Vacancy-like defects in SI GaAs: post-growth treatment

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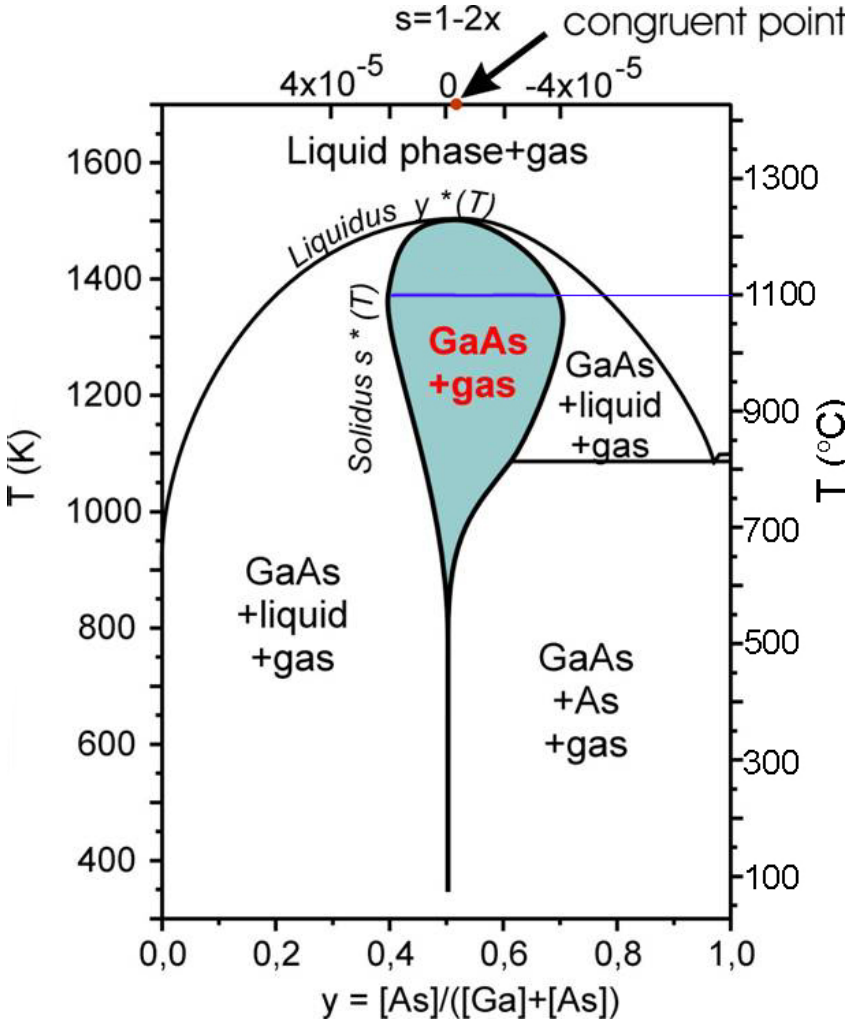
- Motivation
- Results of previous investigations on n-type GaAs
- Undoped GaAs
  - positron annihilation results
  - defects identification
- Summary

Motivation

- **Idea**: investigation of the native point defects configuration in different equilibrium states
- **Material**: semi-insulating GaAs
- Continuation of the work done on n-type GaAs: **GaAs:Si, GaAs:Te**



*H. Wenzl et al., J. Cryst. Growth **109**, 191 (1991).*

Native point defects in GaAs

GaAs Vapor – Solid system has F = C – P + 2 = 2 degrees of freedom

Six native point defects demand six reactions:

$$\frac{1}{4}As_{4,vap} \leftrightarrow I_{As} \Rightarrow K_1(T) = \frac{[I_{As}]}{P_{As_4}^{1/4}}$$

$$Ga_{vap} \leftrightarrow I_{Ga} \Rightarrow K_2(T) = \frac{I_{Ga}}{P_{Ga}}$$

$$As_{As} \leftrightarrow I_{As} + V_{As} \Rightarrow K_3(T) = [I_{As}][V_{As}]$$

$$Ga_{Ga} \leftrightarrow I_{Ga} + V_{Ga} \Rightarrow K_4(T) = [I_{Ga}][V_{Ga}]$$

$$Ga_{Ga} + I_{As} \leftrightarrow As_{Ga} + I_{Ga} \Rightarrow K_5(T) = \frac{[As_{Ga}][I_{Ga}]}{[I_{As}]}$$

$$As_{As} + I_{Ga} \leftrightarrow Ga_{Ga} + I_{As} \Rightarrow K_6(T) = \frac{[Ga_{As}][I_{Ga}]}{[I_{Ga}]}$$

