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CAMBRIDGE

# Frequency tuning of THz bound-to-continuum quantum cascade lasers

Joshua Freeman[1], Christopher Worrall[1], Vasilis Apostolopoulos[1], Jesse Alton[2], Harvey Beere[1] and David A. Ritchie[1]

[1]Semiconductor Physics Group, Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, UK. E-mail: jrf40@cam.ac.uk.
[2]Teraview Ltd, Platinum Building, St John's Innovation Park, Cambridge, CB4 0WS, UK.

## Summary

The laser emission frequencies of existing designs are controlled by uniform thickness transformations.

Experimental results from a total of ten wafers are presented. These demonstrate a predictable shift in the emission wavelength and an anticipated alteration in electrical transport.

Wafers based on a design around 2.9THz produced lasers operating over a frequency range of 0.35THz.

## Introduction

Terahertz quantum cascade lasers (QCLs) have been engineered over a range of frequencies, presently from 4.8THz[1] to 1.6THz[2].

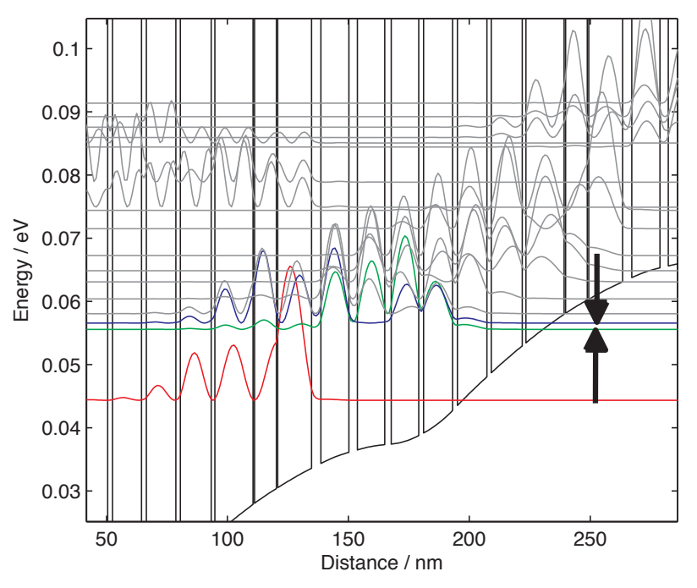
THz QCLs are highly suited to heterodyne spectroscopy applications[3], where there is a lack of compact high-power sources. It is desirable to have a method to alter the emission frequency of a QCL to match that of the application.

Small shifts in emission frequency can be achieved with the distributed feed back (DFB) technique already demonstrated with THz QCLs[4]. The range of this technique however is limited by the width of the gain curve.

This complementary approach is to modify the gain curve by changing the design of the structure, adjusting each well and barrier by the same fractional amount. This change in the period length of a bound-to-continuum THz QCL results in a predicable shift in the emission frequency.

## Simulations

Each structure is generated by multiplying each layer of the original design by a constant factor. This causes a change in superlattice period length.



