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

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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

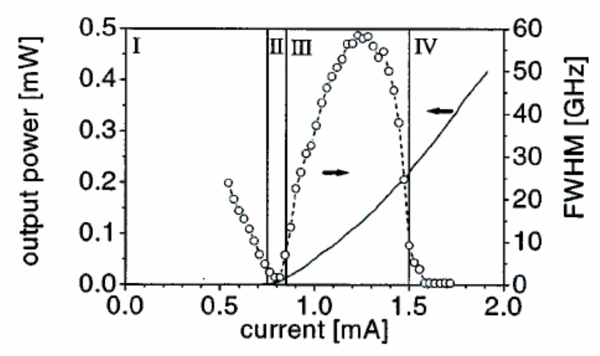
Brief summary of the experimental results

Choice and description of the model

Results of the analysis

Comparison with experiments

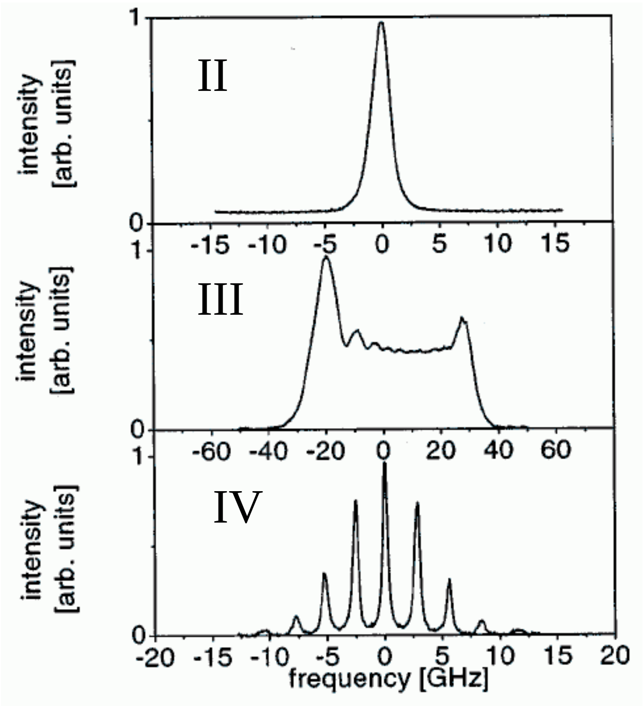
EXPERIMENTAL RESULTS



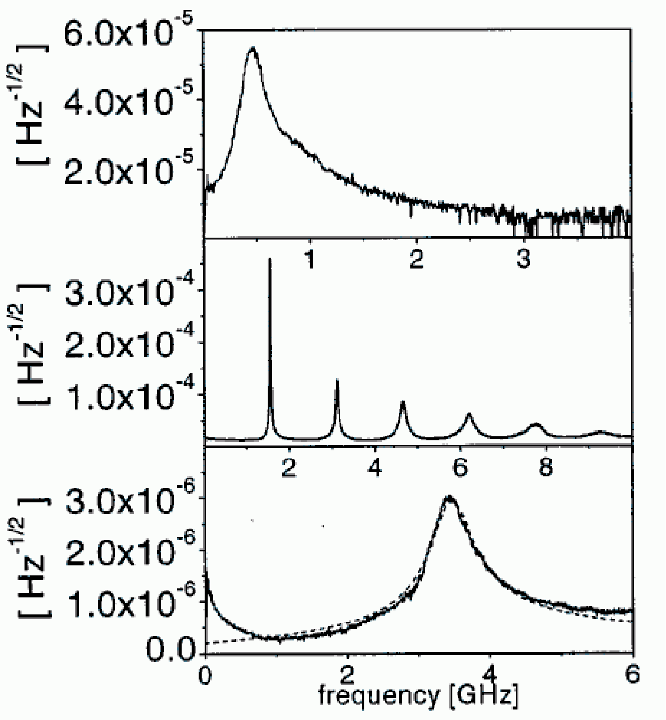
III) the output intensity is concentrated in short,periodic and strongly-chirped optical pulses.

IV) the output intensity shows a combination of harmonic amplitude and phase modulation.

Optical spectra



Power spectra



small-radius (2-3 μm) oxide-confined (node configuration) InGaAs MQW VCSELs @ 962nm

