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Development of Inverted p-Substrate InP/AlGaInAs Lasers for Vertical Integration with Multiple Passive or Active Intrinsic Regions

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Photonic integrated circuits (PICs) often require separate active and passive optoelectronic devices on a single chip. Active devices generate and amplify light while passive devices are for lossless guiding and manipulation. Integration of the two types of optoelectronic devices is challenging as each requires different material. Monolithic vertical integration of passive and active devices allows separate material to be grown one above the other, while tapering of the different layers allows transitions between the now integrated devices.

Vertical integration of junctions requires every alternate device to be inverted from the traditional n-substrate layout to a p-substrate. For example for two devices vertically integrated the lower device may be p-i-n with an n-substrate, requiring the device above it to be n-i-p so that they can share the p-doped layer, resulting in an n-i-p-i-n structure.

Little work has been done on p-substrate semiconductor lasers. N-substrates have been preferred due to the instability of dopants in p-substrates. Typical Zn p-doping diffuses heavily during further growth at high temperatures with a risk of reducing optical efficiency if the intrinsic region is penetrated [4]. Diffusion can be restricted by placing a protecting undoped region between the p-doped and the intrinsic region [1]. It is also difficult to form a low resistance contact to p-doped InP [2], a fact avoided with n-substrate devices by using highly doped GaInAs(P) cap layers. However by using a broad p-substrate back contact the contact resistance is reduced, eliminating the requirement of additional layers, in addition to which the p-substrate should be highly doped and thinned to reduce its resistance as much as possible [2,3].

The p-substrate InP/AlGaInAs 1.5um lasers grown and tested here have a core of 5 quantum wells (QWs) and Figure 1 outlines the doping profiles of each revision used to increase device performance. While the first iteration included an undoped region between the intrinsic and p-doped layers, Figure 2 shows that the material failed to lase under CW operation and required high pulsed currents to work. However the peak wavelength was correctly centred at 1.5um, therefore a very similar epitaxial design was used for two subsequent growths where in one case the doping was pulled back further to absorb diffusion of Zn dopants, while the other case included a carbon doped layer as a stopping layer to prevent Zn diffusion, due to carbon being a more stable dopant [4]. The reason for the first failed growth is believed to have been diffusion into and through the QW core, as justified by ECVP measurement and CV measurements which determine the intrinsic region thickness, Figure 1.

Figure 1 shows that both revised editions had an increased intrinsic region and Figure 2 shows this allowed the samples to lase with thresholds below 40mA with wavelengths centred around 1.55um. These results indicate that either of these p-substrate InP/AlGaInAs lasers can be used for further vertical integration, and this work will present their development.

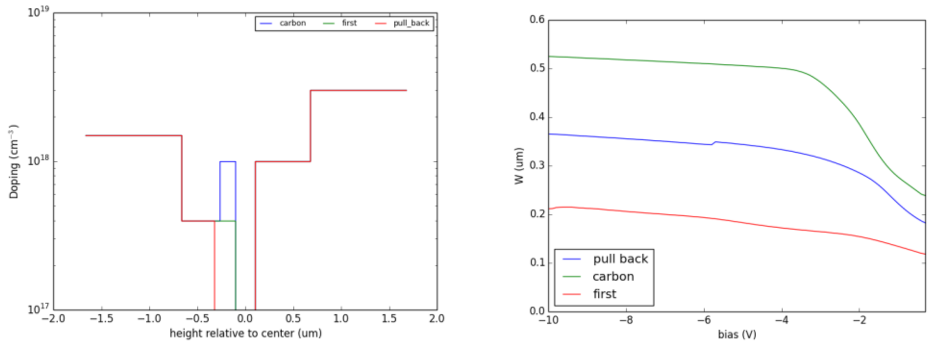

Fig. 1. Left: Doping profiles of the different epitaxial designs of the p-substrate material. The p-doping was pulled back on redesign to prevent diffusion into the core, while another iteration placed a carbon doped layer before the undoped region. Right: Capacitance-Voltage measurements were performed on circular diode structures on each of the different n-i-p wafers, from which the depletion width can be calculated from $C = \frac{\epsilon A}{W}$. The low depletion width W of the first sample was not sufficient to prevent diffusion into the core while the revised editions with the doping pulled back further and a carbon layer prevent diffusion into the core.

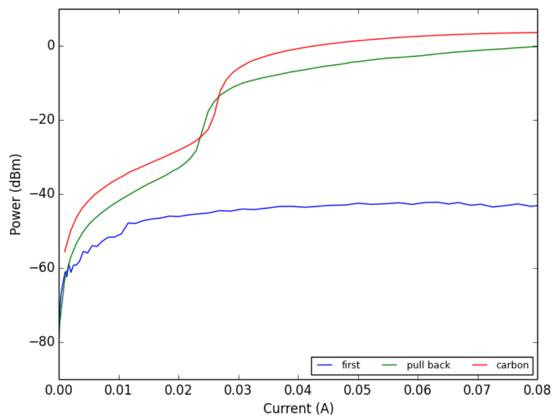

Fig. 2. Optical power vs injected current for Fabry-Perot lasers on each of the epitaxial designs: first iteration, with p-doping layers pulled back from the intrinsic region, and with a carbon doped blocking layer before the undoped region.

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