For given T

$$[I_{As}] \propto P_{As_4}^{1/4}$$

$$[I_{Ga}] \propto P_{As_4}^{-1/4}$$

$$[V_{As}] \propto P_{As_4}^{-1/4}$$

$$[V_{Ga}] \propto P_{As_4}^{1/4}$$

$$[As_{Ga}] \propto P_{As_4}^{1/2}$$

$$[Ga_{As}] \propto P_{As_4}^{-1/2}$$

Scheme of the experiment

- Use of two-Zone oven to control the samples temperature and As pressure

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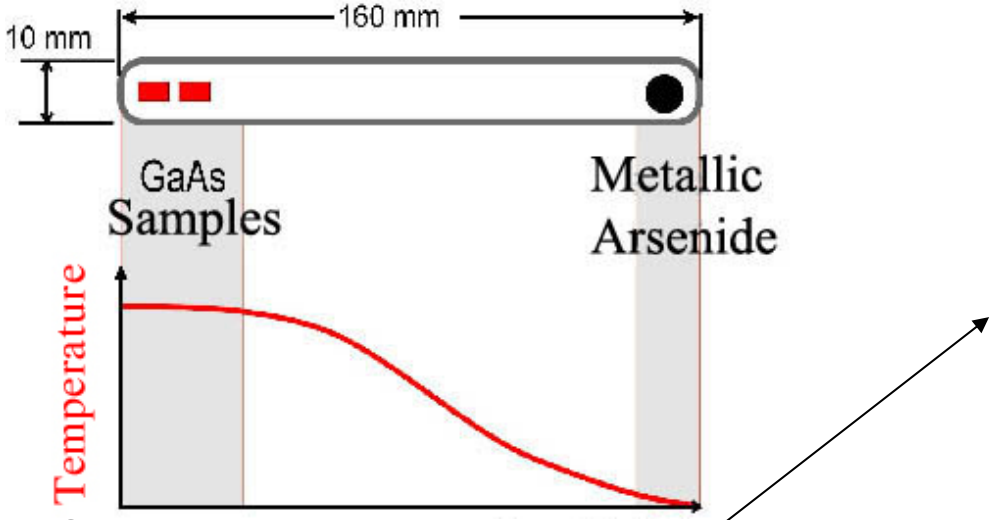
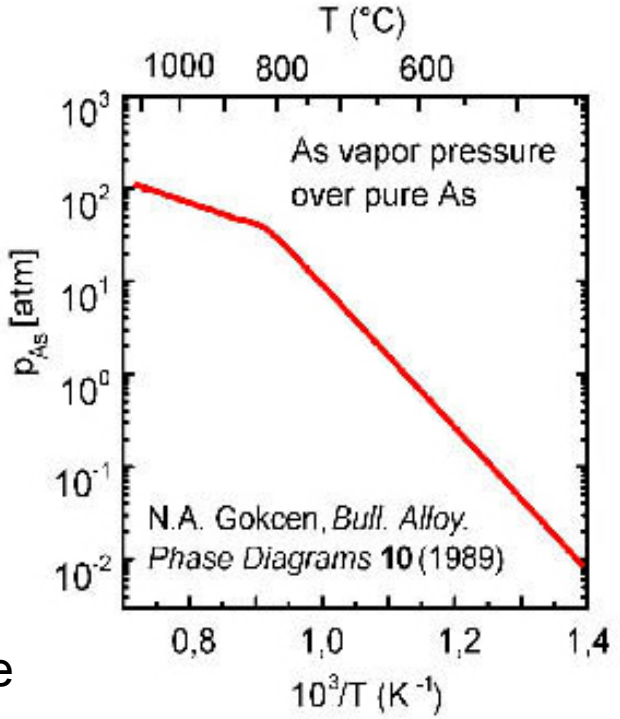
control two necessary degrees of freedom to fix the equilibrium state (T and P_{As})



Sample T:
1100° C

T_{As}
Defines As Pressure

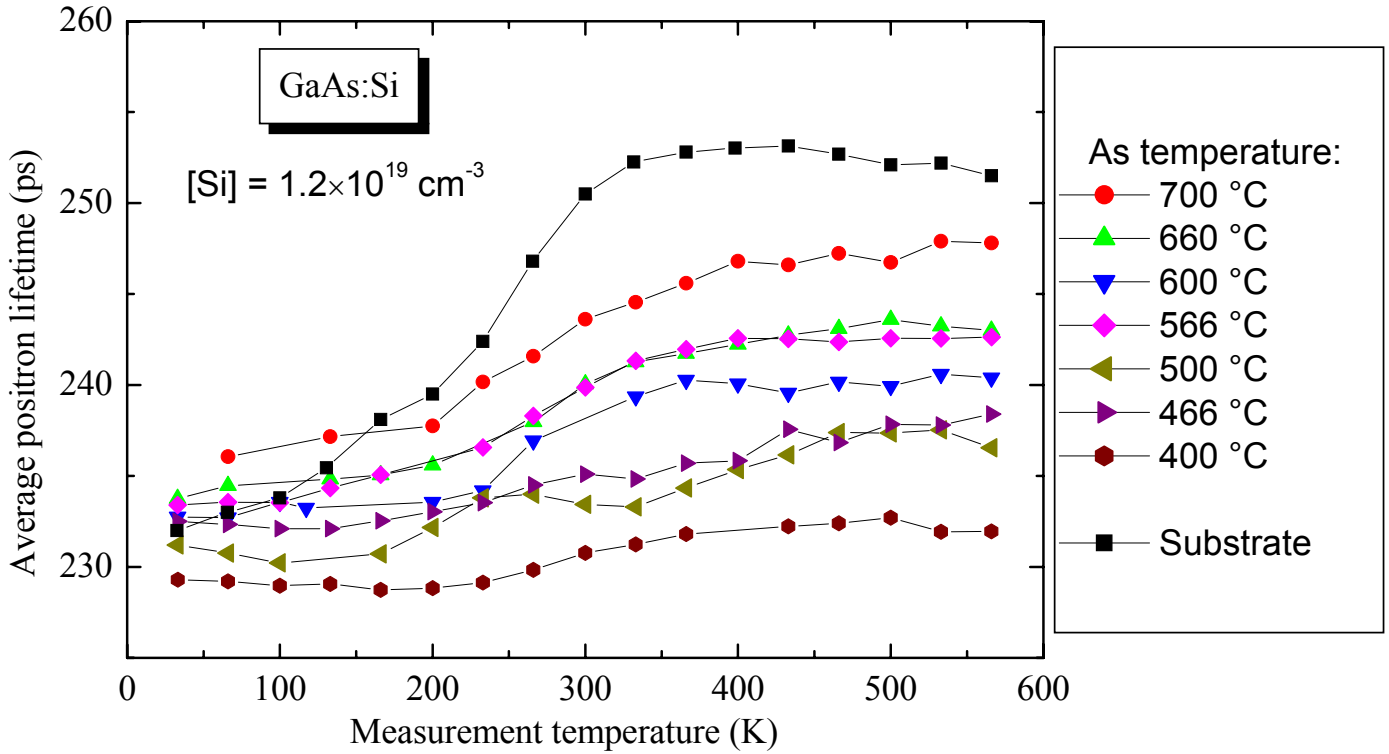


Ampoule: Cu-free quartz (*[Cu] < 0.02 ppm*)
cleaned with 3HCl:1HNO_3

Annealing during 2 hours;
Quenching into the water;
Etching in 2% Bromine Methanol

