



IMEDEA



# Total Intensity and Polarization Self-Pulsations in Vertical-Cavity Surface-Emitting Lasers

Alessandro Scirè<sup>1</sup>, Josep Mulet<sup>1</sup>, Claudio R. Mirasso<sup>2</sup> and Maxi San Miguel<sup>1</sup>

Universitat de les Illes Balears. E-07071 Palma de Mallorca, Spain

1 Instituto Mediterráneo de Estudios Avanzados (CSIC- UIB)

2 Departament de Física

# Motivation

*Self-pulsing in semiconductor lasers have been proved to be less sensitive to feedback and to provide higher contrast for CD applications*

In VCSELs the polarization is not fixed by the structure

Interplay between polarization and self-pulsations

Recently SP have been found in VCSELs

A theoretical framework is required

Can SP in VCSELs be successfully described in a rate equation context ?

# OUTLINE

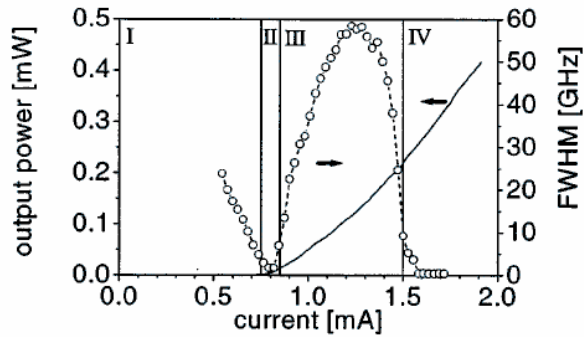
Brief summary of the experimental results

Choice and description of the model

Results of the analysis

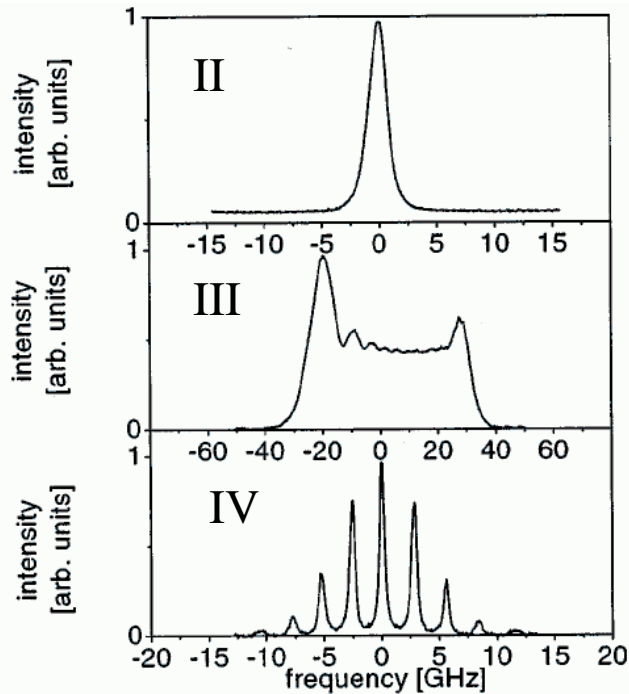
Comparison with experiments

# EXPERIMENTAL RESULTS

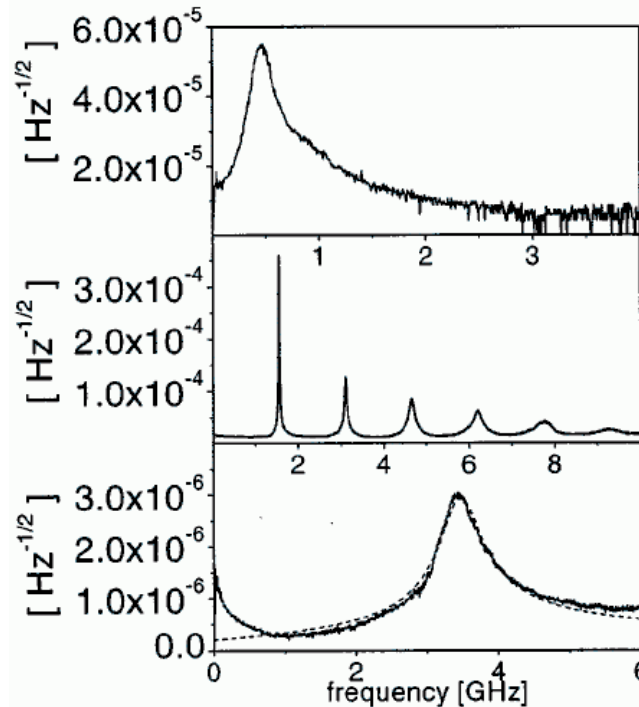


- III) the output intensity is concentrated in short, periodic and strongly-chirped optical pulses.
- IV) the output intensity shows a combination of harmonic amplitude and phase modulation.

