CENTRO DE INVESTIGACIONES
EN OPTICA, A.C.

Diode semiconductor laser under external optical injection: Theory and Experiments

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Outline

A. Introduction

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A. Introduction

The relevant variables: field, population and polarization, decay on very different time scales given by the relaxation rates.

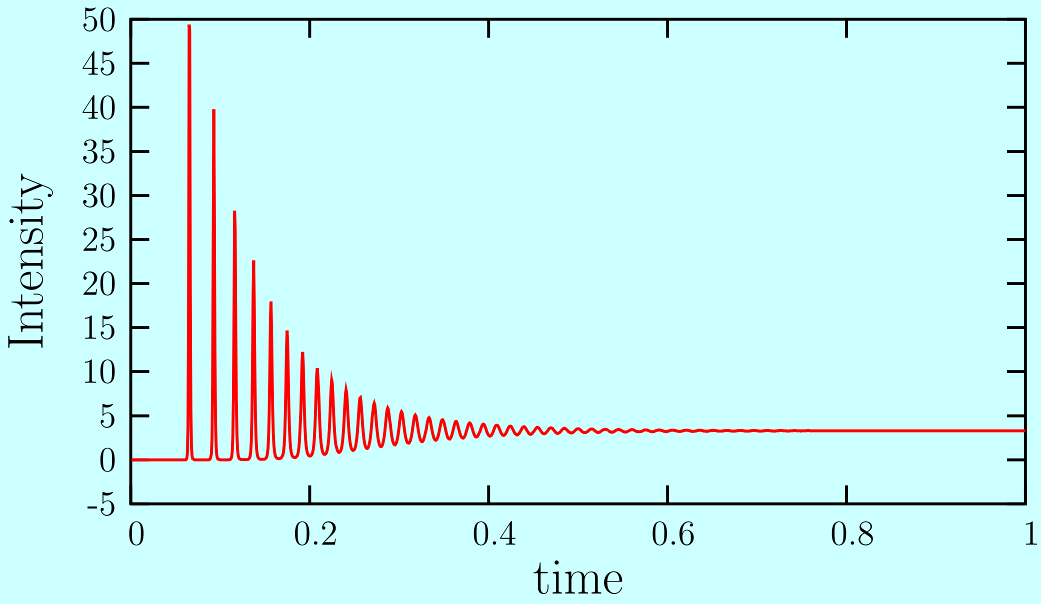
- Class A: Population and polarization decay fast in comparison with the field.
  Constant output solution

- Class C: Relaxation rates of the same magnitude.
  Undamped periodic or no-periodic (chaotic) pulsing.

