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Growth of $Ga_{(1-x)}In_xSb$ alloys by Vertical Bridgman technique under alternating magnetic field

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Abstract

GaInSb samples have been grown by the Vertical Bridgman technique with alternating magnetic field in order to improve mixing of the rejected InSb in the melt. Three values of the magnetic field were used 0, 2, 3 mT and the solid–liquid interface demarcation during solidification has been carried out by Peltier pulse marking technique. The chemical composition of the grown samples has been checked using wavelength dispersive X-ray microanalysis technique (WDX) and particle induced X-ray emission technique (PIXE).

The GaInSb samples with a nominal In concentrations of 3% and 8%, grown under alternating magnetic field, show a radial segregation almost constant along the ingot. The electromagnetic mixing effect is also observed in the profile of interface curvature and axial segregation.

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1. Introduction

Semiconductor concentrated alloys, as for example $Ge_{(1-x)}Si_x$, $Ga_{(1-x)}In_xAs$, $Hg_{(1-x)}Cd_xTe$, $Ga_{(1-x)}In_xSb$ and many others, are promising materials for electronic and optoelectronic industry, because their lattice parameters and band gap are a function of the alloy composition x . The growth of such electronic quality materials is still difficult because of chemical segregation phenomena. Vertical Bridgman experiments [1] and their numerical simulation [2] have shown that the growth of concentrated alloys is subject to huge chemical segregation and interface destabilization, because of a strong coupling between solute segregation, hydrodynamics and variation of melting temperature with concentration. The classical growth techniques have been continuously modified in order to improve the material quality; the use of external magnetic fields could be a solution to control the melt convection during the growth process and then enhance the mixing of components. The researches have been generally focused on the numerical and experimental investigations of the rotating magnetic field (RMF) effect [3–7]; by applying a RMF the solid–liquid interface deflection can be controlled and the dopant inhomogeneities reduced.

In this paper, we propose an alternative solution, simpler from the technical point of view, to reduce the radial segregation and to prevent the interface destabilization during the growth process of ternary alloys: the use of an alternating magnetic field. The first results of the alternating electromagnetic field effect on the solid–liquid interface shape and chemical segregation are presented. The growth of GaInSb by Vertical Bridgman technique under alternating magnetic field has been numerically investigated by Stelian [8,9]. The numerical results demonstrate that an alternating magnetic field applied near the solid–liquid interface can increase the melt flow intensity, then decreasing the radial segregation and the interface deflection.

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The aim of this technique is to improve the chemical homogeneity of polycrystalline GaInSb. Due to the strong mechanical stresses introduced by the chemical heterogeneities, it is only when this problem solved that the attention will be concentrated on the growth of single crystals.

2. Experimental procedure

2.1. Experimental set-up and growth conditions

Growth experiments of GaInSb have been carried out in a Vertical Bridgman furnace adapted to provide a good mixing of the liquid near the interface by an alternating electromagnetic field (Fig. 1). Following the numerical simulation results, the heater geometry has been changed and an induction coil surrounding the boron nitride crucible has been added. When an alternating current is applied to the coil, electromagnetic forces are generated in the melt (interaction between the electromagnetic field and induced currents). These forces reach a maximum value in the middle of the coil and decrease towards the coil edges, so two fluid flow cells are created. The lower one positioned near the solid–liquid interface and opposed to thermal convection is responsible for the liquid mixing near the interface.

The magnetic field optimal parameters and the interface position relative to the coil has been determined from the simulation [8,9]. The characteristic dimensions of the coil are the length $l = 2\,\text{cm}$, the copper wire diameter $\Phi = 1\,\text{mm}$, the number of wire turns, $n = 14$. The current frequency applied to the coil is 5000 Hz and the current intensity is adapted in order to obtain suitable values of the magnetic field. The magnetic field inside the coil has been measured and electrical currents of 2.7 and 4.1 A give magnetic fields of 2 and 3 mT.