Previous investigations

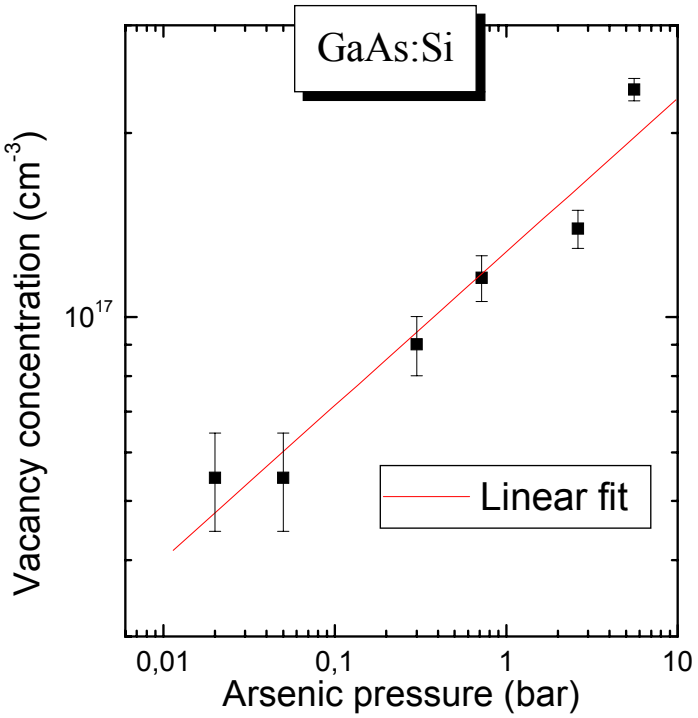
- GaAs:Si well-known $\mathbf{Si_{Ga} - V_{Ga}}$ defect complex



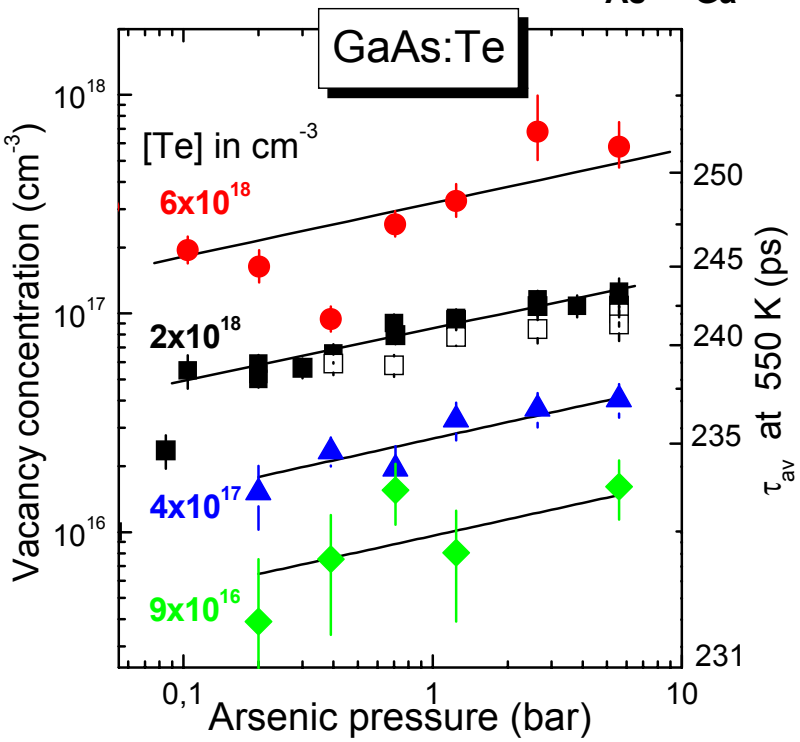
F.Redmann
degree work (1999)

Previous investigations

Si_{Ga}-V_{Ga}



Te_{As}-V_{Ga}



J. Gebauer et al.,
Physica B 273-274, 705 (1999)

Thermodynamic reaction:

$1/4\ As_4^{gas} \leftrightarrow As_{As} + V_{Ga}$

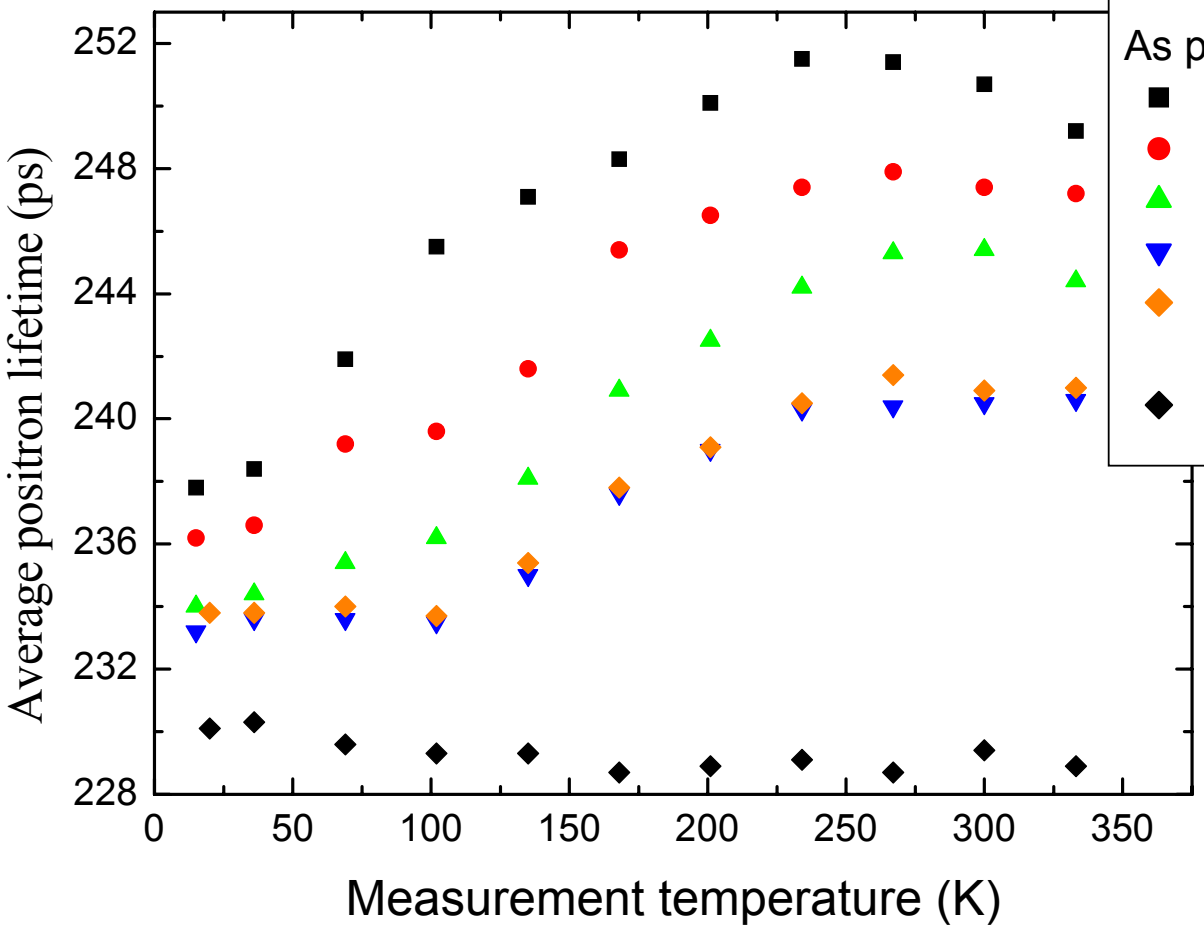
Mass action law:

$[V_{Ga}] = K_{VG} \times p_{As}^{1/4}$

Fit: $[V_{Ga}\text{-Dopant}] \sim p_{As}^{n}$

$\rightarrow n = 1/4$

Undoped GaAs



Defects:
- Vacancy complex
- Shallow traps

Reciprocal dependence
[Vacancies] – As pressure

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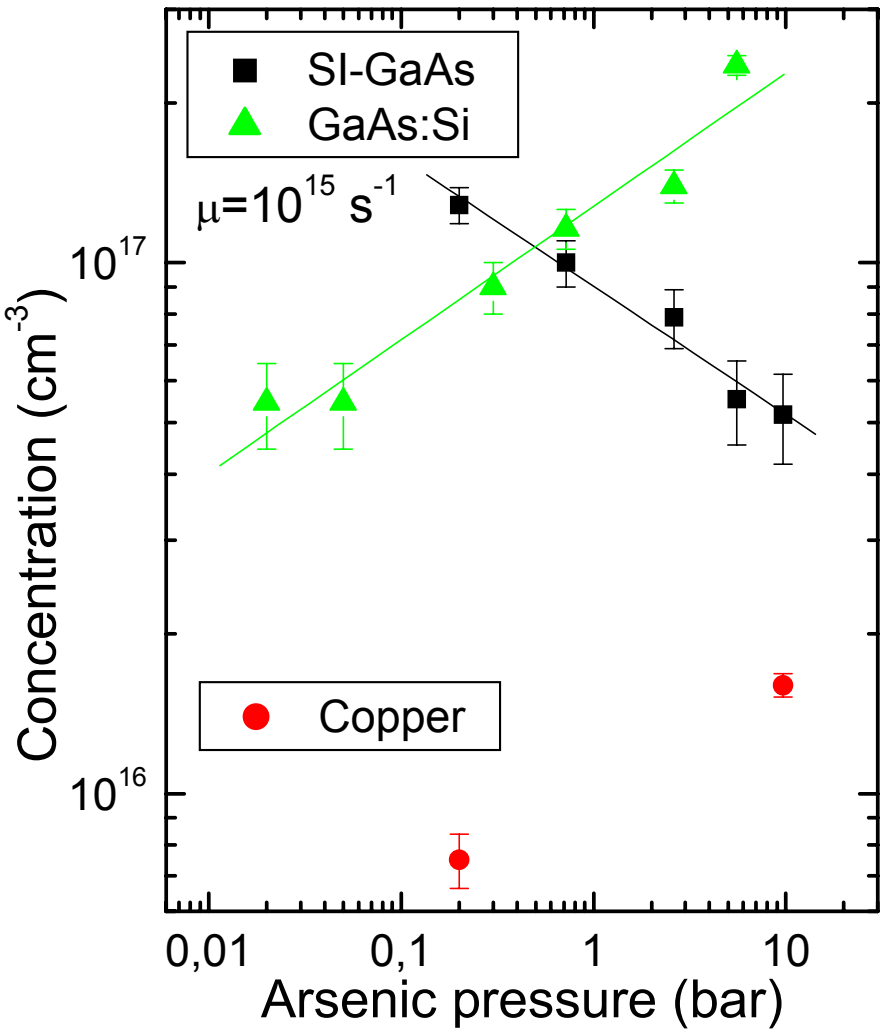
V_{As} - ? complex

2-component decomposition: τ_2 = 293±10 ps
at 300 K I_2 = 40 – 70 %

Defect identification: vacancy complex



Thermodynamic reaction:

$As_{As} \leftrightarrow V_{As} + 1/4As_4^{gas}$

Mass action law:

$[V_{As}] = K_{VAs} \times p_{As}^{-1/4}$

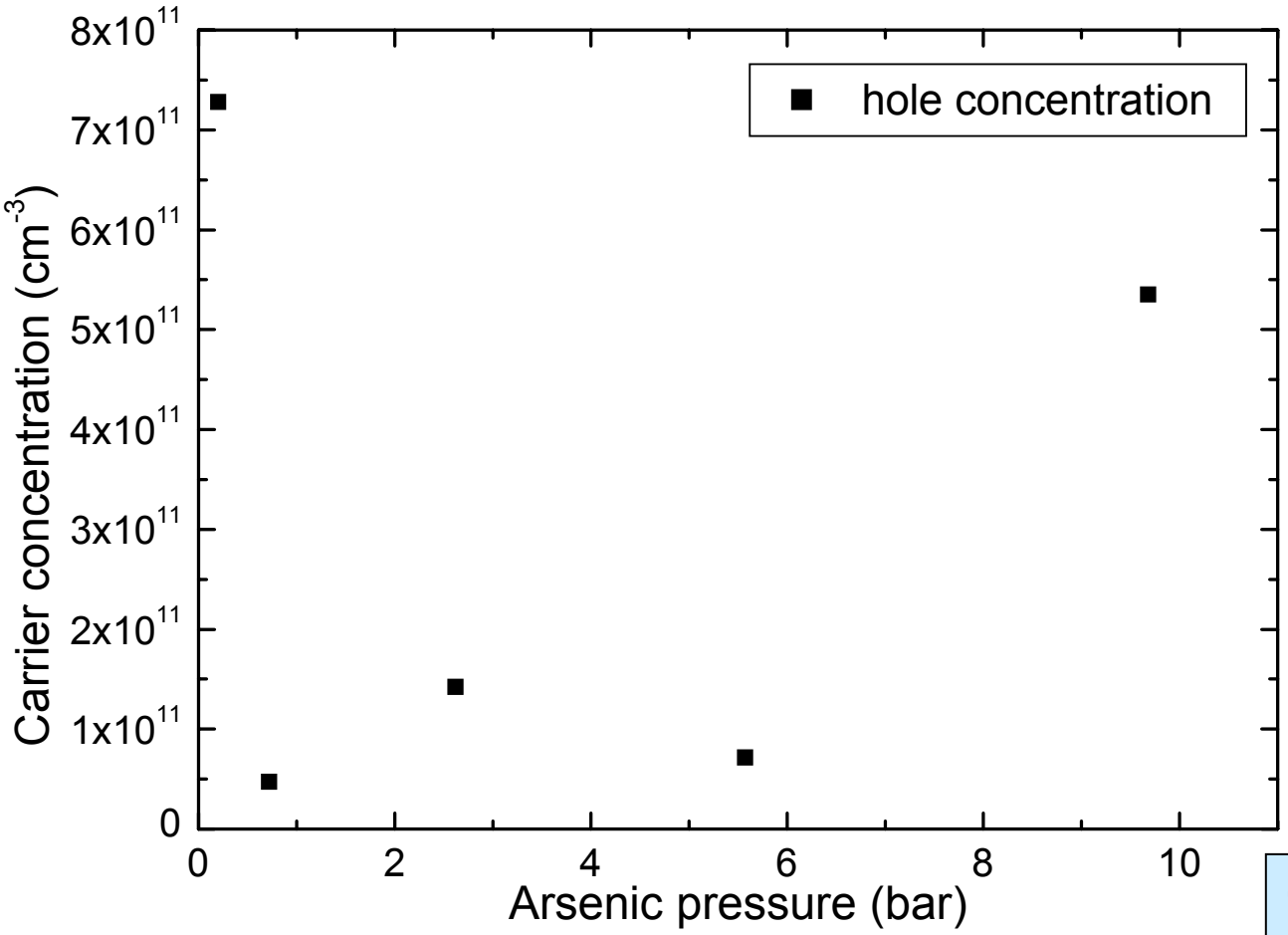
Fit: $[\text{V-complex}] \sim p_{As}^{n}$