- Class B: Only the polarization relaxes fast.
  Relaxation oscillations

A. Introduction

Relaxation oscillation frequency-maximum gain frequency



Diode laser: f_r (GHz)$\approx f_o$

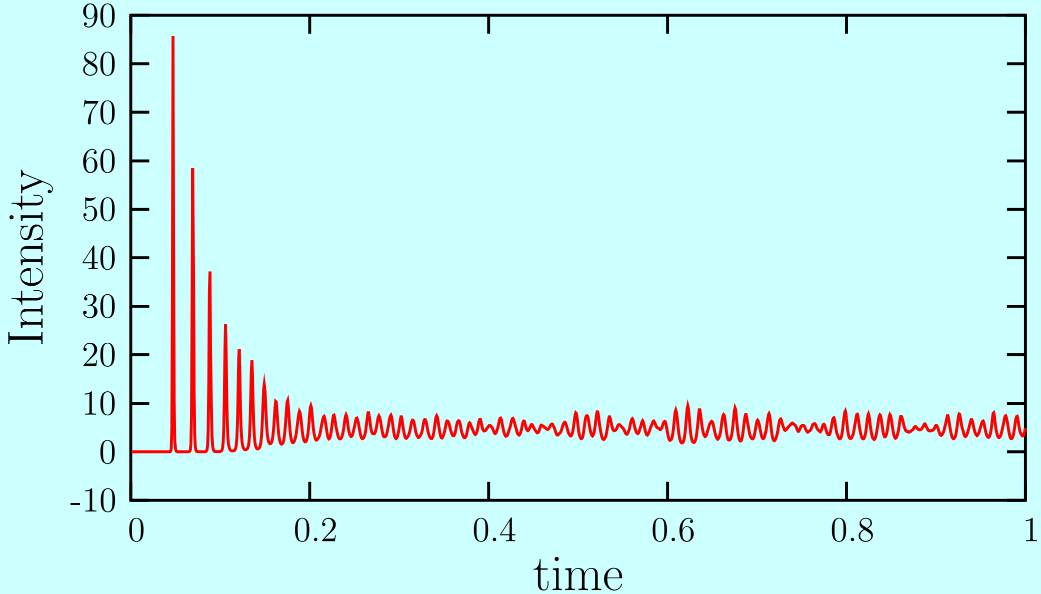
A. Introduction

To add a degree of freedom

- Feedback
- Modulation
- Optical injection
  $f_r = f_M - f_S$

A. Introduction

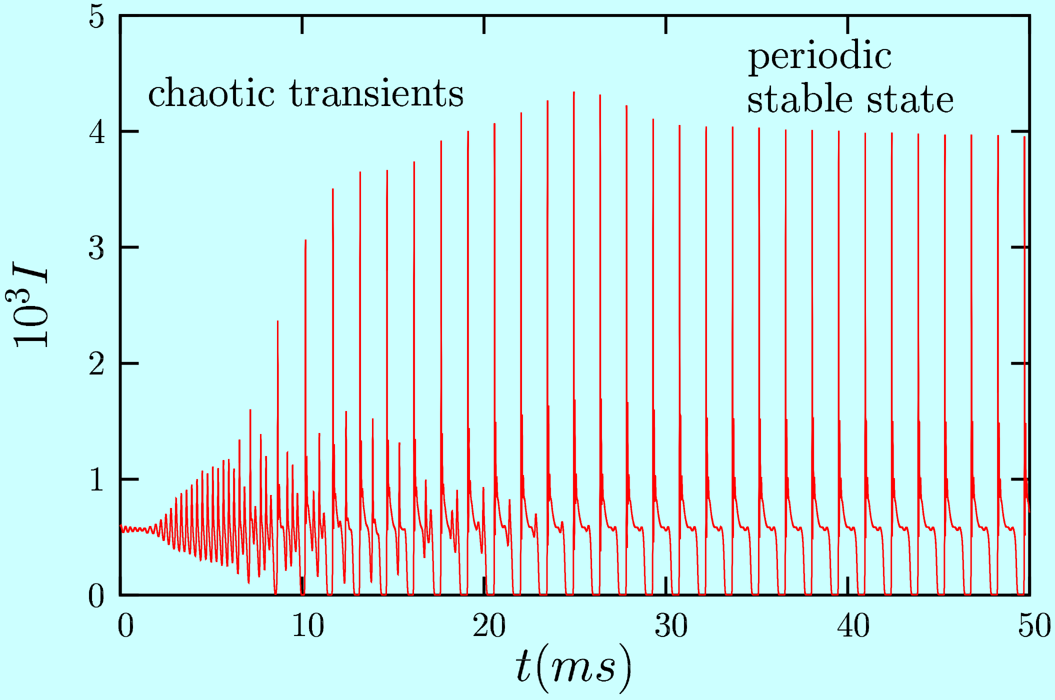
Chaotic oscillations



Diode laser: f_r (GHz)$\approx f_o$

A. Introduction

Undamped periodic oscillations for a class B laser



B. Theory

Model equations

$$\frac{da}{d\tau} = \frac{1}{2}[\widehat{\gamma}_d\widehat{n} - \widehat{\gamma}_n(2a + a^2)](1 + a) + \xi\cos(\widehat{\Omega}\tau + \phi) + F_a$$

$$\frac{d\phi}{d\tau} = -\frac{\xi}{1+a}\sin(\widehat{\Omega}\tau + \phi) + \frac{F_\phi}{1+a} - \frac{b}{2}[\widehat{\gamma}_d\widehat{n} - \mu\widehat{\gamma}_n(2a + a^2)]$$

$$\frac{dn}{d\tau} = -[\widehat{\gamma}_d\widehat{n} - \widehat{\gamma}_n(2a + a^2)](1 + a)^2 + \widehat{\gamma}_s\widehat{n} - (2a + a^2)$$

a is the slave laser normalized field amplitude,
ϕ is the phase difference between master and slave fields,
n is the slave normalized carrier density,
γ_s spontaneous carrier relaxation rate,
γ_d differential carrier relaxation rate,
γ_n nonlinear carrier relaxation rate,
b is the linewidth enhancement factor,
ξ is the injection parameter,
$f = \Omega/2\pi$ is the frequency detuning,
$\tau = t\gamma_c$ represents the normalized time,
μ is the nonlinear gain effect (0 or 1),
F_phi and F_a are noise terms,