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

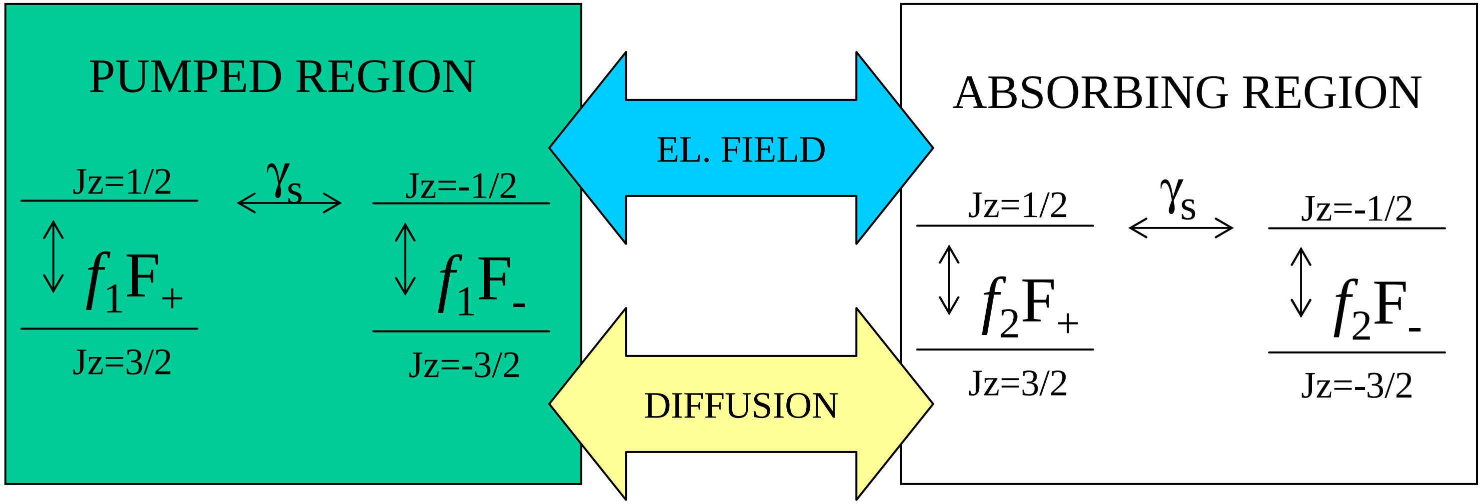
THEORETICAL APPROACH

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



PUMPED REGION

$J_z=1/2$ $\xleftrightarrow{\gamma_s}$ $J_z=-1/2$

f_1F_+ f_1F_-

$J_z=3/2$ $J_z=-3/2$

EL. FIELD

DIFFUSION

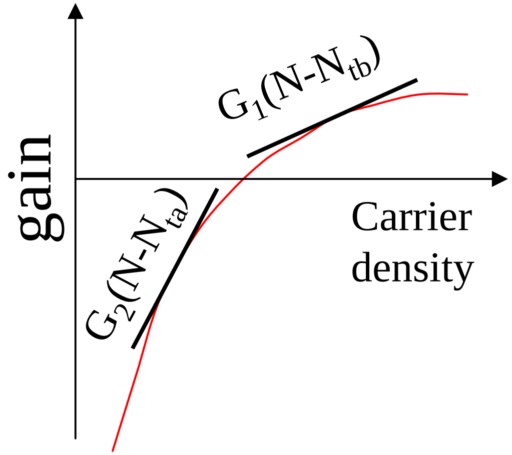
ABSORBING REGION

$J_z=1/2$ $\xleftrightarrow{\gamma_s}$ $J_z=-1/2$

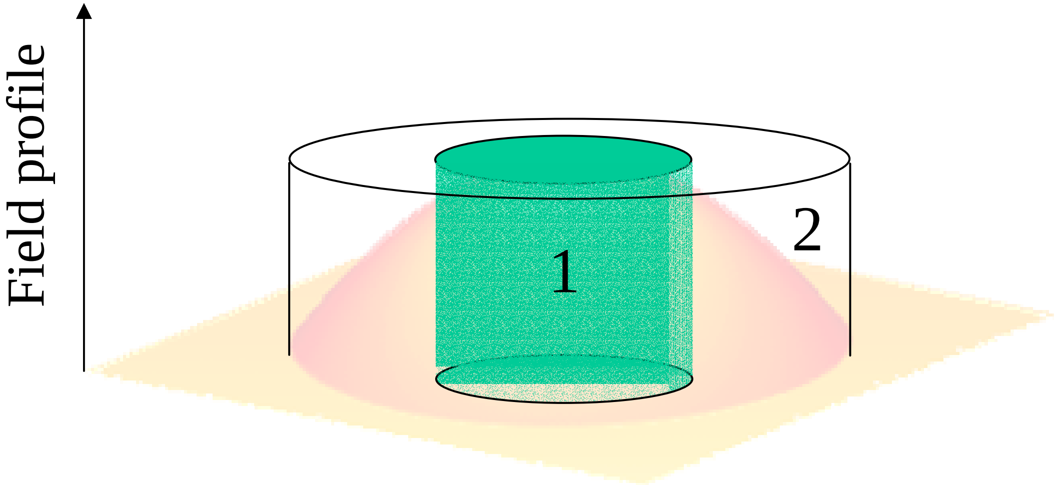
f_2F_+ f_2F_-

$J_z=3/2$ $J_z=-3/2$

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.*

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

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

Total carrier density related to transparency

(1) pumped

(2) absorbing region

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

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

Carrier density difference

(1) pumped

(2) absorbing region

α : phase amplitude coupling

γ_a γ_p : amplitude and phase coupling of c.w. and c.c.

