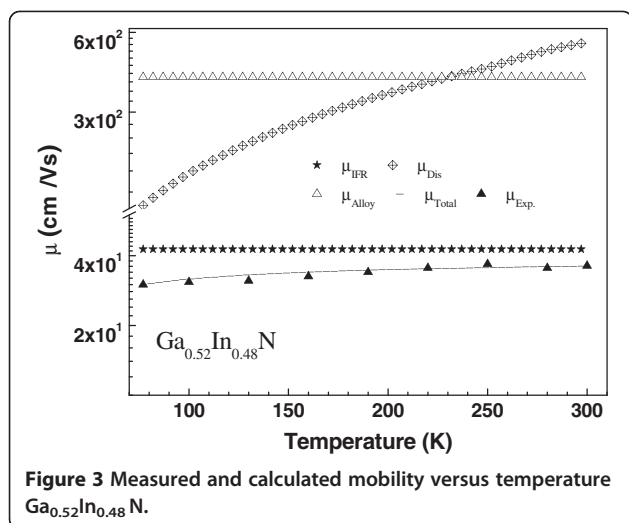
Sample	$\Delta$ (nm)	$\Lambda$ (nm)	Dislocation density ( $\times 10^{10} \text{ cm}^{-2}$ )
$\text{Ga}_{0.06}\text{In}_{0.94}\text{N}$	3.6	1.4 (four monolayer)	0.1
$\text{Ga}_{0.32}\text{In}_{0.68}\text{N}$	6.4	3.4 (ten monolayer)	0.3
$\text{Ga}_{0.52}\text{In}_{0.48}\text{N}$	6.7	3.4 (ten monolayer)	3.8



becomes less dominant as a result of shortening Debye screening length due to higher carrier density. Furthermore, in the high-carrier-concentration regime, electron-phonon scattering is heavily screened, as described above and in references [19,25,29-33].

## Conclusions

In this paper, we have investigated electronic transport properties of nominally undoped In-rich  $\text{Ga}_x\text{In}_{1-x}\text{N}$  structures with different Ga concentrations. Hall effect results show that 2DEG mobility in  $\text{Ga}_x\text{In}_{1-x}\text{N}$  decreases and becomes temperature insensitive with increasing Ga concentrations. The samples are not intentionally doped, but they all have n-type conductivity. Electron density increases with increasing Ga composition. The temperature dependence of electron mobility is determined by taking into account all the major scattering mechanisms. The decrease of the electron mobility with Ga concentration is explained in terms of increased dislocation scattering. The weak temperature dependence



of the mobility at high temperatures might be associated with reduced electron-optical phonon scatterings. Alloy and interface roughness scattering mechanisms are dominant at low temperatures. In samples with higher Ga fractions, dislocation scattering becomes more significant, and at high temperatures, phonon scattering is restricted due to increase of dislocation density. At high temperatures, phonon scattering is only pronounced in the samples with low electron densities.

#### Abbreviations

LO-phonon, longitudinal optical phonon; LA-phonon, longitudinal acoustic phonon; 2DEG, two-dimensional electron gas; TEM, transmission electron microscopy; IFR, interface roughness.

#### Competing interests

The authors declare that they have no competing interest.

#### Authors' contributions

OD and MG carried out the experiments and fitted the Hall mobility data with AE and MCA. OD, MG, AE and MCA wrote the manuscript in conjunction with NB. WJS grew the investigated samples. All authors read and approved the final manuscript.

#### Acknowledgments

This work was supported by Scientific Projects Coordination Unit of Istanbul University with Project Number BYP 25027. We also acknowledge the partial support from Republic of Turkey, Ministry of Development. (Project Number: 2010 K121050).

#### Author details

<sup>1</sup>Science Faculty, Department of Physics, Istanbul University, Veznediler, Istanbul 34134, Turkey. <sup>2</sup>School of Computer Science and Electronic Engineering, University of Essex, Colchester, Essex CO4 3SQ, United Kingdom. <sup>3</sup>Department of Electrical and Computer Engineering, Cornell University, Ithaca, NY 14853, USA.

Received: 16 July 2012 Accepted: 21 August 2012

Published: 31 August 2012

#### References

1. Wu J, Walukiewicz W, Yu KM, Ager JW III, Aller EE, Lu H, Schaff WJ, Saito Y, Nanishi N: Unusual properties of the fundamental band gap of InN. *Appl Phys Lett* 2002, **80**:3967–3969.