Optical spectra



Power spectra



small-radius (2-3  $\mu\text{m}$ )  
oxide-confined (node  
configuration)  
InGaAs MQW VCSELs  
@ 962nm

*Willemsen et al.*  
*APL 77 3514 (2000)*  
*Huygens Laboratory,*  
*Leiden University*

## THEORETICAL APPROACH

We suppose that those pulsations arise from saturable absorption originated by the spreading of the field profile over the surrounding unpumped region

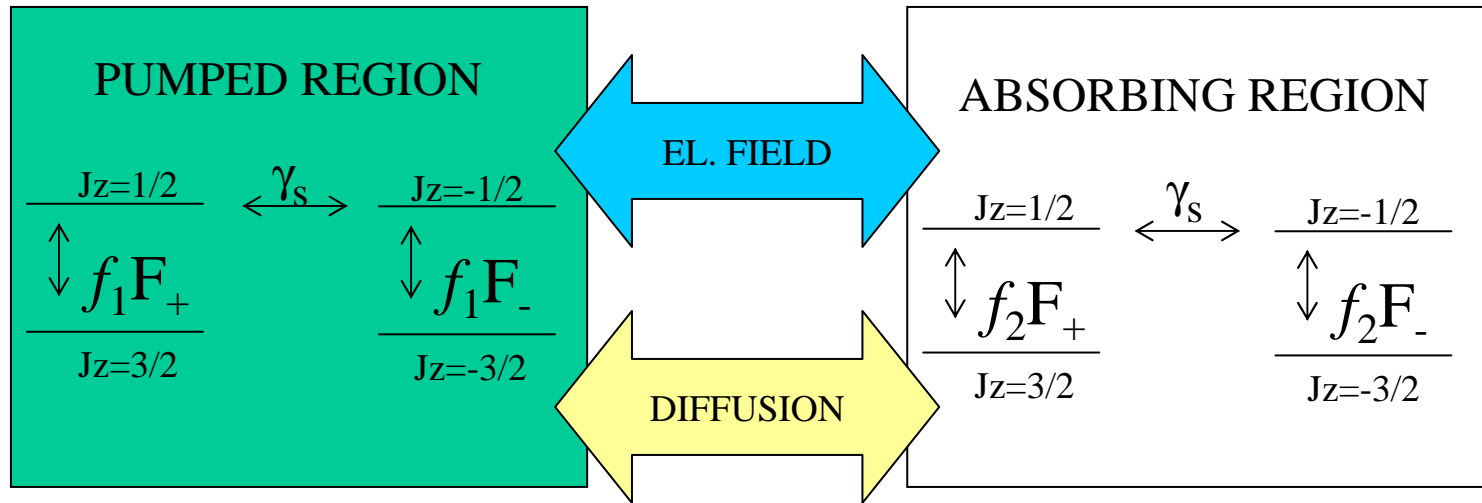
we describe the VCSEL polarization dynamics through the Spin-Flip Model

M.San Miguel *et al. Phys. Rev. A* **52**, 1728 (1995)

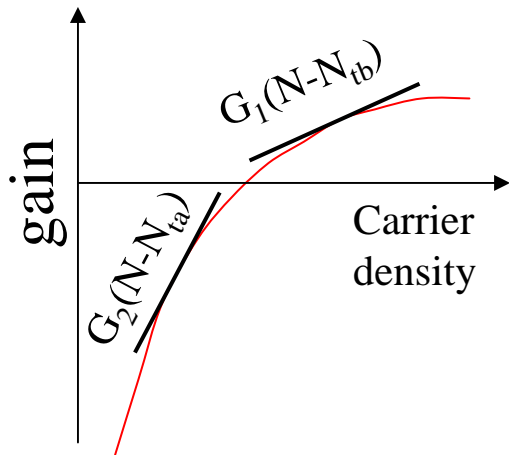
we choose the Yamada approach to model the absorber in our rate-equations

M. Yamada *IEEE Journal of Quantum Electron.* **QE-29**, 1330 (1993)

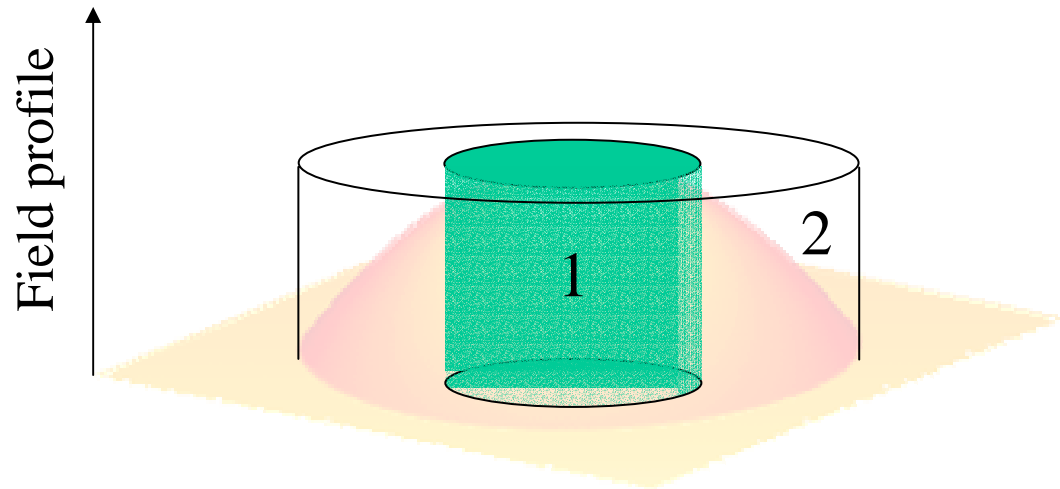
# SPIN FLIP + YAMADA MODEL



Different gain slope



Different field fraction



# THE MODEL

$$\dot{F}_{\pm} = (1 + i\alpha)(D_1 + D_2 \pm d_1 \pm d_2 - 1)F_{\pm} - (\gamma_a + i\gamma_p)F_{\mp}$$

