The influence of different interfaces on electrical and optical characteristics of Te doped ALGaAsSB/ALAsSB Bragg Mirrors on InP

A influência de diferentes interfaces nas características elétricas e ópticas de Espelhos de Bragg de ALGaAsSB/ALAsSB dopados com Te, sobre InP

Dari de Oliveira Toginho Filho[1]; Ivan Frederico Lupiano Dias[1];
José Leonil Duarte[1]; Edson Laureto[1]; Jean C. Harmand[2]

Abstract

The electrical and optical properties of non-doped and Te doped 6.5 periods AlGaAsSb/AlAsSb Bragg mirrors on InP grown by MBE with different types of interfaces between ternary and quaternary layers are reported. The techniques employed were photoluminescence, reflectivity and IxV measurements. The digital alloy gradient interface seems to be the best alternative to optimize conduction without significant reflectivity losses.

Key words: Semiconductor. Bragg mirror. AlGaAsSb. AlAsSb.

Resumo

São apresentadas as propriedades elétricas e ópticas de espelhos de Bragg com 6.5 períodos de AlGaAsSb/AlAsSb não dopado e dopados com Te, sobre InP, crescidos por MBE com diferentes tipos de interface entre as camadas de material ternário e quaternário. As técnicas empregadas foram fotoluminescência, reflectividade e medições de IxV. A interface com liga digital em gradiente parece ser a melhor alternativa para otimizar condução elétrica sem perdas significativas da refletividade.

Palavras-chave: Semicondutor. Espelhos de Bragg. AlGaAsSb. AlAsSb.

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[1] Departamento de Física, Universidade Estadual de Londrina, CP6001,CEP 86051-970, Londrina-Paraná, Brazil.
[2] CNRS, Laboratoire de Photonique et de Nanostructures, Route de Nozay, 91460 , Marcoussis, France.

Introduction

Heterostructures from Sb family materials such as AlGaAsSb/AlAsSb with lattice matched to InP are considered as good alternative in the manufacturing of Bragg mirrors employed in vertical-cavity surface emitting lasers (VCSEL) in the region of 1.55 μm, (BLUM, 1995; DIAS, 1997; GENTY, 1997; KOHL, 1997; DIAS, 1998). The high refractive index contrast (Δn) between alloys AlGaAsSb and AlAsSb allows the preparation of high-reflectivity Bragg mirrors (99%) required for VCSEL operation with a small number of periods (~20) (DIAS,1998). However, material systems with high refractive index contrast present high band discontinuity ΔEc in the conduction band (ΔEv in the valence band) in n-type (p-type) Bragg mirrors, what makes the current flow through heterointerfaces difficult. In order to minimize the serial resistance of the structure, the increase of the doping level or interventions to facilitate the flow of current through the interface become necessary.

This work presents a study of the doping effects on the AlGaAsSb quaternary alloy component of non-doped and Te doped Bragg mirrors AlGaAsSb/AlAsSb lattice matched to InP and different interface interventions, elaborated in order to facilitate the current flow between interfaces, with no significant reflectivity losses. Analyses employing the photoluminescence technique at the AlGaAsSb gap region as well as current-voltage curves and mirrors reflectivity measurements were performed. An initial study comparing the optical and electrical behavior of Bragg mirrors with digital alloy and homogeneous doping had already been previously performed (TOGINHO FILHO, 2002).

Experimental details

Bragg mirrors with 6.5 pairs of undoped and Te doped AlGaAsSb/AlAsSb were grown by MBE nominally lattice matched on a (100) InP:Fe and (100) InP-n substrates respectively. The carrier concentrations in the Te doped samples ($\sim 3.0\text{x}10^{18}\text{cm}^3$ for AlGaAsSb layers and $\sim 1.8\text{x}10^{18}\text{cm}^3$ for AlAsSb layers) were determined by Hall measurements at room temperature using Van der Paw methods in bulk epilayers with equivalent doping. Details of the sample parameters can be seen in Table 1. More details about the growth can be seen in the work of Harmand et al. (1997).

Table 1. Structural, electrical and optical characteristics of samples.