2. Wu J, Walukiewicz W: Band gaps of InN and group III nitride alloys. *Superlattices Microstruct* 2003, **34**:63–75.
3. Bechstedt F, Furthmüller J, Ferhat M, Teles LK, Scolaro LMR, Leite JR, Davydov VY, Ambacher O, Goldhahn R: Energy gap and optical properties of  $\text{In}_x\text{Ga}_{1-x}\text{N}$ . *Phys Status Solidi A* 2003, **195**:628–633.
4. Monemar B, Paskova PP, Kasic A: Optical properties of InN—the bandgap question. *Superlattices Microstruct* 2005, **38**:38–56.
5. Walukiewicz W, Li SX, Wu J, Yu KM, Ager JW III, Haller EE, Lu H, Schaff WJ: Optical properties and electronic structure of InN and In-rich group III-nitride alloys. *J Cryst Growth* 2004, **269**:119–127.
6. Hsu L, Jones RE, Li SX, Yu KM, Walukiewicz W: Electron mobility in InN and III-N alloys. *J Appl Phys* 2007, **102**:073705–073710.
7. Lin SK, Wu KT, Huang CP, Liang CT, Chang YH, Chen YF, Chang PH, Chen NC, Chang CA, Peng HC, Shih CF, Liu KS, Lin TY: Electron transport in In-rich  $\text{In}_x\text{Ga}_{1-x}\text{N}$  films. *J Appl Phys* 2005, **97**:046101.
8. Gunes M, Balkan N, Zanato D, Schaff WJ: A comparative study of electrical and optical properties of InN and In<sub>0.48</sub>Ga<sub>0.52</sub>N. *Microelectron J* 2009, **40**:872–874.
9. Liliental-Weber Z, Zakharov DN, Yu KM, Ager JW III, Walukiewicz W, Haller EE, Lu H, Schaff WJ: Compositional modulation in  $\text{In}_x\text{Ga}_{1-x}\text{N}$ : TEM and X-ray studies. *J Electron Microscop* 2005, **54**:243–250.
10. Tiras E, Gunes M, Balkan N, Schaff WJ: In rich  $\text{In}_{1-x}\text{Ga}_x\text{N}$ : composition dependence of longitudinal optical phonon energy. *Phys Status Solidi B* 2010, **247**:189–193.
11. Zanato D, Gokden S, Balkan N, Ridley BK, Schaff WJ: The effect of interface-roughness and dislocation scattering on low temperature mobility of 2D electron gas in GaN/AlGaIn. *Semicond Sci Technol* 2004, **19**:427–432.
12. Veal TD, Piper LFJ, Phillips MR, Zareie MH, Lu H, Schaff WJ, McConville CF: Scanning tunnelling spectroscopy of quantized electron accumulation at  $\text{In}_x\text{Ga}_{1-x}\text{N}$  surfaces. *Phys Status Solidi A* 2006, **203**:85–92.
13. Morkoc H: *Carrier Transport. Handbook of Nitride Semiconductors and Devices*. Weinheim: Wiley; 2008:165–395.
14. Levinshtein M, Rumyantsev S, Shur M: *Properties of Advanced Semiconductor Materials: GaN, AlN, InN, BN, SiC, SiGe*. Canada: Wiley; 2001.
15. Ridley BK, Foutz BE, Eastman LF: Mobility of electrons in bulk GaN and  $\text{Al}_x\text{Ga}_{1-x}\text{N}$ /GaN heterostructures. *Phys Rev B* 2000, **61**:16862–16869.
16. Hutson AR: Piezoelectric scattering and phonon drag in ZnO and CdS. *J Appl Phys* 1961, **32**:2287–2292.
17. Ridley BK: The electron-phonon interaction in quasi-two-dimensional semiconductor quantum-well structures. *J Phys C: Solid State Phys* 1982, **15**:5899–5917.
18. Hirakawa K, Sakaki H: Mobility of the two-dimensional electron gas at selectively doped n-type  $\text{Al}_x\text{Ga}_{1-x}\text{As}$ /GaAs heterojunctions with controlled electron concentrations. *Phys Rev B* 1986, **33**:8291–8303.
19. Sun Y, Balkan N, Aslan M, Lisesivdin SB, Carrere H, Arkan MC, Marie X: Electronic transport in n- and p-type modulation doped  $\text{Ga}_x\text{In}_{1-x}\text{N}_y\text{As}_{1-y}$ /GaAs quantum wells. *J Phys Condens Matter* 2009, **21**:174210–174217.
20. Kearney MJ, Horrell AI: The effect of alloy scattering on the mobility of holes in a quantum well. *Semicond Sci Technol* 1998, **13**:174–180.
21. Ng HM, Doppalapudi D, Moustakas TD, Weimann NG, Eastman LF: The role of dislocation scattering in n-type GaN films. *Appl Phys Lett* 1998, **73**:821–823.
22. Abdel-Motaleb IM, Korotkov RY: Modeling of electron mobility in GaN materials. *J Appl Phys* 2005, **97**:093715–093721.
23. Kundu J, Sarkar CK, Mallick PS: Calculation of electron mobility and effect of dislocation scattering in GaN. *Semicond Phys, Quantum Elect & Optoelect* 2007, **10**:1–3.
24. Donmez O, Yilmaz M, Erol A, Ulug B, Arkan MC, Ulug A, Ajagunna AO, Iliopoulos E, Georgakilas A: Influence of high electron concentration on band gap and effective electron mass of InN. *Phys Status Solidi B* 2011, **248**:1172–1175.
25. Look DC, Lu H, Schaff WJ, Jasinski J, Liliental-Weber Z: Donor and acceptor concentrations in degenerate InN. *Appl Phys Lett* 2002, **80**:258–261.
26. Wang CX, Tsubaki K, Kobayashi N, Makimoto T, Maeda N: Electron transport properties in AlGaIn/GaN/GaN double heterostructures grown by metalorganic vapor phase epitaxy. *Appl Phys Lett* 2004, **84**:2313–2315.
27. Thakur JS, Naik R, Naik VM, Haddad D, Auner GW, Lu H, Schaff WJ: Electron transport properties in AlGaIn/GaN/GaN double heterostructures grown by metalorganic vapor phase epitaxy. *J Appl Phys* 2006, **99**:023504–023508.