μ_i : effective pump

γ_1 γ_2 : total carrier decay rate ($\gamma_i = \gamma + c_{ij}$)

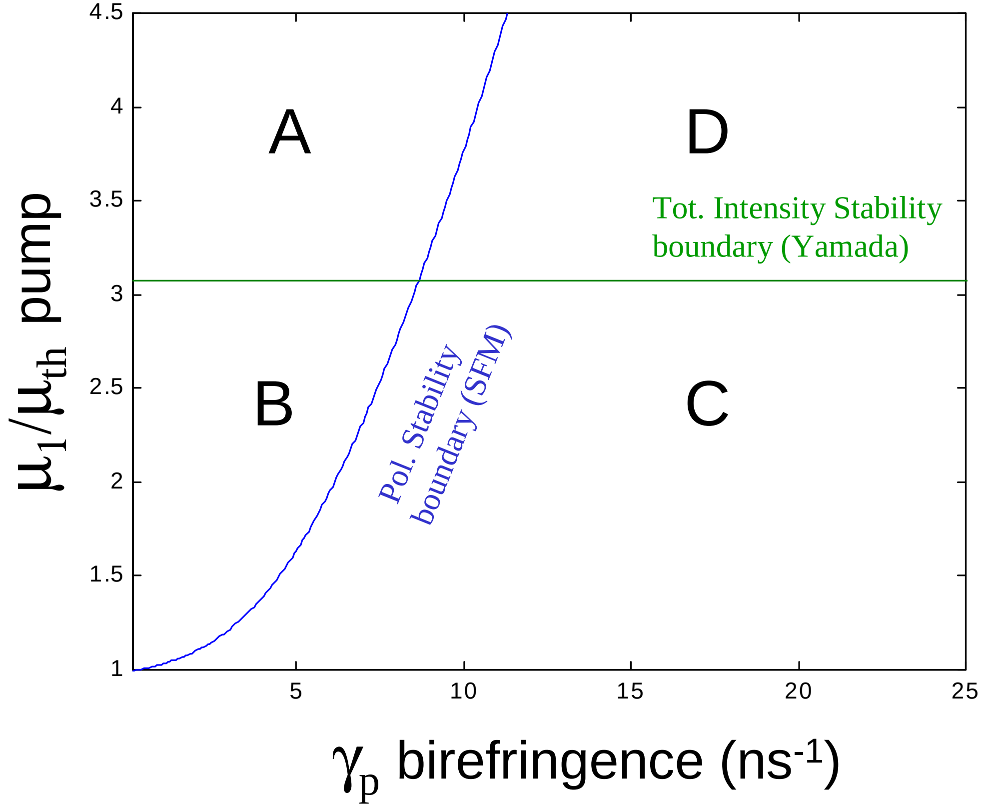
γ_{s1} γ_{s2} : carrier difference rate ($\gamma_{si} = \gamma_s + c_{ij}$)

$a = V_2 G_2 f_2 / V_1 G_1 f_1$ *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

