Surface Photo Voltage Characterization of $In_{0.14}Al_{0.86}N/AlN/GaN$ Heterostructures

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Abstract

Surface Photo Voltage (SPV) Spectroscopy and optical transmission have been used to characterise InAlN/AlN/GaN HEMT structures, which have got a great potential for optoelectronic device applications. The different contributions to SPV spectra from all the layers present within the structure are analyzed. Below the GaN band gap SPV analysis has been performed, and the observed peaks related to red, blue, yellow and green defect states in GaN. A shift in GaN band gap value has been observed for the heterostructures by SPV, while a similar shift was not detected by spectral transmission measurements. This shift has been related to the very high carrier density at AlN/GaN interface due to the two dimensional electron gas (2DEG) present at the interface. The shift was fitted by taking into account the Moss Burstein effect and band gap renormalization.

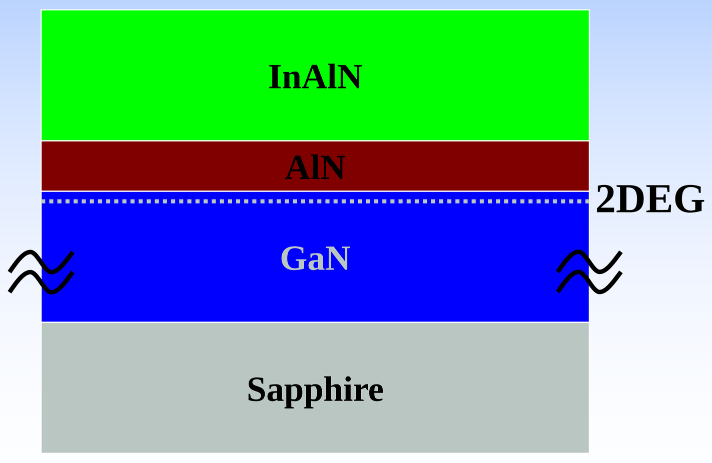
Introduction

AlInN/AlN/GaN HEMT structures

- High 2DEG density due to high polarization field in nitrides
- Insertion of AlN interlayer better confines the 2DEG carriers at AlInN/GaN interfaces
- High electron mobility due to reduction in electron scattering at AlN/GaN interface and reduction in alloy scattering

Applications of III-V nitrides

- Blue, Green LEDs, Lasers
- Bragg reflectors
- HEMTs (high frequency, high power)



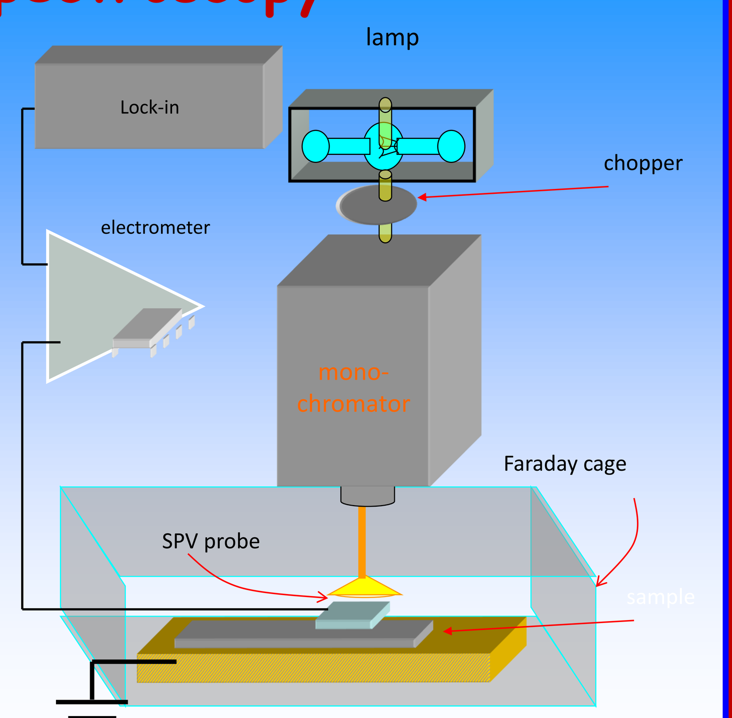
Experimental

Growth

- AIXTRON MOCVD growth of epitaxial films on 3µm GaN template
- Process gas: TMGa, TMAl, TMIn, NH_3, N_2
- Al-N formation at T>1000 ° C, dissociation of InN at 600 ° C
- Four samples with different AlN thicknesses (0.5, 1,1.5, 2.5) have been grown , while InAlN thickness is kept same (=15nm) for all

