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Acceptors in undoped GaSb; the role of vacancy defects

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Abstract.

The conventional lifetime setup was used to study Czochralski grown unintentionally *p*- and *n*- type ($[n] \approx 6 \times 10^{17} \text{cm}^{-3}$) GaSb bulk samples. Several approaches were used to analyze the data. However, it was not possible to successfully analyze the obtained spectrums with the conventional trapping model. From the analyzed data it was derived that the reason for *p*-type behavior of GaSb was not V_{Ga} . Additionally, the role of gallium vacancy was studied and it's effect to lifetime values are shortly discussed.

1. Introduction

Gallium antimonide (GaSb) is an interesting material thanks to its applications in e.g. high speed electronics. GaSb has Zincblende crystal structure and it has a relatively narrow band gap of 0.73 eV. This makes GaSb useful in the fabrication of infrared detectors and sources. GaSb has a melting point of approximately 700 K [1, 2, 3, 4]. The material can be lattice matched with III-V compounds to form a substrate material for various optical communication devices. Furthermore, GaSb has high electron mobility and saturation velocity, which can be utilized in high electron mobility transistors [2]. To some extent, GaSb is a well known compound. There are quite a few studies about it and its structural properties can be found from publicly known sources for e.g. from [1]. However, there are still surprisingly few studies about vacancy properties of said compound. What makes studies on GaSb even more demanding is the fact that GaSb cannot be grown defect free. This makes e.g. the experimental determination of the positron bulk lifetime in GaSb challenging.

2. Experimental details

Czochralski grown bulk *n*- type ($[n] \approx 6 \times 10^{17} \text{cm}^{-3}$) and unintentionally *p*-type GaSb was measured. The standard sandwich setup was used, with a ^{22}Na e^+ -source wrapped in a 1.5 μm thick nickel foil. Aforementioned sample package was placed on a copper holder, which was in thermal contact with a closed cycle helium cryostat for the duration of the measurements. The measurements were performed in vacuum of about 10^{-4} Torr at 30-300 K. To confirm the validity of the results, the same measurement set were ran multiple times, in both directions (i.e. from 30 K to 300K and vice versa). The positron annihilations in the source material, in the covering Ni-foil and e^+ annihilating as positronium was removed from raw spectra.



3. Results

Results for the average positron lifetime (τ_{ave}) in *n*-type and unintentionally *p*-type GaSb is shown in Fig. 1. For the *p*-type GaSb, a plateau can be seen reaching from 30 K all the way to 160 K. After this plateau, a gradual rise can be seen. In average lifetime, the increase is approximately 10 picoseconds in the temperature range of 30-300 K. For *n*-type bulk GaSb, no similar plateau can be seen. Here, τ_{ave} rises gradually from about 255 picoseconds at 30K to 265 picoseconds at 300 K.

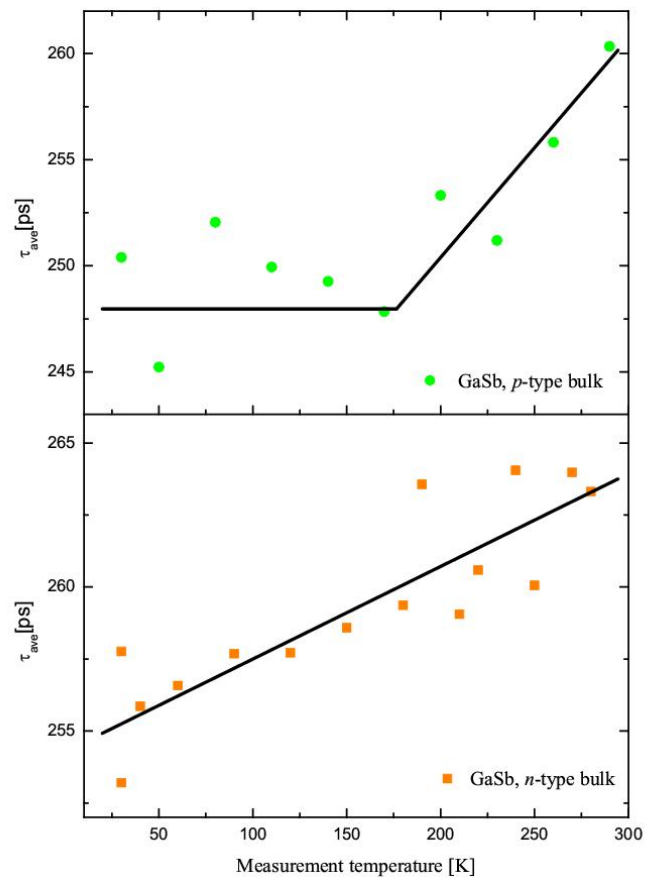


Figure 1. Average annihilation lifetimes τ_{ave} for *n*- and *p*-type bulk GaSb (The lines are drawn to guide the eyes).

A two component trapping model was used when extracting lifetime data from the spectrum. Fig. 2 shows the resulted graphs for *n*-type and unintentionally *p*-type GaSb.

