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Epitaxial Re-growth for Advanced GaAs Based Laser Devices

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1. Introduction

Advanced components require the control of both the confinement and flow electrons and photons. This is often best achieved using semiconductor regrowth technologies where both conductivity and refractive index contrasts may be controlled in 3 dimensions. The development of opto-electronic integrated circuits (OEICs) on InP has been driven by the demand for faster optical networks systems at 1550nm. OEIC development on the InP platform has reached a level of sophistication enabling widespread application to tuneable lasers and WDM systems-on-a-chip with ever increasing component count and associated increasing datacoms bandwidth. Presently, InP based OEIC chips may incorporate over 50 components and several functions including lasers, amplifiers, modulators, detectors, multiplexers, and attenuators combining 40 wavelengths at 40Gb/s giving 1600Gb/s capacity, bringing the prospect of Moore's Law to optical networks.

However, for advanced opto-electronic components at wavelengths shorter than ~1200nm, there is limited existing capability for monolithic integration, and a hybrid method is currently the usual option, limiting scalability. GaAs is the material of choice for the wavelength range 650 - 1300nm. However, aluminium-containing layers are known to readily oxidise when exposed to the atmosphere, thereby precluding etched AlGaAs layers from being re-grown upon since high quality growth upon oxidised layers is problematic.

In this paper, we present a review of the challenges in the epitaxial regrowth of high quality GaAs based laser structures. Our fabrication process relies upon AlGaAs layers never being exposed to air, and on the development of re-growth processes where arsenide alloys are grown upon phosphide alloys. Growth technologies, and device capabilities of our self aligned stripe lasers, window structure superluminescent diodes, distributed feedback lasers, and photonic crystal surface emitting lasers will be discussed. The difficulties and solutions to epitaxial regrowth of alloys of dissimilar group V elements will be described. We will go on to discuss optimised growth conditions for high quality re-growth in the case of very high aspect ratio 3d structures for surface emission. Prospects for future devices will be discussed in terms of pushing this technology to shorter wavelengths (< GaAs band-edge), and in the use of high refractive index contrast semiconductor/void gratings in the device.

2. Self Aligned Stripe Lasers[1]

Self aligned stripe lasers, require both a current blocking layer and index guiding of the optical mode. Our over-growth, applied to this structure, offers the advantages of high refractive index contrast between the InGaP and the GaAs along with excellent interface quality.

Figure 1 shows a TEM cross section through the structure. To note is the high quality regrowth of the structure free from defects. There is some compositional change in the AlGaAs layer due to growth on the different index planes although in reality this seems to have little effect on the device performance.

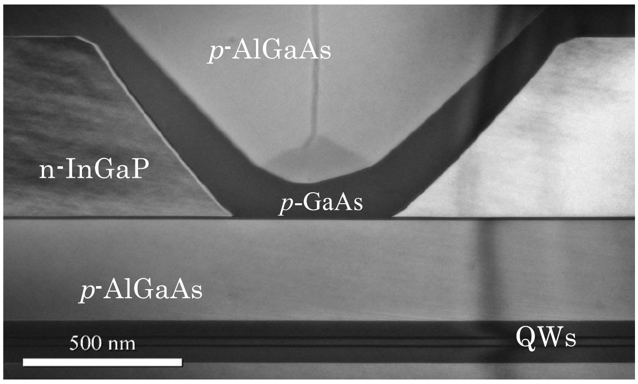


Figure 1. *TEM taken through a SAS structure.*

3. Superluminescent Diode Window structures

Superluminescent Diodes (SLDs) are of interest for applications such as optical gyroscope, WDM testing, and optical coherence tomography due to their ability to give broad spectral band-with and high power. However often the parameter limiting the output power of a SLD is preventing lasing from occurring (i.e. facet reflectivity or using absorber sections). We would like strong amplification of the amplified spontaneous emission whilst suppressing the stimulated emission. Modifying our self aligned strip process enables us to create a window structure in which the electrically driven active element is terminated in an absorptive unguided waveguide. This results in a termination to the waveguide of very low effective reflectivity.

Figure 2 shows a TEM section taken along the ridge and through a "window". The optical mode on the left is strongly index guided, whereas on the right side there is no index guiding. Due to the small difference in group refractive index between the guided and unguided sections of the device, the reflectivity of such a structure is $>10^{-6}$ (measured) with a theoretical value approaching 10^{-9}.

