Genetically Optimized Multi-Wavelengths QCL

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Abstract: We present a genetically optimized multi-wavelengths laser based on an aperiodic sampled grating. We show that the grating phases and amplitudes can be optimized to flatten the spectral signature allowing multi-wavelengths operation.

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1. Introduction

The Quantum Cascade Laser (QCL) development effort is driven by various applications such as greenhouse gas sensing, warfare chemical agents detection and healthcare monitoring. During the recent years, the development of QCLs has been focused on tunable sources, where a single laser wavelength is scanning the gain spectrum. This has been achieved by either an external cavity or an array of single-mode lasers. However, several wavelengths lasing simultaneously could be of great interest for different spectroscopy applications. In particular, a multi-wavelength QCL could be used to implement multi-component gas analysis or targeting molecules on very specified frequencies simultaneously. Moreover, such sources could be used as a high-brightness broadband source for Fourier transform infrared spectrometers.

Here, we show a new type of gratings which can be engineered to emit on very specified frequencies with defined relative amplitudes. By compensating the gain curve, very flat spectral signatures below 7% can be obtained. Thanks to spatial hole burning (SHB) and anti-reflective (AR) coatings to prevent uncontrolled feedback, this will tend to suppress modal discrimination and allows multi-wavelength emission. Here, it will be used as frequency comb DBR in a three sections sampled grating, and as a self multi-wavelength DFB.

2. Grating design and fabrication

Two colors QCL using two DFB gratings defined side by side has already been demonstrated [1], but this method is not suitable to lase on a high number of frequencies.

Here, the grating is designed by summing N sinusoidal: $F=\sum A_i \sin(k_i x + \varphi_i)$, where each frequencies k_i has its own phase φ_i an amplitude A_i. Then, this analogic signal F is digitized using a sampling level S_L: all the amplitudes above S_L are defined as 1 and the rest 0. We obtain a binary signal which constitutes the grating where the etched regions correspond to 0, and the un-etched regions to 1 "Fig. (a),(b)". More recently, the use of an aperiodic grating has been proposed [3] but it was designed by using a deterministic Rudin-Shapiro sequence. Here, we propose to construct the sequence by optimizing amplitudes, phases and sampling level with a genetic algorithm. For a N frequencies grating, we must deal with 2N+1 parameters. The genetic algorithm generates a population of 100 different patterns, and selects two individuals showing the best fitness function to generate the next generation. This fitness function is defined as the combination of three different parameters: first, the envelope of the reflectivity*gain which relates to the modal discrimination between the different frequencies. Secondly, a critical grating dimension of 150nm is used, to favor individuals having large grating width and spacing and kill those below this critical value. Finally, the side-lobe suppression ratio will also be taken into account. These three parameters will be weighted into the fitness function, where the envelope value is prioritized. The reflectivity is calculated by transfer matrix method and then multiplied by experimental spectral gain "Fig. (c)". This method has the advantage to offer great flexibility in the design, and to engineer precisely the spectral response of a DBR, or a DFB. Moreover, compared to a periodic grating, this pattern shows a higher duty cycle with the mode which induces a higher coupling coefficient. Since the optimal coupling coefficient should be $\kappa L=1$, these gratings allow to reduce the length of DBR when used in a three sections sample grating [3]. Grating depth has been calculated by

COMSOL, and should be 30% smaller than a periodic DFB to prevent high reflectivites. Gratings were designed and fabricated as frequency comb of 10 periods, centered on the maximum of the gain (1000cm^{-1}),and with different spacings used in three section sampled gratings. The gratings were processed by using SiO2 mask. E-beam lithography has been used on ZEP resist to define the pattern, with constant dose. The mask has been opened by dry etching technique with RIE, and InGaAs with ICP “Fig. (e)”.