For unintentionally *p*-type GaSb, it can be seen, that at low temperatures, τ_1 component is around 70 ps and above 170 K, it starts gradually to increase to value of 170 ps at RT. Intensity for this component is quite low; starting from 2-3 % and rising to 7 % at RT. The τ_2 component increases from 260 ps unto 280 ps at room temperature. Its intensity is high; over 90 % and although its value is lower closer to the room temperature, it is still relatively high overall. Just

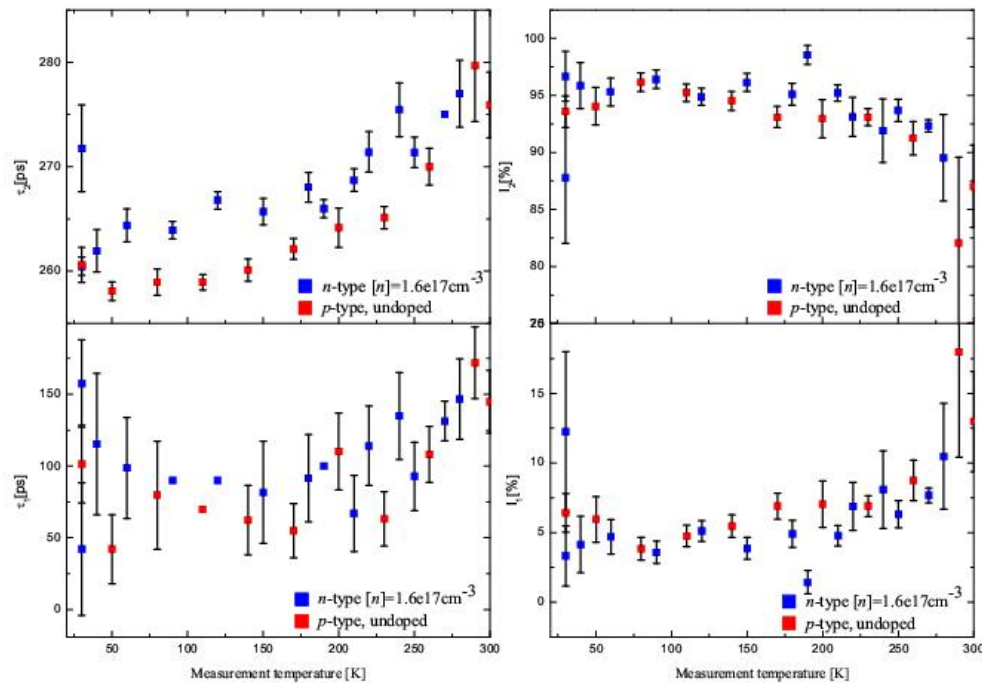


Figure 2. Extracted components from positron annihilation data for GaSb

before room temperature,

I_2 decreases strongly, being about 80 % at 300 K. For n -type GaSb, τ_1 can be seen to stay around 100 ps until 200 K when it slowly starts to rise, all the way to 150 ps. The intensity of τ_1 is around 3 %, until approximately 200 K point, where it increase to 10 %. τ_2 increases first slowly from 260 ps to 265 ps between 30-150 K and then increases faster, being 275 ps in 300 K. The intensity of τ_2 of n -type GaSb is quite stable and stays over 95 %, until around 170 K, it starts to decrease, being about 90 % at the room temperature.

4. Discussion

The best fit to the spectrum was obtained with a two component trapping model. In the Fig. 1 both curves drop to 250-254 ps, which is assumed to be the bulk lifetime for GaSb. At 30-150 K τ_{ave} in the p -type GaSb is constant at 257 ps. For n -type GaSb, a steady increase of 10 ps can be seen in the average lifetime at 30-300 K. Approximately 5 ps of this increase is can be attributed to thermal expansion. The two-trap analysis in Fig. 2 shows some peculiar behavior for both samples. For both samples the intensity in τ_2 is very high, suggesting saturation trapping. However the temperature dependence of the τ_2 component over the whole temperature interval of the measurement is very strong, i.e. decreases with decreasing temperature over a temperature range of almost 300 K. This could be an indication of a charge transition, as in [3]. As can be seen from typical lifetime spectrum shown in Fig. 3, only one lifetime component is visible.

The average lifetime at 30 K is very close to the assumed bulk lifetime, i.e. the dominant positron trap at 30 K has no open volume. Hence, we do not think that the reduction in lifetime with decreasing temperature is due to a charge transition. Rather, that a negatively charged

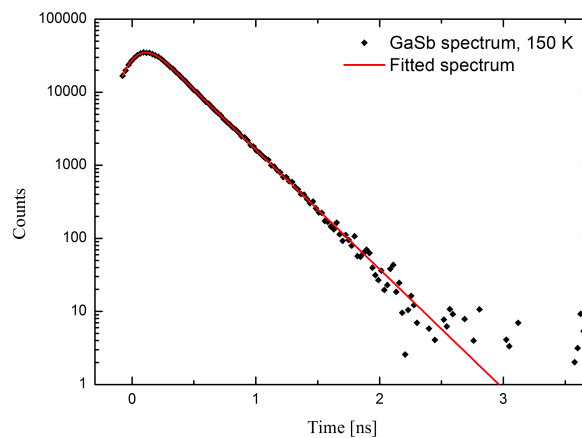


Figure 3. Raw spectrum from lifetime measurement at $T=150$ K

shallow trap (a negatively charged ion) starts to trap positrons with decreasing temperature. This negatively charged ionic defect is most likely the one responsible for the unintentional p -type behavior in as grown GaSb. A possible candidate could be the Ga_{Sb} antisite. The vacancy type defect that causes the average lifetime to increase with increasing temperature is most likely a Ga vacancy. The fact that the shallow trap starts to compete as a trapping center with the Ga vacancy already at room temperature could suggest that the vacancy is neutral.

5. Conclusions

We have used the conventional lifetime setup to study Czochralski grown unintentionally p - and n - type ($[n] \approx 6 \times 10^{17} \text{cm}^{-3}$) GaSb bulk samples. It was tentatively deduced that a Ga vacancy causes the average lifetime to rise with temperature. Decrease in τ_{ave} in low temperatures is possibly due to a negatively charged ion. This trap was assumed to be the Ga_{Sb} antisite.

6. References

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