Sample	17Q29	17Q44	17Q45	17Q36
Type	6.5 pair Bragg mirror			
Structure	undoped	hom.doped	δ doping	dig. alloy
Material	$Al_{0.10}Ga_{0.90}As_{0.51}Sb_{0.49}/AlAs_{0.56}Sb_{0.44}$			
Index type	high index / low index			
Index contrast Δn	0.54			
Doping level	$3.0\text{x}10^{18}\text{cm}^{-3}$ / $1.8\text{x}10^{18}\text{cm}^{-3}$			
Layer thickness (nm)	112/131	108/127	108/127	108/127
Voltage threshold (mV)	-	283	236	215
Voltage drop pair (mV)	-	138	85	62
Resistivity –1kA/cm^2 (10^{-4}.Ω.cm^2)	-	6.5	3.2	2.37
Central wavelength (μm)	1.55	1.46	1.45	1.49
Reflectivity	0.91	0.905	0.905	0.885
Stop band (μm)	0.39	0.37	0.36	0.37

PL (Photoluminescence) measurements were performed in the temperature range of 10 K to 300 K, using the 514.5 nm line of a continuous wave Ar$^+$ laser, with excitation intensity of 532W/cm^2. Temperature variation was obtained by a closed-cycle helium cryostat. The spectral analysis of the luminescence measurements was carried out by a 0.5 m Jarrel-Ash spectrometer coupled to a cooled InGaAs photodetector, using the standard lock-in technique.

Experimental reflectivity was measured with a Fourier transform infrared spectrometer (FTIR) in the so-called VW configuration.

The n-type doped Bragg mirrors were metallized with Ti/Au ohmic contacts evaporated on the top and on the bottom of the samples. The samples were patterned with 100x100 m^2 square mesas etched by an H_2SO_4:H_2O_2:H_2O solution. The substrates underside were thinned to 150 m to decrease the substrate contribution to the electrical measurements. The current-voltage (IxV) dc characteristics are made by transmission line method (TLM) measurements.

Results and discussion

The photoluminescence spectra of the Bragg mirrors was obtained with laser intensity of 532 W/cm^2 from 10K to 300K. The behavior of the main peak energy with excitation intensity of 532 W/cm^2 in function of temperature is shown in Figure 1. The energy variation from the PL predominant peak of doped samples clearly shows an inverted S shape, indicating the presence of localized states. This behavior is characteristic of materials presenting potential fluctuations associated to the alloy concentration and/or the doping concentration variations (OLSTHOORN, 1993). The energy variation of main PL peaks with the increase on the excitation intensity at 10 K in all samples shows a blue-shift with an average shift of ~3.0 meV/decade. This shift is associated to DAP (Donor-Acceptor-Pair) or to QDAP (Quasi-Donor–Acceptor–Pair) transitions usually observed in bulk samples from antimony family alloys (TOGINHO FILHO, 2005a).

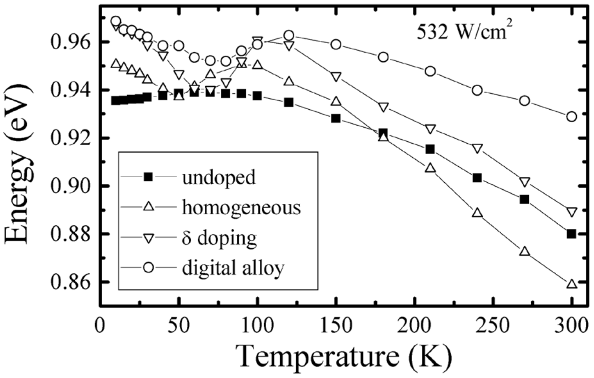

Figure 1. Energy dependence of main peak of PL with the temperature at 532 W/cm^2 , for undoped (17Q29), homogeneous doped (17Q45), doped with δ-doping (17Q45), and doped with digital alloy (17Q36) Bragg mirrors samples.

The dependence of the Full Width Half Maximum (FWHM) with temperature are presented in Figure 2. The doping results in a significant broadening of FWHM of the PL spectra. At 300K, the FWHM of spectra is of ~140 meV for homogeneous doped and δ-doping samples and it is of ~70 meV for the sample with digital alloy, approximately the same as that found for the non-doped sample.