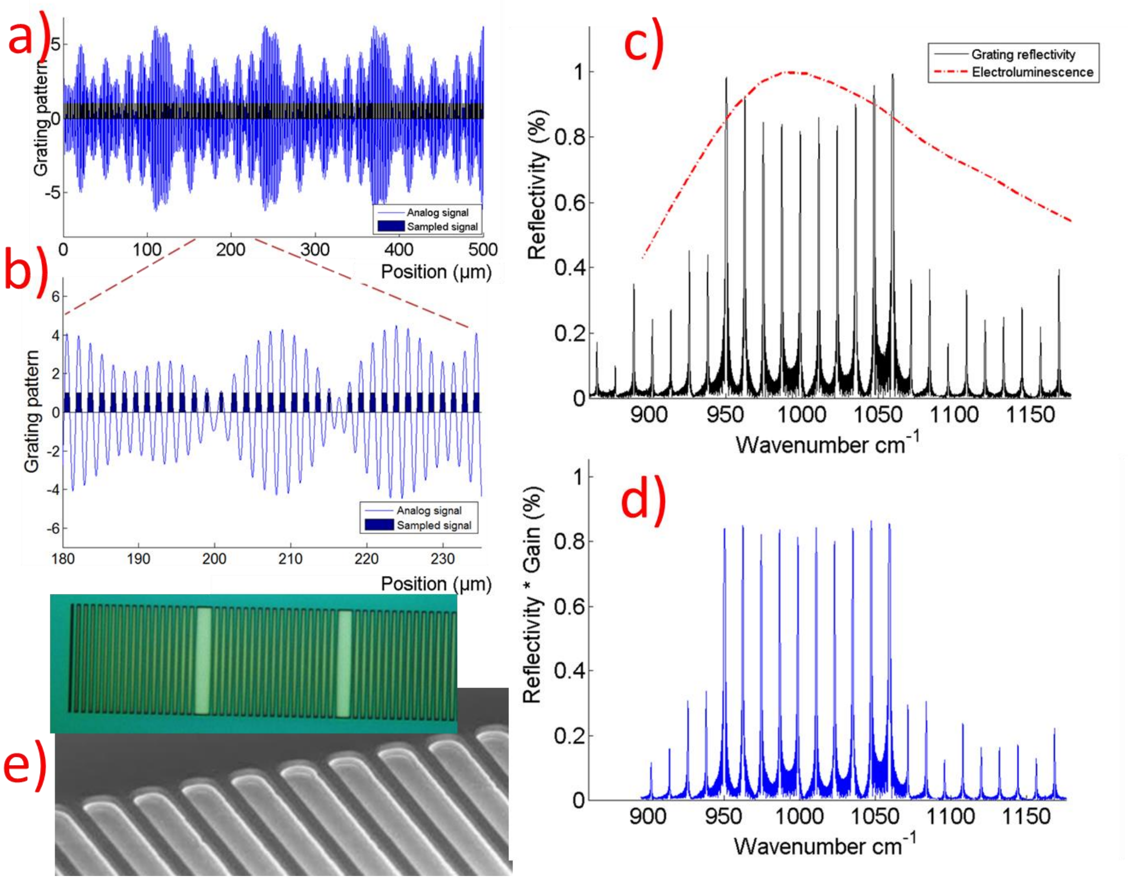

Figure 1 Results for a 10 frequencies comb pattern, centered at 1000cm-1 and 12cm-1 spacing. (a)-(b) Analog grating pattern (blue) and Binary grating pattern (dark). (c) Reflectivity of the grating (black). Experimental gain (red). (d) product of reflectivity*gain. (e) Optical and SEM images of the grating after InGaAs dry etching.

3. Conclusion

We show that a multi-periodic grating can be engineered at precise frequencies and with a flatten spectrum. In the case of a DBR, we will show that a frequency comb can be designed in a three sections device with two different comb spacings, and achieve single frequency tuning, with short mirror length. In the case of a self lasing DFB, multimode emission will be obtained with completely determined frequencies. Support from the U.S. Department of Homeland Security is greatly acknowledged.

4. References

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