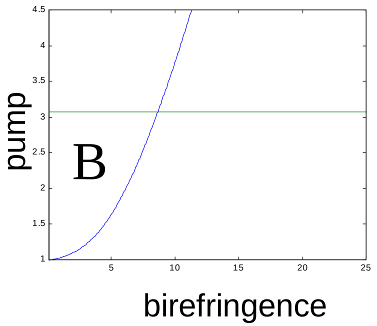
B: total intensity pulsations

C: coupled pulsations

D: polarization pulsations

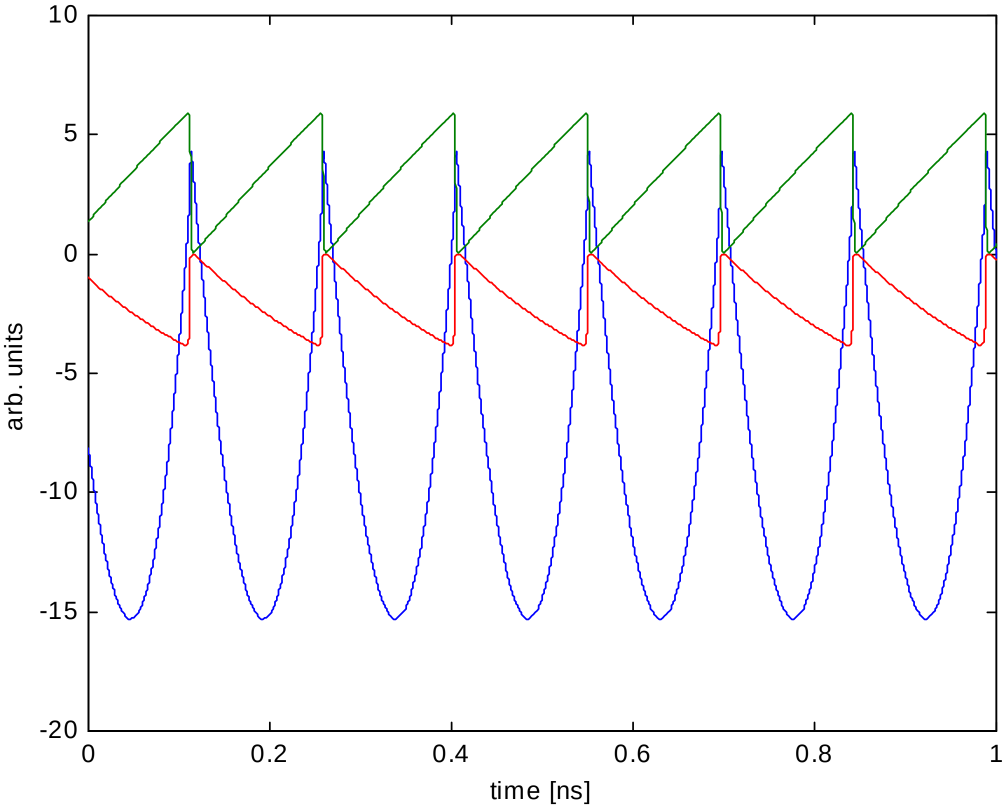
μ_2=-32, γ_1=1.09x10^{-3}, γ_2=1.13x10^{-3}, α =3, c_{12}=2.84x10^{-2}, c_{21}= 1.91, γ_{s1}= 0.25, γ_{s2}= 0.25, a= 8.7, γ_a=0

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 turns depletes D_1, to a below-threshold value, where the stimulated emission stops.

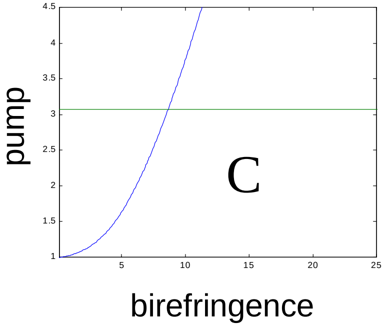
D_1 pumped region carrier density related to transparency

D_2 absorber carrier density r.t.t.

