Available online at www.sciencedirect.com
ScienceDirect
Physica B 401–402 (2007) 246–249
PHYSICA B
www.elsevier.com/locate/physb

Influence of boron on the point defect equilibrium in highly n-doped gallium arsenide single crystals

U. Kretzer[a,*], F. Börner[a], T. Bünger[b], S. Eichler[a]

[a]Freiberger Compound Materials GmbH, Am Junger-Loewe-Schacht 5, 09599 Freiberg, Germany
[b]Norddeutsche Affinerie AG, Hovestrasse 50, 20539 Hamburg, Germany

Abstract

High n-type conductivity of melt-grown gallium arsenide single crystals is usually achieved by doping with tellurium or silicon. The lower carrier concentration and Hall mobility in silicon-doped crystals is attributed to the formation of acceptor defects, in particular Si_{As}^-, the isolated gallium vacancy V_{Ga}^{3-} and the $(Si_{Ga}-V_{Ga})^{2-}$ complex. We show that the contamination of the crystals with boron, which is unavoidable in growing techniques using a boron oxide encapsulant, is decisive for the degree of compensation. In highly n-doped gallium arsenide crystals boron is not only incorporated as the isoelectronic defect B_{Ga}^0. Additionally, high concentrations of B_{As}^{2-} and the negatively charged B_{As}-donor complex are formed. These acceptors can dominate the equilibrium of point defects depending on the concentration ratio of the n-dopant and boron.
© 2007 Elsevier B.V. All rights reserved.

PACS: 71.55.−i; 71.55.Eq; 72.10.Fk; 72.20.Jv

Keywords: Gallium arsenide; Silicon doping; Electrical compensation; Fermi level effect

1. Introduction

Highly n-doped gallium arsenide substrates are used for the fabrication of opto-electronic devices such as high brightness LED and laser diodes. These applications require substrates of low dislocation density and high conductivity. In melt-grown gallium arsenide crystals grown by the vertical Bridgman (VB) and the vertical gradient freeze (VGF) techniques, mainly silicon is used as an n-dopant. The low dislocation density achieved in this material is attributed to lattice hardening by silicon point defects [1]. Crystals doped with tellurium show a cellular dislocation network which is also typical for undoped crystals. Although Si is the favorable n-dopant from the dislocation density point of view Te-doped crystals show better electrical properties. The doping efficiency η_d, which can be defined as the ratio of carrier concentration n to the concentration of the n-dopant N_d, is substantially higher in the range of $N_d = (10^{17} \ldots 10^{19})\,cm^{-3}$ than in the case of Si-doping. This means, that for a given N_d carrier concentration n is higher for Te-doped than for Si-doped crystals. In Fig. 1 this is illustrated on experimental data of about 500 Si-doped and 40 Te-doped GaAs crystals. Moreover, in Si-doped material a limitation of carrier concentration to values below $(3 \ldots 4) \times 10^{18}\,cm^{-3}$ is observed. Fig. 2 shows that the Hall mobility μ_H of Si-doped crystals is lower than of Te-doped crystals for a given n. Similar results, especially for Si-doped material can be found in numerous publications [2–7].

The observed differences in the electrical parameters are attributed mainly to a different incorporation of the dopants into the GaAs lattice. Besides the Si_{Ga}^+ donor, Si can form also the acceptor Si_{As}^- [8], the donor–acceptor complex $(Si_{Ga}-Si_{As})^0$ [9] and the donor–vacancy complex $(Si_{Ga}-V_{Ga})^{2-}$ [10]. Tellurium is only incorporated in the As sublattice, forming the donor Te_{As}^+ and the acceptoric donor-vacancy defect $(Te_{As}-V_{Ga})^{2-}$ [11]. The formation of further types of defects containing donor atoms, as in Si-doped crystals, was not observed. Therefore, the lower η_d in Si-doped crystals should be due to the amphoteric behavior of silicon, leading to a higher concentration of

*Corresponding author. Tel.: +49 3731 280 176; fax: +49 3731 280 106.
E-mail address: kretzer@fcm-germany.com (U. Kretzer).

0921-4526/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.physb.2007.08.158

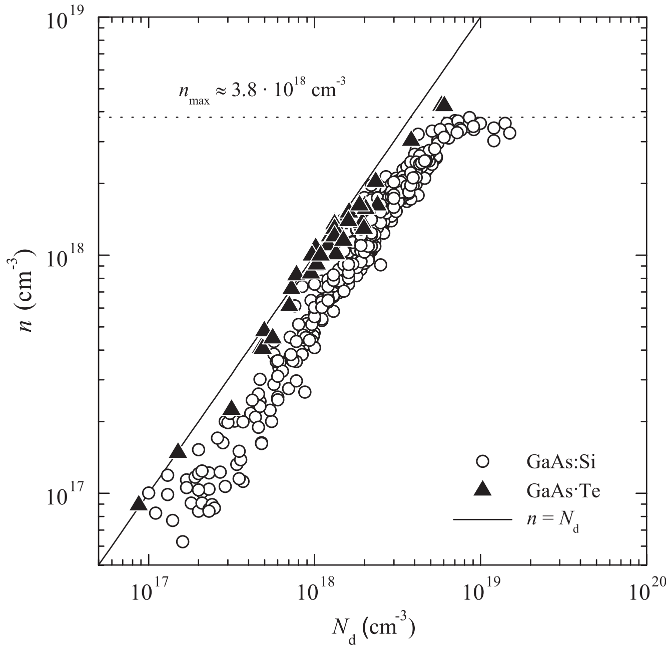

Fig. 1. Hall carrier concentration n of VGF-grown GaAs:Si and LEC-grown GaAs:Te crystals vs. concentration of the n-dopant. For GaAs:Si n is limited to about $3.8 \times 10^{18}\,\mathrm{cm}^{-3}$ (dotted line). The solid line illustrates the case of $\eta_d = 1$.

