Paper

MOVPE InP based material for millimeter and submillimeter wave generation and amplification

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Abstract — The potential of the MOVPE growth process for millimeter and submillimeter wave generation and amplification is presented. The increase in layer quality, the improved homogeneity and purity, the precision of mono-layers growth and wide spectrum III-V compounds makes MOVPE techniques very attractive for modern device applications. The characterisation results of the heterostructures dedicated for HBV varactors and 2-DEG transistors (HEMT) are described.

***Keywords* — epitaxy InP, MOVPE, microwave generation.**

1. Introduction

The rapid development in millimeter and submillimeter wave generation and amplification devices is connected to the new material requirements. MOVPE epitaxy of III-V semiconductors compounds gives the opportunity to realise the heterostructures of outstanding parameters. The heterostructure barrier varactor (HBV) has received considerable attention as a promising symmetric varactor element for frequency multiplier applications at millimeter and submillimeter wave. Heterostructure includes doped and undoped layers of binary and ternary compounds, lattice-matched and strained, relatively thick and very thin. HEMTs structures need very high purity level of undoped layers as well as high structural quality even in the case of pseudomorphic transistors.

2. Experimental

Epitaxial growth has been carried out in automatic controlled horizontal LP-MOVPE Aixtron system, model 200 R&D.

The reactor is a horizontal quartz tube with rectangular cross-section. A carbon susceptor coated with silicon carbide is infrared heated. The temperature of the susceptor is monitored by two thermocouples placed inside susceptor. The growth process is controlled automatically. The group III precursors were trimethylgallium, trimethylaluminum, trimethylindium. Phosphine and arsine were used for the group V elements. Laminar flow of high purity hydrogen as a carrier gas, high linear velocity of gases and low pressure (100 mbar) in the reactor enable the growth of the layers of the outstanding parameters. According to the type of deposited epilayers, in this case – InP:Fe (SI) and InP:S substrates were used. Typical orientation was (100) and diameter 2 inches.

In order to optimise the epitaxial growth considering purity of starting materials, substrates quality, growth parameters, etc, single layers of InP, InGaAs and InAlAs were deposited and characterised.

3. Results

The growth temperature was optimised very carefully considering surface morphology and electrical parameters of undoped InP layers. As the result of the above mentioned investigations InP undoped epilayers can be grown in temperature 655°C with very good electrical parameters. Figure 1 presents the results of our measurements of mobility versus carrier concentration compared with the results from literature. For undoped InP layers, 1.5 – 2.5 mm thick, mobility $m_{77} = 70000$ cm^2/Vs was achieved for $n = 1.1 \cdot 10^{14}$ cm^{-3}. For the thicker layer – $m_{77} = 165000$ cm^2/Vs for $n = 2.4 \cdot 10^{14}$ cm^{-3} and $m_{\max} = 205000$ cm^2/Vs at 50 K where measured.

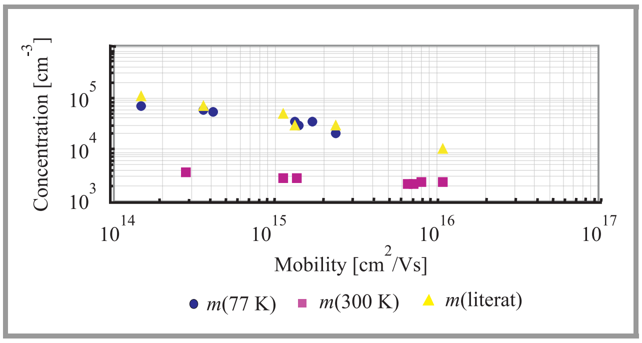

Fig. 1. Mobility versus carrier concentration in InP ($d = 2.5$ μm) undoped epilayer in comparison with data from literature.

The quality of InP layers was examined by photoluminescence. From Fig. 2 it is evident that the acceptor concentration is very low. High exciton peak in comparison to donor peaks (D^0X, D^+X) informs that layer is very pure.