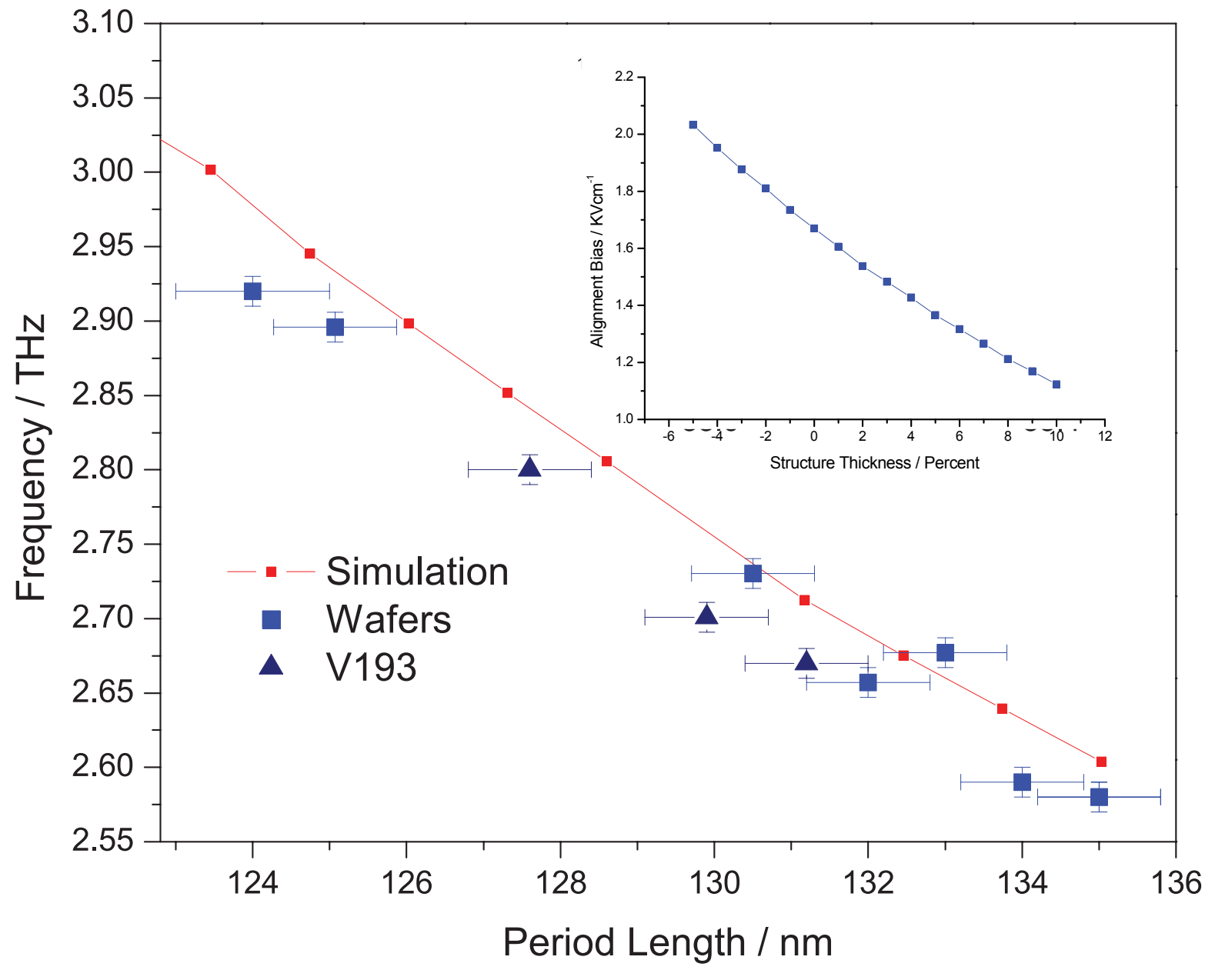
The QCL alignment condition was taken as the field at which the anti-crossing between the upper and injector states occurs. This resonance characterizes a maxima in conduction.

The modified structure is modelled self-consistently at the alignment field to determine the emission frequency of the laser.

The simulations suggest that thicker structures should have a smaller splitting between the upper and injector states and align at a lower electric field.

We present eight wafers exhibiting period variation of a 2.9THz[5] design.

There is very good agreement between data from wafers and simulations, the frequency of the wafers span a range of 0.35THz.