**Electric field:** (+) c.w.  
(-) c.c.

$$\dot{D}_1 = \gamma_1 \left[ \mu_1 - D_1 - (D_1 + d_1)|F_+|^2 - (D_1 - d_1)|F_-|^2 - c_{12}D_2 \right]$$

**Total carrier density related to transparency**

$$\dot{D}_2 = \gamma_2 \left[ \mu_2 - D_2 - a(D_2 + d_2)|F_+|^2 - a(D_2 - d_2)|F_-|^2 - c_{21}D_1 \right]$$

(1) pumped  
(2) absorbing region

$$\dot{d}_1 = -\gamma_{s1}d_1 - \gamma_1 \left[ (D_1 + d_1)|F_+|^2 - (D_1 - d_1)|F_-|^2 - c_{12}d_2 \right]$$

**Carrier density difference**

$$\dot{d}_2 = -\gamma_{s2}d_2 - \gamma_2 \left[ a(D_2 + d_2)|F_+|^2 - a(D_2 - d_2)|F_-|^2 - c_{21}d_1 \right]$$

(1) pumped  
(2) absorbing region

$\alpha$  : phase amplitude coupling

$\gamma_a \gamma_p$  : amplitude and phase coupling of c.w. and c.c.

$\mu_i$  : effective pump

$\gamma_1 \gamma_2$  : total carrier decay rate ( $\gamma_i = \gamma + c_{ij}$ )

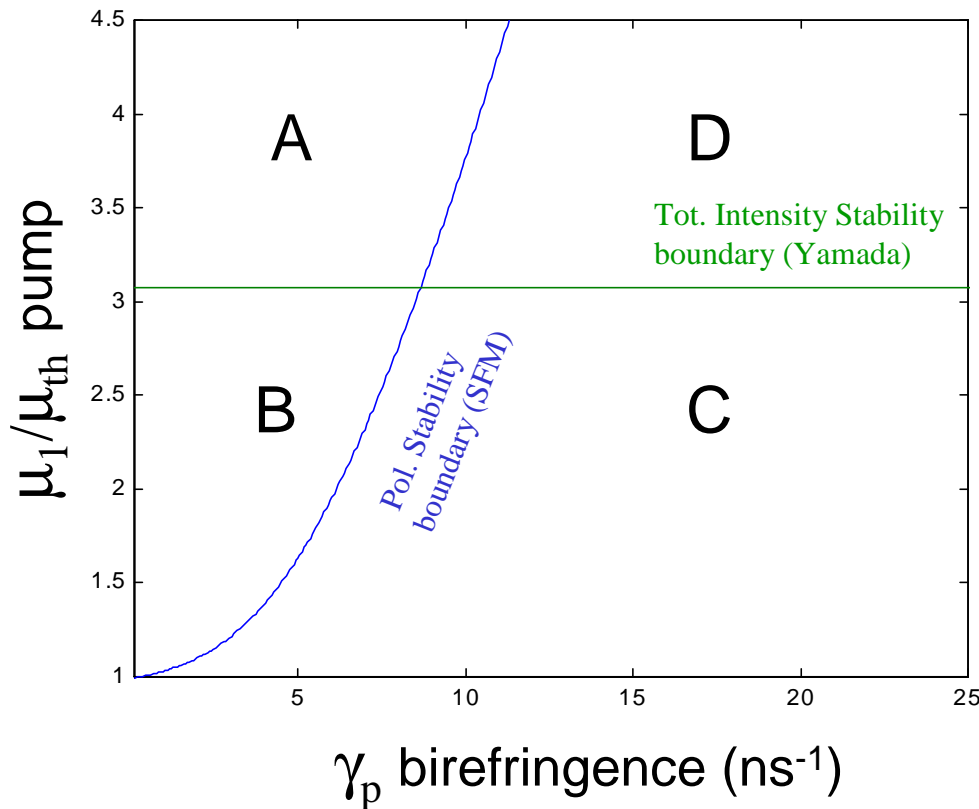
$\gamma_{s1} \gamma_{s2}$  : carrier difference rate ( $\gamma_{si} = \gamma_s + c_{ij}$ )

$$a = V_2 G_2 f_2 / V_1 G_1 f_1 \quad \text{gain ratio}$$

$c_{ij}$  diffusion rates

## LINEAR ANALYSIS

A standard linear stability analysis of the LP solutions led to four different regions of operation



A: stable LP solution

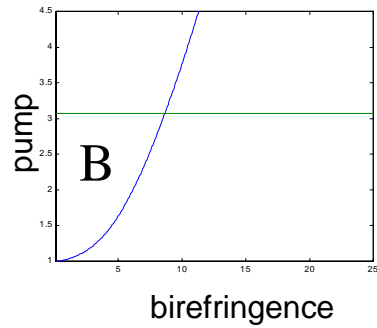
B: total intensity pulsations

C: coupled pulsations

D: polarization pulsations

$$\mu_2 = -32, \gamma_1 = 1.09 \times 10^{-3}, \gamma_2 = 1.13 \times 10^{-3}, \alpha = 3, c_{12} = 2.84 \times 10^{-2}, c_{21} = 1.91, \\ \gamma_{s1} = 0.25, \gamma_{s2} = 0.25, a = 8.7, \gamma_a = 0$$

