Optimisation of the growth of terahertz quantum cascade lasers

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Terahertz (THz) quantum cascade lasers (QCLs) are extremely challenging structures to grow by techniques such as molecular beam epitaxy (MBE). They require precise calibration of growth rates, and the minimization of flux drifts (to typically <2%) throughout the active region, which usually exceeds 10 µm in thickness and often contains over 1000 separate interfaces. We will demonstrate the successful growth of these sophisticated modulated semiconductor structures, and outline some of our latest results. Furthermore, we will show how pyrometric spectrometry [1] (kSA BandiT; www.k-space.com/), through a heated viewport, can be used real-time to (a) 'calibrate' GaAs and AlAs growth rates and (b) monitor the growth of QCLs.

As an example, a 2.9 THz QCL (wafer L140) was grown in an Oxford Instruments V-80H MBE system. Based on a bound-to-continuum active region design and a single plasmon waveguide [2], the 2.9 THz laser consists of 90 repeat periods of a $GaAs/Al_{0.15}Ga_{0.85}As$ heterostructure.

To grow such QCLs, calibration of the GaAs growth rate was achieved by growing a thick GaAs layer on AlAs and vice-versa. Growth rates were then calculated from the pyrometric data using the formula:

$$G = \frac{1}{T} \times \frac{\lambda}{2\eta}$$

where G is the growth rate, T is the time period of intensity oscillations at a specific wavelength, λ is the wavelength and η is the refractive index. The refractive indices were referenced to x-ray diffraction data obtained from specifically-grown calibration structures.

Pyrometric oscillations were, however, not only used to calculate growth rates, they were also used to monitor real time growth of a THz QCL. Typical pyrometric oscillations are shown in Fig. 1 for two nominally identical QCL structures, with a typical line profile being shown in Fig. 2. The pyrometric data, in principle, gives extensive information about the precision of the wafer growth, not only acting as an additional calibration but also potentially giving information about flux drifts. Use of the kSA Bandit system for such calibration and monitoring of modulated semiconductor structure growth will be reviewed and discussed.

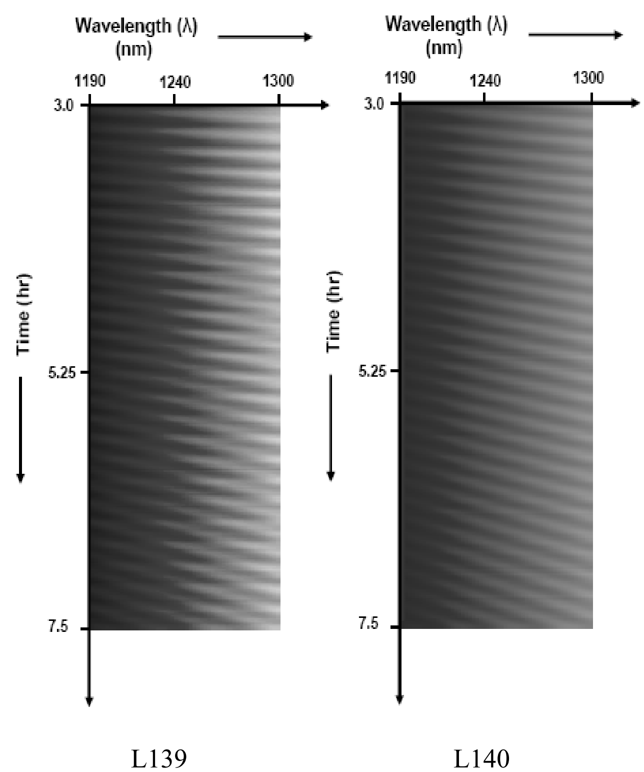

Fig. 1. Typical pyrometric data (intensity oscillations) of two, nominally identical, QCLs acquired real-time during growth using the kSA Bandit spectrometer.

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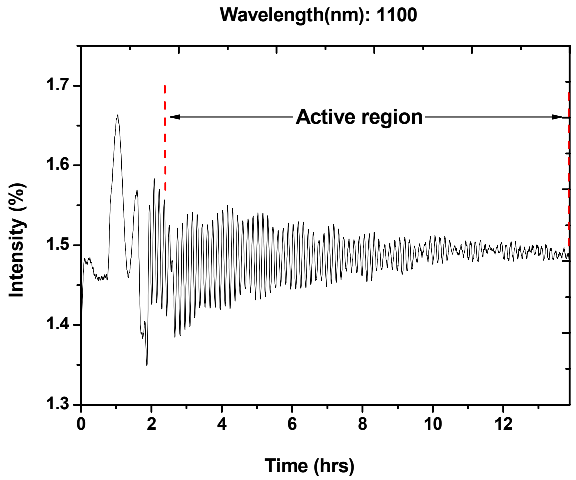

Fig. 2. Line profile of the intensity oscillations acquired at a specific wavelength (1100 nm), during the growth of a THz QCL.

REFERENCES

[1] F. G. Boebel, H. Moller, B. Hertel, H. Grothe, G. Schraud, S. Schroder, and P. Chow, "In situ film thickness and temperature control of molecular beam epitaxy growth by pyrometric interferometry," *Journal of Crystal Growth*, vol. 150, pp. 54, 1995.

[2] S. Barbieri, J. Alton, H. E. Beere, J. Fowler, E. H. Linfield, and D. A. Ritchie, "2.9 THz quantum cascade lasers operating up to 70 K in continuous wave," *Applied Physics Letters*, vol. 85, pp. 1674, 2004.