High quality molecular-beam epitaxial InAlAs for UHF photodiodes

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We report a study of the quality and growth technique optimization of InAlAs for high-frequency photodiodes for microwave photonics applications. The InAlAs alloy is used as an efficient potential barrier material in phosphorus-free heterostructures based on InGaAs light emission and absorption layers grown on InP for the 1.33 and 1.55 μm spectral ranges. Despite the seeming maturity of the growth technology, there have been reports recently showing that layers of InAlAs might exhibit characteristics deteriorating the device parameters. In particular, it has been shown that large leakage currents of InAlAs, tentatively assigned to the presence of a high concentration of deep levels, have limited the attainable sensitivity of photodiodes. In the present work we report on the growth of InAlAs on InP by the molecular beam epitaxy (MBE), discuss the substrate preparation, growth regimes and their optimization aimed at obtaining high-quality layers lattice matched to InP, and optical properties of these layers.

The samples were grown by solid-source MBE in a Riber Compact-21T system on semi-insulating Fe-doped (001) InP substrates from AXT. The growth sequence was initiated with substrate annealing in the flux of excessive arsenic, which was followed by the layer growth. To determine the optimum conditions for growth of $In_xAl_{1-x}As$ layers lattice matched to InP ($x=0.52$) a set films was grown using As fluxes in a wide range of beam equivalent pressure values $F_{As}=(0.5–7)\times10^{-5}$ Torr and growth temperatures in the range of 460–560°C. X-ray diffraction (XRD), atomic force microscopy (AFM) and low-temperature photoluminescence (PL) data were used to determine the optimal growth conditions. In the growth temperature range of 520–535°C and an arsenic flux of $F_{As}=1.5\times10^{-5}$ Torr the AFM images show atomically-flat terraces that indicate a 2D layer-by-layer growth mode with a mean surface roughness of 0.113 nm. Under these growth conditions, the FWHM width of XRD rocking curve peaks were as low as 20 arcsec. The low-temperature PL spectra of these layers exhibited a single near band edge line as narrow as 19 meV (5 K). We found however that at intermediate temperatures of 60–160 K a novel longer-wavelength line located by 120–200 meV below the near band edge line appears in the PL spectra. The intensity of the new line is anti-correlated with the sample's room-temperature PL efficiency. This new line is attributed to radiative transitions involving defects in the material. We show that by carefully selecting the growth conditions in order to establish the quasi-stoichiometric conditions on the growth surface we were able to grow layers with high-temperature PL efficiency by 1–2 orders of magnitude greater than that in the samples grown under otherwise standard conditions, and which show virtually zero intensity of the defect-related long-wavelength transitions.