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ABSTRACT

$In_xGa_{1-x}As$ based MODFET (modulation doped field effect transistor) material was grown by MBE (molecular beam epitaxy) on semi-insulating InP substrates. Several structures were made, including lattice matched and strained layer InGaAs. All structures also included several layers of $In_{0.52}Al_{0.48}As$. Variable angle spectroscopic ellipsometry (VASE) was used to characterize the structures. The experimental data, together with the calibration function for the constituent materials, were analyzed to yield the thickness of all the layers of the MODFET structure. Results of the ellipsometrically determined thicknesses compare very well with the RHEED (reflection high energy electron diffraction) in situ thickness measurements.

INTRODUCTION

Recently $In_xGa_{1-x}As$ became the material of choice for MODFET devices, both on InP [1] and GaAs [2] substrates. The $In_xGa_{1-x}As$ serves as the conduction channel, mainly due to its high electron mobility and saturated velocity. The most commonly studied indium concentration is X=0.53, the InP lattice matched composition. However, strained layer structures are now available, both on InP and GaAs. The heterostructure material used for MODFET fabrication is grown mostly by MBE. In this growth method, the thickness is measured in situ using the RHEED technique. In this paper we will describe the application of the variable angle spectroscopic ellipsometry technique to the characterization of MBE grown $In_xGa_{1-x}As$ based MODFET structures. This non-destructive technique can estimate not only the thicknesses of all the layers within the optical penetration depth, but also the quality of the interface and possibly the indium concentration. The capabilities of VASE for complete MODFET characterization were demonstrated on the MBE grown AlGaAs/GaAs structures [3]. Detailed interface work on InGaAs/InP was performed on MOCVD (metal-organic chemical vapor deposition) grown material [4]. This paper will concentrate on MBE grown structures. In this growth technique, InP cannot be grown and it is replaced by $In_{0.52}Ga_{0.48}As$, which is lattice matched to InP and provides the high band gap donor layer of the MODFET.

EXPERIMENTAL

The MODFET structures studied here were grown by MBE on semi-insulating InP substrates, with continuous RHEED monitoring. The structures studied here

are shown in Fig. 1(a). Starting from the bottom, these structures nominally contain the following layers: a superlattice (S.L.) buffer made of 30 period $In_{0.53}Ga_{0.47}As/In_{0.52}Al_{0.48}As$, a 4000 Å isolation layer of $In_{0.52}Al_{0.48}As$, a complex conduction channel made of 400 Å undoped $In_{0.53}Ga_{0.47}As$, and a layer of thickness d of undoped $In_XGa_{1-X}As$ with d=150 Å for X=0.53 and 0.65 and d=100 Å for X=0.70, a 50 Å $In_{0.52}Al_{0.48}As$ spacer layer, a 350 Å $In_{0.52}Al_{0.48}As$ donor layer with only 150 Å of doped material, and a 100 Å doped cap layer of $In_{0.53}Ga_{0.47}As$ for contacts. Ellipsometry cannot differentiate between doped and undoped material, but it will be sensitive to a surface oxide layer. Thus, the nominal structure for ellipsometric purposes will be different from the MBE nominal structure. For example, the nominal structure for ellipsometric purposes for the X=0.53 material is given in Fig. 1(b), on the left side of the graph. The 4000 Å $In_{0.52}Al_{0.48}As$ layer is considered the substrate for ellipsometric purposes, as the optical penetration length in most of the experimental range is smaller than the thickness shown in Fig. 1(b).

Actual		Structure	
100 Å	n+	$In_{0.53}Ga_{0.47}As$	
200 Å	i	$In_{0.52}Al_{0.48}As$	
150 Å	n+	$In_{0.53}Al_{0.48}As$	$5x10^{18}$
50 Å	i	$In_{0.52}Al_{0.48}As$	
d	i	$In_XGa_{1-X}As$	
400 Å	i	$In_{0.53}Ga_{0.47}As$	
4000 Å	i	$In_{0.52}Al_{0.48}As$	
30 prd	30 Å/30 Å	S.L. InGaAs/InAlAs	
	SI	InP Substrate	

(a)

Nominal			Ellips.
t1	0 Å	Oxide	47 ± 0.8 Å
t2	100 Å	$In_{0.53}Ga_{0.47}As$	49 ± 1.4 Å
t3	400 Å	$In_{0.52}Al_{0.48}As$	424 ± 4 Å
t4	550 Å	$In_{0.53}Ga_{0.47}As$	553 ± 6 Å
	4000 Å	$In_{0.52}Al_{0.48}As$	—

(b)

Figure 1.—(a) Actual structure grown by MBE. (b) Nominal structure used for ellipsometry and the result obtained from the experiment.

The ellipsometric technique was described previously [3,5] and will not be repeated here. In this study, we use a mean square error (M.S.E.) criterion based on tan ψ and cos Δ fits of experimental data to model calculations. The variables of the fit were the thicknesses, t_i (i=1-4 in Fig. 1(b)), of the different layers in the structure.

Ellipsometric calibration functions (i.e. the dielectric functions) for the constituent material were taken from the following sources: $In_{0.52}Al_{0.48}As$ from previous measurements at NASA-Lewis [6], $In_{0.53}Ga_{0.47}As$ from [7], $In_XGa_{1-X}As$ as a function of X from [8] and the oxide from [9]. The results obtained in reference [8] are for thermodynamically stable material and thus may have to be modified for application to a strained configuration. The oxide results [9] are for GaAs oxide and they may give an erroneous thickness for the oxide.