B. Model Equations

Laser parameters

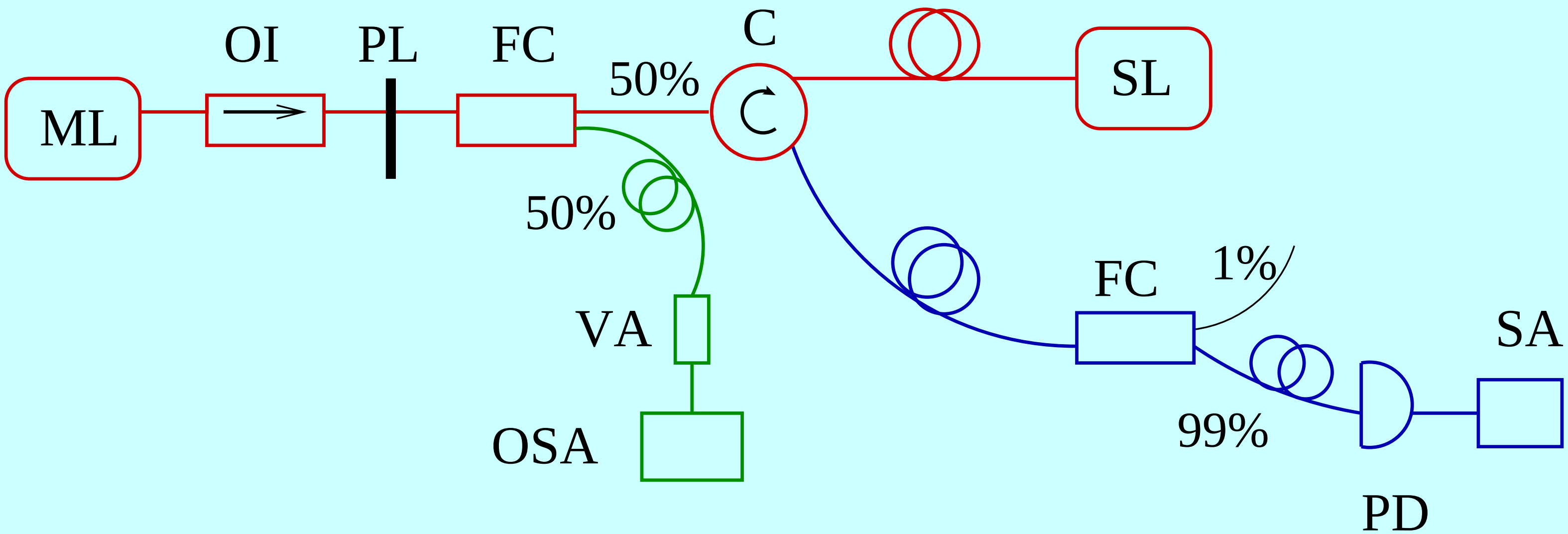
J	b	$\widehat{\gamma_c}$
4.0	6.0	5.0x10^{11}s^{-1}
γ_s/γ_c	$\widehat{\gamma_d}$	$\widehat{\gamma_n}$
6.92x10^{-3}	4.23x$10^{-3}J$	9.6075x$10^{-3}J$

