Dynamic Internal Optical Field Patterns for Self-Pulsating Two-Section DFB Lasers

Jer-Shien Chen[1], Hong-Chang Kung[2],
San-Liang Lee[3], and Hen-Wai Tsao[1]

[1]*Graduate Institute of Communication Engineering and*
Department of Electrical Engineering, National Taiwan University
[2]*Electrical Engineering Department of Tung Nan Institute of Technology*
[3]*Graduate Institute of Electronic Engineering and Department of*
Electronic Engineering,National Taiwan University of Science and Technology

Outline

- Introduction
- Existed Simulation Tools
- Optical Field Analysis and Numerical Calculation & Three Cases
- Conclusion
- Reference
- Appendix:

  Model Math Equations

output waveform
vs.
internal optical field pattern

Introduction

- Investigate the mode beating self-pulsation in a two-section distributed feedback (TS-DFB) laser.
- Study the relationship between output waveform and optical field patterns for with/without AR-coating cases.
- It is more **difficult to measure the internal variation inside the device**, especial for the internal optical field analysis in space distribution and in time domain.
- **What is the relationship between output waveform and internal optical field pattern?**

Existed Simulation Tools

- OptiSystem
    - Optical communication system
    - Providing laser module
    - No self-pulsating simulation
- OptiSim
- VPItransmissionMaker WDM VPIcomponentMaker Active Photonics
    - Optical communication system
    - Providing laser module with detailed parameters
    - Transmission Line Laser Model
    - **Providing self-pulsating simulation output waveform**

Optical Field Analysis and Numerical Calculation

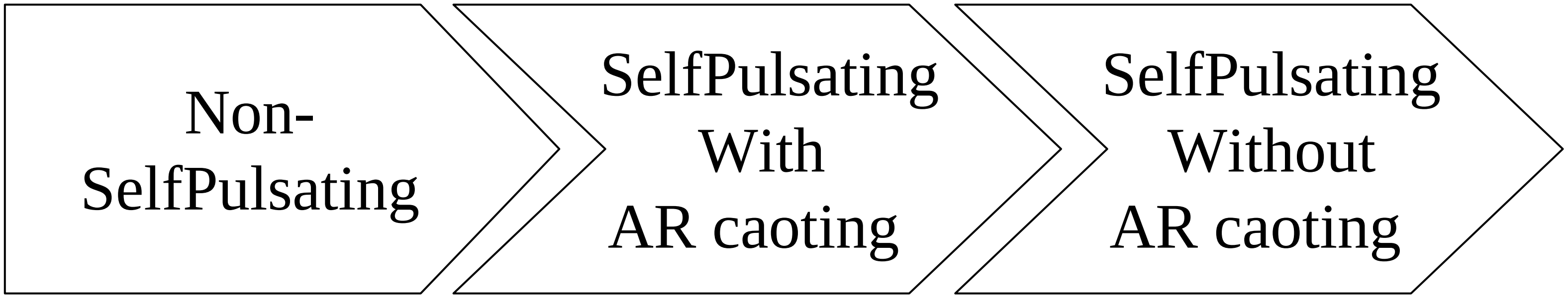
1. **Finite-Difference method** works well for laser, with spectral mixing, or with noise.
2. The typical field patterns for the DFB with **λ/4 phase shift have a peak** on the location of phase shift.
3. The finite difference method could be also applied to **analyze the multi-section DFB**. In addition, setting different section length will create mode depression.

Optical Field Analysis and Numerical Calculation

4. In a clock source, the excitation is due to random ‘spontaneous noise’. Hence, the outputs are **not precisely the same for run-to-run, or iterations**.
5. The result traces of iteration-to-iteration could be calculated, and **the accumulative field pattern of all iterations could be visualized**.
6. It is interesting to view the difference between optical field under **non-self-pulsation and optical field under self-pulsation**.

Optical Field Analysis and Numerical Calculation

7. For the former, the **output is stable**. Hence, it is intuitional to image that the optical field should be more stable. That is, for different calculation iterations, the optical field patterns in space should be “**almost over-lapped (Case1)**”.
8. For the latter, we consider **two branches: anti-reflective (AR) coating and natural facets**.