A Peltier pulse marking system has been developed in order to investigate the shape and the position of the interface during the growth: when an electrical pulse passes trough the solid–liquid interface, a quantity of heat is emitted or adsorbed due to the thermal phenomena, Joule, Peltier and Thomson effects, modifying the growth velocity and in consequence the incorporation of components in the ingot. The electrical pulses are sent in the samples through a bronze clamp in contact with the crucible support, which acts as reference potential, and a graphite piece immersed in the liquid. The observation of the marking is possible after cutting, polishing and chemical etching of the Te doped samples. The amount of tellurium in the sample has to be 10^{19}–$10^{20}\,\text{at/cm}^3$ in the feed material for good demarcation and visualization. The parameters of the Peltier pulse marking are: duration 1500 ms, amplitude 18 A and they are sent every $\frac{1}{2}$h. A few pulses with an interval of 15 min have been inserted among the $\frac{1}{2}$h spaced pulses, for a better identification of each individual mark.

The heater of the furnace is a conical resistor that dissipates a longitudinally variable power. The thermal field is measured in real time using four thermocouples placed on the external side of the crucible. The thermal gradient is 50 °C/cm in the lower part of the resistor and 60 °C/cm in the upper part. The experiments are performed under argon atmosphere (≈ 1 atm) which limits efficiently the antimony evaporation (partial pressure $\approx 10^{-3}$ atm at 1000 °C). The pulling rate is 1 μm/s.

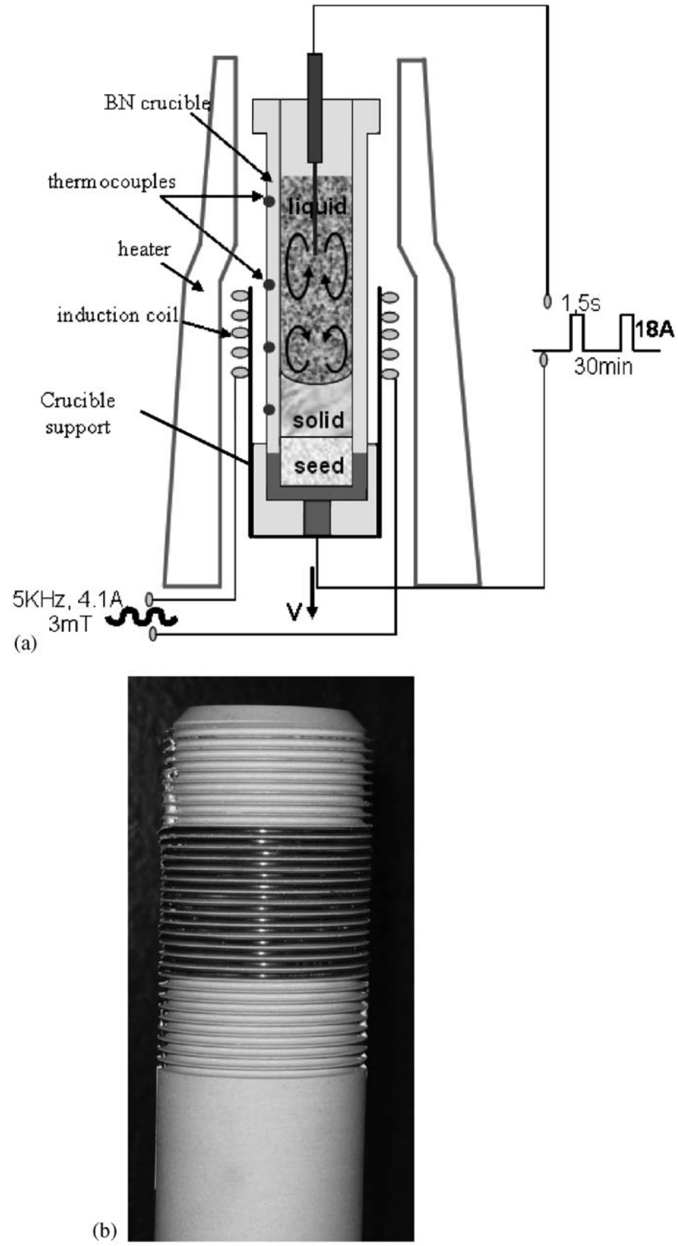

Fig. 1. (a) Sketch of the experimental set-up. (b) Picture of the electromagnetic coil ($\Phi = 30$ mm, with 20 mm of 14 turns of 1 mm Cu wire)

2.2. Semiconductor alloys

The effect of the alternating magnetic field has been investigated for three $Ga_{(1-x)}In_xSb$ samples with nominal