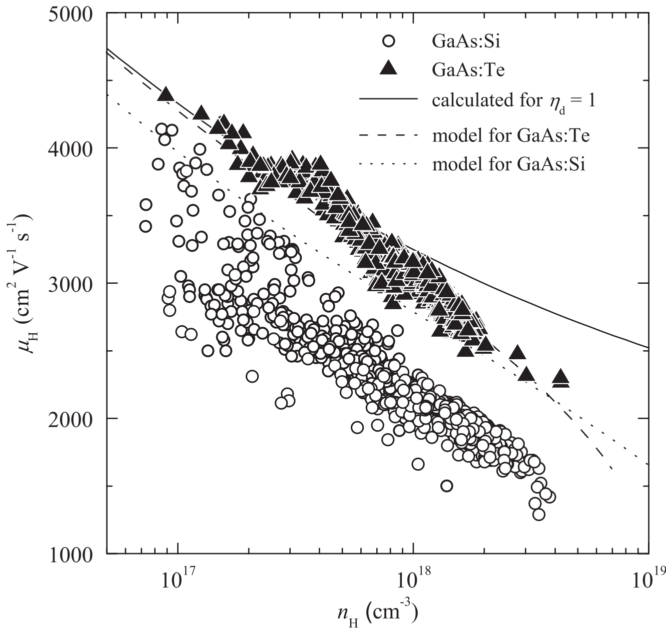

Fig. 2. Hall mobility μ_H of VGF-grown GaAs:Si and LEC-grown GaAs:Te crystals vs. carrier concentration n. The lines show the calculated Hall mobility for the cases of $\eta_d = 1$ and for models for GaAs:Te and GaAs:Si, respectively, valid for material with low boron content. For details of the calculation see Section 3.

acceptoric or electrical inactive defects, respectively [4,7]. We will show, however, by a comparison of experimental data and results from calculations of the $\mu_H(n)$ dependency, that for crystals, which contain boron in a concentration comparable to that of the n-dopant, this model cannot describe the observed differences.

2. Experiments

The experimental data shown in Figs. 1 and 2 have been measured by the van-der-Pauw/Hall method at samples taken from Si-doped VGF-grown and Te-doped LEC-grown GaAs crystals. The diameter of the crystals was 100 mm in the case of Si-doping and 3 inch in the case of Te-doping. Details of the growing conditions can be found in Refs. [12,13]. In both growing techniques an encapsulation of the GaAs melt by liquid boron oxide was used to prevent a decomposition of the melt. The B_2O_3 melt undergoes complex physical and chemical interactions with the GaAs melt and the dissolved dopants and impurities as well as with the ambient gas atmosphere [14,15]. The reaction

$$3\,\mathrm{Si} + 2\,\mathrm{B_2O_3} \leftrightarrows 3\,\mathrm{SiO_2} + 4\mathrm{B} \quad (1)$$

leads to a loss of Si dopant. The GaAs melt and the grown crystals are contaminated with boron [16]. It becomes clear from Eq. (1) that the concentration of boron in the GaAs melt can even exceed the Si concentration. Tellurium shows a much lower chemical activity, so that in Te-doped crystals a contamination of boron in the concentration range of only $10^{16}\,\mathrm{cm}^{-3}$ is found, which arises from thermal decomposition of B_2O_3. In semi-insulating GaAs boron is incorporated nearly completely as the isoelectronic defect B^0_{Ga}. For Si-doped crystals the existence of B_{As} and $(Si_{Ga}-B_{As})$ defects has been proved by localized vibrational modes (LVM) spectroscopy [17]. It can be assumed that also in Te-doped crystals the donor-B_{As} complex is formed, provided a sufficiently high boron concentration. For a systematic investigation of the formation of boron acceptors in GaAs two special VGF crystals have been grown. One crystal was obtained from a melt containing an initial Te concentration of $3.75 \times 10^{19}\,\mathrm{cm}^{-3}$ and a B concentration of $1.3 \times 10^{19}\,\mathrm{cm}^{-3}$. For the growth of the other crystal the same amount of Te has been added to the melt. The second dopant was Si instead of boron, with a initial concentration of $1.1 \times 10^{19}\,\mathrm{cm}^{-3}$. The crystals have been sliced into wafers. A selection of wafers from different axial positions has been characterized by van-der-Pauw/Hall measurements and chemical analysis by glow discharge mass spectrometry (GDMS).

In Fig. 3 the $\mu_H(n)$ dependency for these samples is plotted by analogy with Fig. 2. In contrast to Te-doped crystals not intentionally doped with B, the Hall mobility in the Te–B-doped samples drops by more than $1000\,\mathrm{cm^2\,V^{-1}\,s^{-1}}$ while n increases from 1.0 to $1.6 \times 10^{18}\,\mathrm{cm}^{-3}$. A similar decrease of μ_H is observed for the crystal doubly doped with Te and Si. Although no boron has been added to the melt in this case, a high concentration of B was expected because of Eq. (1). This was proved by chemical analysis. The boron content amounts to $1.1 \times 10^{18}\,\mathrm{cm}^{-3}$ at the seed end and $7.2 \times$

Download English Version:

https://daneshyari.com/en/article/1814989

Download Persian Version:

https://daneshyari.com/article/1814989

Daneshyari.com