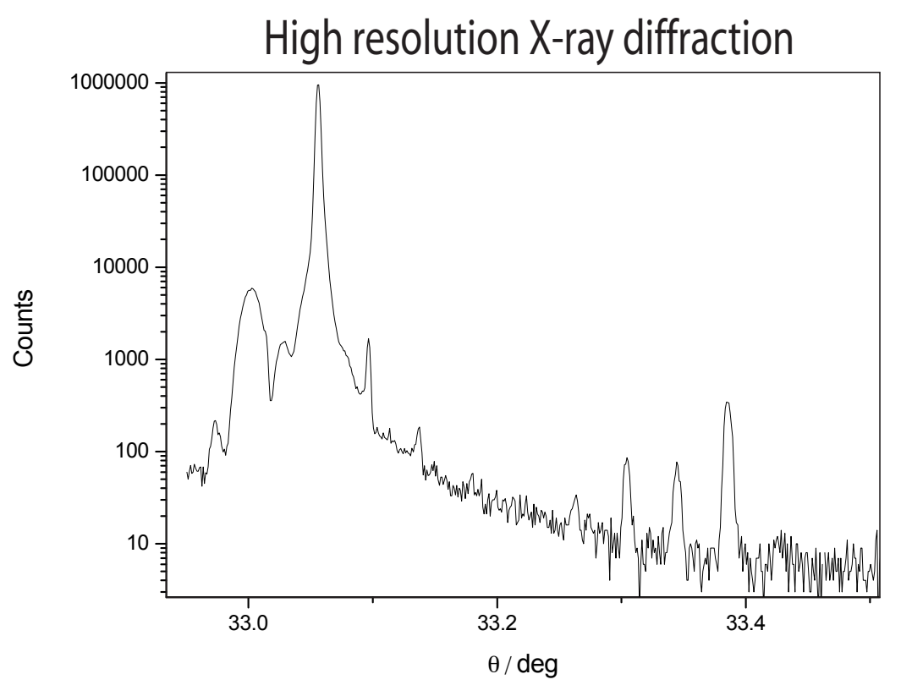


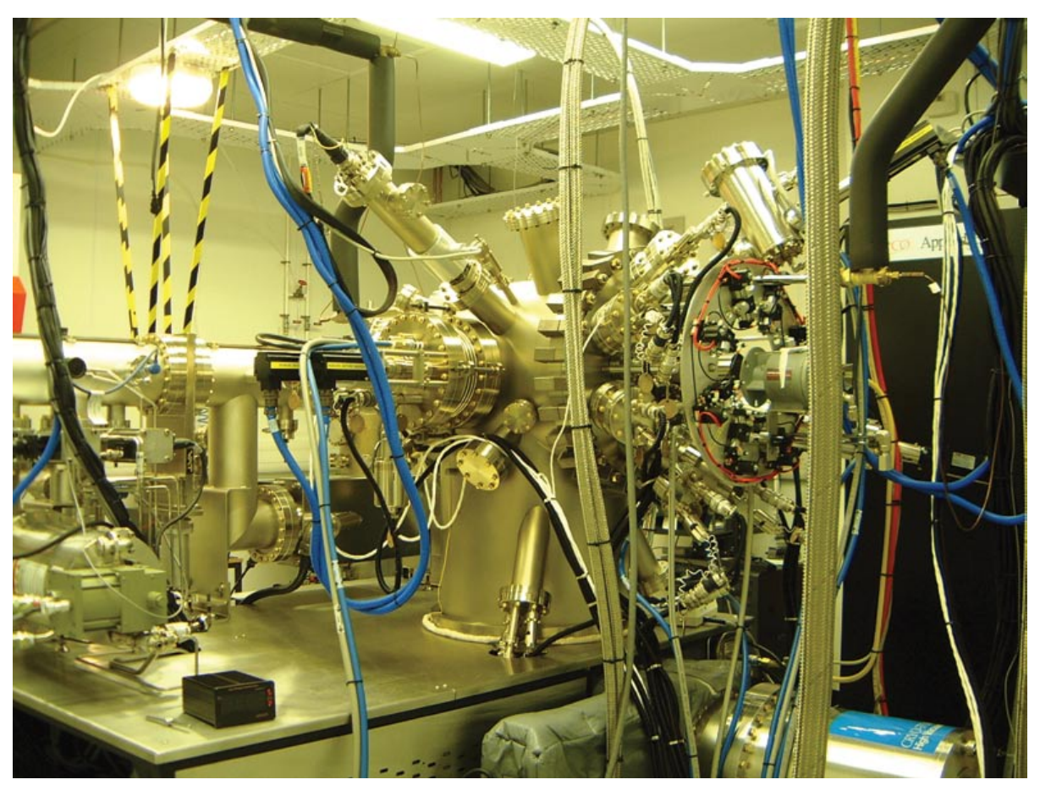
## Growth and processing

All wafers were grown on a Veeco ModGen II molecular beam epitaxy (MBE) reactor on semi-insulating GaAs substrates.

The period length of each wafer was determined by high resolution X-ray diffraction (HRXRD).

The spacing of satellite peaks around the GaAs [004] lattice reflection was used to determine the period length of the superlatice





The wafers were processed into 250μm wide, 3mm long single plasmon waveguides.

The devices were mounted in a helium continuous-flow cryostat and cooled to 4K. Electrical measurements were made in a three terminal configuration.