28. Donmez O, Gunes M, Erol A, Arıkan MC, Balkan N: **High carrier concentration induced effects on the bowing parameter and the temperature dependence of the band gap of Ga<sub>x</sub>In<sub>1-x</sub>N.** *J Appl Phys* 2011, **110**:103506–103511.
29. Zanato D, Tiras E, Balkan N, Boland-Thoms A, Wah JY, Hill G: **Momentum relaxation of electrons in InN.** *Phys Status Solidi C* 2005, **2**:3077–3081.
30. Ridley BK: *Quantum Processes in Semiconductors*. New York: Oxford University Press; 1999.
31. Sun Y, Vaughan M, Agarwal A, Yilmaz M, Ulug B, Ulug A, Balkan N, Sopanen M, Reentilä O, Mattila M, Fontaine C, Arnoult A: **Inhibition of negative differential resistance in modulation-doped n-type Ga<sub>x</sub>In<sub>1-x</sub>N<sub>y</sub>As<sub>1-y</sub>/GaAs quantum wells.** *Phys Rev B* 2007, **75**:205306–205316.
32. Su Y, Wen Y, Hong Y, Lee HM, Gwo S, Lin YT, Tu LW, Lui HL, Sun CK: **Using hole screening effect on hole–phonon interaction to estimate hole density in Mg-doped InN.** *Appl Phys Lett* 2011, **98**:252106–252108.
33. Kirillov D, Lee H, Harris JS: **Raman scattering study of GaN films.** *J Appl Phys* 1996, **80**:4058–4062.
34. Thomsen M, Jönen H, Rossow U, Hangleiter A: **Spontaneous polarization field in polar and nonpolar GaInN/GaN quantum well structures.** *Phys Status Solidi B* 2001, **248**:627–631.
35. Feneberg M, Thonke K, Wunderer T, Lipski F, Scholz F: **Piezoelectric polarization of semipolar and polar GaInN quantum wells grown on strained GaN templates.** *J Appl Phys* 2010, **107**:103517–103522.
36. Lu CJ, Bendersky LA, Lu H, Schaff WJ: **Threading dislocations in epitaxial InN thin films grown on (0001) sapphire with a GaN buffer layer.** *Appl Phys Lett* 2003, **83**:2817–2819.

doi:10.1186/1556-276X-7-490

**Cite this article as:** Donmez et al.: The role of dislocation-induced scattering in electronic transport in Ga<sub>x</sub>In<sub>1-x</sub>N alloys. *Nanoscale Research Letters* 2012 **7**:490.

**Submit your manuscript to a SpringerOpen<sup>®</sup> journal and benefit from:**

- ▶ Convenient online submission
- ▶ Rigorous peer review
- ▶ Immediate publication on acceptance
- ▶ Open access: articles freely available online
- ▶ High visibility within the field
- ▶ Retaining the copyright to your article

---

Submit your next manuscript at ▶ [springeropen.com](http://springeropen.com)

---