J is the injection current

γ_c is the cavity decay rate

C. Experiments

Experimental setup



Fixed slave operating parameters

λ_s =1535.454nm

$T_s = 20^o$C

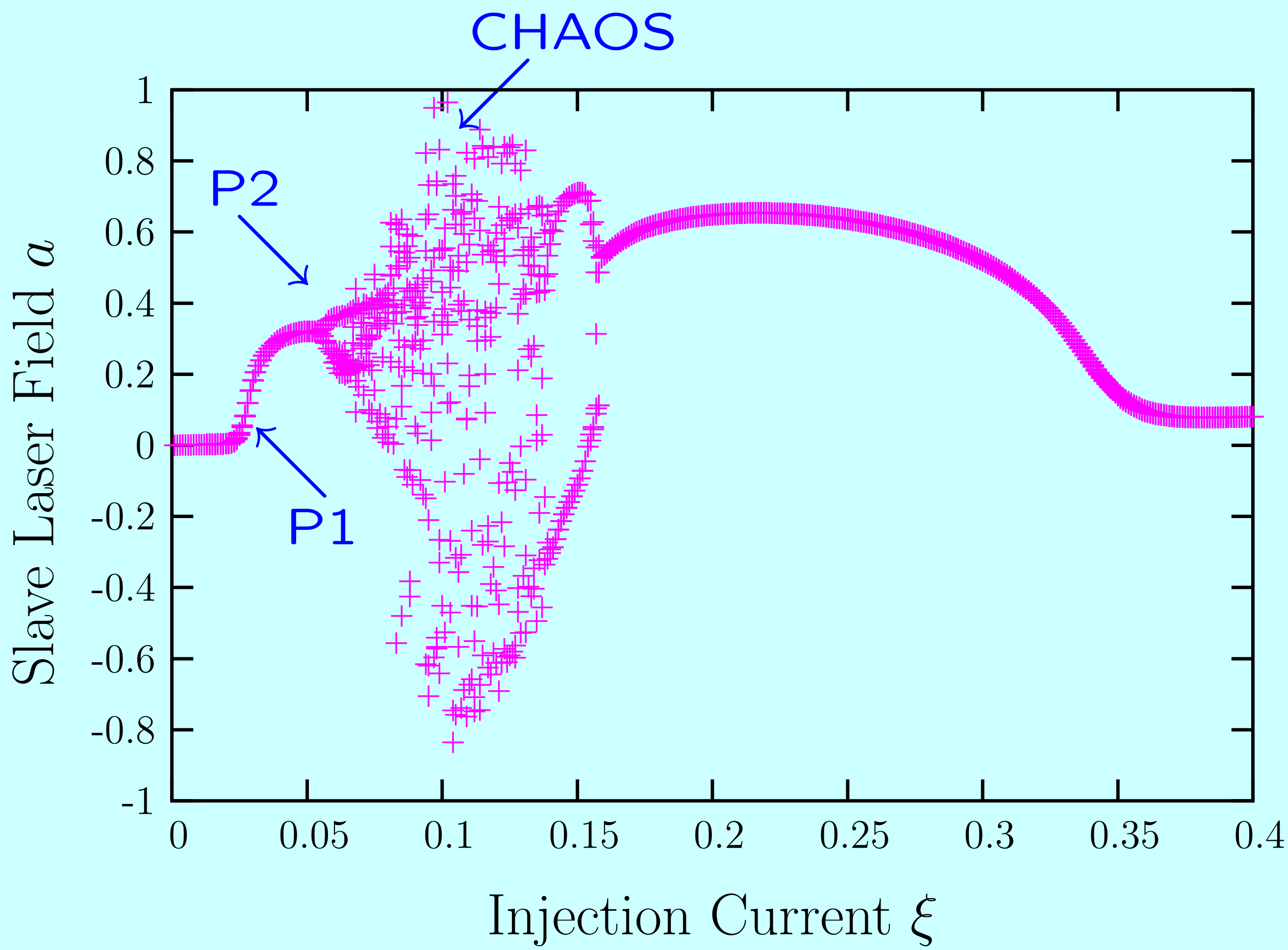
I_s =20mA

Detuning frequency is defined as

$f_D = f_M - f_S$

C. Results

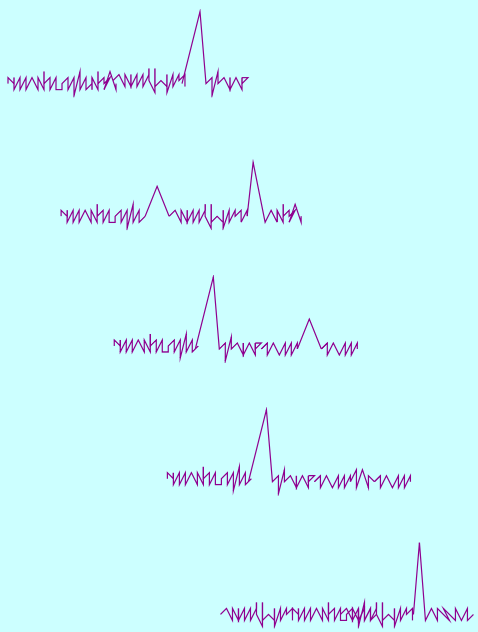
Bifurcation Diagram

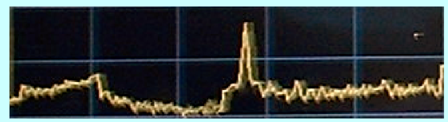


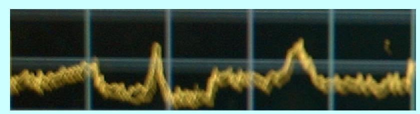
1975 Feigenbaum - Period-2 route to chaos Logistic map