$\rightarrow n = -1/4$

As vacancy

Cu is the first candidate for the complex, due to unavoidable contamination - confirmed by titration and photoluminescence measurements

Hall measurements

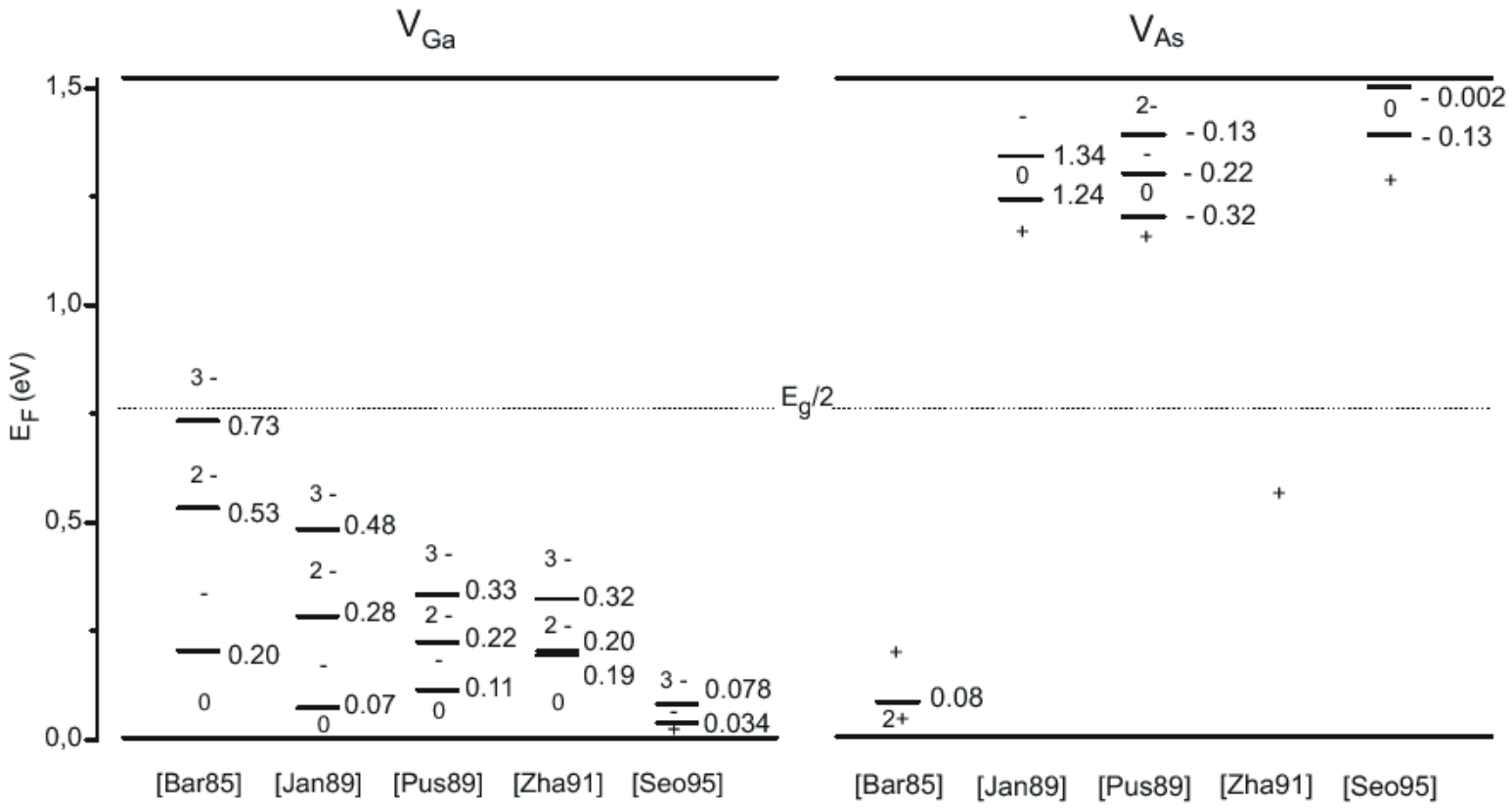


All the samples became p-type: $p \sim 10^{11}$ cm^{-3} independent on the As-pressure

