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InGaAsP visible laser crystal

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Visible-spectrum lasers, one of the major interests of semiconductor material research, will realize in near future the first big-market for semiconductor laser equipments such as audio/video disc playback devices, laser printers and so on. Already GaAlAs visible lasers which emit 780 nm wavelength light are commercially available. However research and development of visible lasers are still increasing in activities. They are aimed at shorter wavelength and higher output power lasers with high reliability.

The present paper describes a comparative study on the visible-spectrum InGaAsP crystal, that is on GaAs substrate while the well known infrared InGaAsP laser is on InP substrate, and several visible-spectrum quaternary alloys. Also growth techniques and preliminary characteristics of visible InGaAsP lasers grown by the vapor phase epitaxy will be discussed.

Figure 1 shows nine quaternary alloys having GaAs-lattice-matched alloy composition, shown by dotted lines. Five candidate crystals, GaAlAsP, InGaAsP, InGaSbP, GaSbAsP and InGaAlP, have visible-spectrum direct bandgaps larger than 1.55 eV (800 nm). They are drawn as squares (III^2-V^2 type quaternary) or triangles (III-V^3 or III^3-V type quaternary). It is an interesting fact that a "square quaternary" can not be expressed as a mixture of unique amounts of four corner binaries. Numbers of four different atomic bonds, i.e. Ga-P, Ga-As, In-P and In-As in InGaAsP, are not determined even if two variables of the alloy composition are kept constant. Inversely, square quaternaries have an extra freedom in the lattice construction. The wide tolerance of the lattice misfit without dislocation introduction is considered to be owing to this extra freedom. This kind of advantage is not found in ternary and triangle quaternary crystals.

InGaAsP as well as InGaSbP and GaSbAsP contains no aluminium. The advantage of aluminium-free materials will be found in the epitaxial growth process. Oxygen incorporation into the grown layer, which is remarkably enhanced by the presence of aluminium, results in compensated high-resistivity and poor luminescence efficiency. Furthermore, facet coating of cleaved mirror surface with anti-oxidation film will be indispensable to suppress the rapid oxide-induced degradation, particularly in high aluminium composition, namely shorter wavelength lasers.

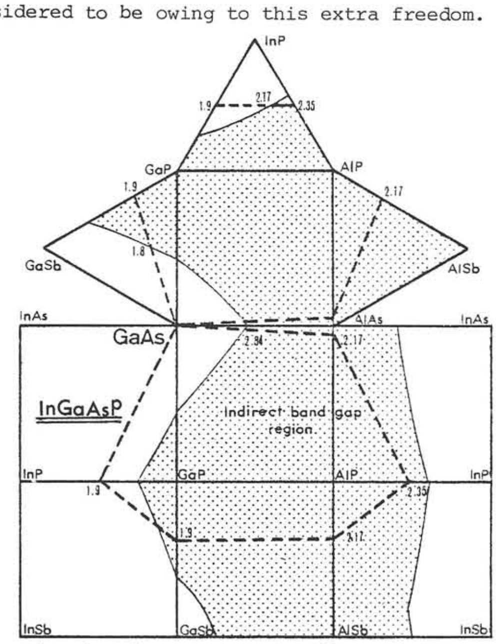

Fig. 1 Nine quaternary alloys lattice-matched to GaAs substrate

Because of the miscibility gap it is difficult to grow InGaSbP and GaSbAsP. A non-equilibrium growth technique such as MOCVD or MBE has been proposed to overcome the miscibility gap. But it may not be easy when more than two volatile group V elements exist simultaneously. Fortunately, visible-spectrum InGaAsP is situated close to but out of the miscibility gap region. In consequence, InGaAsP is a unique material in that it is "square" quaternary having no aluminium and no miscibility gap problem.

$In_{1-x}Ga_xAs_xP_{1-y}$ with x = 0.65-0.80 and y = 0.35-0.60 is required as active layer together with $In_{0.49}Ga_{0.51}P$ as clad layer. Liquid phase epitaxy of this InGaAsP and InGaP sometimes has trouble of irregular hetero-interfaces caused by the meltback of GaAs. MOCVD needs further improvement to suppress the extraneous vapor reaction between In- metalorganic and group V hydrides and to increase the growth controllability of alloys which contain more than two group V elements. In the present study, the hydride VPE in the $In/Ga/HCl/AsH_3/PH_3$ system was used. A specially designed system called dual-growth-chamber (DGC) VPE shown in Fig. 2 was necessary to obtain abrupt hetero-interfaces. The growth condition of InGaAsP alloy in the wavelength range of 720-780 nm was studied at 740°C as function of HCl(Ga)/(HCl(Ga)+HCl(In)) and $AsH_3/(AsH_3+PH_3)$. In order to obtain mirror surface with $y<0.5$, high AsH_3 flow rate but low $AsH_3/(AsH_3+PH_3)$ ratio were needed. Low growth temperature ($\sim$710°C) was also found effective to grow mirror surface layer. Zn-diffused planar stripe laser diodes with stripe widths of 8μm to 16μm and cavity length of 250μm were fabricated from the five-layer DH wafer. Threshold currents were 160-300 mA and 220-300 mA under pulsed and cw operations, respectively. Typical optical output against the injection current is shown in Fig. 3. The characteristic temperature T_0 written as $I_{th}=I_0\exp(T/T_0)$ was 98 K at 25-70°C. These characteristics are comparable to LPE GaAlAs visible lasers.

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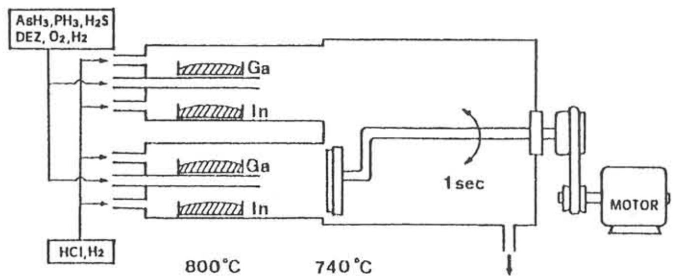

Fig. 2 Dual-growth-chamber hydride VPE system

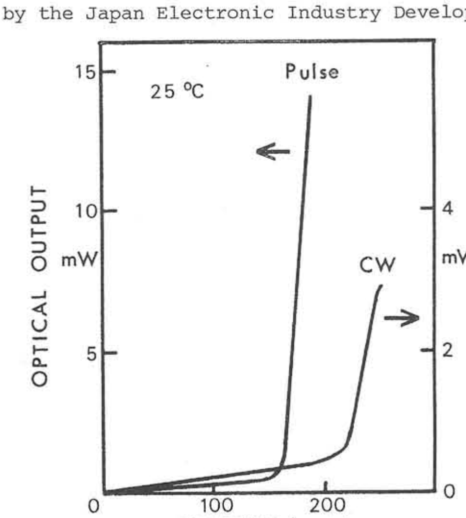

Fig. 3 Optical output of 770 nm InGaAsP visible laser