# TOTAL INTENSITY PULSATIONS

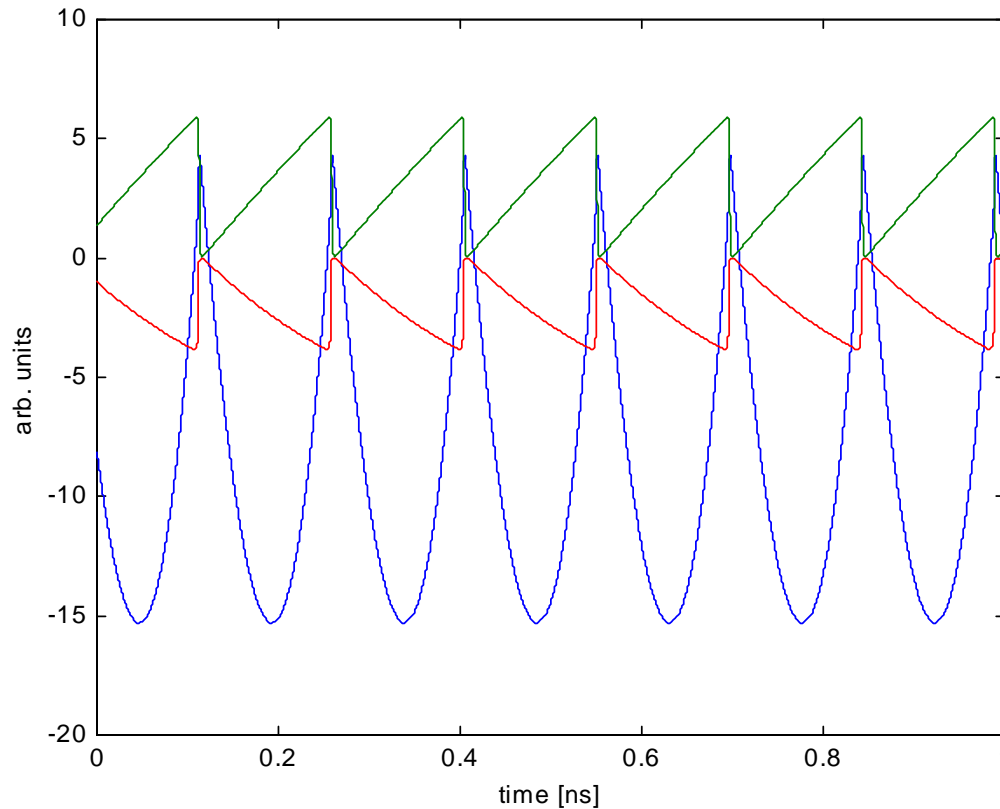


A pulsating regime is induced by saturable absorption. Polarization is **not** involved in the pulsations. This regime is similar to what one finds in EEL.

R. W. Dixon, W.B. Joyce, *IEEE JQE* **QE-15**, 470 (1979)

## Pulsation mechanism

When the carrier density in the pumped region ( $D_1$ ) reaches the threshold, the stimulated emission rise suddenly. This in turn depletes  $D_1$ , to a below-threshold value, where the stimulated emission stops.



$D_1$  pumped region carrier density related to transparency

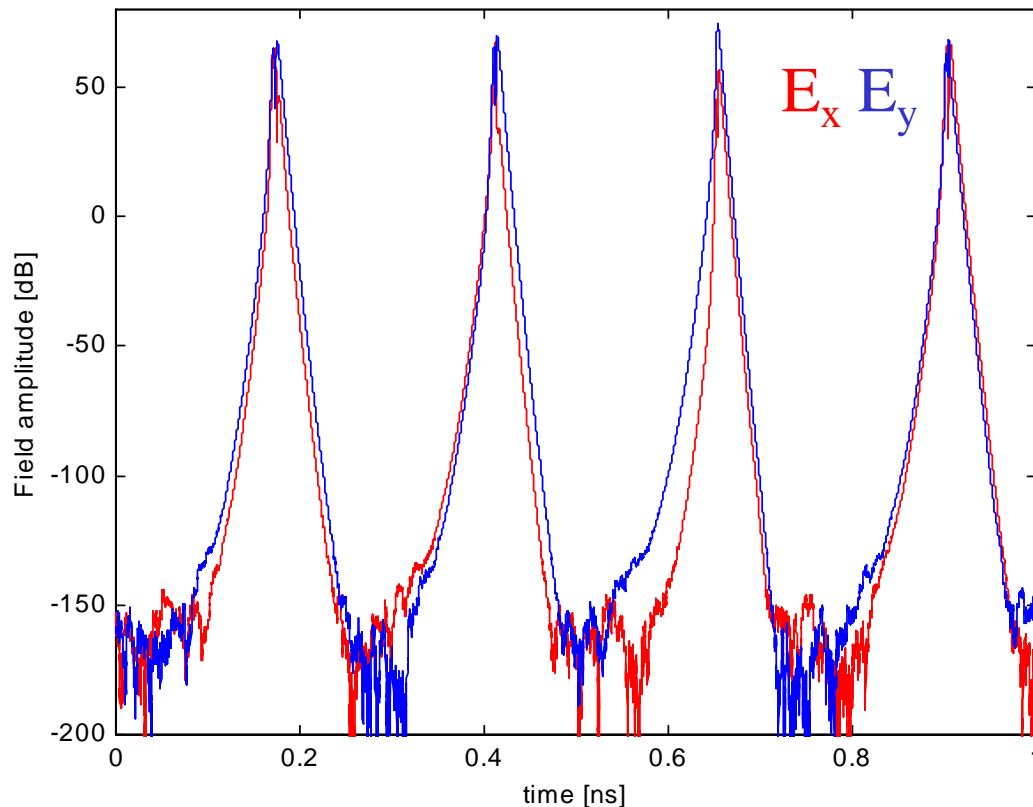
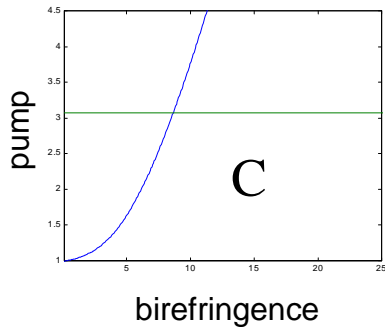
$D_2$  absorber carrier density r.t.t.

