Vacancylike defects in GaAs after ion implantation

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Outline:
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• Doping effects
• Weak damage
• Strong damage
• Summary
Modeling of damage evolution in III-V-semiconductors

by Hecking et al. Nucl. Instr. and Meth. B 15, 1986, 760

Modeling of damage evolution in III-V-semiconductors

\[ f(\Phi) = f_{pd}(\Phi) + f_a(\Phi) \]

differential equations:

\[ \frac{d f_{pd}}{d \Phi} = g_{pd}(f_a, \Phi) + r_{pd}(f_{pd}, f_a) \]

\[ \frac{d f_a}{d \Phi} = g_a(f_{pd}, f_a, \Phi) \]

- point defects are mobile: recombination in region II
- point defects are not mobile: defect accumulation
Experimental techniques

Rutherford Backscattering Spectrometry (two beam approximation)

- integral damage
- layer thickness

Slow positron beam technique

- open-volume defects
- annealing behavior

Detector equipment

Energy resolution (at 514 keV): 1.45 keV

S: \((511.0 \pm 0.8)\) keV

W: \((2.76 < |E_\gamma -511| < 3.96)\) keV
Charge state of open-volume defects in GaAs

\[ E_{d-E_v} (\text{eV}) \]

- \(-/0\)
- \(0/+\)
- \(1.0\)
- \(0.5\)
- \(V_{\text{Ga}}\)
- \(V_{\text{As}}\)
- \(2/-\)
- \(3/-2/-\)
- \(\text{fermi level after implantation}\)

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Identification of gallium vacancy-related defects

Annihilation parameter $V_{Ga-X}$

$S_V/S_{bulk} = 1.024$

$W_V/W_{bulk} = 0.079$

$S = R(W-W_b) + S_b$

$R = (S_V - S_b)/(W_V - W_b)$

Experimental conditions

- **oxygen**
  $10^{13} - 10^{15}$ cm$^{-2}$; (80, 200) keV

- **silicon**
  $10^{13} - 10^{15}$ cm$^{-2}$; (100, 200) keV

- **tellurium**
  $10^{12} - 10^{14}$ cm$^{-2}$; 300 keV

- **arsenic**
  $10^{14} - 10^{16}$ cm$^{-2}$; (200, 400) keV

Implantation at room temperature

Substrates: undoped, $p = 10^{19}$ cm$^{-3}$, $n = 10^{18}$ cm$^{-3}$
Doping effects: reference surfaces

chemical or structural changes at the surface
p-type: electric fields push off positrons from the surface
Doping effects: RBS

no significant differences for differently doped samples
Doping effects: outdiffused defects

- outdiffused defects are positively charged in p-type GaAs
  or possibly
- outdiffusion occurs in undoped and n-type material only

\[
[V_{Ga-X}] = 2 \times 10^{17} \text{ cm}^{-3}
\]

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Doping effects: LT implantation

As:GaAs (undoped) 200, 300 keV
2×10^{16} cm^{-2}

S/S_{bulk} vs W/W_{bulk}

- amorphous
- RT implantation
- LT implantation

V_{Ga-X}
Weak damage: oxygen implantation

according to phase I of the Hecking model
Weak damage: formation of $V_{Ga-X}$

![Graph showing positron depth and energy with reference to $V_{Ga-X}$](image)
Weak damage: annealing behavior

formation of larger defects during the annealing
Speculations

Y contains \( V_{Ga} \) and \( V_{As} \) ?

[4] this work
Strong damage: tellurium implantation (RBS-spectra)

![Graph showing RBS yield vs. channel for Te:GaAs (undoped) with GaAs amorphous reference and GaAs crystalline reference.](image)

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Strong damage: tellurium implantation (RBS)

collaps-like amorphization at a critical fluence

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Strong damage: tellurium implantation (slow positrons)

Te:GaAs (undoped) 300 keV

S/S\text{bulk}

mean positron depth (µm)

0 0.31 1.02 2.03

positron energy (keV)

0 10 20 30

W/W\text{bulk}

0.80 0.85 0.90 0.95 1.00

gallium vacancy-related defects \rightarrow amorphous structures

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Strong damage: isochronal annealing

annealing temperature (K)

mean positron depth (μm)

As:GaAs (Zn doped) 200, 300 keV
2×10^{14} cm^{-2}

isochronal annealed (10 min)

S\text{layer}/S\text{bulk}

S/S\text{bulk}

positron energy (keV)
Strong damage: recrystallization and annealing behavior

Summary:

- outdiffusion of gallium vacancy-related defect
- defect evolution agrees with model by Hecking et al.
  - weak damage: gallium vacancy-related defects
  - equilibrium between generation and recombination of point defects
  - strong damage: collaps-like formation of amorphous structures
- formation of larger vacancy-like defects during annealing of gallium vacancy-related defects at 500 K
- recrystallization of amorphous layers at 500 K and formation of stable open-volume agglomerates