Linear Current-dependent Gain Model on the Polarization Switching in VCSEL

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OUTLINES

- 1.0 of VCSEL, A Laser Light Source
- Polarization Switching(PS)
- Linear Current-dependent Gain Model(LGM) on PS
- LGM on PS with Optical feedback
- Conclusions

1.0 VCSEL

(Vertical-Cavity Surface-Emitting Laser)

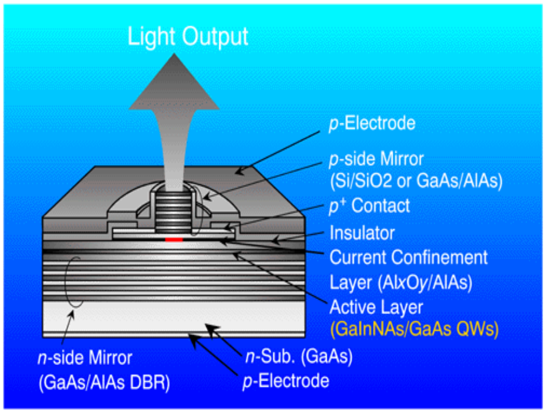
Laser

+

Microcavity

+

Linear polarization



Applications:

- Communication
- Optical Switch
- Laser array
- Display
- 3D Display
- ....

Engineering development:

- Lowering threshold current
- Longer wavelength, 1.3 μm
- Laser array
- Quantum dot in the active layer
- ……….

Scientific research: (a treasure trove)

- Mechanisms behind the linear polarization, the PS, the mode hopping, etc…
- Synchronization of a VCSEL array
- VCSEL + photonic crystal
- Wave chaos
- Polariton (photon + exciton)
- Quantum phase transition
- ……….

理論光學研究群
Theoretical Optics Group

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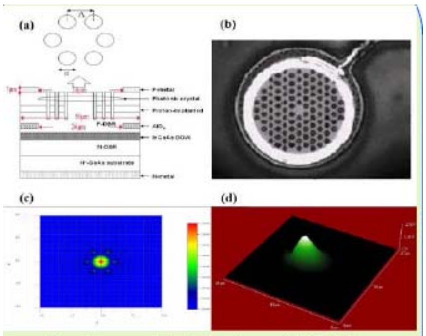
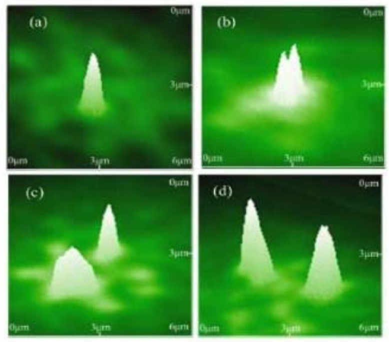
National Tsing Hua University

Theo. optics Group

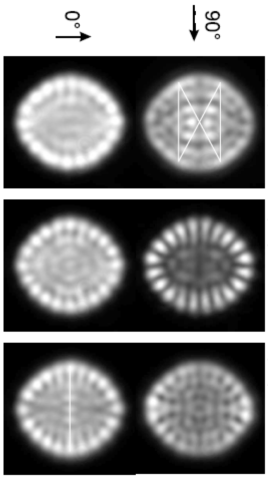


Design and fabrication of VCSELs with photonic crystals[7]



Observation of cavity solitons[1]

Wave chaos in a oval shaped VCSEL

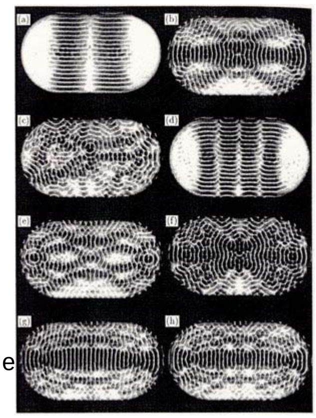


I_{pump}=15 mA

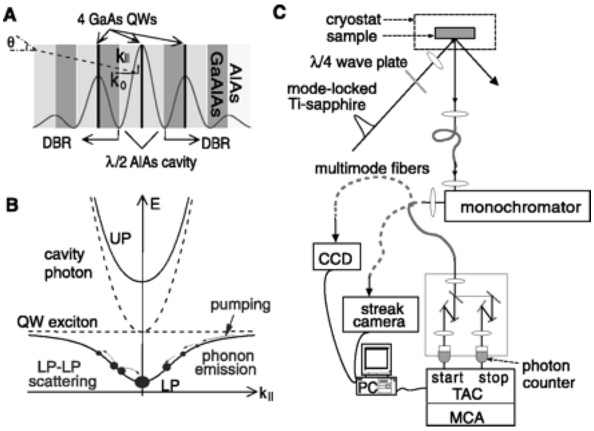
I_{pump}=20 mA

I_{pump}=30 mA

Gensty e



Microcavity Exciton Polaritons



Condensation of Semiconductor Microcavity Exciton Polaritons

Hui Deng,[1*] Gregor Weihs,[1, 2] Charles Santori,[1] Jacqueline Bloch,[3] Yoshihisa Yamamoto[1,