$E_y$  y LP intensity

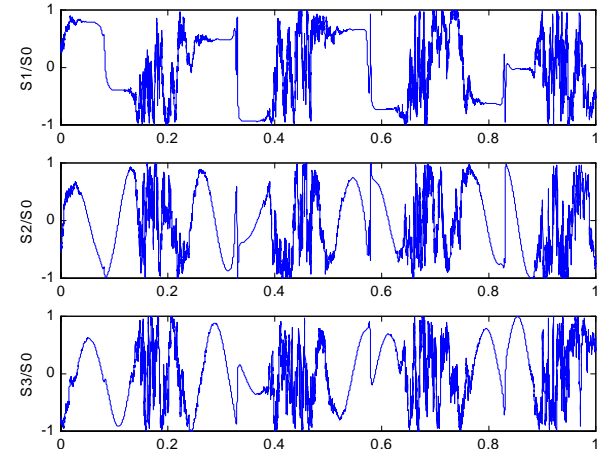
# COUPLED PULSATIONS

## time traces

Increasing the birefringence, the two polarizations participate the pulsing. The amplitude-phase coupling ( $\alpha$ -factor) and the birefringence  $\gamma_p$  lead to complex polarization dynamics



## Stokes parameters



Since the noise has been proved to be important in self-pulsing lasers we add to the field eqs a noise term

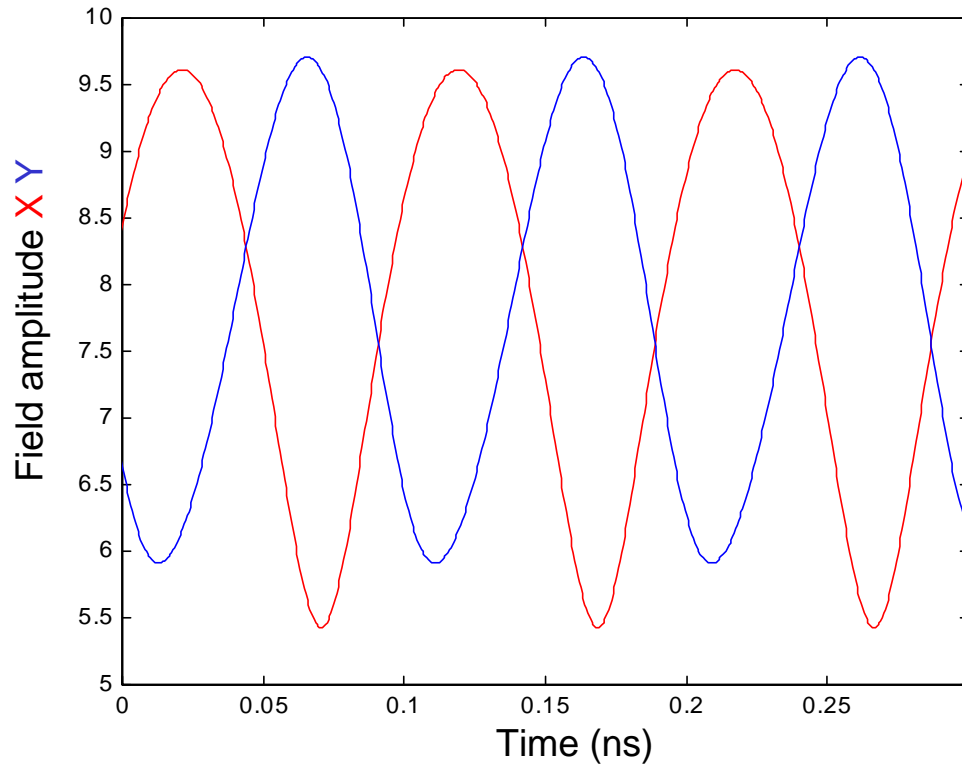
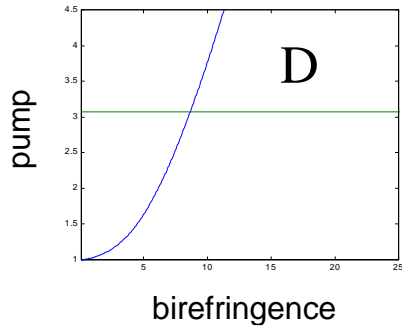
$$f_{\pm}(t) = \sqrt{\beta(D_1 \pm d_1)}_1 \xi_{\pm}(t)$$

