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The Development and Applications of Terahertz Quantum Cascade Lasers

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Abstract: This paper will review the development of terahertz frequency quantum cascade lasers, including the achievement of >1W output powers. It will also discuss self-mixing imaging, where the laser cavity is used as a coherent detector.

OCIS codes: 250.0250 Optoelectronics; 110.0110 Imaging systems

1. Introduction

Over recent years, researchers have made rapid progress in developing systems to exploit the so-called 'Terahertz Gap', with potential application areas including non-destructive testing of pharmaceuticals, and the detection of drugs-of-abuse and explosives [1]. Much of this research has made use of broadband terahertz (THz) frequency time-domain spectroscopy systems based on pulsed, femtosecond, Ti:sapphire laser technology.

Quantum cascade lasers (QCLs) offer the prospect of a compact, high power, spectrally-pure source for the THz range, opening up new application areas for THz technology. In this paper we will review how these sophisticated opto-electronic devices have recently been demonstrated to be capable of emitting output powers > 1W [2].

Developments in QCL technology have also allowed novel THz systems to be designed and constructed. We will outline the development of self-mixing imaging systems, which use the QCL both as the source and as a coherent detector [3], and have allowed reflection imaging at distances exceeding 10 m (>20 m round-trip) [4]. Furthermore, we will discuss the demonstration of swept-frequency interferometry [5], and coherent three-dimensional imaging systems [6] using the self-mixing approach.

2. High power THz QCLs

Our development of high power THz QCLs is based on the active region reported in [7]. The GaAs and AlAs growth rates were calibrated precisely *in situ* using a kSA BandiT spectrometer, with self-compensation of the growth rate being used to ensure that the structure thicknesses were controlled to within 0.5% of their design thicknesses throughout the 10 µm active region [3]. Typical results, showing emission from a single facet of a THz QCL operated in pulsed mode are shown in Fig. 1, for a pulse repetition rate of 10 kHz and a duty cycle of 2%. Output powers exceeding 1 W were achieved at a 10 K heat sink temperature, with >400 µW still achieved at 77 K.

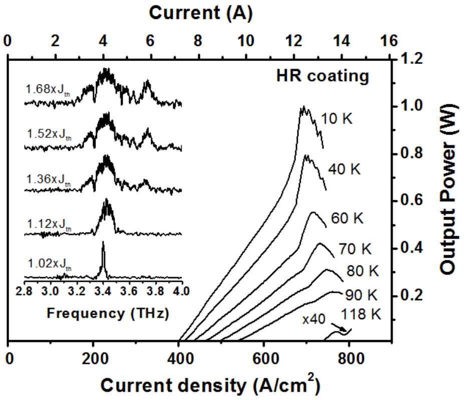

Fig. 1 Output power as a function of current from a rear facet-coated QCL of dimensions 4.2 mm x 425 µm [2]. The laser was measured in pulsed mode with a 10 kHz repetition rate, and a 2 % duty cycle (Inset: Typical lasing spectra for different device current densities at 10 K).

3. Current-modulated self-mixing imaging

Figure 2 shows apparatus used to demonstrate a current-modulated self-mixing (SM) imaging scheme. THz radiation from a QCL is reflected from a target back into the laser cavity, and the QCL terminal voltage is monitored as a frequency-chirp is applied to the laser via a modulation of the driving current.

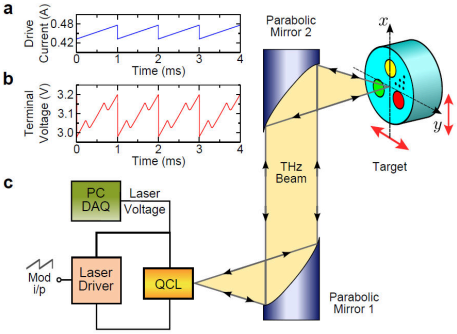

Fig. 2 Schematic diagram (from [5]) of the experimental apparatus used for current-modulated SM imaging: (a) Current stimulus signal; (b) Corresponding voltage signal measured across the laser terminals; (c) Voltage variations in the QCL acquired using a PC-based data acquisition card (PC DAQ). Parabolic mirrors focus the beam onto a remote target, mounted on a computer-controlled translation stage.

Fig. 3(a) shows three exemplar target materials (polyoxymethylene (POM), polyvinyl chloride (PVC), and nylon 6 (PA6)). Through fitting the detected SM voltage signal in response to the modulated current, both amplitude- and phase-like images can be extracted (Figs. 3(b) and 3(c), respectively). Good agreement between the resulting refractive indices and absorption coefficients are obtained for each material [5].

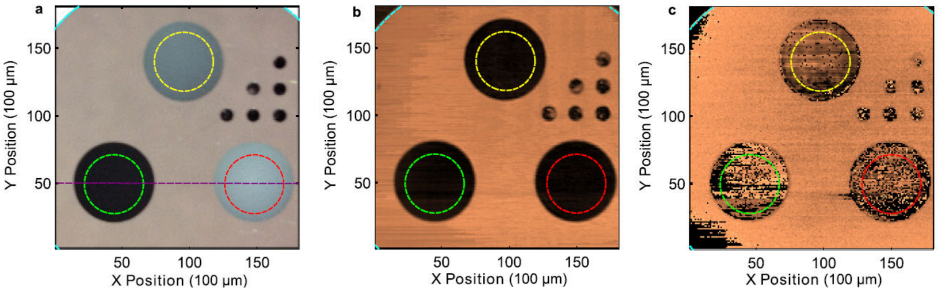

Fig. 3 (a) Photograph of the front surfaces of the target. The three circular regions are materials embedded in an aluminium holder: Yellow – PA6; Green – PVC: Red – POM. (b) Image based on the amplitude of the SM signal. (c) Image based on the phase of the SM signal [5].

3. Conclusions

We have presented results from THz QCLs emitting >1 W peak power, and also discussed how THz QCLs can be used in a current-modulated SM imaging system, leading to the extraction of amplitude and phase data from a target.

4. References

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