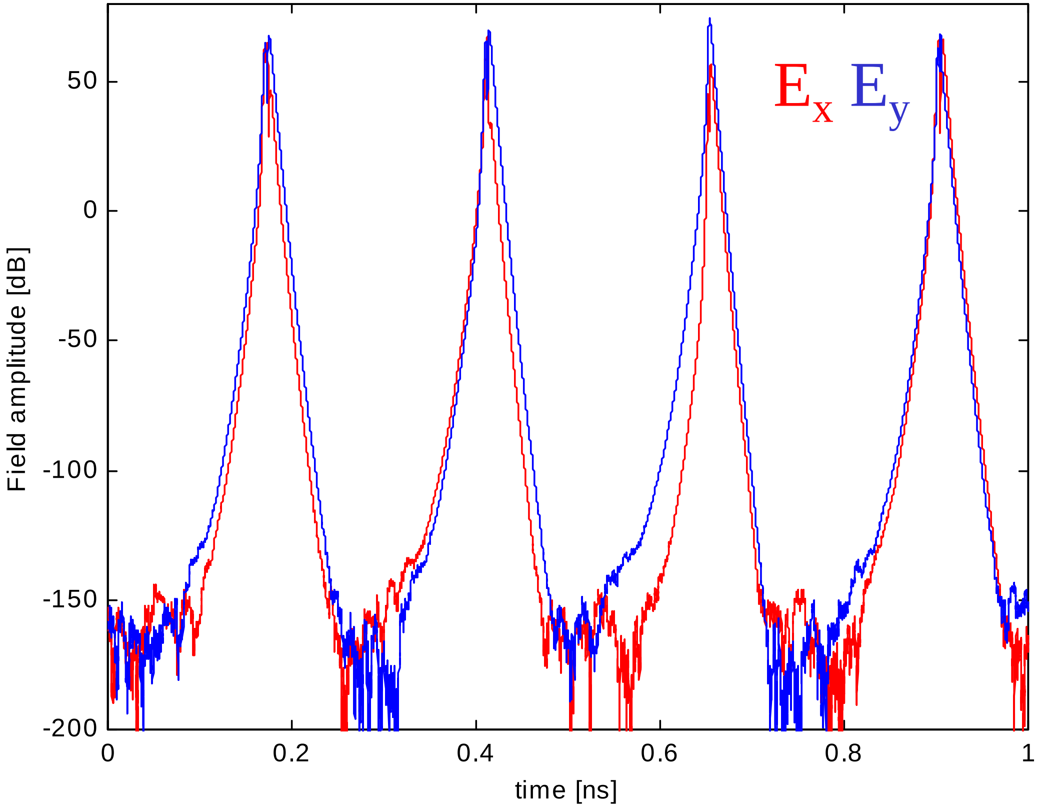
E_y y LP intensity

COUPLED PULSATIONS

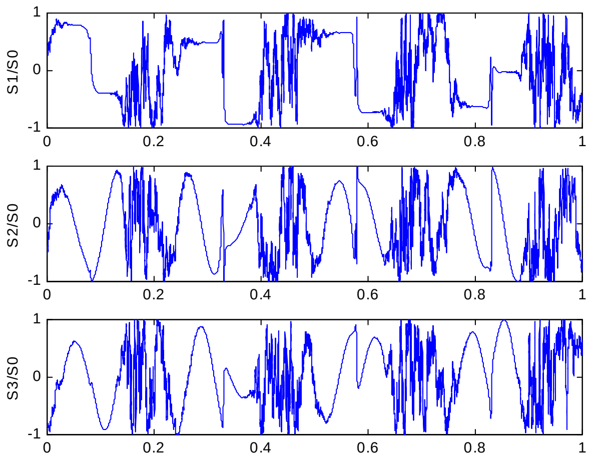
time traces



Increasing the birefringence, the two polarizations participate the pulsing. The amplitude-phase coupling (α-factor) and the *birefringence* γ_p lead to complex polarization dynamics



Stokes parameters



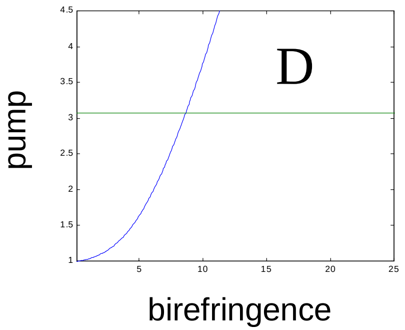
Since the noise has been proved to be important in self-pulsing lasers we add to the field eqs a noise term

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

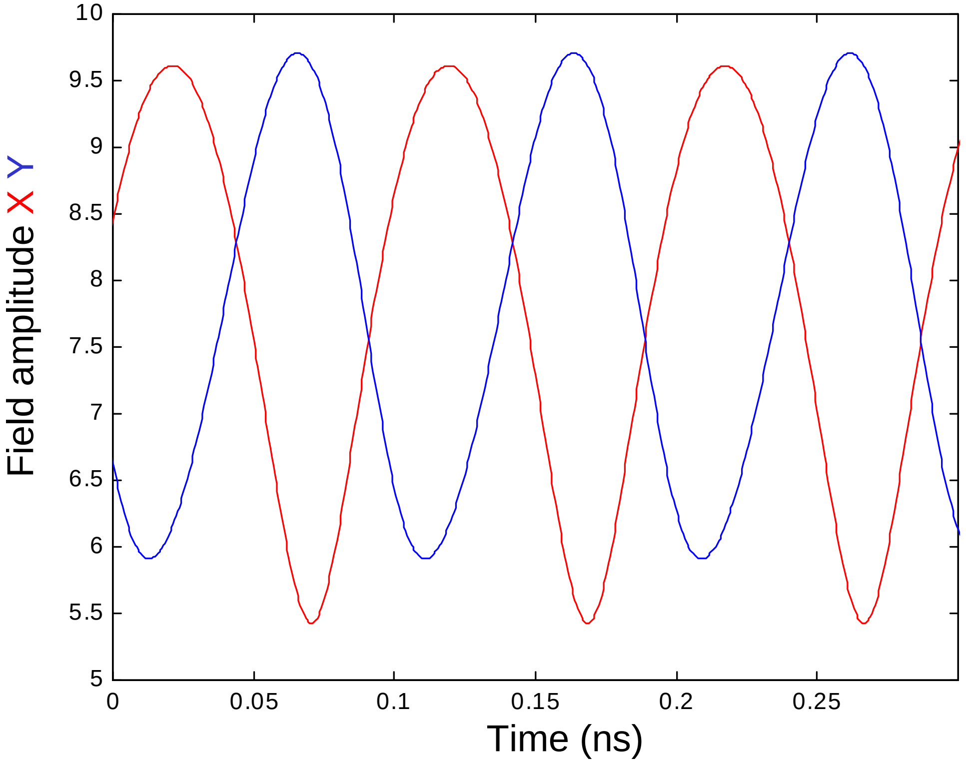
G.H.M. Van Tartwijk et al. *IEEE JQE*, **QE-32** 1191 (1996)