G.H.M. Van Tartwijk et al. *IEEE JQE*, QE-32 1191 (1996)

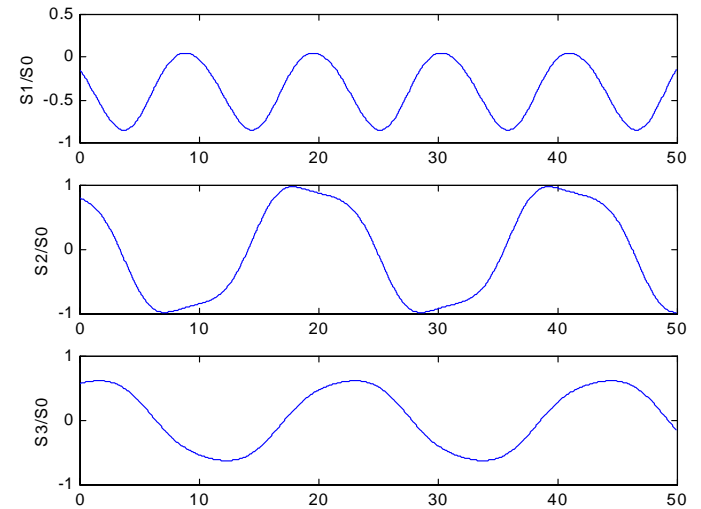
# POLARIZATION PULSATIONS

## time traces

The two polarizations **X** and **Y** oscillate nearly out-of-phase.  
The polarization move through different states with constant total intensity.

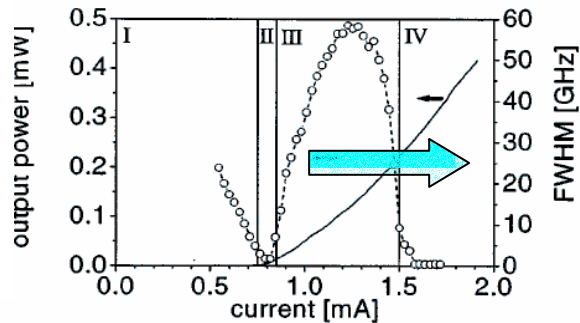
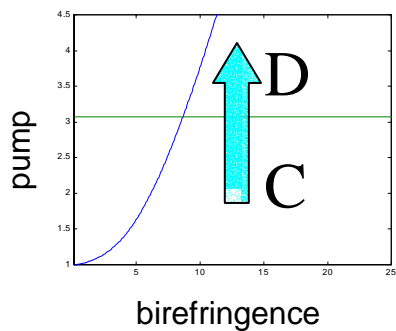


## Stokes parameters

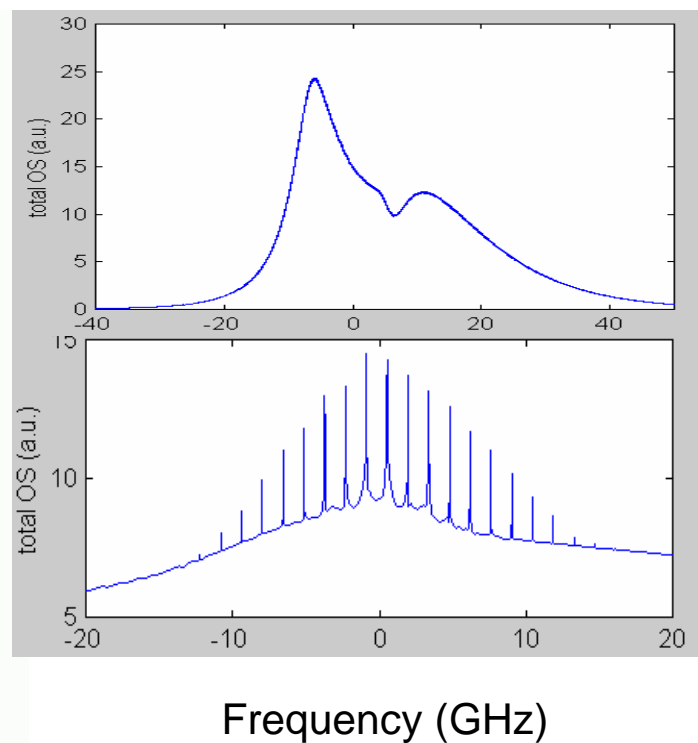
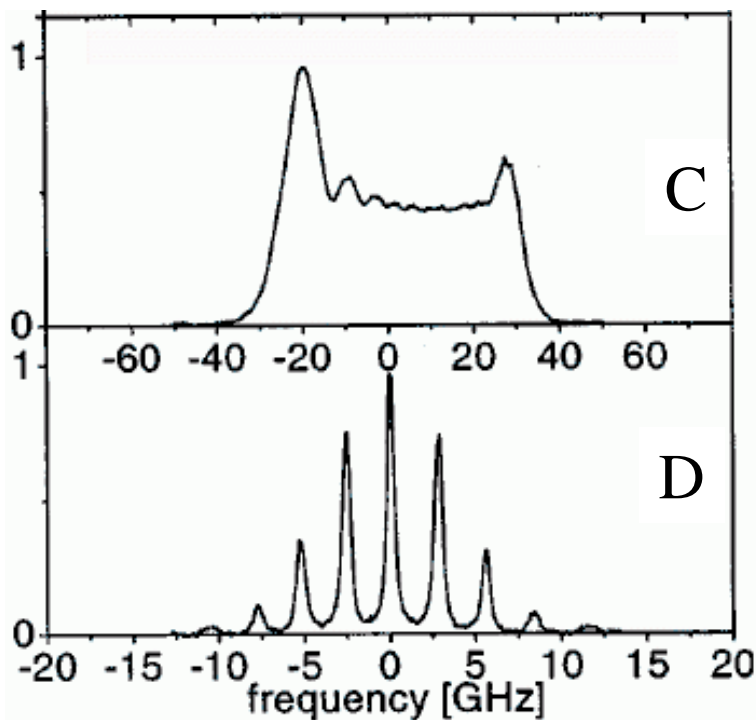