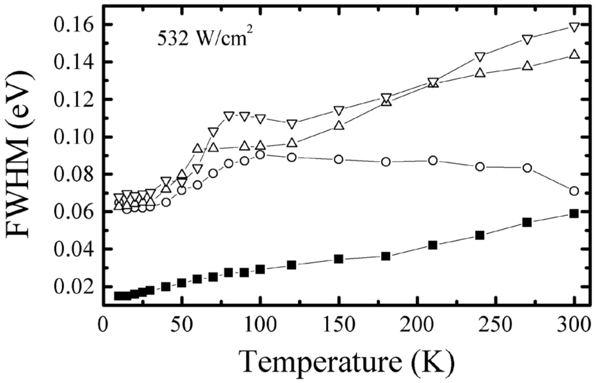

Figure 2. FWHM dependence of main peak of PL with the temperature at 532 W/cm^2 for all Bragg mirrors samples.

In samples with homogeneous doping and with δ-doping, the FWHM presents a plateau at the region of temperature between ~50K and 120K and ~70K and 120K respectively, and then grows with increased temperature. This observed plateau indicates the existence of two recombination channels in the respective temperature intervals. The sample with digital alloy presents a slow decrease on the FWHM as the temperature increases from ~100K on, becoming close from the value obtained for the non-doped samples at 300K. This behavior (increase and reduction of FWHM in function of T) was also observed in GaAsSb non-doped bulk samples (TOGINHO FILHO, 2005a), in Te doped GaAsSb samples (~10^{18} cm^{-3}) (TOGINHO FILHO, 2005b) and in not intentionally doped AlInAs (OLSTHOORN, 1993). The increase in the FWHM in these cases is associated to a thermal widening and the reduction to the progressive ionization of impurities with the increased temperature (YOON et al., 1995). This differentiated FWHM behavior among the three samples prepared at the same conditions seems to indicate a significant role played by the effect of the different interventions at the interfaces in each sample. The presence of the digital alloy seems to contribute for a lower band curvature at the interface region, thus avoiding the broadening of transitions associated to the potential valleys due to fluctuations of the alloy chemical composition and/or to the doping fluctuations. We believe that the band curvature at the interface may lead to the recombination involving potential valleys that usually are not interrelated in transitions in flat band conditions. Variations on the relative As/Sb and Al/Ga concentrations from one sample to another could lead to an increase or decrease of the gap and of the FWHM. However, the PL main energy peak of samples with δ-doping and digital alloy (~967 meV) measured at 10 K are almost the same, demonstrating that there are no differences in the alloy composition between the different samples. This way, we could associate the differentiated PL behavior between samples to the presence of digital alloy at the interface. However, a more detailed analysis of this effect involving a higher number of samples must be performed. The FWHM at 300 K at high power conditions is an important data, once it stresses the existence of recombination channels with energy levels next to the conduction band edge (or valence band) that could lead to the absorption or emission of electromagnetic radiation generated in the VCSEL active layer in values similar to those selected for its operation, thus compromising its optical and electrical properties.

The serial resistance found in a Bragg mirror is mainly due to the existence of potential barriers in the interfaces of the different materials that compose the quarterwave layers. In the case of the AlGaAsSb/AlAsSb system on InP, type-I interfaces can be found between AlGaAsSb and AlAsSb layers (Γ-X valleys) with barrier of ~0.47 eV and an type-II interface between the most inner AlGaAsSb layer and the InP substrate (Γ-Γ valleys) with barrier of ~0.31 eV (DIAS, 1997; GENTY, 1997). A schematic diagram of the band structure with alignment between conduction and valence bands of the AlAsSb materials (valley X, dotted line), AlGaAsSb and InP is presented in Figure 3.

The current-voltage characteristic curves of doped mirrors are presented in Figure 4. The voltage threshold, the voltage drop per period and the serial resistance values are presented in Table I. The voltage drop per period is obtained considering the current density value of $1kA/cm^2$. The voltage threshold value is obtained considering the potential interval in which the current increases from zero to a positive value. The origin of the voltage threshold and the non-ohmic behavior verified in the IxV curve is related to several factors, especially the Γ-Γ barrier between AlGaAsSb and the InP substrate that induces to an asymmetry for the electrons flow.

