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High Quality AlGaInP/GaInP/GaAs Heterostructures for Optical and Electrical Devices

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Abstract : Atmospheric pressure organometallic vapor phase epitaxy is used for the growth of GaInP-AlGaInP lattice matched to GaAs substrate. The investigation of the GaInP/GaAs heterostructure has been carried out and mobility as high as 75.000 cm^2 $V^{-1}s^{-1}$ for a sheet carrier concentration of 7.5 10^{11} cm^{-2} has been measured by Shubnikov-de Haas at 4K. Red and yellow LED's have been obtained with emission wavelength of 670 nm and 576 nm respectively. Oxide stripe laser emitting at 660 nm in pulsed mode have been performed and present a threshold current density of 5 KA cm^{-2}. A three ridge waveguide laser diodes array with maximum output power of 108 meV has also been achieved.

$(Al_yGa_{1-y})_{1-x}In_xP$ and GaInP compounds, materials have been investigated for both modulation doped field effect transistors[1,2,3] and for visible opto-electronic applications[4,5,6,7]. In this paper, we present N type selectively doped GaInP/GaAs heterostructures grown by MOVPE, as well as GaInP-GaInAlP laser and LED structures.

1. CRYSTAL GROWTH

GaInP and AlGaInP layers have been grown at atmospheric pressure by MOVPE system in a horizontal and rectangular cross-section reactor[8]. Large hydrogen flow (26 l/min) prevent the parasitic reactions between triethylindium and phosphine and is essential to the realization of a sharp transition.

The epitaxial layers were grown on (001) 6° off GaAs substrate in the 640-740°C temperature range. Growth rates were found to be about 1.2 µm/h. The V/III ratio was established at 40 and 100 for the GaInP and AlGaInP respectively.

2. GaInP LAYERS

Mobilities can reach 5400 and 66000 cm^2 $v^{-1}s^{-1}$ at 300 and 77 K respectively for a residual electron carrier concentration of 1.2 10^{16} cm^{-3}.

Photoluminescence and photoluminescence excitation measurements at 300 and 2 K have been performed[9] and band gap energy versus alloy composition and misfit strain for compressive and tensile strain have been investigated. Excitonic features have been observed in PLE which confirm the high quality of the material. Moreover, the results indicate the band to band recombination process changes from electron-light hole recombination for indium rich alloy to electron-heavy hole recombination for Ga rich alloy ; the heavy and light holes being degenerated for lattice matched compounds (fig. 1).

The GaInP films grown on (100) 6° off towards (011) have also been characterized by Transmission Electron Microscopy. A strong ordering effects have been observed

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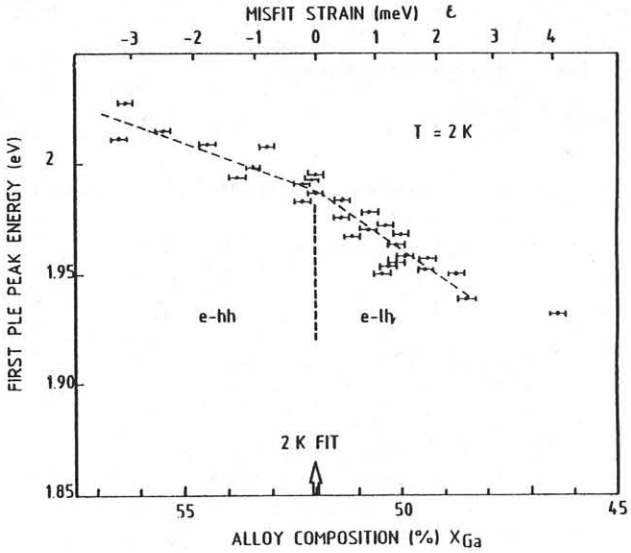

Figure 1 : Photoluminescence excitation peak energy as a function of Ga composition in GaInP layers.