The main purpose of this part of work was the growth of lattice-matched InGaAs and InAlAs layer on InP buffer. The relation between partial pressures of TMIn, TMGa, TMAl and AsH$_3$ was crucial for the realisation of it. As

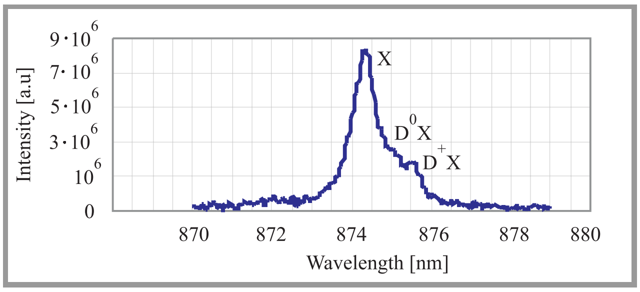

Fig. 2. Photoluminescence spectrum of InP undoped epilayer (thickness -2 μm).

the consequence of many growth runs the ability of controlling lattice-mismatch (Da/a) with resolution $50-100$ ppm was achieved. This means that lattice-mismatch between InGaAs or InAlAs and InP can be intentionaly changed from region of tensile stress, through lattice-match to comprehensive stress region. Figure 3 presents X-ray diffraction results where rocking curve of the substrate and epilayer are practically in the same position ($\Delta a/a < 220$ ppm).

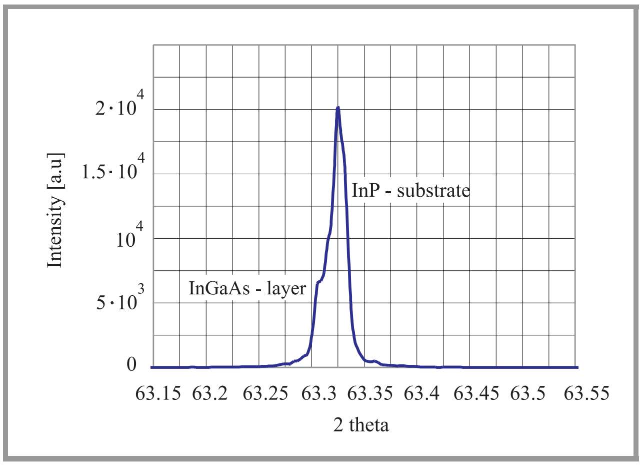

Fig. 3. X-ray diffraction result of lattice-matched InGaAs on InP substrate.

The varactors and transistors structures require strain layers grown on lattice-matched layers-sequences, like $In_{0.75}GaAs$ in HEMT or AlAs and InGaP in varactor.

The critical thickness of such layers, characteristic for the lattice-mismatch parameter, plays the key role in the growth of strain layers. Above the critical thickness, due to lattice relaxation processes, defects, mainly misfit dislocations, are created. However, in the case when the difference between lattice parameters of the substrate and the layer is too high, the deposited material crystalises in 3D mode. The islands of the dimensions, which depend on the growth parameters, are created on the very thin planar wetting layer. Further observations show that the driving force for the 2D-3D transition can be minimised by slowing the relaxation of misfit strain. As a result – the relatively smooth layer can be deposited in lower temperature for the optimal growth rate. The quality of the InGaAs, InGaP, AlAs strained layers deposited on InP substrate have been examined by the X-ray, AFM and SIMS methods. Atomic Force Microscopy allows to observe 3D growth mode even for very thin layers. Relatively strong relaxation effects are recognised by surface roughness. Two-dimensional diffraction measurements are much more sensitive tool for estimation of relaxation degree. Apart from the estimation of the lattice parameter in two perpendicular directions it is also possible to measure the diffusion scattering caused by linear density of misfit dislocations. Experimentally determined values of critical thickness were determined and compared to theoretical values calculated from formula of Matthews-Blakeslee for $In_xGa_{1-x}As$, for x up to 0.75.

4. Conclusions

The characterisation results of MOVPE heterostructures enable their optimisation for their application for millimetre and submillimetre devices for wave generation and amplification. New concepts of devices, in which the growth precision of mono-layers, accurate lattice-matching or intentional stress of layers, and high purity are needed, can be realised.

References

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Włodzimierz Strupiński received the M.Sc. degree in material science from Technical University of Warsaw in 1981. In 1991, he received the Ph.D. degree in physics from Technical University of Warsaw. His thesis work involved developing GaP epitaxial layers doped with nitrogen for green LEDs. Since joining the Institute of Electronic Materials Technology in 1983 he has been working on vapor phase epitaxy and metallorganic vapor phase epitaxy of III-V semiconductors, GaAs and InP-related. His research interest includes epi-structures for HEMT transistors, HBV varactors, lasers, photodetectors, etc.

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