Butte et al. **Proc. SPIE, Vol. 7216, 721619 (2009)**

The authors report on room temperature (RT) lasing action in two different types of nitride-based microcavities (MCs): vertical cavity surface emitting lasers (VCSELs) and polariton lasers which operate in the weak and in the strong coupling regime, respectively.

PRL **98,** 126405 (2007) PHYSICAL REVIEW LETTERS week ending 23 MARCH 2007

Room-Temperature Polariton Lasing in Semiconductor Microcavities

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(Received 22 September 2006; published 21 March 2007)

Polarization Switching

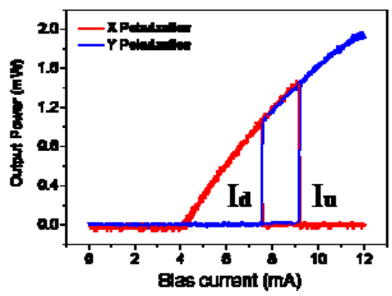
Anisotropic gain can cause a linear polarized light.

Many mechanisms can produce anisotropic gain such as,

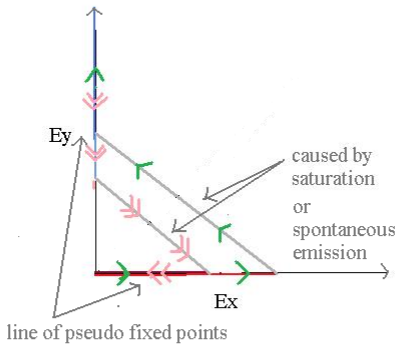
- geometry
- lattice structure
- materials
- strain
- temperature
- electric field
- ……

The polarization switching, then, occurs due to reversing of the anisotropic gain.

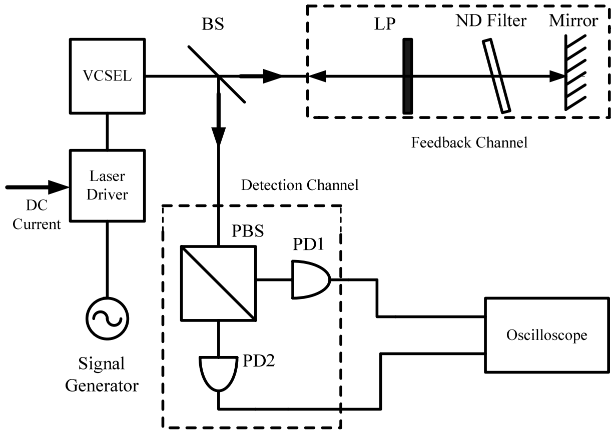
Typical L-I curve



Traces on plane of Ex-Ey

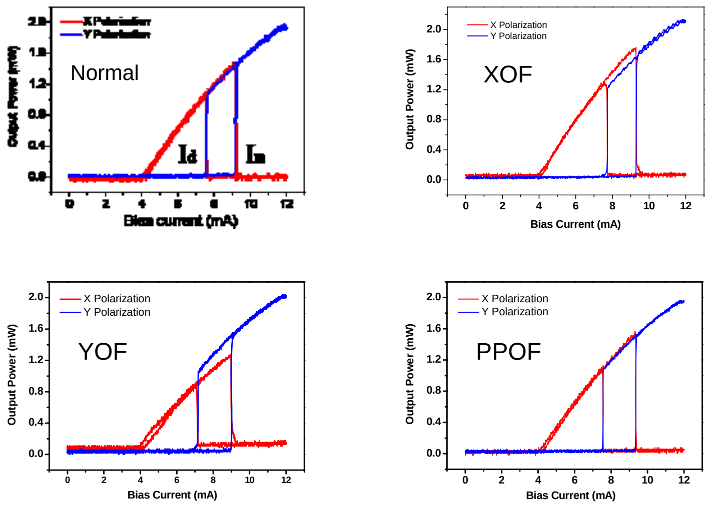


The experiment-setup:



Polarization Switching

The PS with and w/o optical feedbacks:



Linear Current-dependent Gain Model

The rate equations of Lang-Kobayashi:

$$\frac{dE_x}{dt} = \frac{1}{2}(1+i\alpha)(\Gamma_x G_x - \gamma_x)E_x(t) + \kappa_x E_x(t-\tau)\exp(-i\omega_x \tau) + \sqrt{R_{sp}}$$

$$\frac{dE_y}{dt} = \frac{1}{2}(1+i\alpha)(\Gamma_y G_y - \gamma_y)E_y(t) + \kappa_y E_y(t-\tau)\exp(-i\omega_y \tau) + \sqrt{R_{sp}}$$

$$\frac{dN}{dt} = \frac{J}{eV} - \frac{N}{\tau_s} - G_x|E_x|^2 - G_y|E_y|^2$$

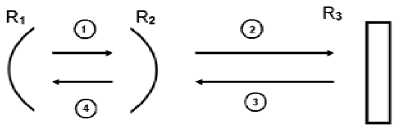
$$G_{x,y} = g_{x,y}(N-N_0)\left(1-\varepsilon^s_{x,y}\left|E_{x,y}\right|^2 - \varepsilon^c_{x,y}\left|E_{y,x}\right|^2\right)$$

$$g_x = g_{0x} + g_{1x}\left(1 - \frac{I}{I_n}\right) \qquad g_y = g_{0y} - g_{1y}\left(1 - \frac{I}{I_n}\right)$$

$$\kappa_y = \frac{1}{\tau_{\text{in}}}\frac{(1-R_2)\sqrt{R_3}}{\sqrt{R_2}}$$

Where the gain coefficients Gx and Gy are linearly dependent on the current,

The coupling constant κ



$$E_r e^{i\omega t} = \left(\sqrt{R_2} + (1-R_2)\sqrt{R_3}e^{-i\omega\tau} + (1-R_2)R_3\sqrt{R_2}e^{-2i\omega\tau} + \cdots\right)E_i e^{i\omega t}$$

R.Lang &,K.Kobayashi ,1980

$$\frac{E_r}{E_i} = r_{eff} = \sqrt{R_2} + (1-R_2)\sqrt{R_3}e^{-i\omega\tau}$$

$$r_{eff} = \sqrt{R_2}\left(1 + (1-R_2)\frac{\sqrt{R_3}}{\sqrt{R_2}}e^{-i\omega\tau}\right)$$

$$\kappa = \frac{1}{\tau_{in}}\frac{(1-R_2)\sqrt{R_3}}{\sqrt{R_2}}$$

LGM

The minimum model,

Danckaert et al. (2002)

$$\frac{dP_x}{dt'} = (\Gamma_x a_x(N - N_t) - \tau_{px}^{-1})P_x + \beta_{sp,x}N,$$

$$\frac{dP_y}{dt'} = (\Gamma_y a_y(N - N_t) - \tau_{py}^{-1})P_y + \beta_{sp,y}N,$$

$$\frac{dN}{dt'} = \frac{I}{eV} - \frac{N}{\tau_c} - a_x(N - N_t)P_x - a_y(N - N_t)P_y.$$

$$t \equiv \frac{t'}{\tau_c}, \quad p_{x,y} \equiv \tau_c a_{x,y} P_{x,y}, \quad n \equiv \frac{N}{N_t} - 1.$$

$$\rho_{x,y} \equiv \frac{\tau_{px,y}}{\tau_c}, \quad \beta_{x,y} \equiv \beta_{sp,x,y} a_{x,y} \tau_{px,y} N_t \tau_c,$$

$$g_{x,y} \equiv \tau_{px,y} \Gamma_{x,y} a_{x,y} N_t \text{ and } j \equiv \frac{I\tau_c}{eVN_t} - 1.$$