# COMPARISON with EXPERIMENTS

## 1: optical spectra

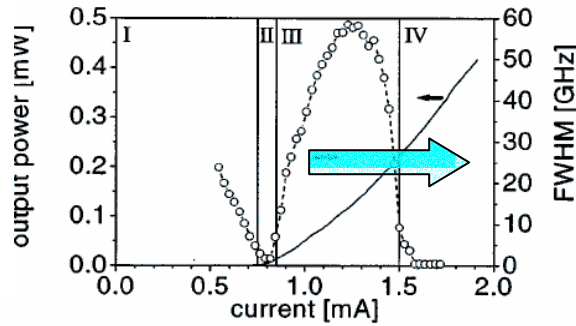
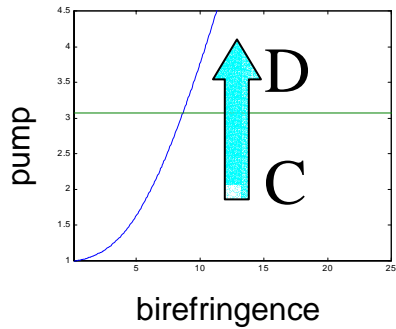


The transition found in the experiments, from region III to IV is similar to what our model shows, moving from C to D.

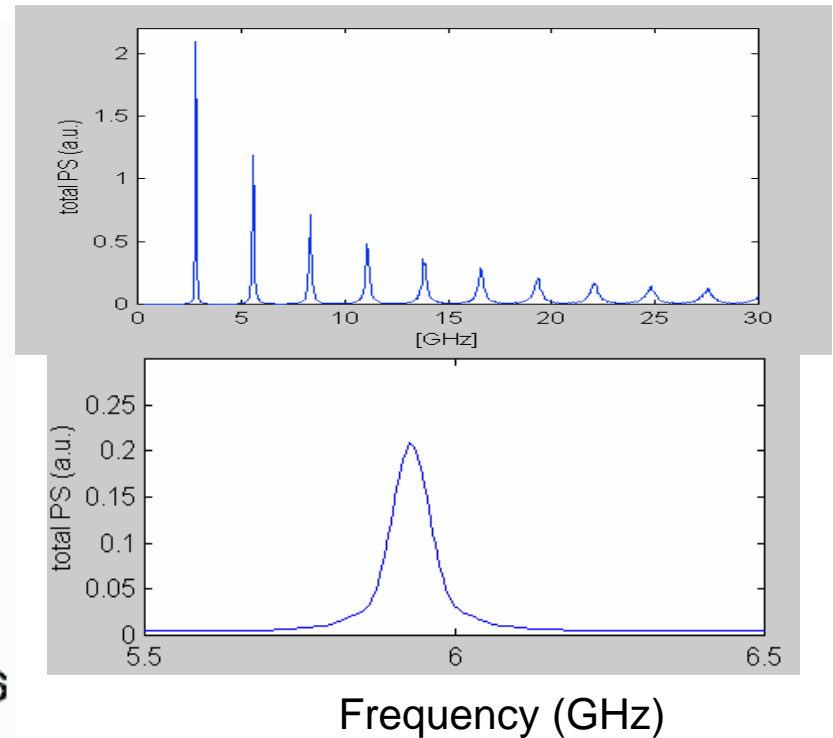
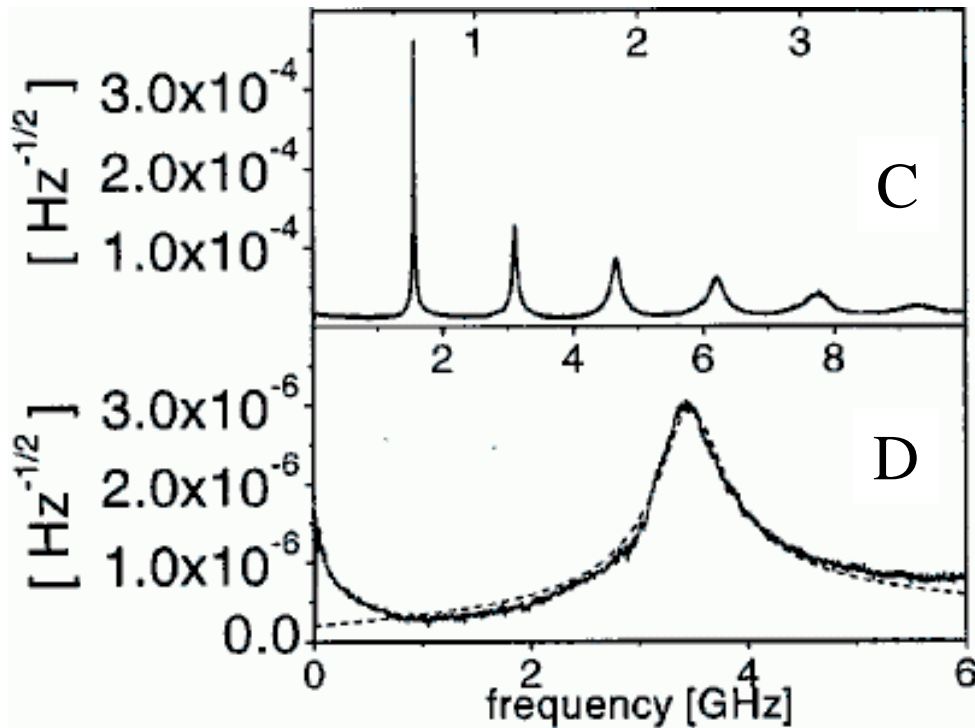