D. Results

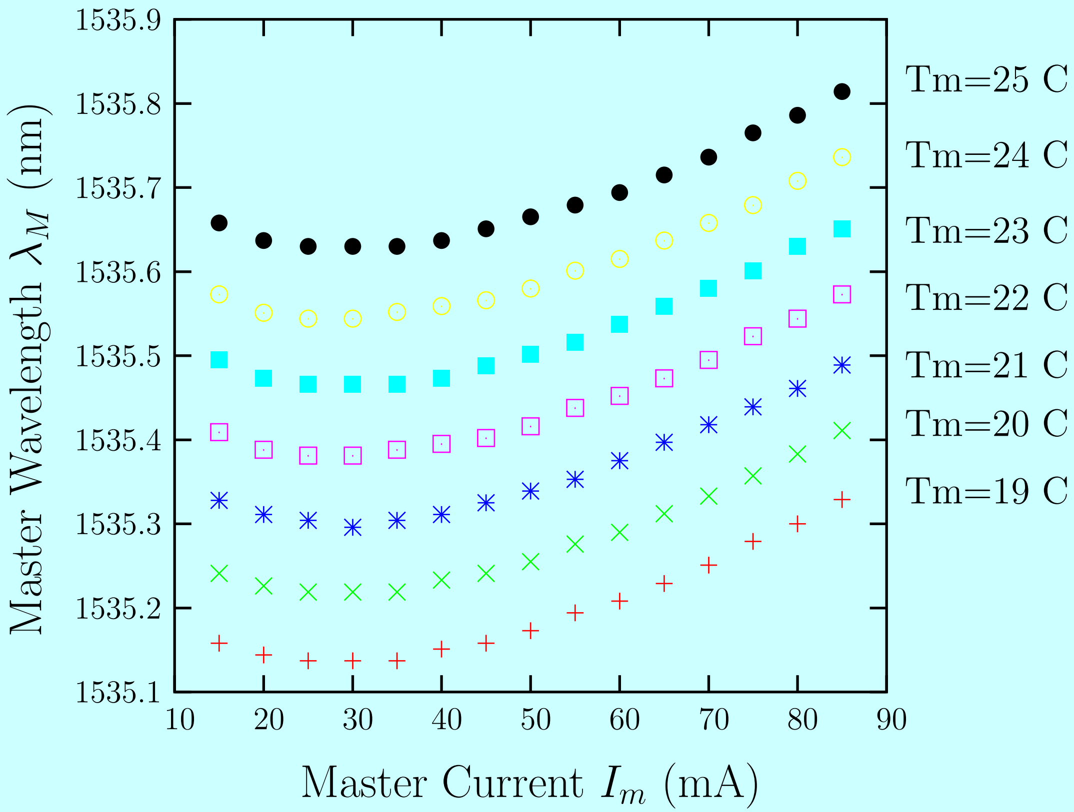
Spectrum





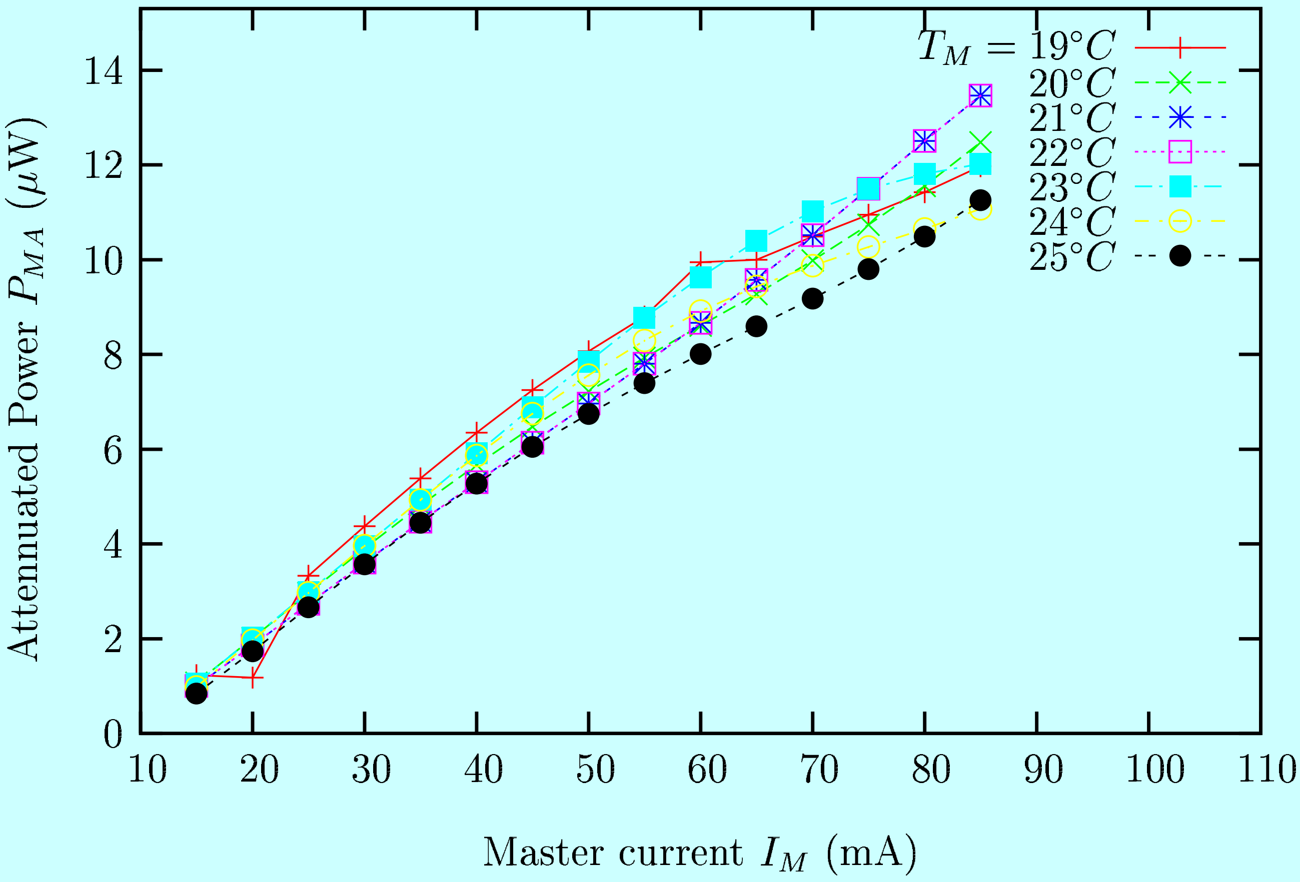


D. Results



Master Wavelength λ_M (nm)
1535.9
1535.8
1535.7
1535.6
1535.5
1535.4
1535.3
1535.2
1535.1
10
20
30
40
50
60
70
80
90
Master Current I_m (mA)
Tm=25 C
Tm=24 C
Tm=23 C
Tm=22 C
Tm=21 C
Tm=20 C
Tm=19 C