Surface Photovoltage Spectroscopy

- SPV measurements were performed for all samples at 300K. QTH lamp was used for illumination
- Photogenerated electron-hole pairs collected by the semiconductor surface barrier induce the SPV signal
- Measured SPV data are normalized to the photon flux



SPS set-up

Results and Discussions

Surface Photo Voltage Spectra analysis

Below GaN Bandgap SPV

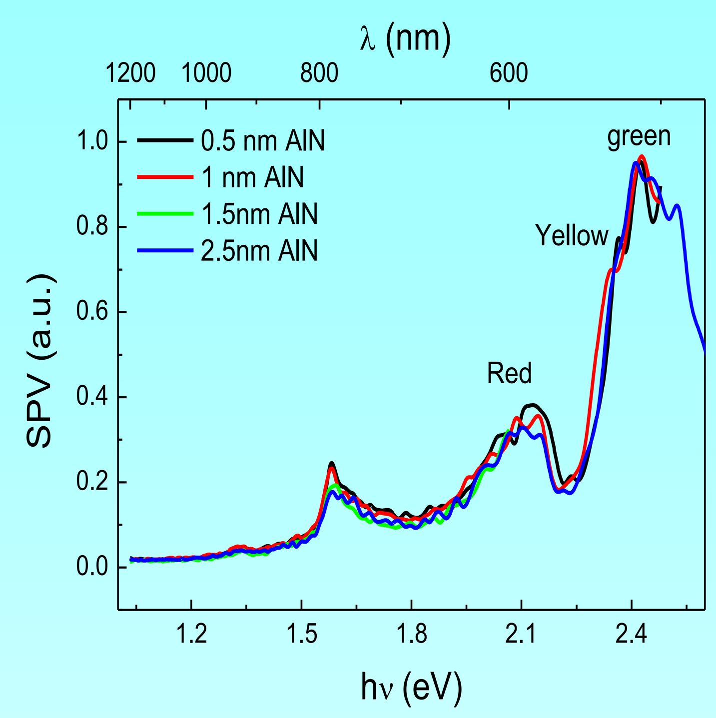


Fig. 1

- Red, Yellow, Green defect related transitions in GaN compared with ref. 1

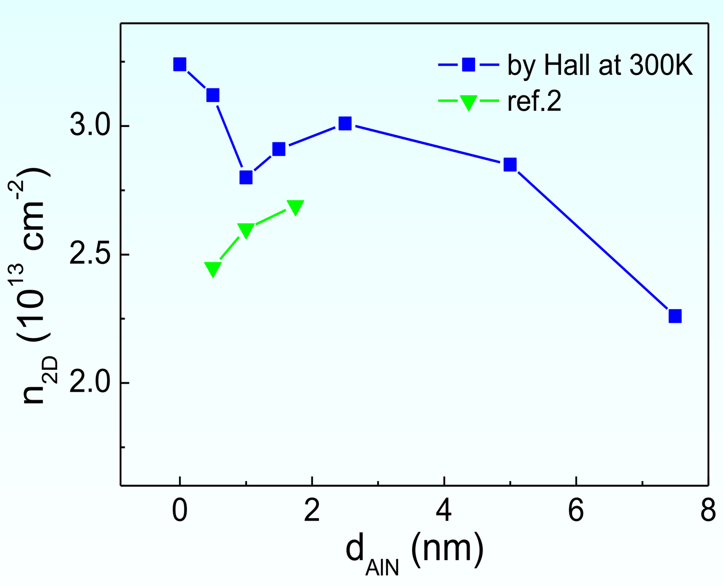


Fig. 3

- Hall Effect measurements was performed to measure carrier concentration

near GaN Bandgap SPV

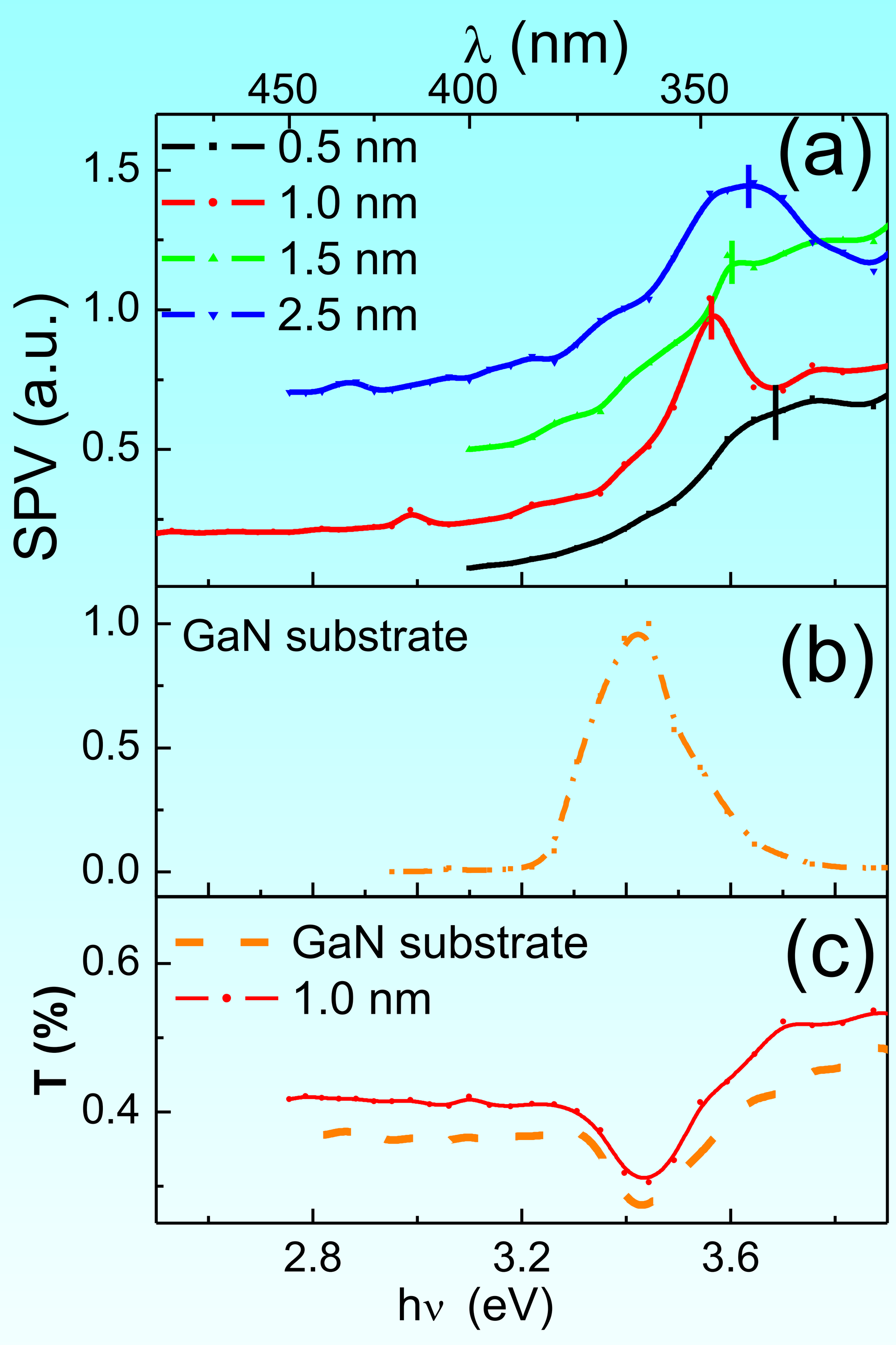


Fig. 2

- Normalized SPV spectra for different interlayer thickness
- shift in peak position of GaN band- edge, SPV and not detected in transmission spectra

- Band gap shift induced by the 2DEG (our hypothesis)
- In more detail shift in GaN bandgap could be attributed **to Moss-Burstein effect (BM), renormalization (RN)** effect and it can be written as :

$$\Delta E_G = \Delta E_{BM} + \Delta E_{RN} \qquad \text{.................................. (1)}$$

Where,

$$\Delta E_{BM} = \frac{\hbar^2}{2m^*}\left(3\pi^2 n_e\right)^{2/3} \qquad \text{............ (2) and} \qquad \Delta E_{RN} = -4.72\times10^{-10} n_e^{1/3}$$

ΔE_{RN} has been used as fitting parameter and values are in good agreement with ref. 3

