MBE growth of terahertz quantum cascade lasers – the challenges and opportunities of working with the GaAs-AlGaAs materials system

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The last two decades have witnessed a remarkable growth in terahertz (THz) frequency science and engineering (300 GHz – 10 THz), which has matured into a vibrant international research area. A wide range of organic and inorganic crystalline materials and gases exhibit characteristic vibrational/rotational modes in the terahertz frequency range, which have been exploited to create new methodologies for process monitoring and non-destructive testing in the pharmaceutical and electronics sectors, *inter alia*.

One of the most promising, high power, compact sources of THz radiation is the quantum cascade laser (QCL). First demonstrated in 2002 [1], these inter-subband semiconductor lasers have led to a new research field, which has blossomed and grown over the last two decades. Nevertheless, despite this success, and the flourishing research field that has developed, there has been little change in the materials system and techniques used to define these heterostructures, which typically consist of over 1000 separate interfaces each defined to atomic monolayer precision. In fact, most THz QCLs reported to date have been grown by the same molecular beam epitaxy (MBE) growth process, and in the same GaAs-AlGaAs materials system, that was used to demonstrate the first laser in 2002.

In this presentation, I will overview some of the advances that have taken place over the last twenty years, and which have made the THz QCL such an ubiquitous source. I will then reflect on the challenges in growing these sophisticated layered superlattices, and explain why, despite the maturity of this materials system and growth process, there still remain many issues to be resolved. For example, how can one ensure that the growth rates are calibrated and remain constant over the > 10 hours required to grow a typical ~ 10 μm thick THz QCL active region? How can one assess, let alone optimize, the roughness of each interface, which will influence the efficiency of electron transport through the THz QCL, and hence the performance? How easy is it to replicate a theoretical design when, at the elevated temperatures of MBE growth (~ 600°C), there will be both atomic diffusion and segregation occurring? How can one ensure that the active region doping, which is critical for QCL performance, is optimized, when the average doping in a THz QCL is low (typically in the range ~ 5×10^{15} cm^{-3} – 1×10^{16} cm^{-3}), and susceptible to changes in background doping level in the system? In considering these issues, I will reflect upon the accuracy with which high performance literature designs can be replicated.

I will conclude by reflecting on lessons learnt, and how this learning might be applied to growth of new materials systems of contemporary interest.

References

[1] Köhler R et al. Terahertz semiconductor-heterostructure laser. Nature 2010;417:156-159.