# COMPARISON with EXPERIMENTS

## 2: power spectra

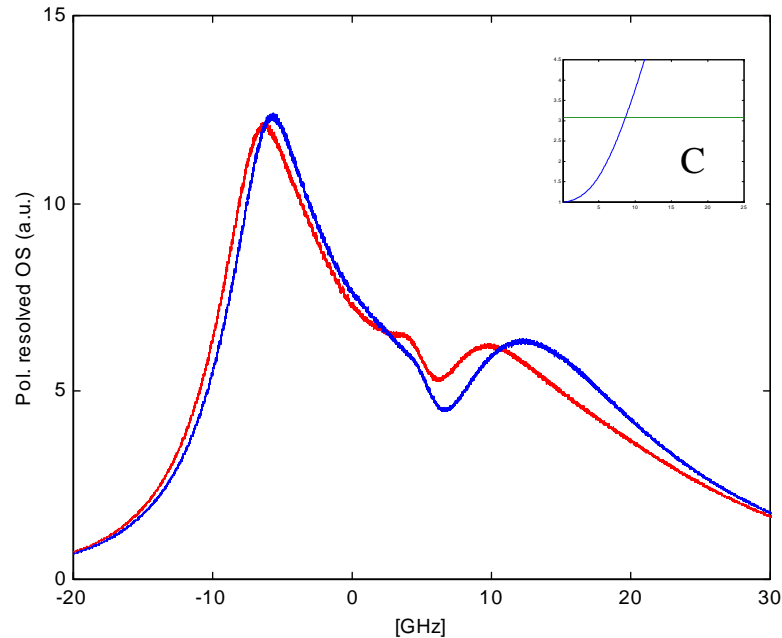


Comparison of the power spectra in region C and D

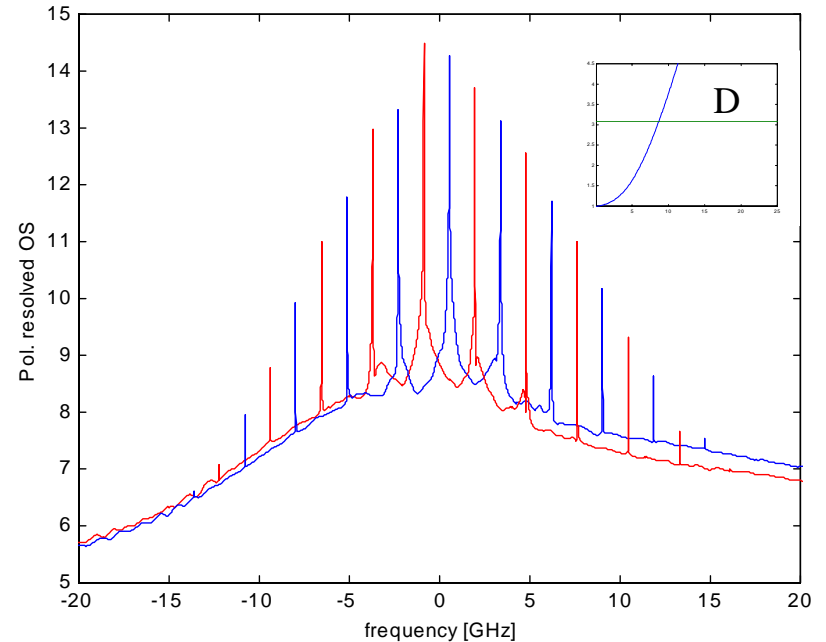


# POLARIZATION RESOLVED OPTICAL SPECTRA

**X** and **Y** polarization contribution to optical spectra



In region C the phase-amplitude coupling dominates the behaviour. The shape of the spectra is determined by the chirp



In region D the phase-amplitude coupling is much less important. The out-of-phase dynamic leads to two shifted optical spectra for **X** and **Y** pol.

## CONCLUSIONS

We introduced a framework to study self-pulsations in VCSELs due to saturable absorption

Our model contains the polarization degree of freedom, which plays an important role in the dynamics

Regions of different behaviour have been found, in the plane of pump Vs birefringence: **amplitude**, **coupled** and **polarization** pulsations appear

Our results are in qualitative agreement with experiments