POLARIZATION PULSATIONS

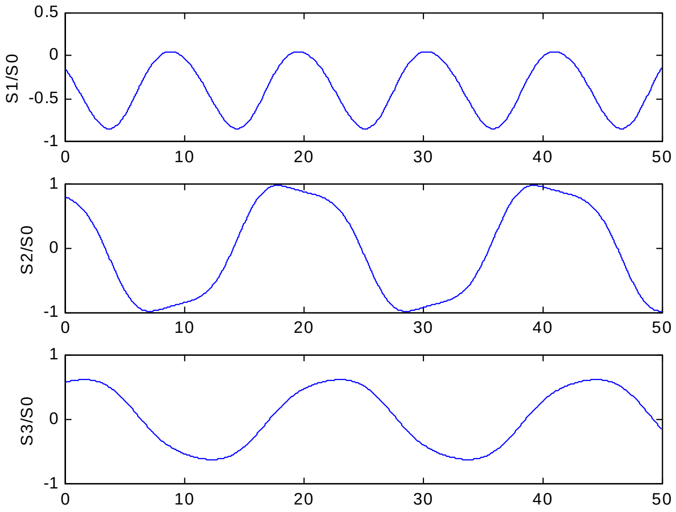
time traces



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

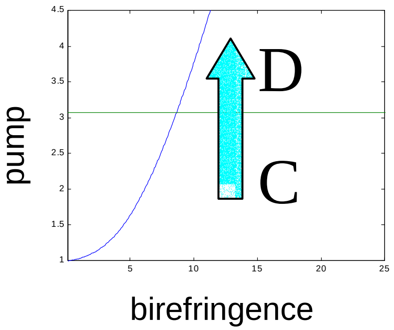


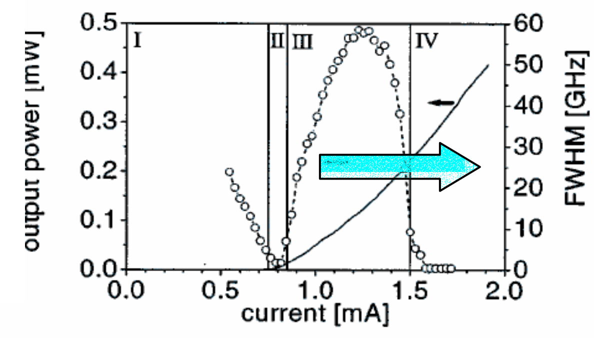
Stokes parameters



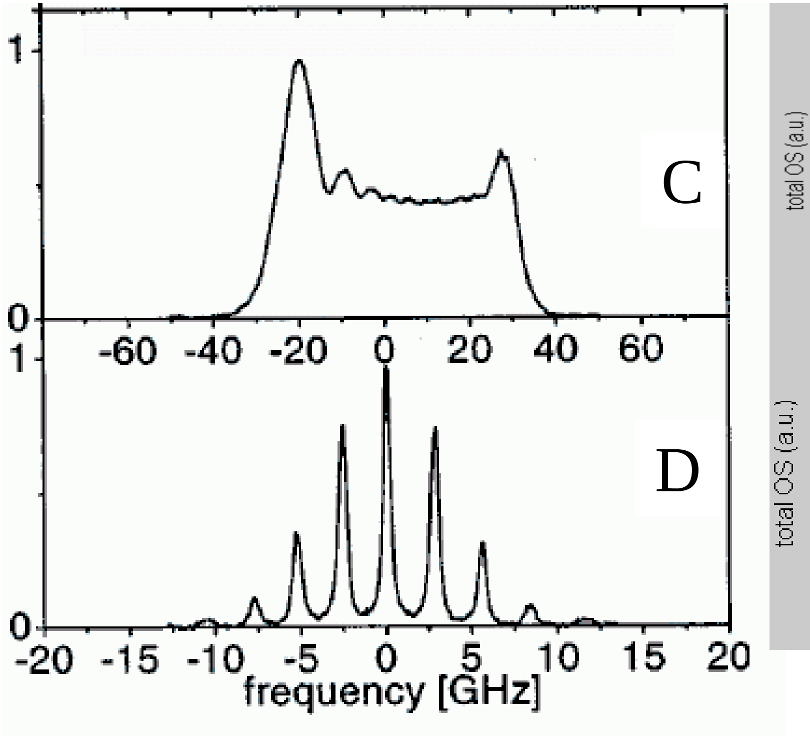
COMPARISON with EXPERIMENTS

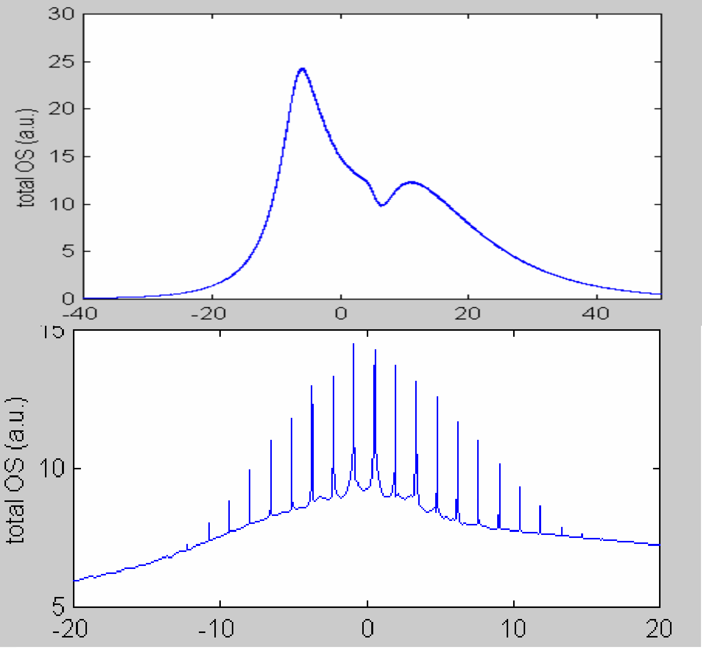
1: optical spectra





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

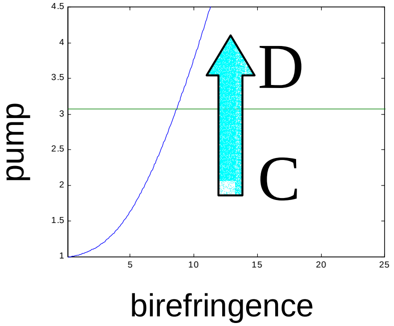


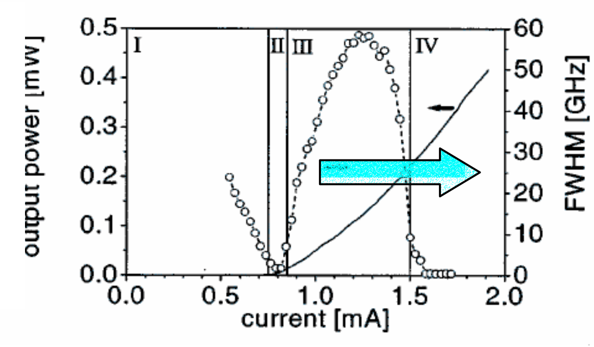


Frequency (GHz)