Mobility 200 – 400 cm^2/V s

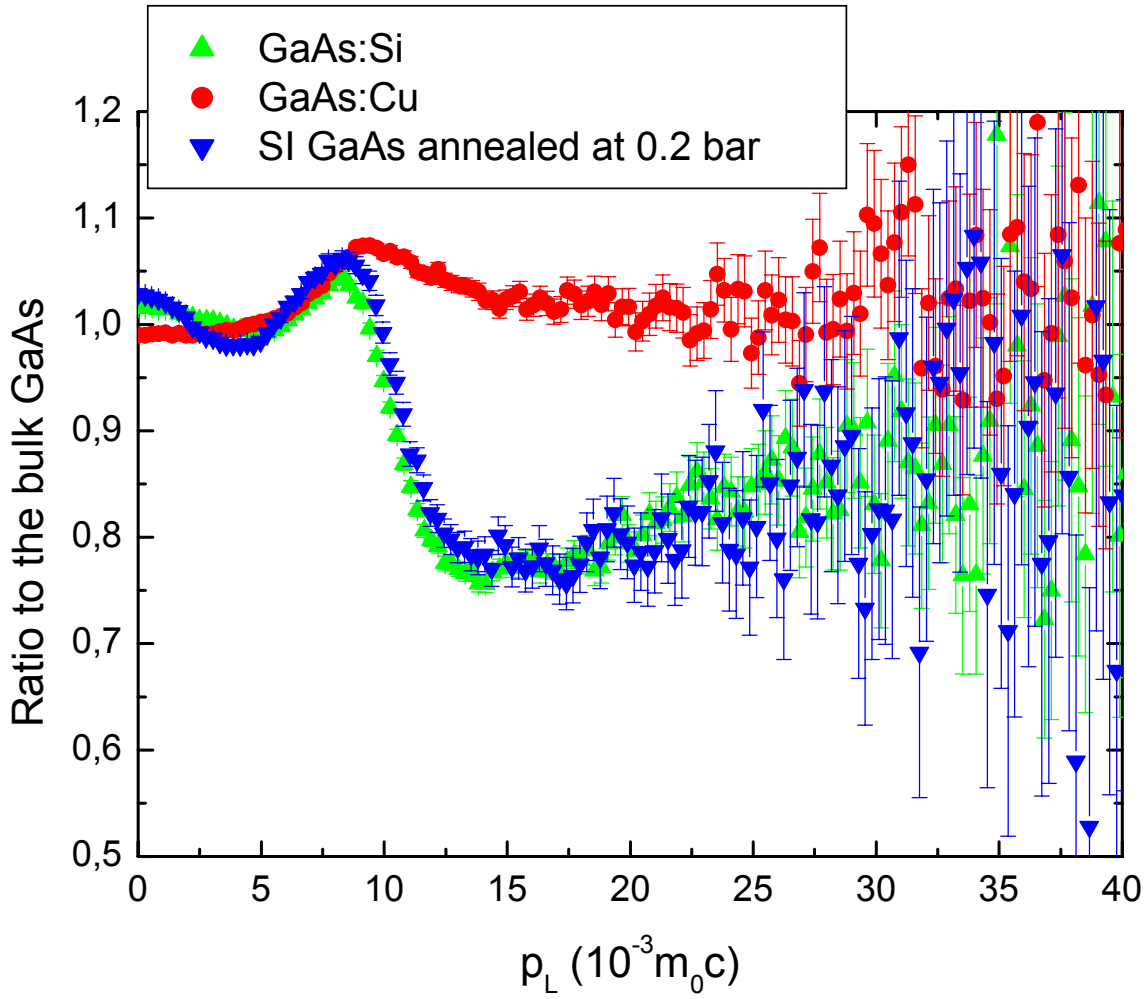
Observed vacancy complex is electrically inactive

Defect identification



According to all theoretical calculations V_{As} are always positive in SI an p-type GaAs $\Rightarrow$ not visible for positrons

Doppler Coincidence measurements



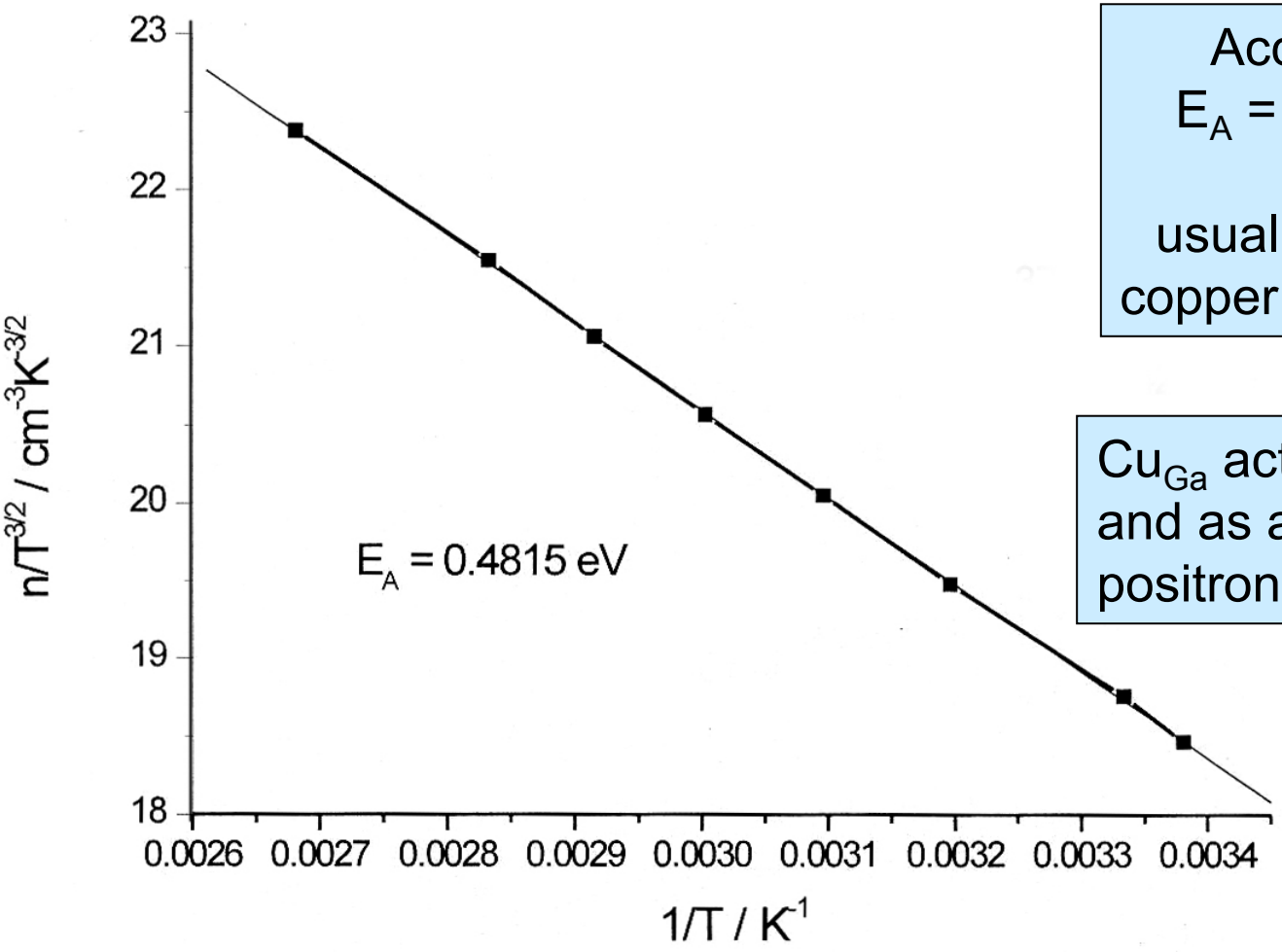
Most popular candidates:
$V_{As}Cu_{Ga}V_{As}$
$Cu_{Ga}V_{As}$
$Cu_{Ga}V_{As}Cu_{Ga}$