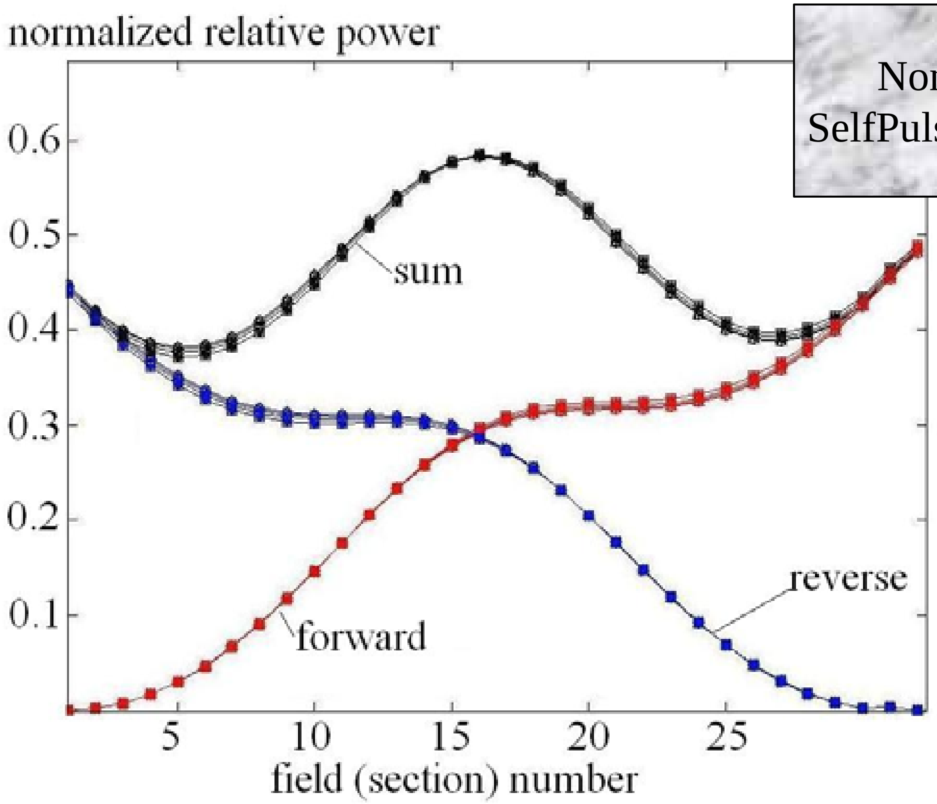


Non-SelfPulsating

SelfPulsating With AR caoting

SelfPulsating Without AR caoting

Optical Field Analysis and Numerical Calculation **Case1**



Non-SelfPulsating

SelfPulsating With AR caoting

SelfPulsating Without AR caoting

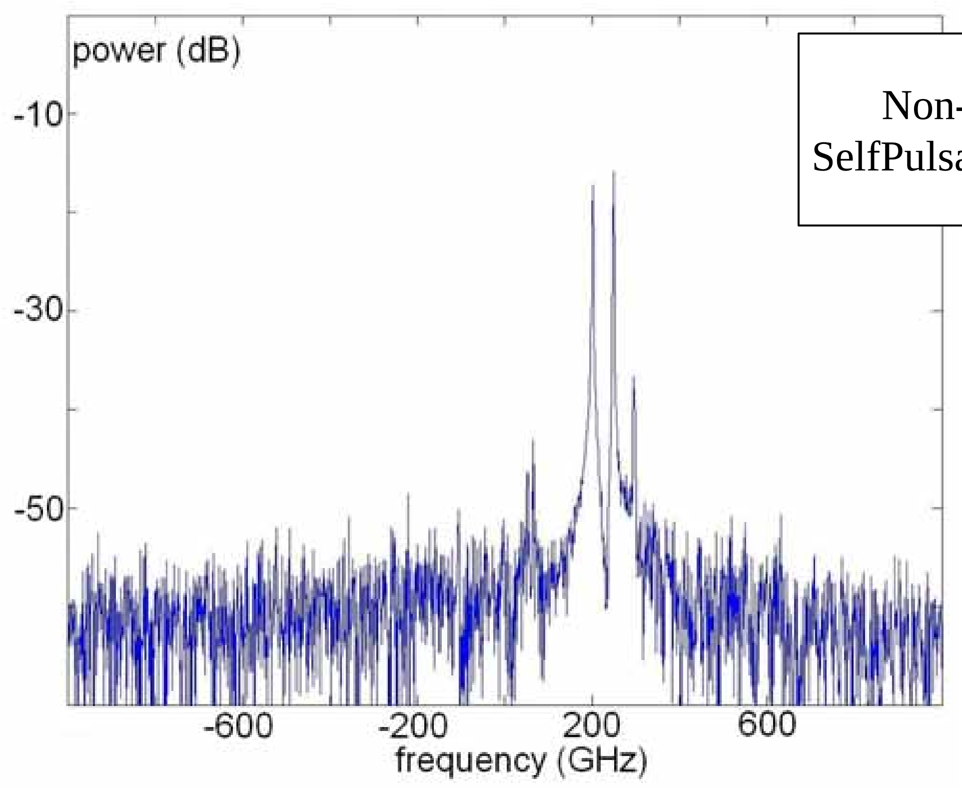
almost over-lapped

- Calculated normalized space optical field (normalized relative power) for the proposed TS-DFB without self-pulsation, including forward field (from left to right, the leftest point has smallest field), reverse field (from left to right, the leftest point has largest field), and **sum field**.

Optical Field Analysis and Numerical Calculation