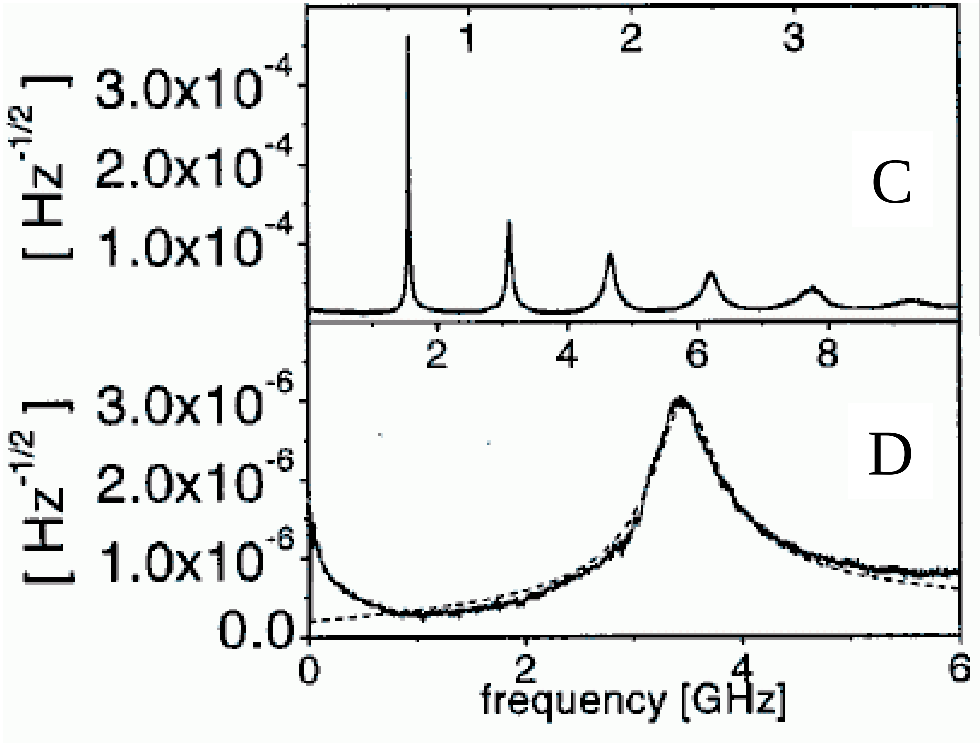
COMPARISON with EXPERIMENTS

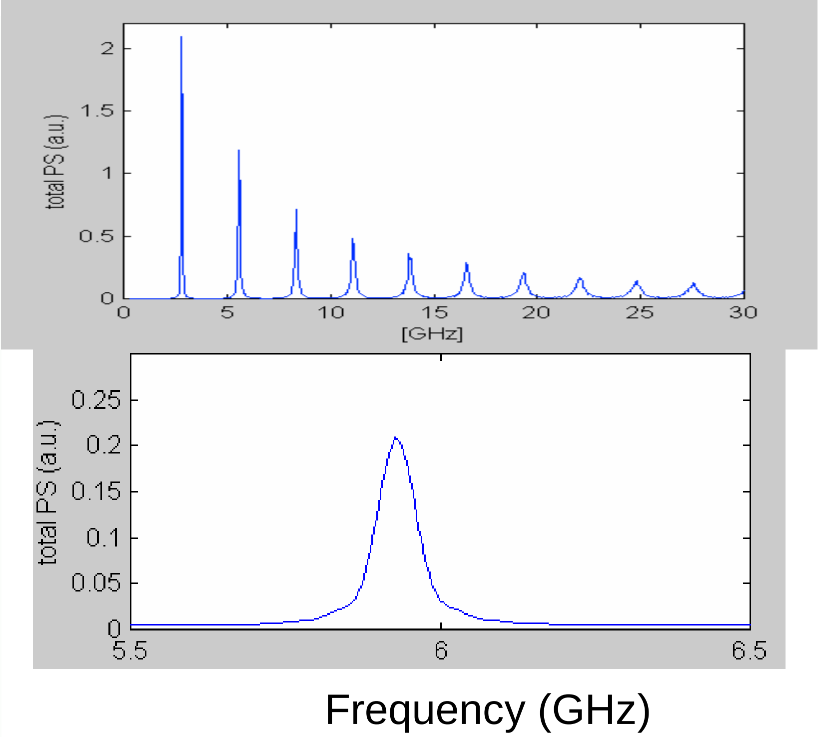
2: power spectra





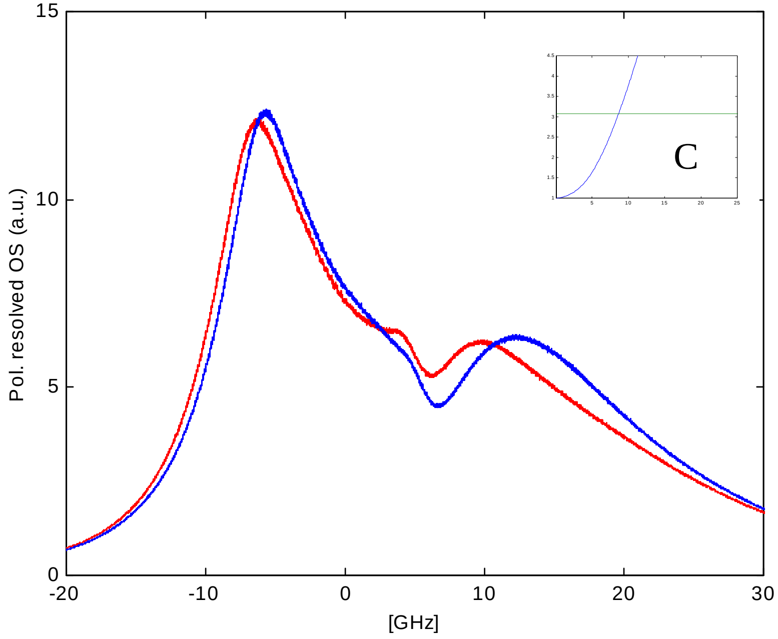
