Jurnal Teknologi

Full Paper

FOCUSED BEAM BROFILING FROM A TERAHERTZ QUANTUM CASCADE LASER

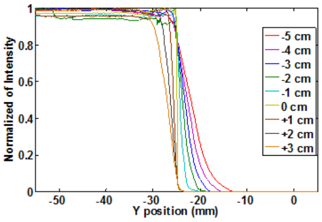
Nor Kamilah Saat[a]*, Paul Dean[b], Suraj P. Khanna[b], Mohamed Salih[b], Edmund Harold Linfield[b], Alexander Giles Davies[b]

[a]Department of Physics, Faculty of Science, Universiti Putra Malaysia, Malaysia
[b]School of Electronic and Electrical Engineering, University of Leeds, Woodhouse Lane Leeds LS2 9JT, UK

Article history
Received
15 August 2015
Received in revised form
15 November 2015
Accepted
30 December 2015

*Corresponding author
kamilah@upm.edu.my

Graphical abstract



Abstract

A quick, simple and inexpensive method of profiling the focused beam from terahertz quantum cascade laser (THz QCL) is presented. Using knife edge technique beam width and astigmatism of the THZ QCL imaging system have successfully been obtained.

Keywords: Knife edge technique, Gaussian beam, beam profiling, terahertz quantum cascade laser

Abstrak

Satu kaedah yang cepat, mudah dan murah untuk pemprofilan alur terfokus dari Terahertz kuantum cascade laser (THz QCL) dibentangkan. Menggunakan teknik mata pisau lebar alur dan astigmatisme sistem pengimejan THz QCL telah berjaya diperolehi.

Kata kunci: Teknik mata pisau, alur Gassian, pemprofilan alur, terahertz kuantum cascade laser

1.0 INTRODUCTION

The characterization of the beam profile is important in order to give information about the depth of focus, beam resolution and the level of astigmatism of the focused beam. Generally, there are two major techniques for studying beam profiles: scanning aperture techniques and CCD camera/detector array techniques. For the scanning aperture technique, a photodetector is placed behind an aperture which is scanned through the beam. Aperture techniques include the knife-edge technique [1, 2] the scanning-slit technique [3, 4] and the scanning-pinhole technique [5]. In knife-edge technique, the large aperture using sharp and straight edge like knife-edge or blade is passed through the beam. When this aperture transverses the beam, the detector will measure the intensity as function of the blade position. In scanning-slit, the beam is scanned across along narrow aperture which covers the full width of beam. It then measures the transmitted power through the slit as function of slit position. For the scanning-pinhole, the beam scans a small narrow aperture-like pin hole and plots the transmitted power as function of axial position. In CCD camera methods, the beam must first be attenuated to avoid saturation before being projected onto the CCD (most commonly a silicon CCD), allowing the beam profile to be measured directly in two-dimensions. This technique can be done in real-time, and it is only suitable for the visible up to near-infrared spectral range. The use of a CCD camera for the characterisation of THz QCLs is impossible. It is because the CCDs is suitable for profiling pixel size range from 5 to 10 μm in diameter, and when the CCD camera is applied for the fine beam, the fine detail possibly invisible[6]. Of the scanning aperture techniques, the knife-edge technique is the most popular, as it is a cheap and quick technique. The downside is an increase of error since differentiating the step response function (SRF), in order to fit to a Gaussian beam equation [2, 3], amplifies the noise. Alternatively to avoid the amplification of noise is by fitting equation into the SRF and extract the beam width of the beam focus. In this section, the knife-edge technique for characterising the focussed beam profile of a QCL is described.