## 2.9THz Lasers

The three samples were taken from a single 3″ wafer (V193), period length was found by HRXRD:

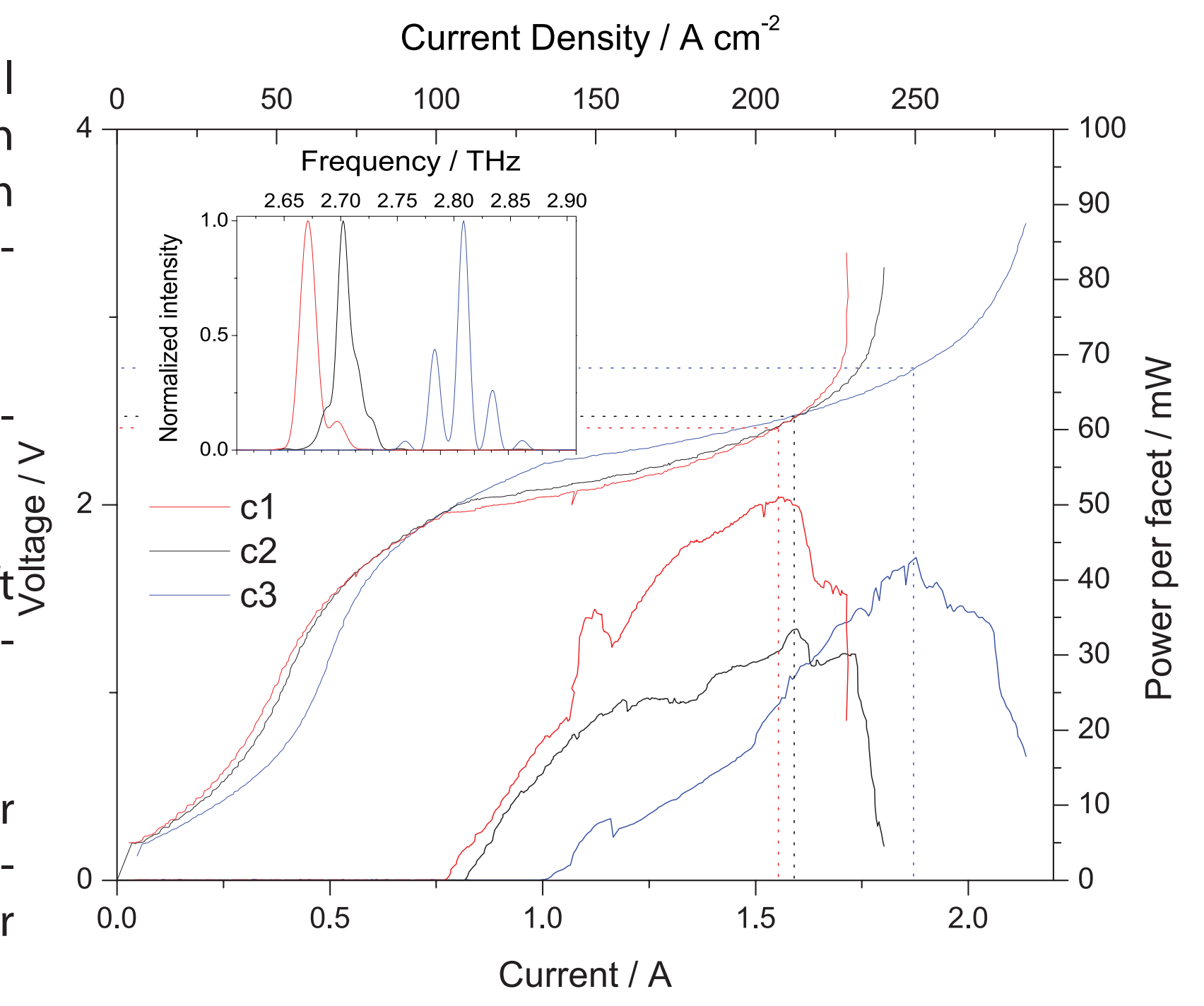
| Name | Position | Period Length |
|---|---|---|
| c1 | Centre | 131.2±0.8nm |
| c2 | Mid-way | 129.9±0.8nm |
| c3 | Edge | 126.7±0.8nm |

The frequency data from these samples fits well with simulations and other wafers. The emission frequency of c3 has increased by 0.125THz from the thicker sample, c1, close to the 0.130THz predicted by modelling.

An electrical comparison between the three samples from V193 is shown.

A change in alignment voltage is visible by a shift in the bias where all periods are aligned, at maximum optical power.

An increase in threshold current for the thinner samples is accounted for by an increase in conduction, due to the increased splitting between upper and injector states (predicted by modelling).