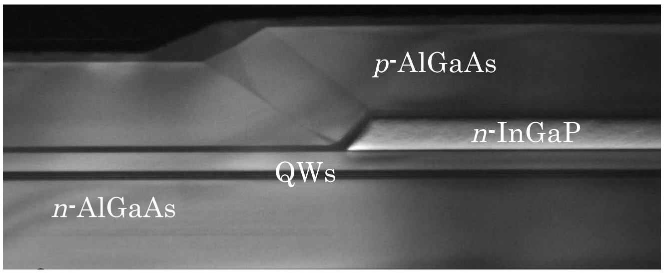
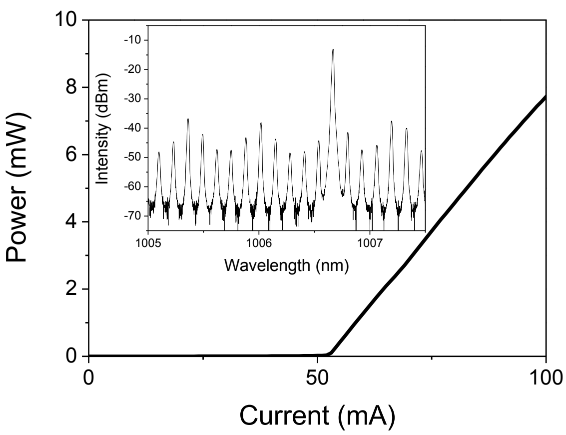
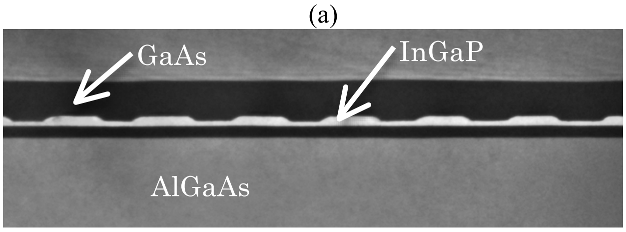


Figure 2. *TEM cross section taken along the ridge. The guided region is to the left, unguided to the right. A section through the guided region would look similar to Fig. 1.*

4. Distributed Feedback Lasers[2]



(a)



(b)

Figure 3*. (a) LI curve with inset showng spectrum. (b)TEM image showing an overgrown DFB grating. The grating has not been etched completely through the InGaP.* **.**

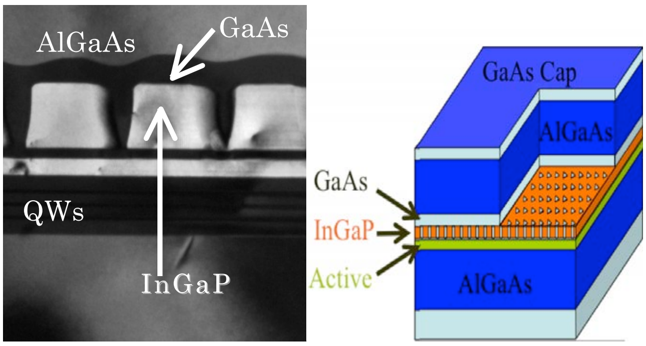
Distributed feedback lasers, in which there is a periodic change in refractive index along the laser cavity, can utilise our overgrowth technologies to achieve high refractive index contrast gratings. Alternative methods to achieving DFB lasers such as etching sidewall gratings in a ridge are effected strongly by etch depth and exact etching parameters controlling verticality and mask reproduction. In our process, we have demonstrated the coupling coefficient of the grating is controlled by the refractive index contrast constant) and the distance between the grating and the active region, both of which are controlled by the epitaxial process which can consistently deliver far greater control.

5. Photonic Crystal Surface Emitting Lasers[3]

Photonic crystal surface emitting lasers (PCSEL) are of significant interest due to their low and tailorable beam pattern, selection of poalrization through phoronic crystal design, and their power scalability with area.

Applying our overgrowth technology to these structures has eliminated the need for complex wafer processing techniques such as wafer bonding that have typically been used to realise such structures.

In addition to the latest results for these structures the optimisation of the epitaxial process to achieve optimised infilled gratings, or at the other extreme, the creation of void inclusions will be discussed. The short wavelength limits for such GaAs based structures will be discussed, along with prospects for more advanced device structures.



(a) (b)

Figure 4. *(a) TEM section image through an overgrown PCSEL structure. The lower InGaP layer forms an etch stop layer. (b) Device shcematic*

References

All TEM courtesy Richard Beanland, Integrity Scientiffic
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3. D.M Williams et al. IEEE Photonics Technology Letters 24, 966-969 (2012).