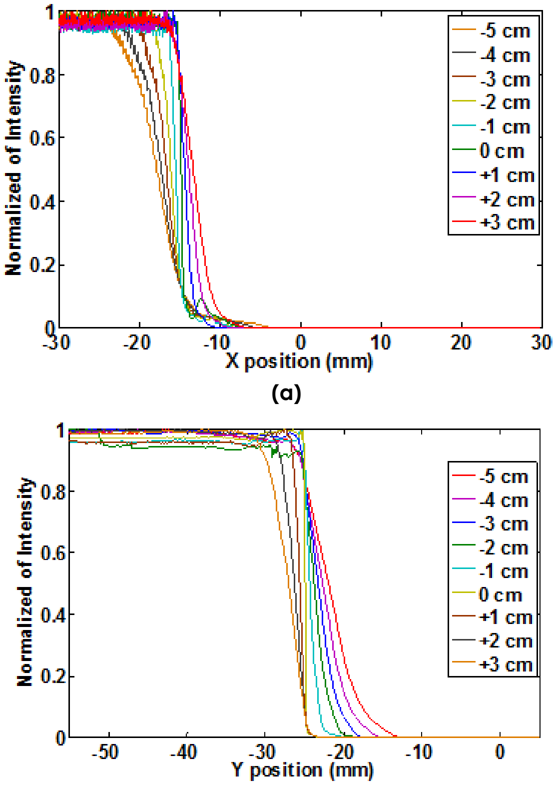
2.0 EXPERIMENTAL

The THz QCL source that was employed for this work is based on a GaAs-AlGaAs three-well phonon-depopulation active module [7] and a semi-insulating surface plasmon waveguide. The device was cooled to 15 K using a helium-cooled cold-finger continuous-flow cryostat. Radiation from the QCL was collimated using a 3-inch-diameter f/2 off-axis parabolic reflector and focused onto the sample using a second f/2 reflector. The radiation transmitted through the sample was collected and coupled into a helium-cooled silicon bolometer using two further f /2 reflectors. The QCL was driven with 2 μs current pulses at a repetition rate of 10 kHz, with lock-in detection at a frequency of 190 Hz was used to improve the detection sensitivity. The measurements were carried out at frequency of 3.05 THz, obtained by the QCL was biased at 14.2 V, which the peak power collected by detector was approximately 5 mW.

To study the beam profile of focused beam, a radiation-blocking plate was mounted on a computer-controlled two-dimensional translation stage. This plate was moved across the THz beam in x (horizontal) and y (vertical) orientations at different positions along the z axis (beam axis) using a 10 μm step size. In this case, the positions along z axis were manually controlled. The step responses for both orientations were recorded, allowing the step response function (SRF) to be plotted.

3.0 RESULTS AND DISCUSSION

Error! Reference source not found.1 shows the SRF at different positions along the beam axis for both horizontal and vertical orientations, at a frequency of 3.05 THz. As seen in Figure 1 the SRF at a position of 0 cm, measured from beam focus shows the maximum gradient in both horizontal and vertical orientations, representing the minimum beam width of the beam focus.



(a)

(b)

Figure 1 Step response function (SRF) of (a) horizontal and (b) vertical orientations at a frequency of 3.05 THz

Figure 2 shows an example fit of the expression given by;

$$p = \int_{-\infty}^{\infty}\int_{a}^{\infty} I(x,y)dxdy = \frac{p_o}{2} erfc\left(\frac{a\sqrt{2}}{w}\right) \quad [8]$$

to experimental data in order to find the beam width w. The fraction of transmitted power p/p_o depends on the term $\left(\frac{a\sqrt{2}}{w}\right)$ where a and w denote the position of the knife edge and the beam width, respectively. From **Error! Reference source not found.**, the beam width at +1 cm from the beam focus is ~1.4 mm. The x-axis is labelled as $\frac{x-x_o}{w}$, where x_o is the beam centre and x is the distance from the beam centre. The gradient of the curve p/p_o is related to the beam width, where the shallower the gradient of p/p_o is, the larger the beam width.

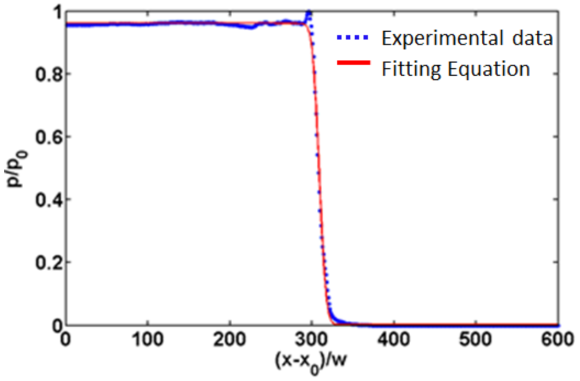


Figure 2 Example of fitting equation to the experimental data to find the beam width in the vertical (*y*) direction, at a beam axis position of +1 cm, measured from the beam focus

Figure 3 shows the beam widths deduced from the SRFs in (a) horizontal and (b) vertical directions. The minimum beam width (or the minimum effective beam waist) for both orientations was 0.57 mm in the *x*-direction and 0.20 mm in the *y*-direction.