Results for the lattice matched structure are shown in Figs. 1(b) and 2 together with the 90% confidence limits. An excellent fit was obtained between the ψ and Δ values measured experimentally and the values calculated from a model that uses the thickness parameters given in Fig. 1(b), right hand side. There is also a good fit between the nominal and experimental layer thicknesses. The M.S.E. of the fit for experimental data in the range 3000-6000 Å was $2.3x10^{-4}$. A marked deterioration in the M.S.E occurred when the fitting range was extended to cover our full experimental range of 3000-8000 Å, probably due to the fact that the optical penetration length becomes comparable to total thickness of our model, as shown in Fig. 1(a). We also note that the fit is not perfect for the ψ fits in the lower wavelength region (i.e. below ~3500 Å). This denotes a poor

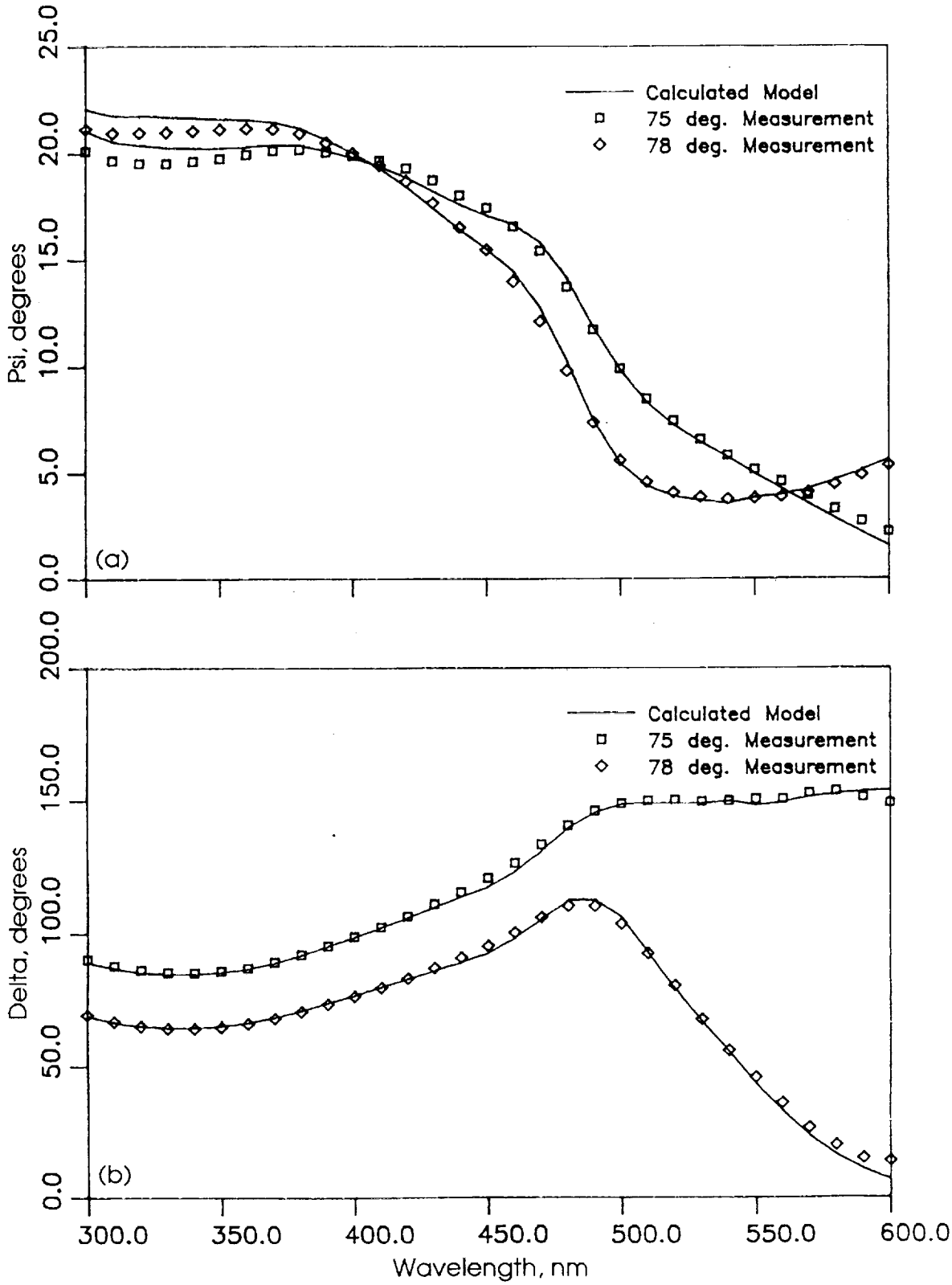

Figure 2.—Experimental and model calculation results for (a) Psi and (b) Delta for $In_{0.53}Ga_{0.47}As$ MODFET material at two angles of incidence.

fit for the surface layers. This fact can also be deduced from the anomalous thickness of the oxide layer, which is much larger than normal for compound semiconductors [3]. We believe that the approximation used here for the oxide is not very accurate. Another problem in the fit of the surface layers is the difference in the thickness of the $In_{0.53}Ga_{0.47}As$ cap layer estimated by ellipsometry as compared to the nominal thickness. This difference indicates that this layer is probably not a perfectly smooth, homogeneous, stoichiometric layer, and therefore our model is also not perfect.

Results for the samples with strained $In_XGa_{1-X}As$ layers show only a slight dependence of the measured ψ and Δ with the indium concentration X. Thus, it is very hard to obtain the effects of strain on the dielectric function of $In_XGa_{1-X}As$ from these MODFET structures.

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16. Abstract

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