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LIQUID PHASE EPITAXY OF QUATERNARY SOLID SOLUTIONS ON PROFILED GALLIUM ANTIMONIDE SUBSTRATES

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In the present work heterostructures were grown in a whole technological process on relief ("terrace" and "double channel") GaSb substrates. The best results were etched on a substrate by photolithographic techniques. Terrace direction and etchant composition were chosen so that terrace slopes were formed with (111)–A planes. On the substrates formed the n-AlGaAsSb, p-AlGaAsSb, p-InGaAsSb, n-AlGaAsSb and p-GaSb layers were successively grown up.

Selection of the proper solution-melt supersaturation allows to prevent the first n-AlGaAsSb layer from being grown up on the terrace–slope surface, and the layer thickness on the other part of the surface was up to $1 \div 2$ μm. The next p-AlGaAsSb layer was already grown without break on the terrace slope.

Injection lasers on the base of such structures operate in the 2–2.4 μm spectral range with minimum threshold current (CW operation at 300 K) at the level of up to 45 mA.

Indium–gallium–arsenic–antimony solid solutions, lattice-matched to gallium antimonide, are the most prospective materials for optoelectronic devices (photoreceivers, light-emitting diodes, lasers) in the 1.8–2.5 μm spectral range. This spectral range is of great interest for optical methods of moisture metering in various media, gas analysis as well as for prospective optical fibre communication links (OFCL) with minimum loss level in optical fibers [1]. In the latter case non-cooled injection lasers, operating in a continuous wave mode, prove to be the most effective OFCL radiation sources.

There was information [2–3] on the fabrication of such devices based on double heterostructures in lattice-matched InGaAsSb/GaSb system where a stripe geometry was provided by ridge waveguide. Laser threshold currents were in the $70 \div 150$ mA range at room temperature. Further reduction of the threshold current can be achieved in the stripe structures with "built-in" lateral current and optical confinement in the process of epitaxial growth.

The traditional way of manufacturing such structures, developed mainly for InGaAsP/InP-based heterostructures, implies an application of several sequential epitaxial processes intermittent with etching and photolithographic operations. That approach is not very promising for the InGaAsSb/AlGaAsSb system on GaSb substrates since repeated epitaxy on stripped AlGaAsSb layers causes significant difficulties.

Therefore, in the present work various procedures for structure production in the single LPE technological process on non-planar gallium antimonide substrates were tested. Principal investigations were carried out on terraced and double channel patterns substrates (Fig. 1), made by photolithographic and etching techniques on (100) GaSb substrates.

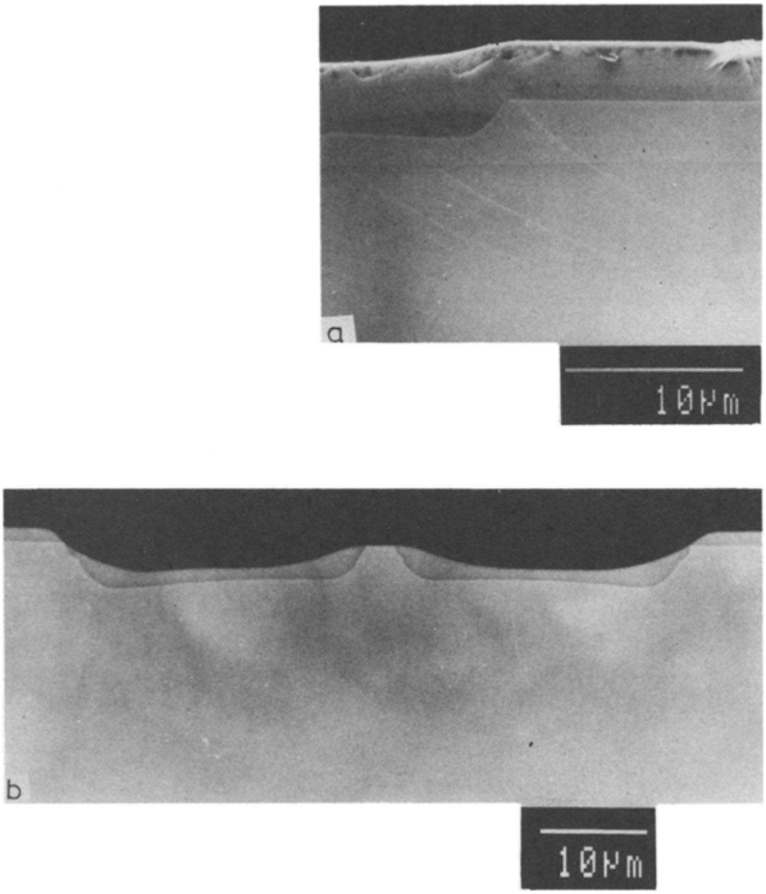

Fig. 1. Microphotographs of cleaved gallium antimonide substrates with terrace (a) and double channel (b) profiles. Epitaxial layers nAlGaAsSb and pAlGaAsSb (a) and nAlGaAsSb (b) are grown on profiled GaSb substrates

