The influence of inter-valley scattering on λ~3.7μm InGaAs/AlAs(Sb) quantum cascade lasers.

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Semiconductor lasers emitting in mid infra-red region are of increasing interest owing to their use in wide range of applications. One of the important applications is a sensor for monitoring gases such as CO_2, SO_2 and CH_4. This requires inexpensive, room temperature and reliable mid-infrared light emitting devices. Despite significant advances in conventional long wavelength inter-band lasers, their performance remains limited by large losses due to non-radiative Auger recombination and inter-valence band absorption which are fundamental processes in narrow band gap III-V material systems. In the 3-4μm region, quantum cascade lasers (QCLs) can potentially be used as a solution to overcome Auger recombination which limits the performance of standard inter-band lasers. They can also be grown on more readily available substrates, such as InP which reduces their cost and eases manufacture. Since the transition occurs between two confined electron levels in the conduction band, a large conduction band offset is required to provide a short emission wavelength. Large separations between the Γ and indirect L- and X- valleys are also needed to avoid inter-valley scattering processes which may deteriorate the performance of QCLs.

This work is conducted on short wavelength strain-compensated InGaAs/AlAsSb structures on InP substrates to study the influence of temperature on the operation of QCLs emitting at 3.5-3.7μm using cryogenic and hydrostatic pressure techniques. Self-heating effects were minimised by using short 100-200ns pulses. Figure 1 shows the temperature dependence of the threshold current density (J_{th}) and includes the characteristic temperature, T_0 ($1/T_0 = d\ln J_{th}/dT$). T_0 was found to be 190K at 200K and 60K at room temperature indicating the occurrence of temperature-induced losses, which may be related to inter-valley scattering. The corresponding temperature dependence of the lasing energy is shown in Figure 2. High hydrostatic pressure measurements were carried out to investigate the possible role of inter-valley scattering as high pressure can be used to reversibly and continuously change the Γ-X and Γ-L energy separations.

Figure 3 shows threshold current versus pressure dependencies taken at 100K and 290K. The threshold current increases at a rate of ~ 1.3%/kbar at 100K and ~2.7%/kbar at room temperature. This indicates that the loss process which influences the threshold current with increasing temperature is also increasing when high pressure is applied. This behavior is in agreement with Γ-L inter-valley carrier scattering. The contribution of this process varies with emission wavelength, which is attributed to a small variation of its activation energy in different structures. Figure 4 shows that the increase of the transition energy with pressure is approximately -0.5 meV/kbar. Further details of the influence of this scattering process on device performance will be presented at the conference.

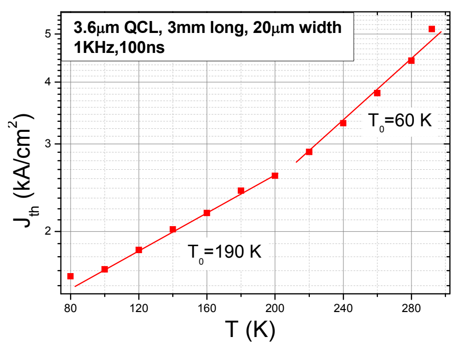

Fig. 1. T-dependence of Jth in λ=3.6μm QCL.

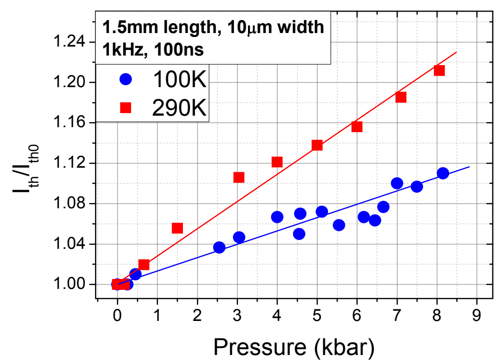

Fig.3. Normalised pressure dependence of the threshold current at 100K and 290K.

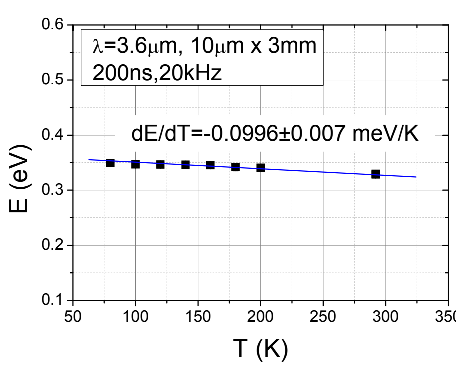

Fig. 2. Lasing photon energy as a function of temperature.

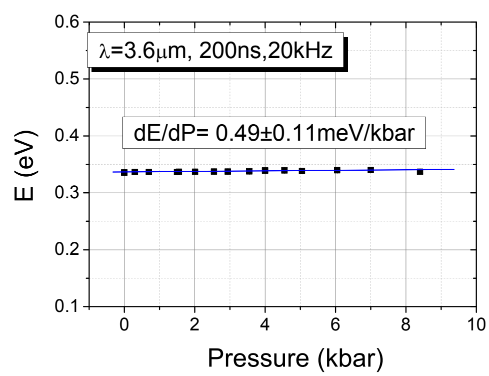

Fig.4. Lasing photon energy as a function of pressure at RT.

Keywords: quantum cascade laser, inter-valley scattering, sensing, gas monitoring.

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