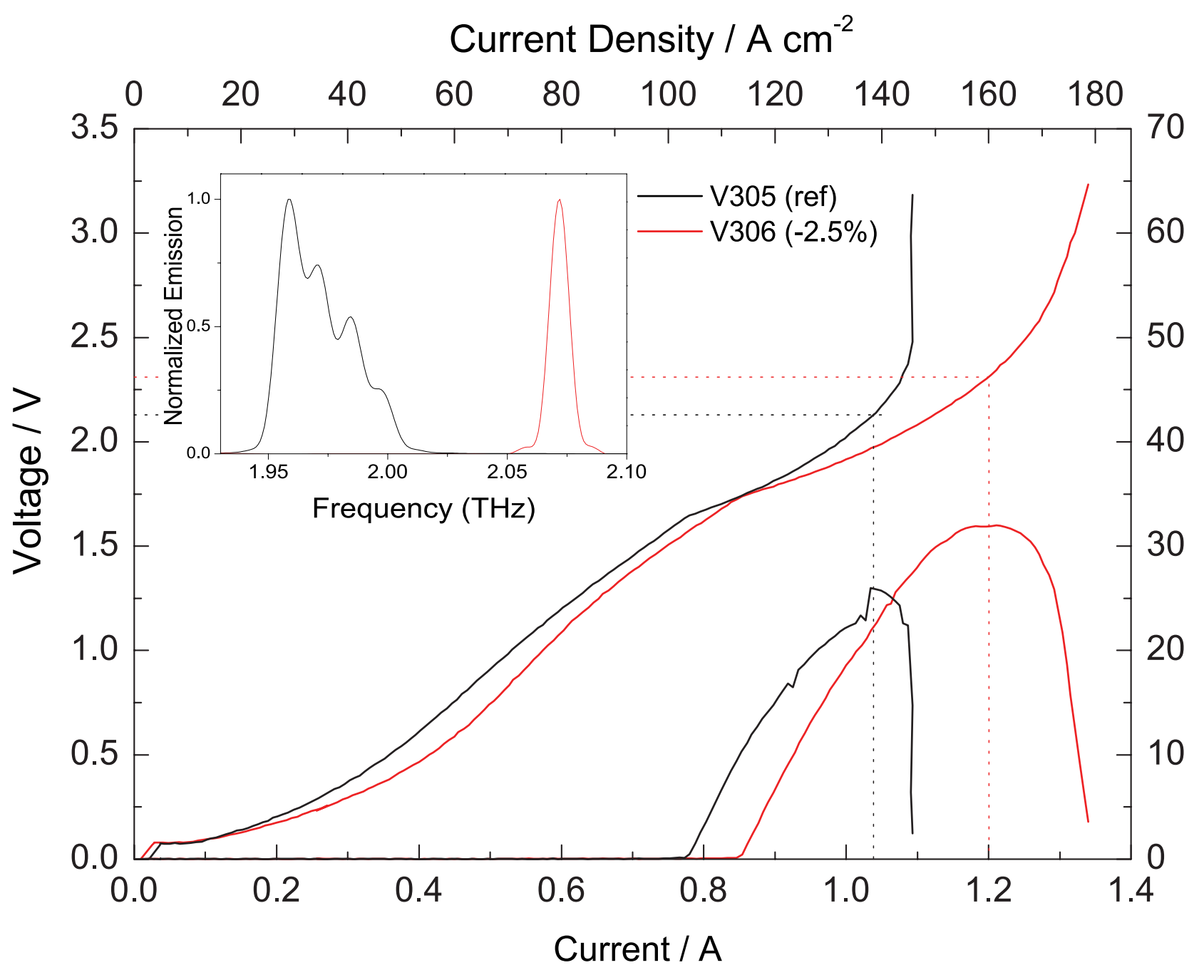


## 2.0THz Lasers

Wafer V305 was grown to the 2.0THz recipe given in [6] and V306 was grown with all wells and barriers reduced in thickness by 2.5%.

The emission frequency differs by 0.10THz between the two structures, in good agreement with a predicted shift of 0.15THz.

The bias at which the thinner structure reaches full alignment (maximum optical power) has increased by 0.18V in line with a prediction of 0.25V.



## Conclusions

Changing the period length of a THz bound-to-continuum quantum cascade laser can be used to controllably alter the emission frequency and the transport properties of a known active region.

Data was presented from ten wafers demonstrating how this technique has been used to tune the emission frequency of two separate bound-to-continuum designs operating around 2.0THz and 2.9THz.

In the case of our 2.9THz design we tuned emission over a range of 0.35THz.

## References

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