Phase matched frequency mixing between telecom wavelengths and THz radiation in a quantum cascade laser

S. Dhillon,[1,3] C. Sirtori,[1,3] J. Alton,[2,4] S. Barbieri,[2,4] A. De Rossi,[3] M. Calligaro,[3] H. E. Beere[4] and D. A. Ritchie[4]

[1]*Matériaux et Phénomènes Quantiques, Université Denis Diderot - Paris 7, Paris, France*
[2]*TeraView Ltd., 304 Platinum Building, St John's Innovation Park, Cambridge, CB4 0WS, United Kingdom*
[3]*Thales Research and Technology, 91404 Orsay, France*
[4]*Cavendish Laboratory, University of Cambridge, Madingley Road, Cambridge CB3 0HE, United Kingdom*

Abstract: Intra-cavity THz sideband generation at ~1.3μm wavelength is demonstrated, achieved by injecting a near-infrared beam into a THz quantum cascade laser (f=2.9THz, λ=104μm). This process is shown to be phase matched due to the phonon-induced anomalous dispersion.

Owing to its large second-order susceptibility, GaAs is an interesting material for non-linear optical generation [1]. The lack of birefringence on the other hand makes phase matching difficult to realise, therefore limiting the non-linear conversion efficiency. However, owing to the anomalous dispersion produced by the *restrahlenband*, the refractive index at long wavelengths (the far-infrared or terahertz (THz) range) is larger than that in the mid- and most of the near infrared (NIR). This opens up the possibility of a 'natural' phase matching between the THz range and the NIR [2].

In this investigation a GaAs-based quantum cascade laser (QCL) [3] operating at 104μm (f=2.9THz, E=11.9meV) is used both as a THz source and a non-linear medium. A NIR tunable diode laser, operating around 1300nm, is coupled into the THz QCL. Figure 1a shows the generated intra-cavity side-bands, which are clearly observed at the difference and sum frequency of the THz and NIR radiation [4]. The phase matching condition was verified by tuning the NIR wavelength between 1260nm and 1340nm and showed a phase matched point at 1305nm (Fig 1b). The conversion efficiency for the frequency mixing processes, $P(\omega_1 \pm \Omega_3)/P(\omega_1)$, is 1×10^{-5} at the peak of the phase matching curve, in reasonable agreement with the expected value. Recent investigations have demonstrated that this phase matched point can be tuned towards 1550nm using modal engineering of the THz guide, such that the THz refractive index is varied without effecting that of the NIR mode.

These results illustrate the possibility of detecting THz radiation using a up-conversion process of a low power NIR laser and to transport the THz radiation on an optical carrier.

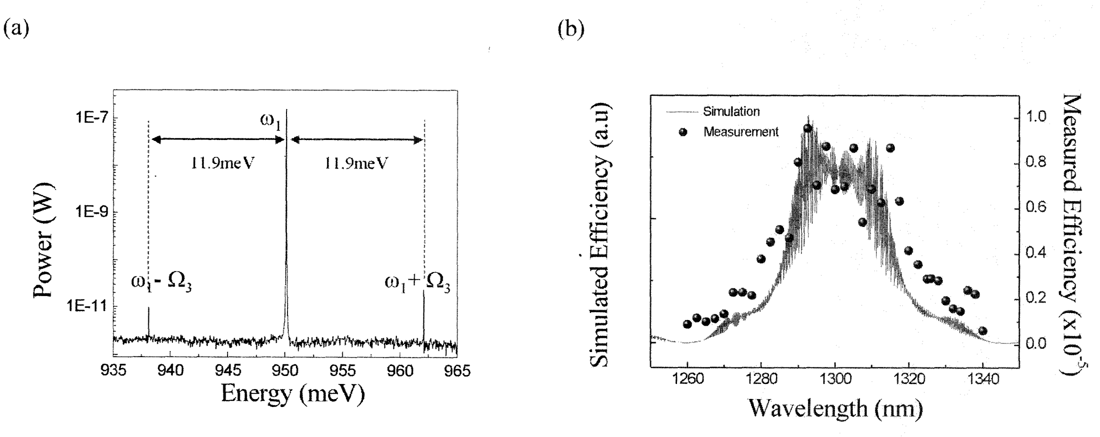

Figure 1. (a) Near infrared spectrum from the output of the THz QCL (fiber coupled). The QCL is cooled to 14K and is operated in CW. Side-bands are observed at $\omega_1+\Omega_3$ and $\omega_1-\Omega_3$. b) Measured and expected efficiency as a function of pump wavelength for the sum frequency process showing a broad phase matching.

[1] J-Y. Bengloan, A. De Rossi, V. Ortiz, X. Marcadet, M. Calligaro, I. Maurin and C. Sirtori, *Appl. Phys.Lett.*, **84**, 2019 (2004).
[2] V. Berger and C. Sirtori, *Semicond. Sci. Technol.* **19**, 964 (2004).
[3] R. Köhler, A. Tredicucci, F. Beltram, H. Beere, E. H. Linfield, A. G. Davies, D. A. Ritchie, R. C. Iotti, and F. Rossi, Nature **417**, 156 (2002).
[4] S. S. Dhillon, C. Sirtori, A. de Rossi, M. Calligaro, H. E. Beere, S. Barbieri, E. H Linfield, and D. A Ritchie, *Appl. Phys. Lett.*, **87**, 071101 (2005).

email: sukhdeep.dhillon@thalesgroup.com