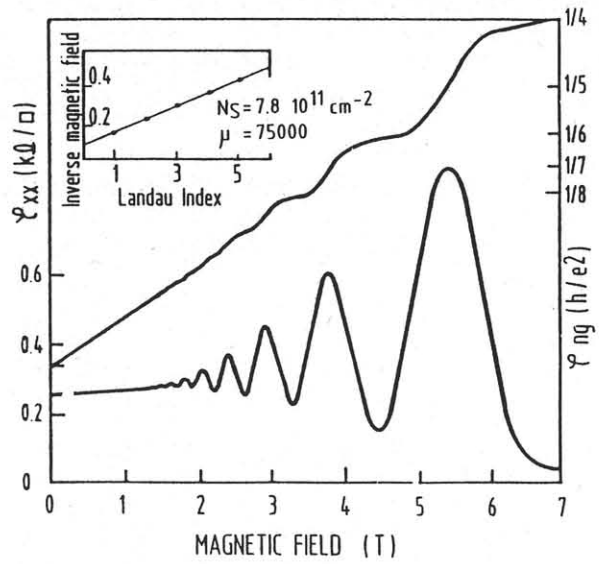

Figure 2 : Magneto-resistance oscillations versus the magnetic field in GaInP/GaAs structure.

which can be due to the successive Ga-rich In-rich layers formed along the $[\bar{1}11]$ and $[1\bar{1}1]$ direction[10].

3. GaInP/GaAs HETEROSTRUCTURE

The GaInP-GaAs transition has been optimized in order to be as sharp as 10 Å as measured by spectroscopic ellipsometry.

The presence of a 2 DEG at the interface has been revealed by Shubnikov-de Haas measurements (fig. 2). The sheet carrier concentration deduced from the positions of the minima is 7.5 x 10^{11} cm^{-2}, which allows to deduce a value of mobility as high as 75.000 cm^{-2} $V^{-1}s^{-1}$. This value is one of the best published up to now.

4. AlGaInP-GaInP-AlGaInP

Quaternary material has been successfully grown at 740°C. The aluminium content is generally fixed at 24 % and the V/III ratio, which has not been optimized, has been kept constant at a value of 100. The optical and electrical properties have been essentially limited by the residual oxygen and/or water contamination in the reactor due to imperfect loading or unloading system used at that time.

$Al_{0.24}Ga_{0.26}In_{0.5}P$-$Ga_{0.5}In_{0.5}P$ multi-quantum wells have been achieved, the quaternary material being deposited at 740°C and the ternary at 640°C. The growth was stopped at each interface for changing the growth temperature and the hydrogen flow in the organometallic sources. The photoluminescence spectrum of three quantum wells is shown in fig. 3 . The 20 Å thick well corresponds to a shift of 120 meV in energy, while the composition of the ternary

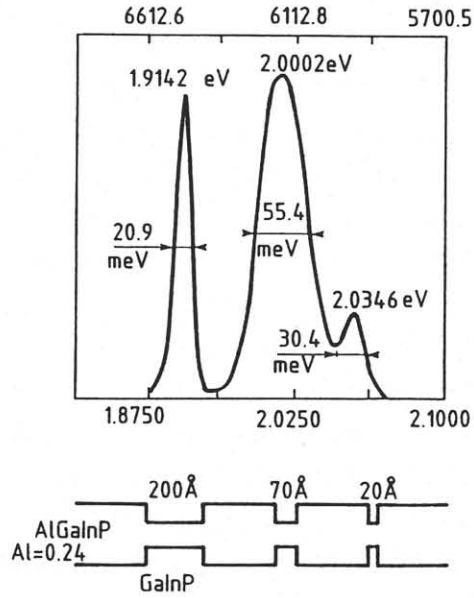

Figure 3 : 4 K photoluminescence spectrum of three quantum wells 200 - 70 - 20 Å thick