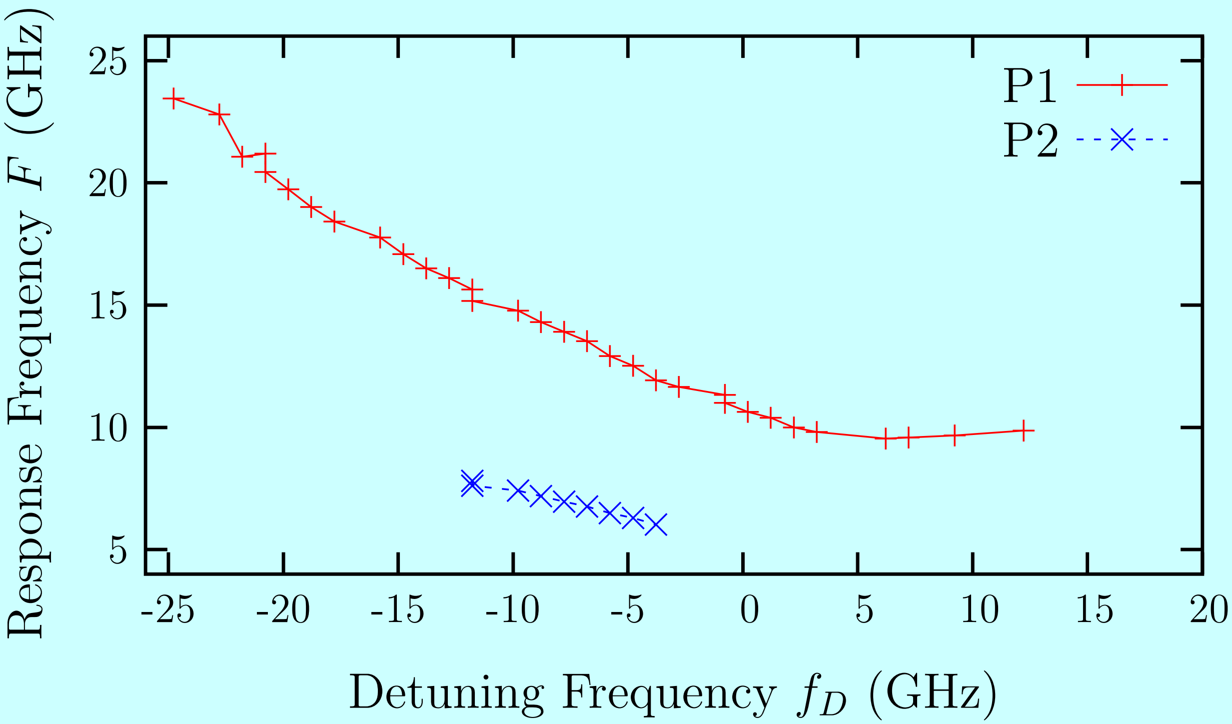
D. Results



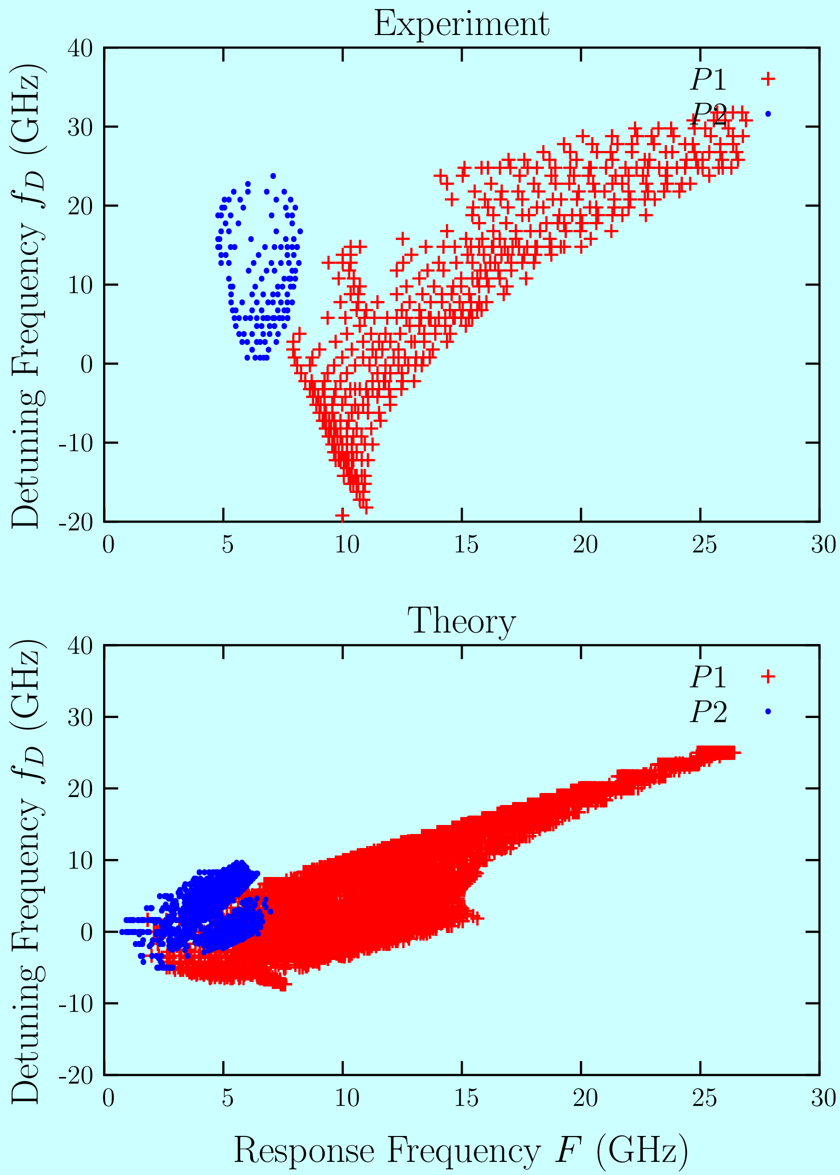
$T_M = 19°C$
$20°C$
$21°C$
$22°C$
$23°C$
$24°C$
$25°C$
Attenuated Power P_{MA} (μW)
Master current I_M (mA)
0
2
4
6
8
10
12
14
10
20
30
40
50
60
70
80
90
100
110

