Proceedings Paper:

Krysa, A. orcid.org/0000-0001-8320-7354, Roberts, J.S., Devenson, J. et al. (4 more authors) (2016) Growth and characterisation of InAsP/AlGaInP QD laser structures. In: Compound Semiconductor Week (CSW) [Includes 28th International Conference on Indium Phosphide & Related Materials (IPRM) & 43rd International Symposium on Compound Semiconductors (ISCS), 2016. Compound Semiconductor Week (CSW) [Includes 28th International Conference on Indium Phosphide & Related Materials (IPRM) & 43rd International Symposium on Compound Semiconductors (ISCS), 2016, 26-30 Jun 2016, Toyama, Japan. IEEE . ISBN 978-1-5090-1964-9

https://doi.org/10.1109/ICIPRM.2016.7528566

Growth and characterisation of InAsP/AlGaInP QD laser structures

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Abstract—We present a study of metalorganic vapour phase epitaxy of ternary InAsP quantum dots on AlGaInP/GaAs. The properties of InAsP QD laser structures were compared with reference samples containing binary InP QDs. Based on X-ray diffraction, the molar fraction of As in InAsP QDs was estimated to be ~25%. Room temperature liquid contact electro-luminescence measurements revealed a long wavelength shift of the InAsP QD emission to ~775 nm as compared with the InP QD emission at 716 nm and an increased full width at half maximum of the spontaneous emission (71 meV vs 50 meV). As cleaved, 4 mm long and 50 µm wide InAsP QD lasers operated in a pulsed regime at room temperature at ~770 nm with a threshold current density of 155 A/cm2 and a maximum output optical power of at least ~200 mW. The maximum operation temperature was at least 380 K.

Keywords—metalorganic vapour phase epitaxy; InAsP quantum dot; liquid contact electro-luminescence; laser diode

InP quantum dots (QDs) have attracted much interest for optoelectronic applications, primarily laser diodes in the red – near infra-red spectral band. A significant improvement of the threshold current in InP QD lasers has been achieved [1], and other devices such as, semiconductor disc lasers [2], dual-wavelength laser diodes [3], optical amplifiers with ultrafast gain dynamics [4], saturable absorber mirrors [5] have been demonstrated. Also, rich nuclear spin phenomena have been observed in InP QDs [6, 7]. Further to these studies, photonic crystal cavities comprising InP QDs have been fabricated [8], which would enable realisation of optically controllable spin qubits. The operating wavelengths in the above examples have certain limits. In this research, we used a mixture of PH_3 and AsH_3 for InAsP QD growth to extend long wavelength operation limit of InP QD lasers at least to ~770 nm.

The samples were grown by MOVPE at 710 ^{o}C or 730 ^{o}C. The description of the samples is presented in Table 1. Prior to device processing, the epi-wafers were examined using pulsed liquid contact electro-luminescence (LCEL) [9]. The emission spectrum of nominally binary InP QDs was dominated by an emission centred at 716 nm with a full width at half maximum (FWHM) of 20.6 nm (equivalent to ~50 meV). Adding arsine to the reactor during the QD growth resulted into a wavelength shift of the QD emission to 775 nm, a decreased peak intensity and an increased FWHM of 34.3 nm (~71 meV). The latter indicates a higher degree of compositional and size inhomogeneity of InAsP QDs. The long wavelength shift of ~60 nm (132 meV) of the InAsP QDs is considerably smaller than expected from the As fraction derived from the X-ray diffraction data and the corresponding bandgap reduction of InAsP. This discrepancy can be explained by a smaller average InAsP QD size in comparison to InP QDs. TEM studies showed that the QDs are aligned in isolated vertical stacks with a density of the order of 10^{9}-10^{10} cm^{-2}. The InP QDs generally appear larger and the stacks more regular than the InAsP QDs, with a height of 4-5 nm and a lowermost dot diameter of 40-50 nm, whereas the InAsP dots have a height of 2-3 nm, a lowermost dot diameter of 20-30 nm and greater variability in dot diameter through the stack. The observed greater variability and smaller average size of the InAsP QDs are in a good agreement with their LCEL properties.

The epitaxial wafers were processed in 4 mm long, 50 µm wide, oxide isolated stripe lasers with uncoated facets. The lasers were operated in pulsed mode (1 kHz, 1000 ns). RT laser oscillations of InP and InAsP QD samples were observed at around 720 nm and 770 nm, respectively, close to the corresponding LCEL wavelengths. Both samples delivered optical powers of near 200 mW. The laser showed reasonably small threshold current densities (123 A/cm^2 and 155 A/cm^2 at RT for InP and InAsP QD samples, respectively) and lased up to at least 380 K.

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Table 1. Description of layers

Reps	Material	Thickness, nm
1	p-GaAs	50
1	p-$Ga_{0.52}In_{0.48}P$	50
1	p-$Al_{0.52}In_{0.48}P$	1000
1	$(Al_{0.3}Ga_{0.7})_{0.52}InP$	84
5	$(Al_{0.3}Ga_{0.7})_{0.52}InP$	16
5	$Ga_{0.52}In_{0.48}P$	8
5	InP or InAsP	0.76
1	$(Al_{0.3}Ga_{0.7})_{0.52}In_{0.48}P$	100
1	n-$Al_{0.52}In_{0.48}P$	1000
1	n-$Ga_{0.52}In_{0.48}P$	50
1	n-GaAs buffer	500
n-GaAs substrate		