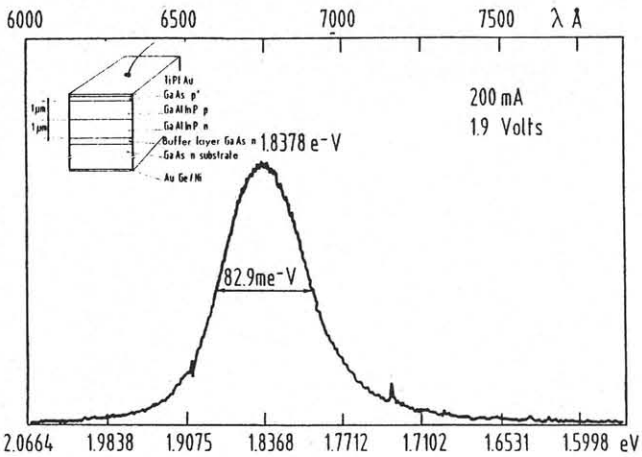

Figure 4 : Electroluminescence spectrum of P/N junction GaInP at 300 K.

material, slightly rich in In with respect to the lattice matched composition, is given by the 200 Å thick well energy.

5. LED's

Red and yellow LED's have been obtained with GaInP and $Al_{0.24}Ga_{0.26}In_{0.5}P$ respectively. The diode structures are schematically shown in figures 4, 5 and 6. For the red LED, two different structures have been grown, one with simple P/N GaInP homojunction and another one with double heterostructure P/N junction, the active layer being GaInP. The electroluminescence spectra measured at 300 K on a broad sample with a direct polarisation of 1.9 volts and a current injection of 200 mA are well defined with FWHM of 82.9 meV and 70 meV respectively, the emission wavelength being in the range 674-680 nm.

The yellow LED's were made of three layers : i) Se doped $Al_{0.24}GaInP$ layer (d = 1 µm, n = 7 10^{17} cm^{-3}), ii) Zn doped $Al_{0.24}$-GaInP layer (d = 1 µm, p = 5 10^{17} cm^{-3}), iii) a Zn doped GaAs cap layer (d = 0.35 µm, P = 3 10^{18} cm^{-3}). The ohmic contacts were formed with AuGeNi on the N type and TiPtAu on the p type. 350 μm^2 chip were cut from the wafer. The size of the ohmic contact dot being 110 μm^2. Direct current (3.5 V- 50 mA)

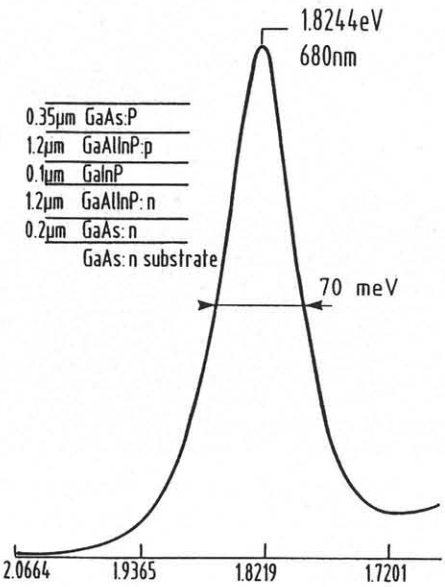

Figure 5 : Electroluminescence spectrum of D.H. AlGaInP/GaInP structure at 300 K

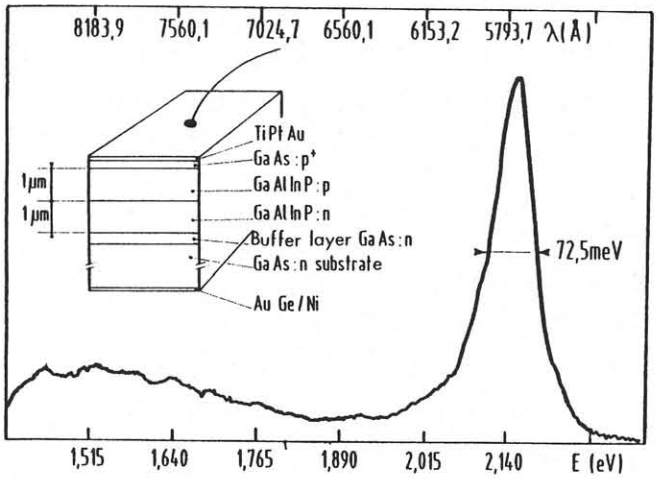

Figure 6 : Electroluminescence spectrum of P/N junction homojunction AlGaInP at 300 K with a yellow emission 576 nm.

was applied on the diode, standard current voltage characteristic is observed and no leakage current appears up to - 5 V.

