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Note

Distribution coefficient of tellurium in GaSb single crystals

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Abstract

The series of tellurium-doped GaSb single crystals were grown by the Czochralski method. The distribution coefficient k_{ef} of tellurium in GaSb crystals was calculated from the free carrier concentration. Its value is $k_{\mathrm{ef}} = 0.32 \pm 0.16$ for a low concentration of tellurium in the melt.

INTRODUCTION

Gallium antimonide single crystals are very important for the fabrication of long wavelength ($\lambda \geqslant 1.5$ μm) detectors and lasers. The use of these longer wavelengths makes it possible to significantly reduce the losses due to Rayleigh scattering. The advantage of gallium antimonide is the very small difference in lattice parameters, when compared to other ternary or quaternary substrates of III–V compounds that would be suitable for these wavelengths [1].

The relatively low vapour pressure of the volatile component (antimony, 100 Pa) at the low melting point (712°C) [2] makes possible the growth of single gallium antimonide crystals by the Czochralski technique, without the application of either inert gas or encapsulant. The main problem is avoiding a thin oxide film on the surface of the gallium antimonide melt, so the Czochralski method with a flowing hydrogen atmosphere [3] seems most convenient.

EXPERIMENTS AND RESULTS

The growth apparatus was used as described in a previous paper [4]. Feed gallium antimonide was directly synthesized from gallium (99.9999%) and antimony (99.9995%) in a quartz crucible. Although the vapour pres-

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TABLE 1

List of tellurium-doped GaSb measured single crystals

Crystal number	Concentration of tellurium in the melt (atom cm^{-3})	Free carrier concentration ($cm^2\ V^{-1}\ s^{-1}$)	Distribution coefficient relation (1) $x = 0.1$	Distribution coefficient relation (2)
GaSb-85	9.243×10^{16}	$+4.878 \times 10^{16}$	0.50	0.53
GaSb-59	2.026×10^{17}	$+1.041 \times 10^{17}$	0.49	0.51
GaSb-58	4.364×10^{17}	$+1.026 \times 10^{17}$	0.22	0.24
GaSb-60	7.973×10^{17}	-1.853×10^{17}	0.21	0.23
GaSb-74	2.182×10^{18}	-1.400×10^{18}	0.62	0.64
GaSb-41	2.208×10^{18}	-2.361×10^{17}	0.10	0.11
GaSb-84	2.260×10^{18}	-3.531×10^{17}	0.14	0.16
GaSb-83	2.293×10^{18}	-8.045×10^{17}	0.33	0.35
GaSb-75	2.358×10^{18}	-6.237×10^{17}	0.25	0.27
GaSb-43	4.374×10^{18}	-1.350×10^{18}	0.29	0.31
GaSb-42	4.517×10^{18}	-1.298×10^{18}	0.27	0.29
GaSb-40	8.838×10^{18}	-3.575×10^{18}	0.38	0.40

sure of antimony is only 100 Pa, it was necessary to compensate for its volatilization by adding about 0.1% excess antimony to the starting material [3]: some antimony escapes from the melt during the synthesis and the growth.

Both the synthesis and the growth were performed in a flowing hydrogen atmosphere, well purified by the palladium purifier, with a flow rate of 70 $cm^3\ min^{-1}$. After the synthesis, the gallium antimonide ingot was removed from the crucible, cleaned by grinding and etching and then used as the starting material for the pulling of single crystals. For doping, elementary tellurium (99.9999%) was added to the melt, in an amount ranging from 0.0003–0.03 wt.%.

The gallium antimonide crystal seed with $\langle 111 \rangle$b orientation was used. The pulling rate was 12 mm h^{-1} and the rotation rate of the seed varied in the range 20–25 rev min^{-1}. The quartz crucible was stationary.

Twelve gallium antimonide single crystals were grown with various tellurium concentrations in the melt. A wafer was cut from each crystal at a distance of one tenth of the crystal length. The free carrier concentration was then measured by the standard van der Pauw method [5] (see Table 1). Consequently, we calculated the distribution coefficient (k_{ef}) of tellurium in gallium antimonide single crystals from eqn. (1)

$$[\mathrm{Te}]_c = [\mathrm{Te}]_m k_{ef}(1-x)^{(k_{ef}-1)} \qquad (1)$$

where x is the fraction of the solidified part of the melt (in our case $x = 0.1$), $[\mathrm{Te}]_m$ is the starting value of the tellurium concentration in the melt and $[\mathrm{Te}]_c$ is the concentration in the solid part [6]. We substituted a free carrier concentration for $[\mathrm{Te}]_c$ and calculated the distribution coefficient [7]. As a check, we also used the simplified relation

$$[\mathrm{Te}]_c = [\mathrm{Te}]_m k_{ef} \tag{2}$$

which is possible because x falls within the range 0–0.5 [8]. The calculated values for both relations are also listed in Table 1, showing that the average distribution coefficient for eqn. (1) is $k_{ef} = 0.32 \pm 0.16$ and for eqn. (2) $k_{ef} = 0.34 \pm 0.16$.

DISCUSSION

The average value of the distribution coefficient of tellurium in gallium antimonide single crystals calculated from the free carrier concentration is in good agreement with the data mentioned elsewhere [7,9,10]. For the tellurium concentration used, it is possible and sufficient to describe the distribution of tellurium in gallium antimonide crystals by mere measurement of the free carrier concentration. If the starting tellurium concentration were higher than the highest one of 9×10^{18} atom cm^{-3} used, it would be possible that a "saturated state" might occur. This situation was recently described for silicon-doped gallium arsenide single crystals [11], i.e. after reaching a certain concentration of silicon in the starting melt of gallium arsenide, the free carrier concentration is not unable to keep up with the increase of the silicon concentration in the solid part of the growing crystal.

In so far as the distribution coefficient of tellurium in gallium antimonide single crystals calculated from the free carrier concentration (k_{ef} = 0.32) is in good agreement with chemical measurements [9], we can suppose that the measurement of the free carrier concentration describes very well the concentration of tellurium in gallium antimonide crystals in the range 9×10^{16}–9×10^{18} atom cm^{-3} in the starting melt.

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