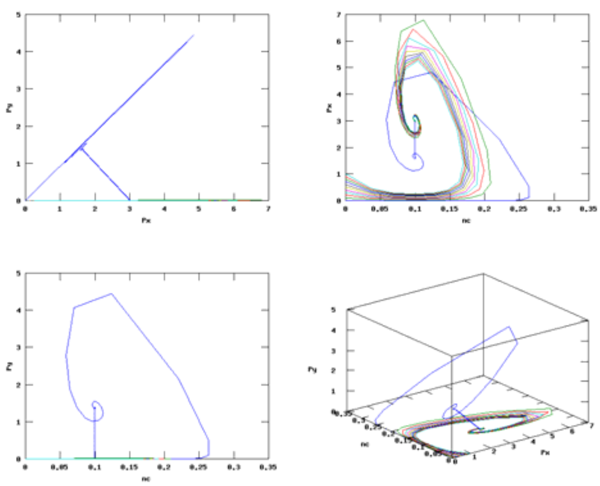
$$\rho_x \frac{dp_x}{dt} = (g_x n - 1)p_x + \beta_x(1 + n),$$

$$\rho_y \frac{dp_y}{dt} = (g_y n - 1)p_y + \beta_y(1 + n),$$

$$\frac{dn}{dt} = j - n - n(p_x + p_y),$$

LGM

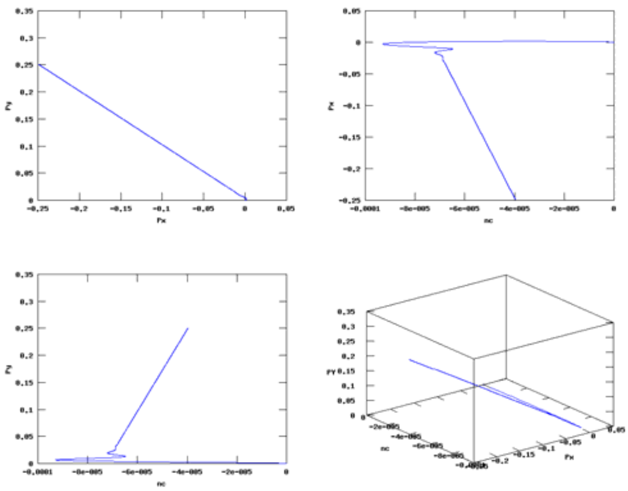
A typical simulation on the minimum model



g0 = 10

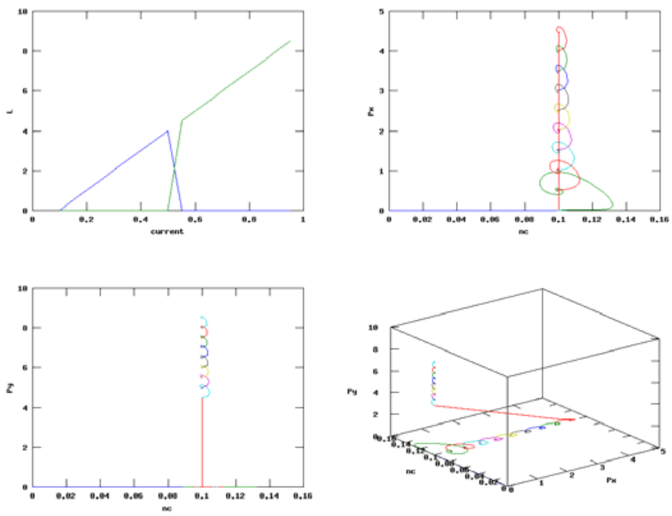
LGM

A typical relaxation



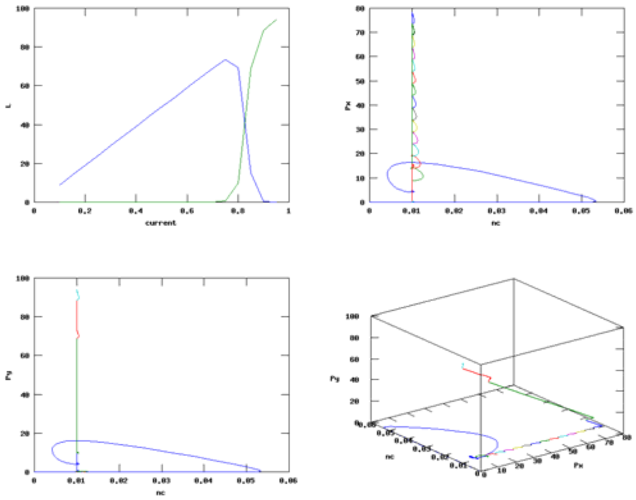
g0 = 10

LGM



g0 = 10

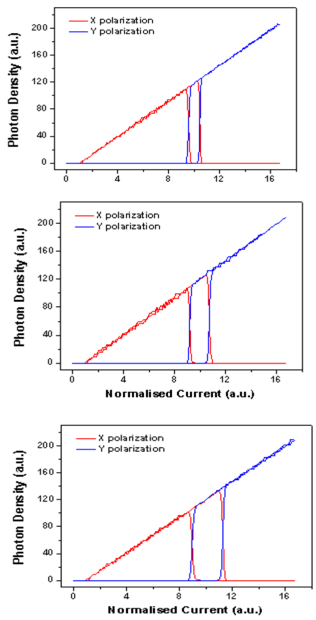
LGM



g0 = 100

LGM

A smaller SE gets a larger loop



LGM

The LGM is successful in explaining the PS and hysteretic behavior.