but

Cu cannot be the nearest neighbor in our case

Defect identification: shallow traps

Temperature-dependent Hall-effect measurements



Acceptor level:
$E_A = E_V + 0.48$ eV

usually attributed to copper defect complex

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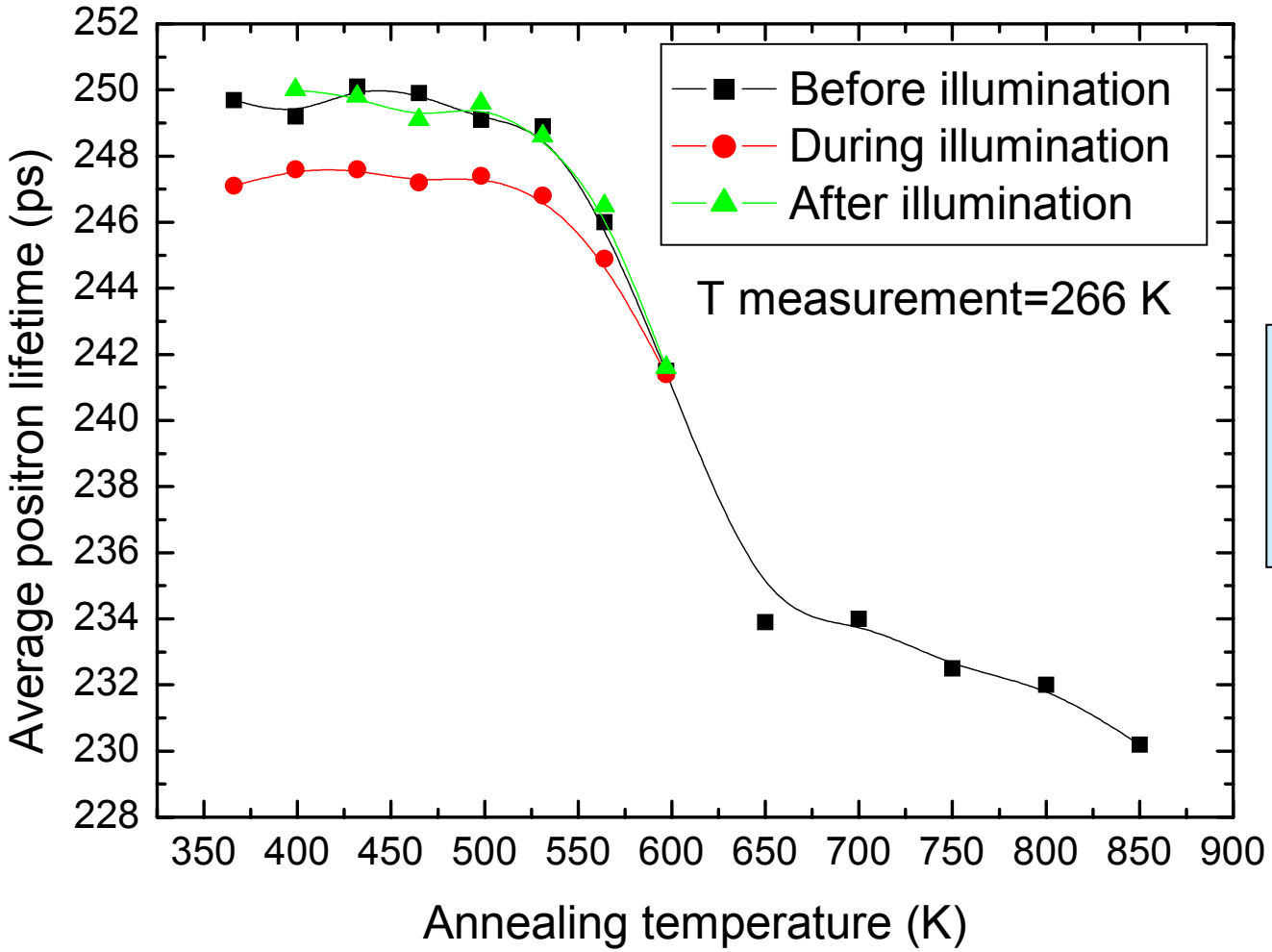
Cu_{Ga} acts as an acceptor and as a shallow trap for positrons