The electroluminescence spectrum at 300 K shows (fig. 6) a sharp single peak at 576 nm with a FWHM of 72 meV. The electroluminescence intensity of the diodes was clearly lower than that of a standard GaAsP LED's. This can be explained by the low doping level N and P type used in the quaternary material and by the abscence of confinement of the carrier in the homojunction.

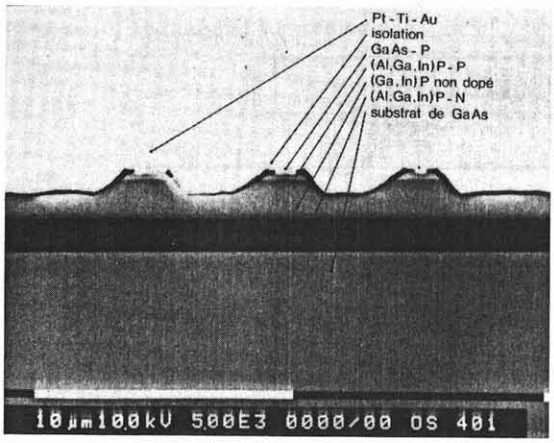

Figure 7 : Cross-section of three ridge waveguide AlGaInP laser diode array.

6. LASER DIODES

Double heterostructure lasers have been also grown. The structure consists of five epitaxial layers deposited on Si doped (100) 6° off GaAs substrate. A selenium doped GaAs buffer layer followed by the Se doped $Al_{0.24}Ga_{0.88}In_{0.48}P$ cladding layer (n = 7 10^{17}, d = 1 um), an undoped GaInP active layer (d = 0.07 µm), a Zn doped $Al_{0.24}Ga_{0.28}In_{0.48}P$ cladding layer (p = 5 10_{17} d = 1 µm) and a Zn doped GaAs cap layer are grown in the temperature range 700-740°C [11].

10 µm wide oxide stripe lasers were fabricated and laser chips with a cavity length of 1500 µm were cleaved. The typical value of the threshold current was about 5 KA/cm^{-2} under pulsed operation at 300 K. The internal quantum efficiency and the total internal cavity loss were 75 % and 5.8 cm^{-1} respectively.

A three-ridge laser diodes array has also been fabricated for the first time (fig. 7). The pulsed maximum output power at 660 nm wavelength was 108 mW without use of facet coatings (fig. 8).

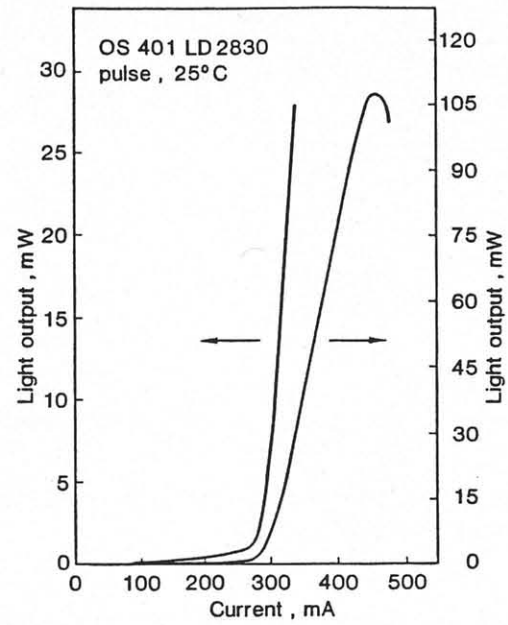

Figure 8 : Light output pulsed current characteristic of three ridge laser diode array at 300 K.

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