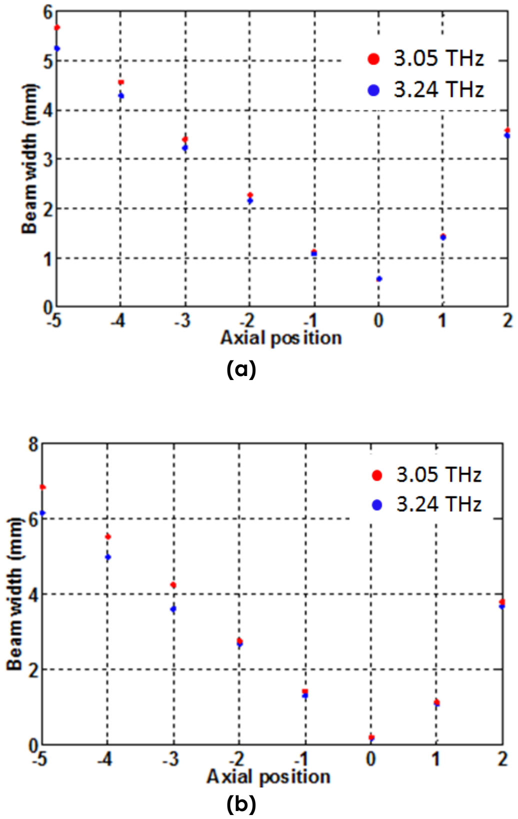


Figure 3 Beam width *w* obtained from Gaussian fits to the experimental data for (a) horizontal and (b) vertical orientation

The minimum effective beam waists are 0.57 mm and 0.20 mm in the horizontal and vertical orientations, respectively. The dotted red and dotted blue is the frequency at 3.05 THz and 3.24 THz, respectively. The grid lines are only used to guide the eye. The difference between minimum beam waists in the horizontal and vertical is 0.37 mm. This astigmatism effect was expected owing to the difference in dimensions between the width and the thickness of the QCL device.

4.0 CONCLUSION

In conclusion, using the knife-edge technique, the size of the beam focus of the imaging system was characterised along the beam axis. The beam width of focused beam in horizontal and vertical were 0.57 mm and 0.20 mm respectively, with small astigmatism effect.

Acknowledgement

We acknowledge support from the EPSRC (UK), EC (NOTES program), and the Government of Malaysia.

References

[1] Chamberlin, D. R., Robrish, P. R., Trutna, W. R., Scalari, G., Giovannini, M., Ajili, L. and Faist, J. 2005. Imaging at 3.4 THz with a Quantum Cascade Laser. *Optics Latters*. 44: 21-125.

[2] Marcos, A. C., Robens, S. E., Daniel, P. P. and Oliveira, P. C. D. 2009. Measurement of Gaussian Laser Beam Radius using the Knife-Edge Technique: Improvement on Data Analysis. *Applied Optics*. 48: 393-396.

[3] Paul, D., Mohamed, U. S., Edmund H. L. and Davies, A. G. 2007. Three-Dimensional Characterization of the Gaussian Beam from a Terahertz Quantum Cascade Laser. *Conference on Lasers and electro-optics (CLEO 07)*.

[4] McCally, R. L. 1984. Measurement of Gaussian Beam Parameters. *Applied Optics*. 23: 2227.

[5] Shayler, P. J. 1978. Laser Beam Distribution in the Focal Region. *Applied Optics*. 23: 2673-2674.

[6] Carry, A. Photon Inc. Beam Profiling. 1-8.

[7] Luo, H., Laframboise, S. R., Wasilewski, Z. R., Aers, G. C., Liu, H. C. and Cao, J. C. 2007. Terahertz Quantum-Cascade Lasers based on a Three-Well Active Module. *Applied Physics Letters*. 90: 041112-3.

[8] Skinner, D. R. and Whitcher, R. E. 1972. Measurement of the Radius of a High-Power Beam near the Focus of a Lens. *Journal pf Physics E*. 22: 3406-3410.