D. Results

$I_M = 65mA$

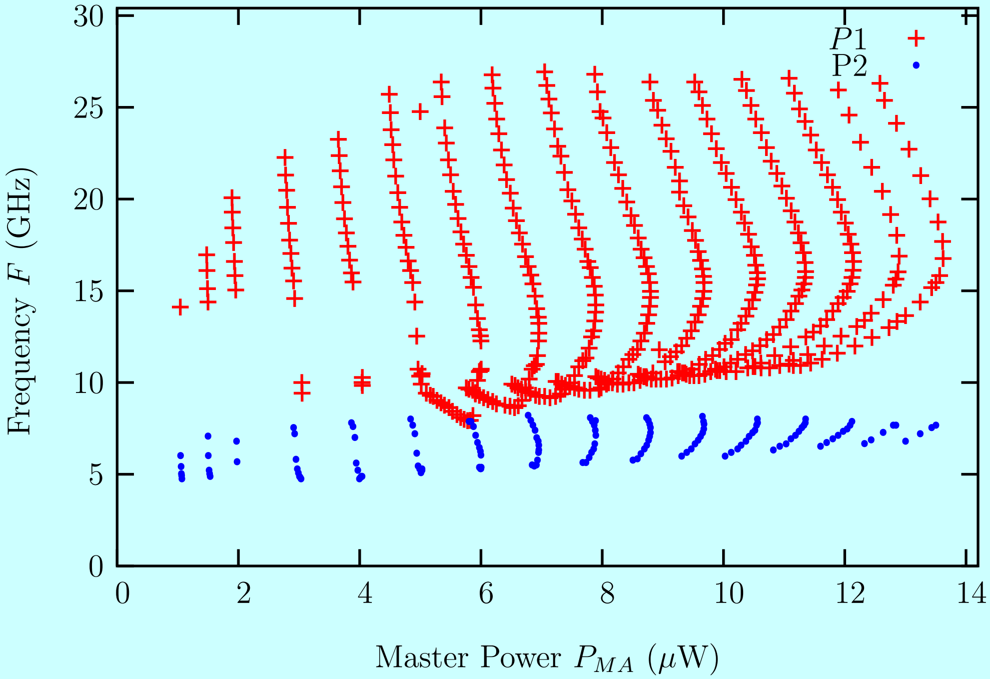


D. Results



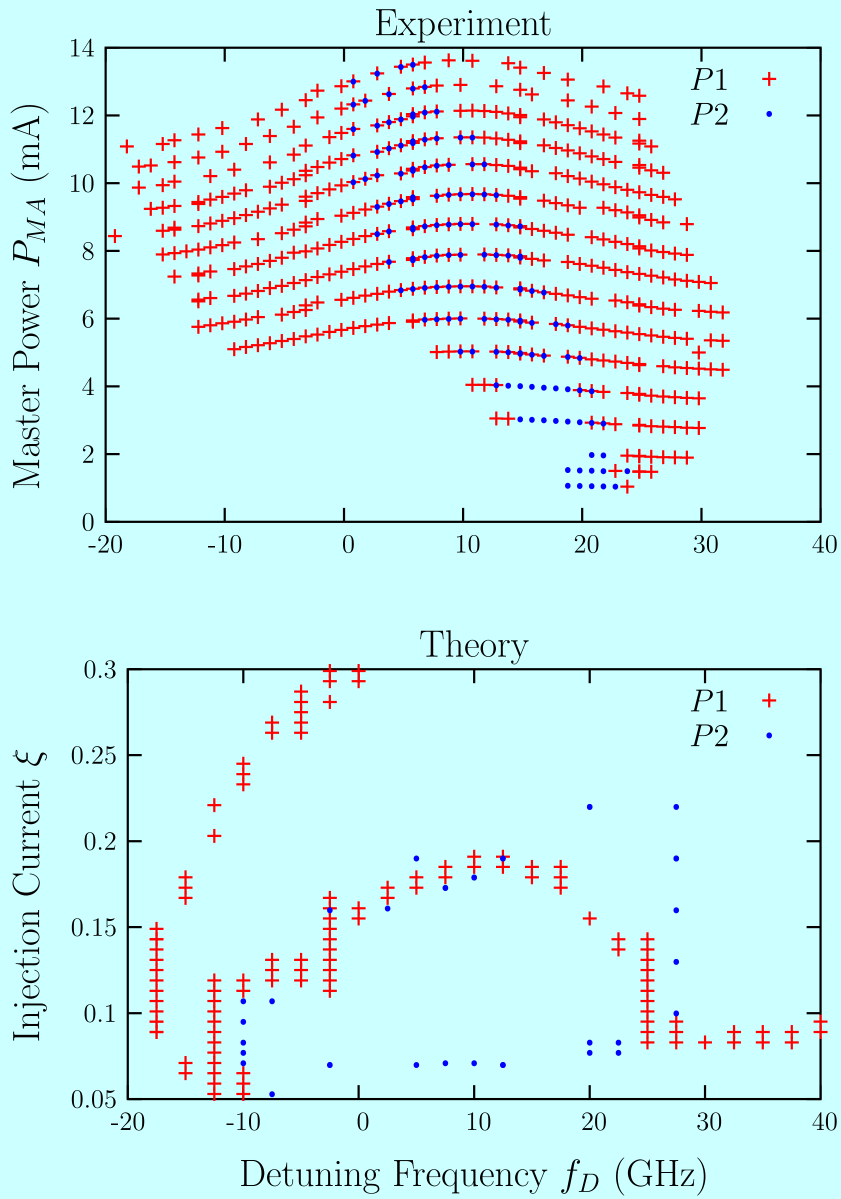
Experiment
Theory
Detuning Frequency f_D (GHz)
Response Frequency F (GHz)
$P1$
$P2$
40
30
20
10
0
-10
-20
0
5
10
15
20
25
30

D. Results



30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
Frequency F (GHz)
Master Power P_{MA} (μW)
$P1$
P2

D. Results



Experiment
Master Power P_{MA} (mA)
14
12
10
8
6
4
2
0
-20
-10
0
10
20
30
40
$P1$
$P2$
Theory
Injection Current ξ
0.3
0.25
0.2
0.15
0.1
0.05
-20
-10
0
10
20
30
40
$P1$
$P2$
Detuning Frequency f_D (GHz)

E. Conclusions

- We present theoretical and experimental evidence that optical injected diode lasers shows period-1 and period-2 oscillations.

- First we studied the master output power and its optical frequency (wavelength) dependence on temperature and current variations.

- We sampled the spectra of an optically injected diode laser as the injection power was increased.

- The changes in the frequency separation between the principal oscillations were studied as a function of the detuning frequency and the injection power.

- We found qualitatively agreement between theory and experiments.

- We believe that our results can be useful to understand period-one oscillations in optically injected semiconductor lasers as a function of some parameter that are accessible for the experimental point of view.

- We believe that high period oscillations may be lost in our experiment by the peaks becoming to small.

- Still a lot work to do in order to understand the dynamics!

Thank you!