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Characterization of $In_xGa_{1-x}As_{1-y}P_y$ Epitaxial layers and Relation to Lattice Mismatching

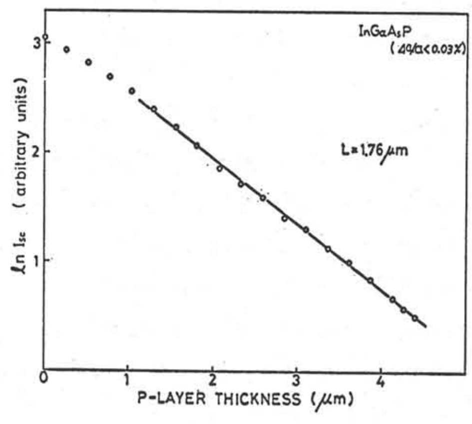
Akiyoshi TAMURA, Koji OKA, Junji SHIRAFUJI and Yoshio INUISHI
Department of Electrical Engineering, Faculty of Engin., Osaka Univ.
Yamada-kami, Suita, Osaka, 565,Japan

Stimulative development of optical fibers with an extremely low propagation loss at 1.2 - 1.3 μm has driven world-wide interests in epitaxial $In_xGa_{1-x}As_{1-y}P_y$/InP and Al_xGa_{1-x}-$As_{1-y}Sb_y$/GaSb quaternary compounds and related optoelectronic devices. Doubel-heterostructure lasers using these quaternary alloys were already succeeded. However, inherent stability of the laser performances in $In_xGa_{1-x}As_{1-y}P_y$/InP double-heterostructure lasers makes us expect its promising quality for optoelectronic material appropriate in the 1.2 - 1.3 μm range. In order to realize long-range optical fiber communication systems employing double-heterostructure lasers and APD detectors composed of $In_xGa_{1-x}As_{1-y}P_y$/InP epitaxial layers, thorough characterization of those epitaxial layers is inevitably necessary. We have studied optical properties, minority carrier diffusion length and deep trap levels in $In_xGa_{1-x}As_{1-y}P_y$ thin layers epitaxially grown on InP substrates; particular attention was payed on the effect of lattice mismatching on these basic properties.

$In_xGa_{1-x}As_{1-y}P_y$ thin layers were grown by conventional LPE method on (111)B or (100) n^+-InP substrates using a usual graphite sliding boat. To improve the crystallinity of InP substrate, an undoped or doped buffer layer of InP was inserted. The alloy composition, subsequently the magnitude of lattice mismatching, can be varied in a well controllable way by adjusting As content in the solution. The lattice mismatching was estimated by conventional X-ray diffraction analysis. The magnitude of the lattice mismatching was ranged ± 0.3 %. The alloy composition at the lattice matching condition was x = 0.74, y = 0.41 for the case of (111)B substrates and x = 0.80, y = 0.56 for (100) substrates.

Absorption spectrum at the fundamental edge in undoped $In_xGa_{1-x}As_{1-y}P_y$ layers ($n \simeq 3 \times 10^{16}$ cm^{-3}) showed Urbach tail in the lower absorption coefficient region, the extent of which depends largely on lattice mismatching. The extent of Urbach tail becomes minimum at the lattice matching condition between epitaxial layer and substrate, when the epitaxial layer was grown on (111)B surface of InP substrate. This indicates that the induced lattice strain (due to lattice mismatching), thus fluctuation of lattice potential, is considerably depend on the magnitude of lattice mismatching. The local fluctuation at the extrema of the energy bands should also affect on shallow impurity levels; this can be reflected on the emission spectrum associating with radiative transitions through shallow levels. The photoluminescence spectrum measured at 4.2 K in $In_xGa_{1-x}As_{1-y}P_y$ layers grown on (111)B substrates showed a single moderately broad peak with half width of 15 - 11 meV which may include both contributions of band-to-shallow level and donor-to-acceptor transitions. The value of the half width varied with the magnitude of lattice mismatching and showed a minimum ($\sim$11 meV) at the lattice matching condition. The similar situation in the half width of photoluminescence peak was also encountered in alloys grown on (100) InP surface. However, in alloys grown on (100) InP surface, no significant change in the extent of Urbach tail with the magnitude of lattice mismatching was observed. The reason of this observation is not clear at present.

Measurement of minority carrier diffusion length was carried out at room temperature on angle-polished p-$In_xGa_{1-x}As_{1-y}P_y$(Zn)/n-InP(Sn) pn junctions by scanning a focused laser (He-Ne) spot (1-2 μm diameter). The induced short-circuit current was measured as a function of translational distance from pn junction and analyzed by the formula given by Loferski and Wysocki[1]. Preliminary experiment showed the electron diffusion length of 1.76 μm in p-$In_xGa_{1-x}As_{1-y}P_y$ ($p \simeq 10^{18}$ cm^{-3}) at lattice matching condition as shown in the Figure. This value can be compared with these in GaAs and GaAlAs[2,3] measured using a similar technique. Lattice mismatching introduces lattice disorders at the interface of the heterojunction and causes a reduction of minority carrier diffusion length. The electron diffusion length in p-InGaAsP with lattice mismatching of -0.2 % in fact decreased to 0.93 μm.



Detailed experiment of minority carrier diffusion length as well as investigation of deep levels near the heterojunction interface by means of transient capacitance measurements are now in progress. Discussions on material characteristics and their relation to lattice mismatching will be presented at the Conference.

References

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