Physical properties of short wavelength 2.6 μ m InAs/AlSb-based quantum cascade lasers

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We used high hydrostatic pressure techniques to understand the deteriorating temperature performance with decreasing wavelength of short wavelength quantum cascade lasers. Influence of inter-valley scattering and distribution of the electron wave functions will be discussed.

There are several challenges in the development of semiconductor lasers for the near mid-infrared region of 2-3 μ m. Approaches being developed to produce lasers in this range include extending the wavelength of inter-band diode lasers which perform relatively well below $\sim 2.5 \mu$ m. Such lasers are, however, strongly affected by increased optical losses and non-radiative Auger recombination which degrade device performance with increasing wavelength. The second approach is based upon the development of short wavelength, inter-subband transition based, quantum cascade lasers (QCLs), which can exhibit a high temperature stability and high output powers for longer wavelengths $>3.8 \mu$ m [1, 2]. It is anticipated that the use of short wavelength QCLs will overcome the problem of non-radiative Auger recombination which plagues inter-band lasers.

There are however several challenges to realise short wavelength QCLs, many of which are band-structure related [1]. Fig.1 shows that the maximum operating temperature of InAs/AlSb QCLs strongly decreases towards shorter wavelengths.

Fig. 1 Maximum operating temperature as a function of wavelength for InAs/AlSb QCLs.

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In our previous study of 2.9 μm and 3.3 μm QCLs we showed that carrier leakage from the upper laser levels into the indirect L-valley of the conduction band in InAs quantum wells is negligible in the 3.3 μm QCLs at RT leading to their superior temperature performance. In the shorter wavelength devices emitting at 2.9 μm , this loss mechanism is more important and accounts for up to 13% of I_{th} at 190K. Taking into account that QCLs require significant injection currents an increased loss could greatly influence the device high temperature performance.

Here we consider shorter wavelength devices emitting at 2.65 μm [3]. QCLs were grown by MBE and processed into ridge lasers using wet chemical etching [1]. The rear facets of the cleaved chips were covered with a high-reflectivity coating. As in [4] we used high hydrostatic pressure techniques to investigate device performance by manipulating the band structure. Since the Γ - and L-minima conduction band minima have different pressure coefficients, hydrostatic pressure enables one to reduce the separation between the Γ and L minima of the conduction band at constant temperature. The 2.9 μm devices have a smaller Γ -L separation and operate up to 280K, whereas the 3.3 μm devices, with a larger Γ -L separation, work up to 400K. In addition, the threshold current in 2.9 μm lasers showed a very strong increase with increasing pressure which is in very good agreement with the model of Γ -L inter-valley scattering [4]. Interestingly, the pressure dependence of threshold current in 2.65 μm devices is very different with an initial reversible increase of I_{th} up to 150MPa at 90K followed by a decrease. The combined influence of inter-valley scattering and distribution of the electron wave functions in the active region (see fig.3) on QCLs operating at 2.65 μm will be discussed further in the presentation in terms of how short wavelength InAs/AlSb QCLs can be optimised for high temperature operation.

Fig.2. Normalised threshold current of 2.65 μm and 2.9 μm QCLs as a function of hydrostatic pressure at $T=90\text{K}$.

Fig.3. Electron wave functions in Γ - and L-subbands in the active region of 2.65 μm QCL.

References

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