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Electronic switching mechanism in Aperiodic DFB Lasers

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Abstract: For the first time, we present direct experimental evidence of the presence of spatial hole burning within switchable aperiodic DFB terahertz quantum cascade lasers. This will lead towards the development of quasicontinuous tuneable terahertz lasers.

OCIS codes: (250.0250) Optoelectronics; (140.5965) Semiconductor lasers, quantum cascade

1. Introduction

Recent work in holographically designed aperiodic distributed feedback (ADFB) gratings has allowed the realisation of THz quantum cascade lasers (QCLs) with multiple electronically switchable dominant single modes [1-3]. These aperiodic gratings consist of scattering sites positioned in such a way along the waveguide in order to produce a multi-band filter response $\rho(f)$. By embedding such a filter inside a Fabry-Perot (FP) cavity (Figure 1a) there can be dynamic switching between individual filter bands for lasing. This electronic switching is an effect not observed in FP or DFB lasers on their own – clearly indicating the usefulness of the novel tuning architecture schematically presented in Figure 1a. In earlier works this switching was explained as arising from the presence of spatial hole burning – for example, during time domain modelling of such devices, an arbitrary phase shift was introduced to the cavity to represent variations in the effective index along the laser and thereby to achieve switching between modes[3]. In this paper, we provide direct experimental evidence to support such recommendations. In particular, our objective is to provide an in-depth analysis of spectral behaviour at the onset of switching. In the transition region, i.e., whilst the device is in transition from one dominant mode to the next dominant mode, we have observed a significant increase in the number of lasing modes. We compare this to published results for uniform DFB lasers, and attribute this to be experimental verification of the role that spatial hole burning plays in an ADFB laser. This insight will lead to the development of purely electrically controlled quasicontinuous tuneable THz QCLs – with higher purity single modes and rapid switching.

2. Device Fabrication, Characterisation and Methods

Terahertz QCLs based upon semi-insulating surface plasmon waveguides, fabricated from a GaAs/Al_{0.15}Ga_{0.85}As wafer using a bound to continuum active region, were characterized in pulsed operation (10kHz pulses at 1% duty cycle) for a range of devices. Laser spectra were taken using a Bruker Vertex 80 FTIR, using an external Bolometer detector. The ADFB grating was introduced into the top layers of the laser waveguide using focussed ion beam milling (FIB). The grating elements are narrow and shallow slits <1 μ m in each direction, so that the surface wave guided by the metal is disrupted, and scattering introduced in order to influence the guided mode. When this grating is milled deep enough, the magnitude of scattering increases, and the laser emission exhibits a spectral signature of the ADFB filter response, $\rho(f)$. This filter response is calculated using the approximate Fourier transform relationship as described in [2, 3] using an effective refractive index contrast $|\Delta n| \sim 0.1$. In order to accurately establish the overall number of lasing modes within a given bandwidth of a spectrum, we adopt the following statistical approach. First, the noise floor of the system was measured by fitting a Gaussian distribution to the background noise, characterized by the standard deviation (σ). Second, any peaks in the spectra stronger than 5σ above background mean are statistically significant above the background, and hence were counted as representing true lasing modes. Finally, in order to minimise erroneous peaks from the Fourier transform being counted, the minimum peak height allowed was 30dB below the peak power.

3. Results and Conclusions

In this paper we present analysis on three of the devices from earlier works [1], where devices D and H are etched with mid strength gratings (showing 5 switchable modes), and device E is etched with a strong grating (showing 3 switchable modes). In Figure 1b we show how in device D the introduction of the ADFB leads to switchable laser modes as the drive current is varied, with a single dominant mode arising from each filter band. The underlying mechanism that leads to switching between bands is the spatial hole burning of population inversion by standing waves. In order to study this effect experimentally we can examine spectra, in the transition region, over a narrow

current range where two modes are switching, as shown in Figure 1c. We observe that as current is increased the device emission goes reversibly from few modes to highly multimode and then back to few modes over a range of only 23mA. In order to establish this behaviour across all drive conditions in different lasers, we can describe each laser spectra by the number of modes present. The results of this mode counting operation for 3 lasers can be seen in Figure 1d-f. After milling, there is a significant reduction in the number of lasing modes for all devices, as has been shown in earlier work [1]. As driving current varies, there is an increase in the number of lasing modes in current regions where there is switching between two modes, observed in all three devices, independent of grating strength. This suggests that an increase in the number of laser modes is a specific characteristic of switching in ADFB QCLs. An increase in the number of laser modes occurs in traditional DFB lasers when there is significant gain saturation and spatial hole burning [4]. Therefore, the increase in the number of lasing modes whilst devices are undergoing switching suggests that the existence of spatial hole burning within the FP-ADFB architecture, illustrated in Figure 1a, is responsible for effective electronic switching.

In conclusion, we have presented the first detailed experimental analysis of the mode switching mechanism, observed in discretely tuneable THz QCLs. We have found that when devices switch from one mode to another a large number of modes begin to emit, an indication of saturation as observed in traditional uniform DFB devices, verifying the earlier hypothesis that spatial hole burning leads multimode switching in these devices. Understanding this process further may lead to electronic switchability in other materials –advantageous for making compact multi frequency devices. This work was supported by EPSRC First Grant EP/G064504/1 and partly supported by HMGCC.

Figure 1. (a) Shows a schematic of the introduction of a multi-band filter based on ADFB grating (b) Current switchable QCL emission for Device D. (c) Selected emission spectra showing multimode behaviour at switching, right hand side shows 10 $\times$ magnification of the y-axis. (d-f) Graphs showing both the strongest mode position, and the number of lasing modes for a device with (d) a medium strength grating, (e) a high strength grating and (f) a medium strength grating showing extended switching. Shaded are the regions of mode switching data for the relevant FP cavity is presented for reference

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