Comparison of the power spectra in region C and D



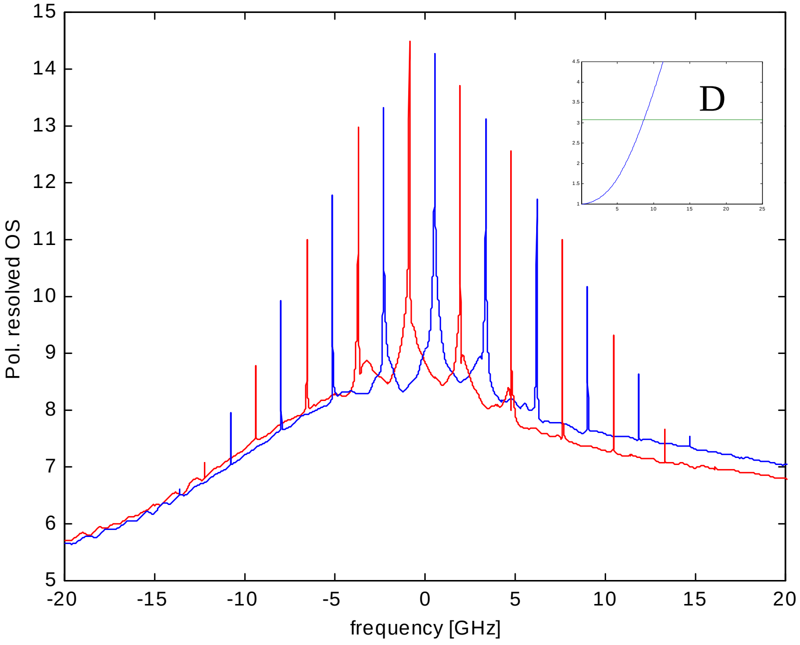


POLARIZATION RESOLVED OPTICAL SPECTRA

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