- In equation (2), effective mass of 2DEG carriers is calculated from following derived equation:

$$m^* = m^*_{e0}\left(1+\frac{2An_e^{2/3}}{E^*}\right) \quad \text{with} \quad A = \frac{\hbar^2(3\pi^2)^{2/3}}{2m^*_{e0}} \qquad \text{................. (3)}$$

- Finally, ΔE_G was plotted as a function of n_e in fig. 4 and fitted by the following derived equation:

$$\Delta E_G = V_o + \frac{\hbar^2}{2m^*_o(1+2An_e^{1/3}/E^*)}\left(3\pi^2 n_e\right)^{2/3} - 4.72\times10^{-10} n_e^{1/3} \qquad \text{..................... (4)}$$

Where, V_0 has been taken in to account for strain induced band gap, ħ is reduced Planck's constant, E* has been taken in to account the effects of non-parabolic band structure on *m**

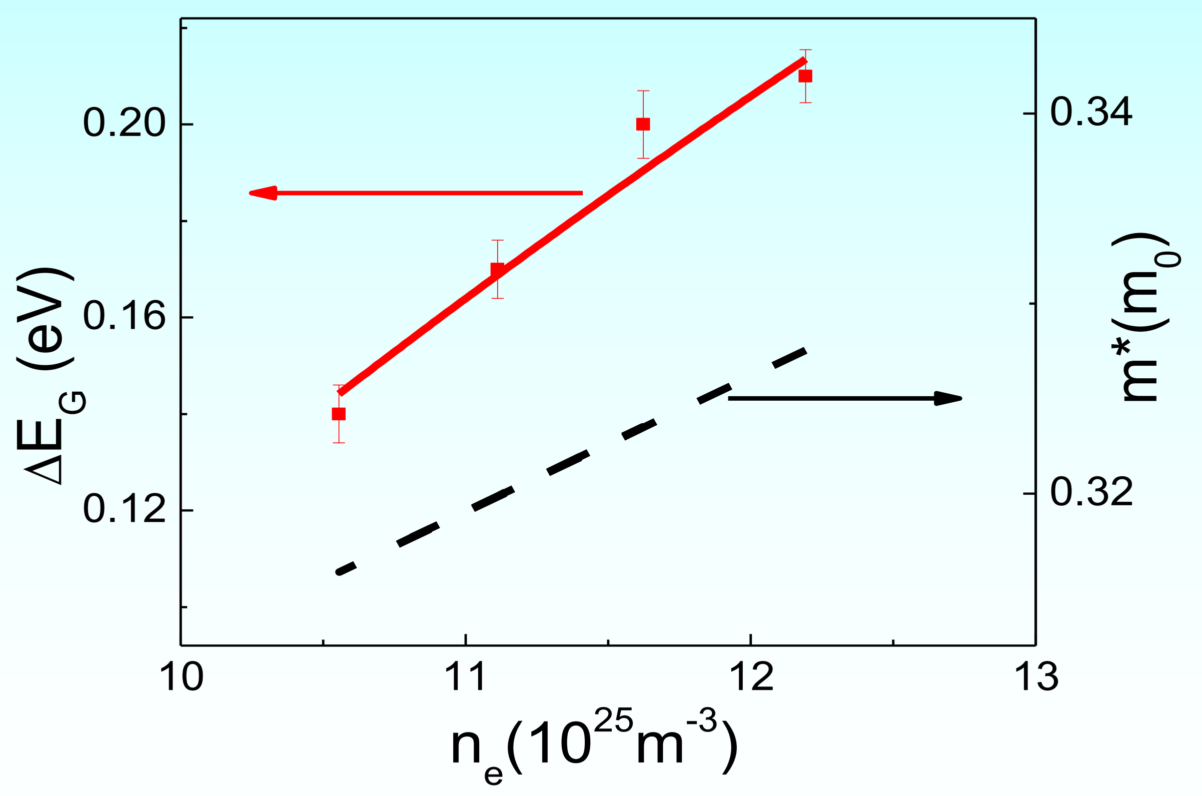


Fig. 4

***Detailed information can be obtained from [4]**

Conclusions

Surface photo voltage spectroscopy on InAlN/AlN/GaN heterostructures allowed us to obtain:

- Defect related transitions have been observed in GaN layer.
- Band gap shift has been measured in GaN layer, this shift increases as a function of the free carrier concentration, related to the 2DEG density.
- This effect is due to the combined Moss Burnstein and renormalization effects.

Acknowledgments

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References

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