Our work was concerned with epitaxial heterostructures of the pGaSb (substrate)-n$Al_xGa_{1-x}As_ySb_{1-y}$ (I)-p$Al_xGa_{1-x}As_ySb_{1-y}$ (II)-p$In_{x_1}Ga_{1-x_1}As_{y_1}Sb_{1-y_1}$ (III)-n$Al_xGa_{1-x}As_ySb_{1-y}$ (IV)-nGaSb (Y)-type. The process was carried out in LPE horizontal-type units, hydrogen flow atmosphere, a traditional sliding boat system providing aluminium introduction into the melt directly on the stage, preceding epitaxy. Conditions for the LPE process to be carried out were similar to those described earlier in [4].

Principal moment in the fabrication of structures is the creation of a gap in the blocking nAlGaAsSb layer (I), that can be more effectively reproduced on terraced substrates (Fig. 1a).

Terrace height was 4–7 μm. Terrace direction and etchant composition used for fabrication of a terraced profile on substrates were chosen so that terrace slopes were formed by the (111)A planes, on which the growth rate of solid solution layers was lower than on the (100) plane.

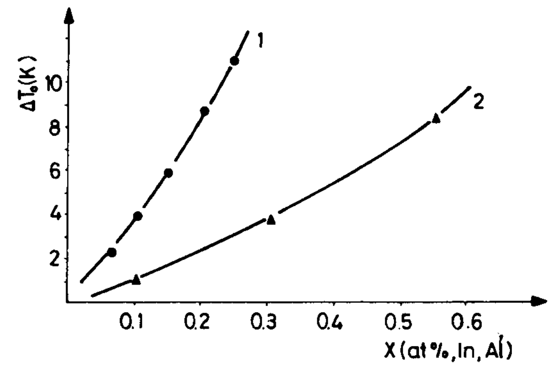

Fig. 2. Indium-gallium-arsenic-antimony (1) and aluminium-gallium-arsenic-antimony (2) melt supercooling, excluding gallium antimonide substrate dissolution (contact temperature is 873 K): —— – calculation; •, ▲ – experiment. Melt composition is specified by the composition of equilibrium $In_xGa_{1-x}As_ySb_{1-y}$ and $Al_xGa_{1-x}As_ySb_{1-y}$ solid solutions lattice-matched to GaSb (expressed as x)

Nevertheless the basic factor for the lack of the n–$Al_xGa_{1-x}As_ySb_{1-y}$ (I) layer growth on terrace slope surface (while the required thickness of this layer on the other substrate surface is $1 \div 2$ μm) is the magnitude of the melt supercooling (ΔT_1). The present experimental investigations made it possible to determine required melt supercooling values during $Al_xGa_{1-x}As_ySb_{1-y}$/GaSb heteroepitaxy (Fig. 2). Considering the necessity of introducing aluminium into $Al_xGa_{1-x}As_ySb_{1-y}$ ($x \sim 0.5 \div 0.55$) solid solution, required for manufacturing low-threshold lasers, the ΔT_1 value must be $\sim 8 \div 9$ K. Besides to provide the required structure geometry when growing the second layer ($pAl_xGa_{1-x}As_ySb_{1-y}$), the magnitude of the melt supercooling must be on the 7–8 K level.

Disregarding the indicated requirements leads to the overgrowth of the sloping terrace surface with the first layer ($\Delta T_1 < \Delta T_1^{opt}$, Fig. 3a), to etch-back of the substrate and/or the first layer when contacting with the first and/or the second melt ($\Delta T_1 < \Delta T_1^{opt}$; $\Delta T_2 \ll \Delta T_2^{opt}$; Fig. 3b), to the lack of necessary interface levelling ($\Delta T_2 > \Delta T_2^{opt}$), non-uniform growth of the sloping terrace surface with the second epitaxial layer and at last, to the formation of the polycrystalline inclusions on this surface ($\Delta T_2 \gg \Delta T_2^{opt}$; Fig. 3c).