- Danckaert et al. (2002) : saturation can produce hysteretic behavior.

- Also, they provided a stochastic spontaneous -emission for mode-hopping VCSELs.

- Our view: “The PS is triggered by the constant kick of the spontaneous emission.”

- The larger SE brings narrower hysteretic width.

- The hysteretic width is roughly proportional to 1/|g1x + g1y|

LGM-OF

LGM on PS with Optical Feedback

We neglect the phase delay of the feedback since the time delay is beyond the correlation time.

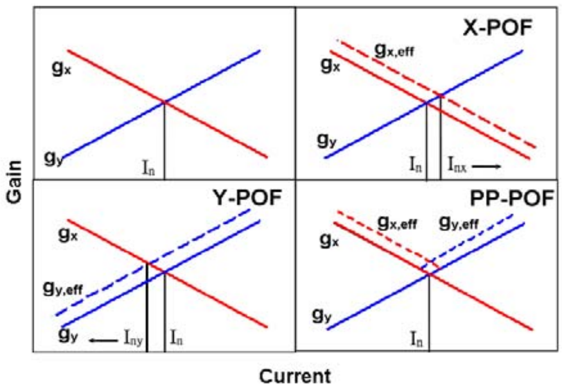
So, the optical feedbacks work as increasing gains.

In shift

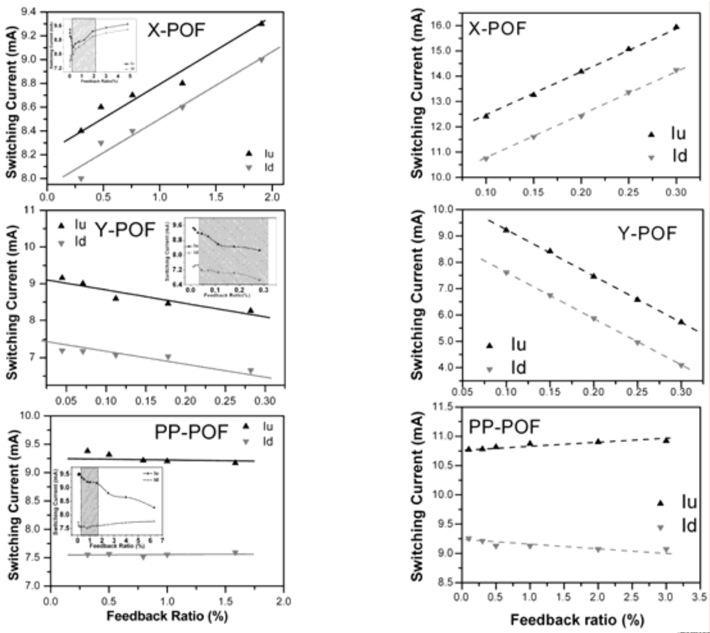
→ XOF

← YOF

‖ PPOF



LGM-OF



LGM-OF

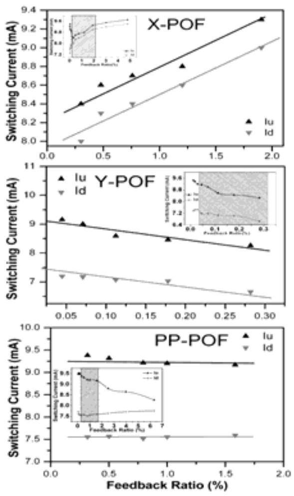
The experimental results basically agree with the LGM.

Anomaly exists.
It seems relating to
X-polarization.

Explanation?

Spontaneous emission
increases under XOF?

Wield? If so, HOW?



Conclusions

- The Linear Current-Dependent Gain Model can explain the polarization switching under the optical feedback.
- The polarization switching is caused by the saturation and/or the spontaneous emission.
- The hysteretic width is roughly proportional to $1/|g1x + g1y|$
- The PS is a slow process, ~μs, not suitable for fast switch but still fast enough to be applied to 3D display.
- Comparing VCSELs' PS under the optical feedback can further characterize their differences.

Thank your attention