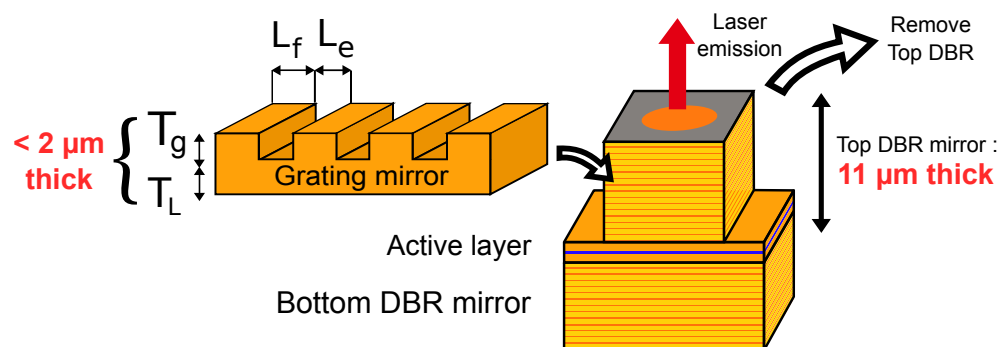


## Introduction

VCSEL emitting in the mid-IR are of high interest for their use as stable and tunable sources for spectroscopic measurements. In this wavelength range, AlGaInAsSb appears as the best material system for VCSEL fabrication but for  $\lambda \geq 2.5 \mu\text{m}$  the distributed Bragg mirror (DBR) become as thick as  $11 \mu\text{m}$  to attain 99.5 % reflectivity which impairs the VCSEL properties. Subwavelength grating mirrors (SGM) with a low index sublayer can advantageously replace this DBR by exhibiting high reflectivity with a low thickness. SGM have already been successfully used as VCSEL top mirror providing a 100 nm large stopband with a 99.9 % reflectivity. Moreover, such mirrors present a polarization sensitivity which should improve the quality of emitted beam. In this work, several mid-IR SGM designs were optimized using different materials (Si, SiO<sub>2</sub>, GaSb, ...) on GaSb substrate.

## VCSEL requirements



For the largest possible stopband, VCSEL mirror requirements have been defined :

$$R_{TM} > 99.9 \% \quad R_{TE} < 90 \%$$

Photolithography and etching process have been taken into account by the choice of :

$$L_f > 500 \text{ nm} \quad L_e > 500 \text{ nm} \quad L_e / T_g > 0.9$$

## Design method

- Definition of a quality factor :

$$Q = \frac{\Delta\lambda}{\lambda_0} \frac{1}{N} \sum_{\Delta\lambda} R_{TM}(\lambda) \times g(\lambda)$$

$g(\lambda)$  : Gaussian function centered at  $\lambda_0$  for a weighted average

$R_{TM}$  : Reflection coefficient for TM mode

$\lambda_0$  : Center of the stopband  $\Delta\lambda$  : Width of the stopband

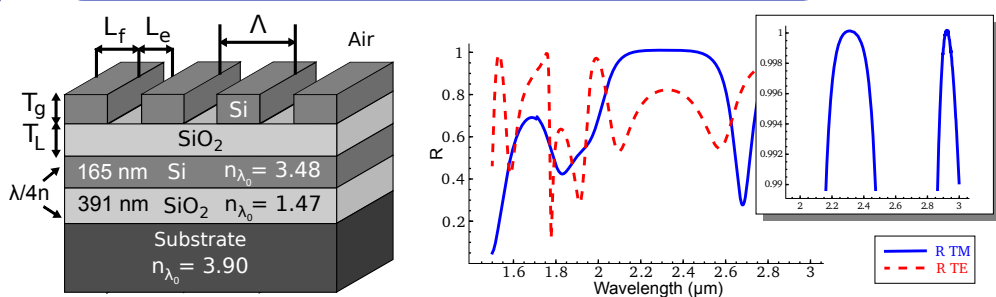
- Simulation of the grating :

Computation of reflection spectra with a Rigorous Coupled-Wave Analysis (RCWA) to evaluate  $Q$

- Optimization of the design :

Search for the best parameters ( $L_e$ ,  $L_f$ ,  $T_g$  and  $T_L$ ) to maximize the quality factor  $Q$  with a global genetic-based algorithm under the technological constraints.

## SGM with SiO<sub>2</sub> sublayer



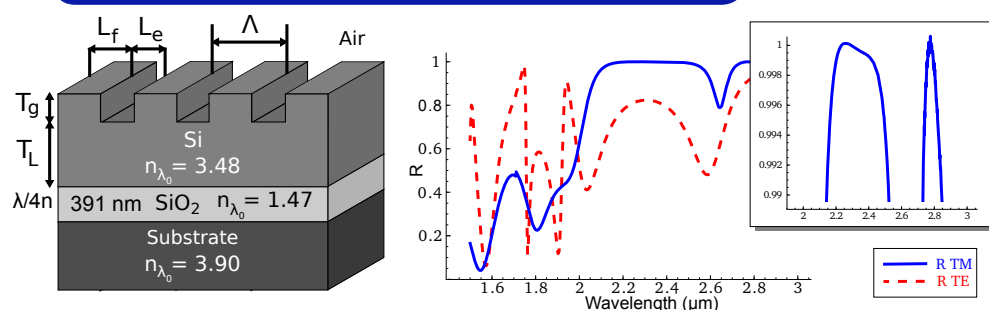
$$\lambda_0 = 2.315 \mu\text{m} \quad \Delta\lambda = 152 \text{ nm} \quad \Delta\lambda / \lambda_0 = 7 \%$$

	Optimum	Tolerances for $R_{TM} > 99.9\%$	
$T_g$	0.715 $\mu\text{m}$	$0.678 \mu\text{m} < T_g < 0.745 \mu\text{m}$	(4.7 %)
$T_L$	0.017 $\mu\text{m}$	$0 \mu\text{m} < T_L < 0.090 \mu\text{m}$	
$\Lambda$	1.304 $\mu\text{m}$	$1.028 \mu\text{m} < \Lambda < 1.436 \mu\text{m}$	(15.6 %)
$L_f / \Lambda$	48 %	$42 \% < L_f / \Lambda < 51 \%$	

😊 Allow selective etching

😞 17 nm thick sublayer

## SGM with Si sublayer



$$\lambda_0 = 2.303 \mu\text{m} \quad \Delta\lambda = 201 \text{ nm} \quad \Delta\lambda / \lambda_0 = 9 \%$$

	Optimum	Tolerances for $R_{TM} > 99.9\%$	
$T_g$	0.700 $\mu\text{m}$	$0.679 \mu\text{m} < T_g < 0.741 \mu\text{m}$	(4.4 %)
$T_L$	0.201 $\mu\text{m}$	$0.119 \mu\text{m} < T_L < 0.256 \mu\text{m}$	(34 %)
$\Lambda$	1.236 $\mu\text{m}$	$1.037 \mu\text{m} < \Lambda < 1.500 \mu\text{m}$	(19 %)
$L_f / \Lambda$	49 %	$47 \% < L_f / \Lambda < 53 \%$	

😊 no nanometric layer & more tolerant

😞 no selective etching