A second layer on the sloping terrace surface, when there is incomplete first layer growth on it, makes it possible to produce the blocking p–n junction on this

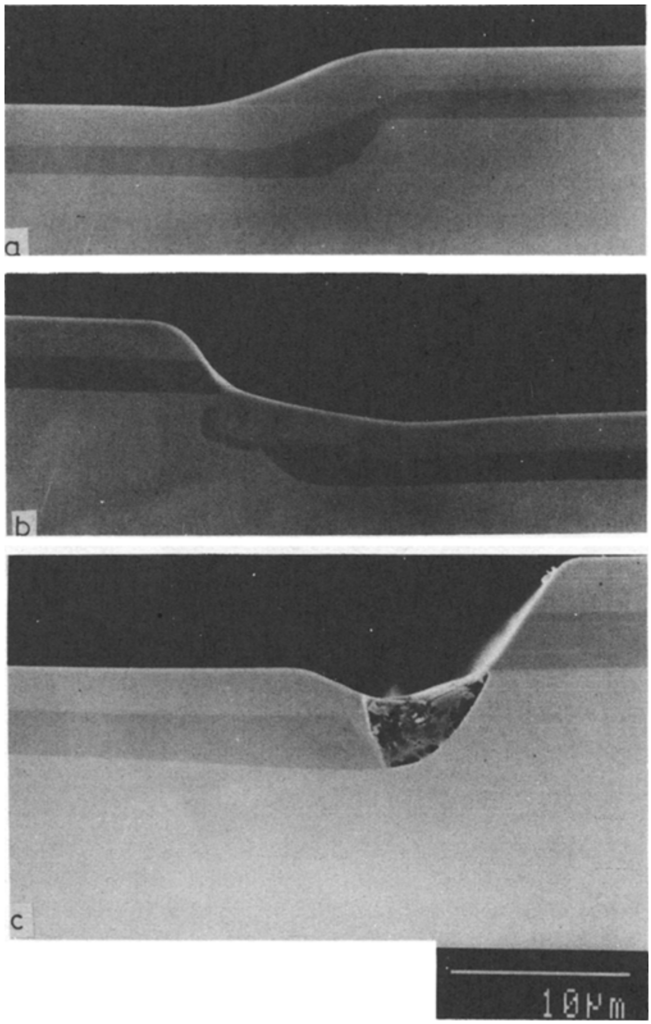

Fig. 3. Microphotographs of epitaxial nGaSb-pAlGaAsSb–nAlGaAsSb structures grown on terraced substrates at various melt supercooling values to grow nAlGaAsSb (ΔT_1) and pAlGaAsSb (ΔT_2) layers: $a - \Delta T_1 < \Delta T_1^{opt}$; $b - \Delta T_2 < \Delta T_2^{opt}$; $c - \Delta T_2 \gg \Delta T_2^{opt}$

terrace surface and realize the required structure geometry, shown in Fig. 4. Bending and some thickening of the active layer (pInGaAsSb) at the terrace slope create lateral optical confinement in a heterostructure.

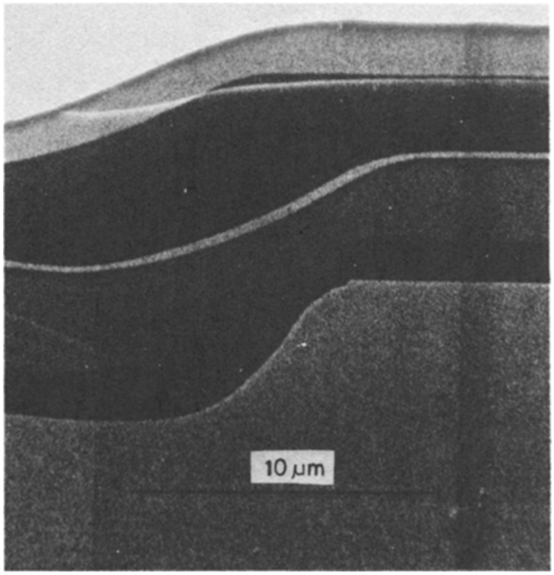

Fig. 4. Microphotograph of structure for injection lasers, grown on a terrace substrate

After standard contacting operations laser diodes with a cavity length $L = 50 \div 200$ μm were fabricated from the wafer. Threshold currents at room temperature were in the $50 \div 200$ mA range. The minimum threshold current value I at room temperature (44 mA) is the lowest for the $1.2 \div 2.5$ μm spectral range. Lasers with threshold current in pulse mode less than 80 mA, were capable of operating in CW mode at room temperature. The wave length of those lasers was in the $1.98 \div 2.20$ m range.

References

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