Native point defects in non-stoichiometric GaAs doped with beryllium

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Introduction

Non-stoichiometric GaAs - grown by MBE at low temperatures (LT-GaAs)

- unique properties (ultrafast carrier recombination, semi-insulating behavior after annealing)
- incorporation of excess As in form of native point defects (As_{Ga} and V_{Ga}) [1,2]
- instability during annealing restricted applications so far
- recently: doping with Be improves thermal stability of point defects in LT-GaAs [3]

→ goal of present work: understanding the influence of Be doping on nature, incorporation and annealing behavior of native point defects in LT-GaAs:Be

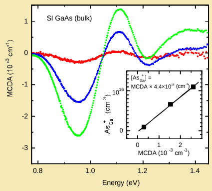
Experimental details

Samples - MBE grown LT-GaAs (200-300°C), Beam equivalent pressure (BEP) 20 (arsenic-rich conditions), growth rate 1 µm/h, Be doping up to 8×10^{19} cm^{-3}

Methods - Near infrared absorption (**NIRA**, to detect As_{Ga}^0)
- Magnetic circular dichroism of absorption (**MCDA**, to detect As_{Ga}^+, B=2T, *T*=1.8 K)
- Positron annihilation spectroscopy (**PAS**, to detect vacancy defects)

Absorption spectroscopy of As_{Ga} antisites

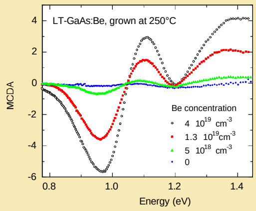
MCDA of As_{Ga}^+



Calibration - MCDA of semi-insulating bulk GaAs

- typical features of As_{Ga}^+ spectrum [4]
- correlation of MCDA intensity at 0.94 eV with As_{Ga}^+ density (determined by EPR, [5])

→ calibration of MCDA signal for our setup



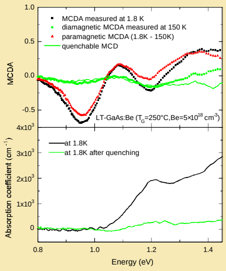
MCDA of LT-GAs:Be

- undoped LT-GaAs - spectra deviates around 1.2 eV [1]

→ As_{Ga} in LT-GaAs was believed to be different from that in bulk GaAs
- MCDA spectra in LT-GaAs:Be show features typical for As_{Ga}^+
- Be doping concentration determines density of As_{Ga}^+ (through compensation)

→ As_{Ga}^+ in LT-GaAs:Be is not significant different from As_{Ga}^+ in SI bulk GaAs, especially, no evidence for complexes with Be

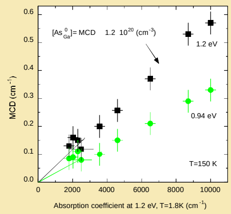
MCDA and NIRA of As_{Ga}^0



Detailed investigation of MCDA signals

- MCDA spectrum consists of paramagnetic (due to As_{Ga}^+, temperature dependent) and diamagnetic part (temperature independent)
- diamagnetic MCDA has same features as previously identified spectra due to As_{Ga}^0 (peaks at1.2 and 0.94 eV, ratio 1.8) [6]
- diamagnetic spectra is quenchable by white light illumination

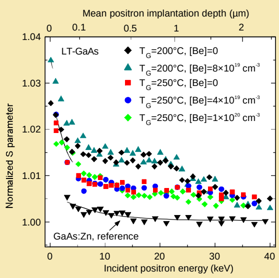
→ diamagnetic spectra may dominate in undoped LT-GaAs where $[As_{Ga}^0]$ is much higher than $[As_{Ga}^+]$, explains previous MCDA results [1]



- intensity of diamagnetic Peaks correlates with absorption due to As_G^{a0}

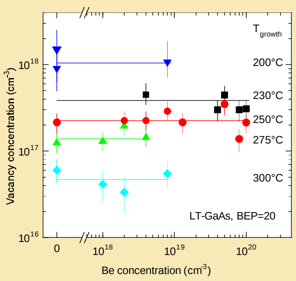
→ nature of diamagnetic MCDA as being due to As_{Ga}^0 is confirmed

Ga Vacancies



Detection of V_{Ga} by positron annihilation

- *S*-parameter from PAS is a measure of vacancy defects [7]
- Increase of *S* above reference value shows positron trapping at vacancy defects
- Defects were identified as Ga vacancies, the same defect as in undoped LT-GaAs [8]

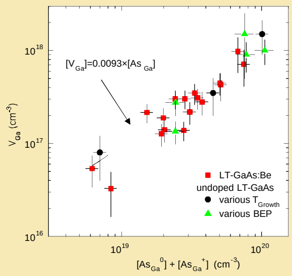


V_{Ga} density vs. Be doping

- Density of V_{Ga} depends only on growth temperature, not on Be concentration

→ Be doping does not decrease incorporation of Ga vacancies [8] as suggested earlier [2]

Correlation $[V_{Ga}]$ - $[As_{Ga}]$ in as grown LT-GaAs:Be



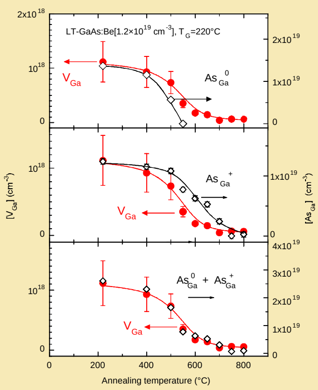
- in undoped LT-GaAs - concentration of As_{Ga}^+ is determined by V_{Ga} concentration
- doping with Be increases As_{Ga}^+ concentration

→ for comparison $[As_{Ga}^0]$ and $[As_{Ga}^+]$ were simultaneously determined

- universal relationship between total $[As_{Ga}]$ and $[V_{Ga}]$, independent of particular doping or growth conditions

→ Be doping has no influence on incorporation of native point defects in LT-GaAs

Annealing behavior



- in undoped LT-GaAs:
  - As_{Ga} anneals at ~ 400°C [1]
  - instead of V_{Ga} , vacancy clusters are detected by PAS [7]
- present results in LT-GaAs:Be:
  - As_{Ga} is stable to higher temperatures
  - no evidence for vacancy clusters, instead, annealing of V_{Ga} is observed
  - V_{Ga} anneals parallel to As_{Ga}

→ thermal stability not related to early annealing of V_{Ga} as suggested earlier [2]

Summary

- Native point defects investigated in LT-GaAs:Be
- As_{Ga} and V_{Ga} detected by MCDA/NIRA and PAS
- V_{Ga} has same properties as in undoped LT-GaAs
- Detailed investigation of MCDA/NIRA spectra shows that As_{Ga} defects are similar to that in bulk GaAs, previous discrepancies regarding the spectral shape of the MCDA signal in LT-GaAs are mainly explained by simultaneous detection of As_{Ga}^0 and As_{Ga}^+ signals
- Concentration of all native point defects (As_{Ga} and V_{Ga}) in LT-GaAs is not influenced by Be doping

→ defect concentrations are kinetically dictated by growth conditions as in undoped LT-GaAs

→ No evidence for defect complexes containing Be as origin of the thermal stability

- V_{Ga} anneals parallel to As_{Ga}

→ thermal stability of LT-GaAs:Be is not related to incorporation of point defects or early annealing of V_{Ga}

→ most likely explanation for thermal stability is strain compensation, i.e. small Be atoms compensate the lattice strain caused by As_{Ga} antisites

Literature

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