Annealing and optical sensitivity of the defect

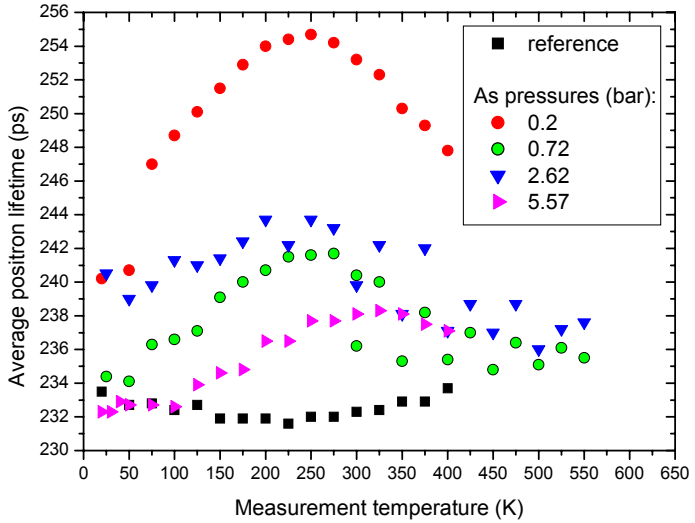


Annealing stage at about 550 – 650 K

During illumination with white light a certain fraction of defects is recharged

Reproducibility

1



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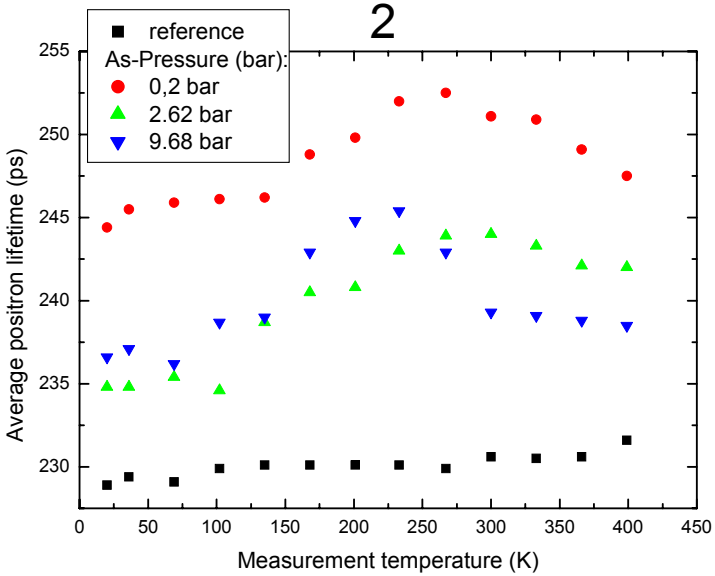

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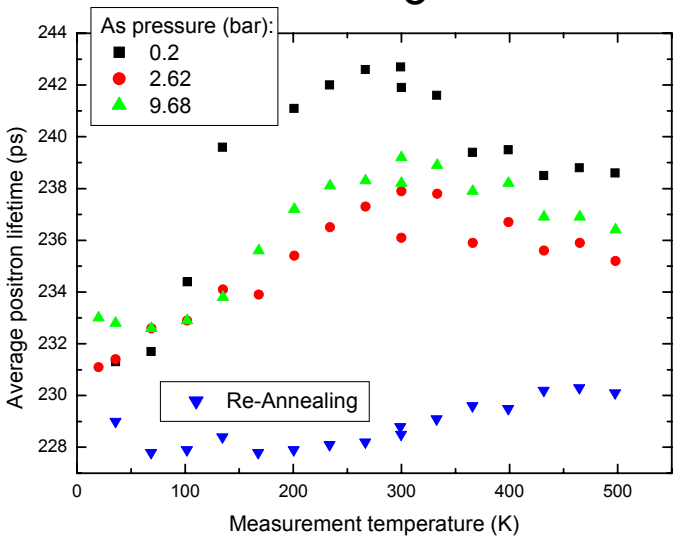
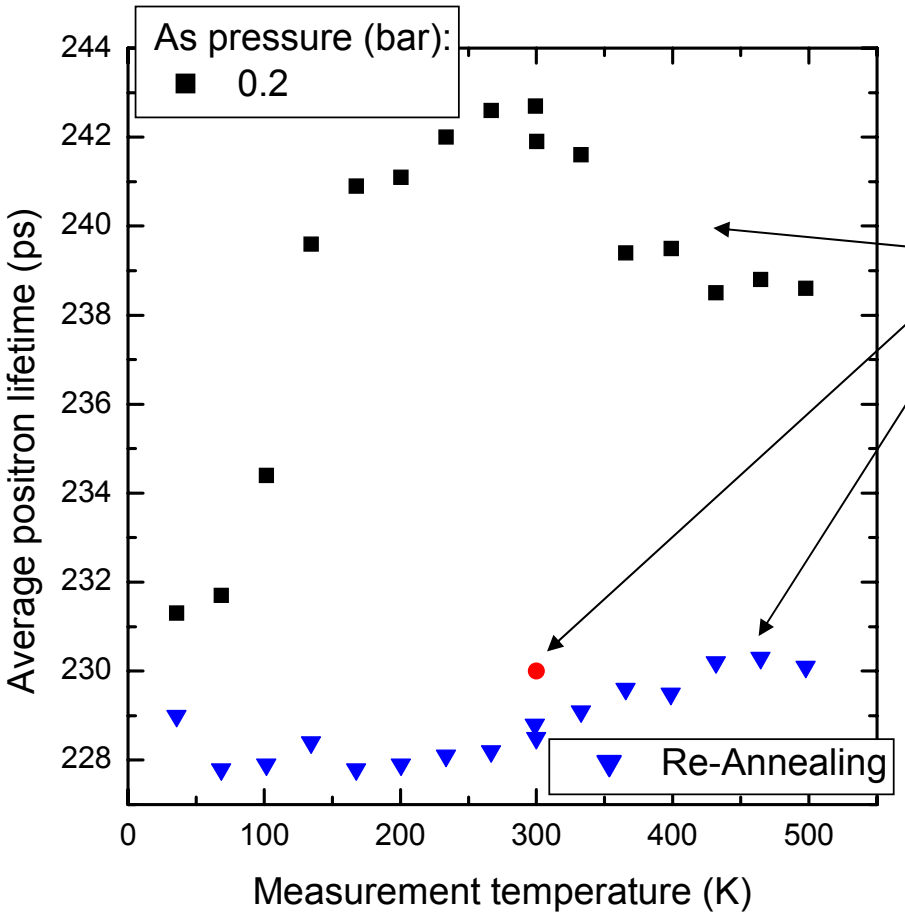


In spite of bad reproducibility the reciprocal dependence on As-pressure is clearly seen

Possible reasons for the results deviations:
- uncontrolled copper contamination
- not the same cooling rate at each quenching

Re-annealing effect



Experiment:

1. Quenching from 1100° C at 0.2 bar;
2. Annealing of defects at 600° C;
3. Second quenching from 1100° C at 0.2 bar

Result:

- Positron signal disappears completely
- The samples became more p-type [p]~10^{16} cm^{-3}

The defect complex is not seen due to the lowering of the Fermi level

Summary

- Defect concentration are defined by the equilibrium state of the system by means of mass action laws
- A reciprocal dependence of the vacancy-complex concentration on the As pressure in SI GaAs was observed
- Such a dependence points to the V_{As} defect complex
- In spite of copper contamination observed the vacancy-like defect is not connected to the copper atom
- The exact nature of the observed complex can't be established from the positron annihilation data alone and is the matter of further investigations