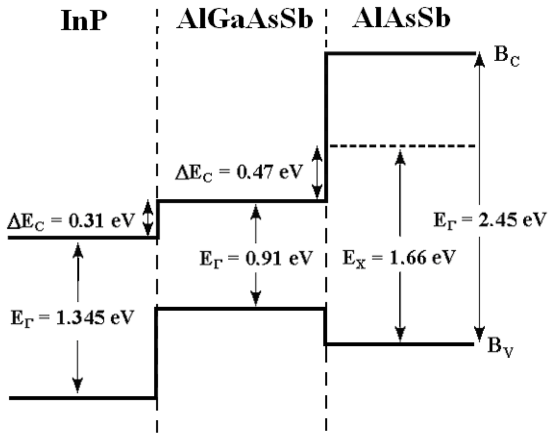

Figure 3. Schematic diagram of the conduction and valence bands for AlAsSb (valley X is in the dotted line), AlGaAsSb and of the InP.

The employment of δ-doping and digital alloy gradient interface structures reduces the voltage threshold value a little and improves the electrical conduction in mirrors. Another factor that may influence the voltage threshold is the asymmetry found in the doping concentration along the quaternary layer, as observed by Toginho Filho et al. (2006). The serial resistance of the mirror doped with digital alloy presents a reduction of over than 50% in comparison with value observed for samples with homogeneous doping. An improvement possibility that could contribute for the reduction of the serial resistance and of the internal voltage would be an AlGaAsSb/GaAsSb digital alloy in the interface between AlGaAsSb and the substrate.

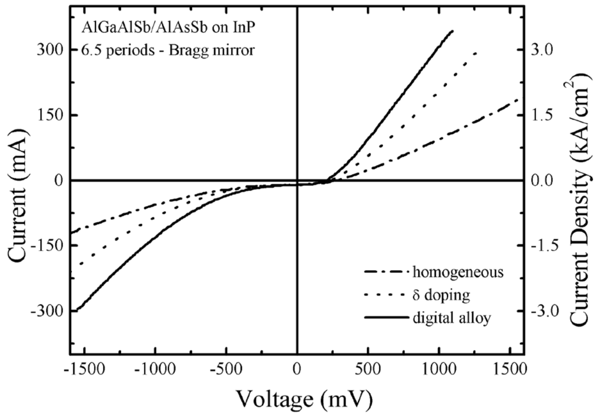

Figure 4. Current-voltage curves of mirrors of Bragg samples with 6,5 doped periods, gotten to the 300 K.

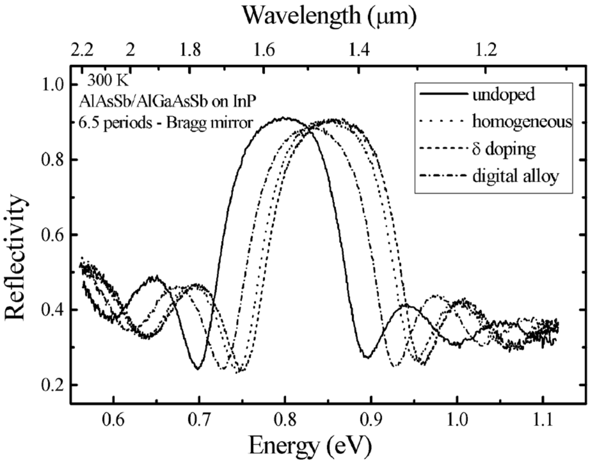

Figure 5. Reflectivity curves for DBRs samples with 6,5 periods, obtained at 300 K.

Reflectivity spectra for Bragg mirrors are presented in Figure 5. The central wavelength value, the mirrors reflectivity and the stopband width may be seen in Table I. The non-doped mirror presents the highest reflectivity value in relation to doped mirrors. In doped samples, the reflectivity decreases according to the following sequence: mirror with homogeneous doping, mirror with δ-doping and mirror with digital alloy. The difference in the reflectivity values between non-doped and doped mirrors is not large. These results are a strong evidence that the doping and the introduction of improvements in the interface aimed at a better electrical conduction do not drop significantly the reflectivity of Bragg mirrors. However, a more systematized study on the effects of the digital alloy with eventual optimization of its structural parameters and other types of interventions in the interface of quarterwave layers should be conducted.

Conclusion

This work investigated the electrical and optical properties of four non-doped and Te doped AlGaAsSb/AlAsSb Bragg mirrors lattice matched on InP with different interventions in the interface grown by MBE. A study on the quaternary layer photoluminescence properties allowed establishing relations between this mirror component and the electrical and optical properties of the structure. The IxV characteristics show that the presence of a digital alloy in the interface may improve the electrical conductivity with no significant reflectivity losses.

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