9. The internal optical field patterns should be dynamic for each periodic waveform; that is, it is difficult for the optical field patterns in space to be almost over-lapped. **Instead, it is changed (Case2)**.
10. A TS-DFB may be processed with AR coating on both facets. Otherwise, the reflective effect from **natural facets should be considered (Case3)**.

Optical Field Analysis and Numerical Calculation **Case2**



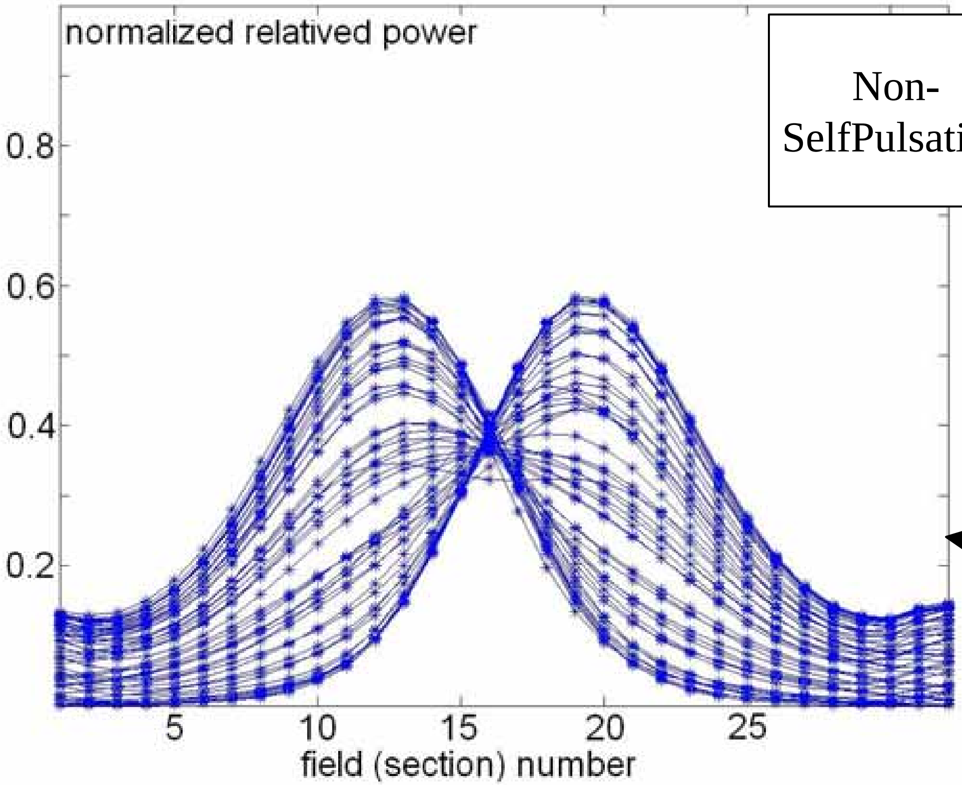
Non-SelfPulsating

SelfPulsating With AR caoting

SelfPulsating Without AR caoting

- Calculated normalized optical power spectrum for TS-DFB (with AR-coating) **mode-beating mechanism** under self-pulsation **for long time simulation**. The central wavelength is 1550nm.

Optical Field Analysis and Numerical Calculation **Case2**



Non-SelfPulsating

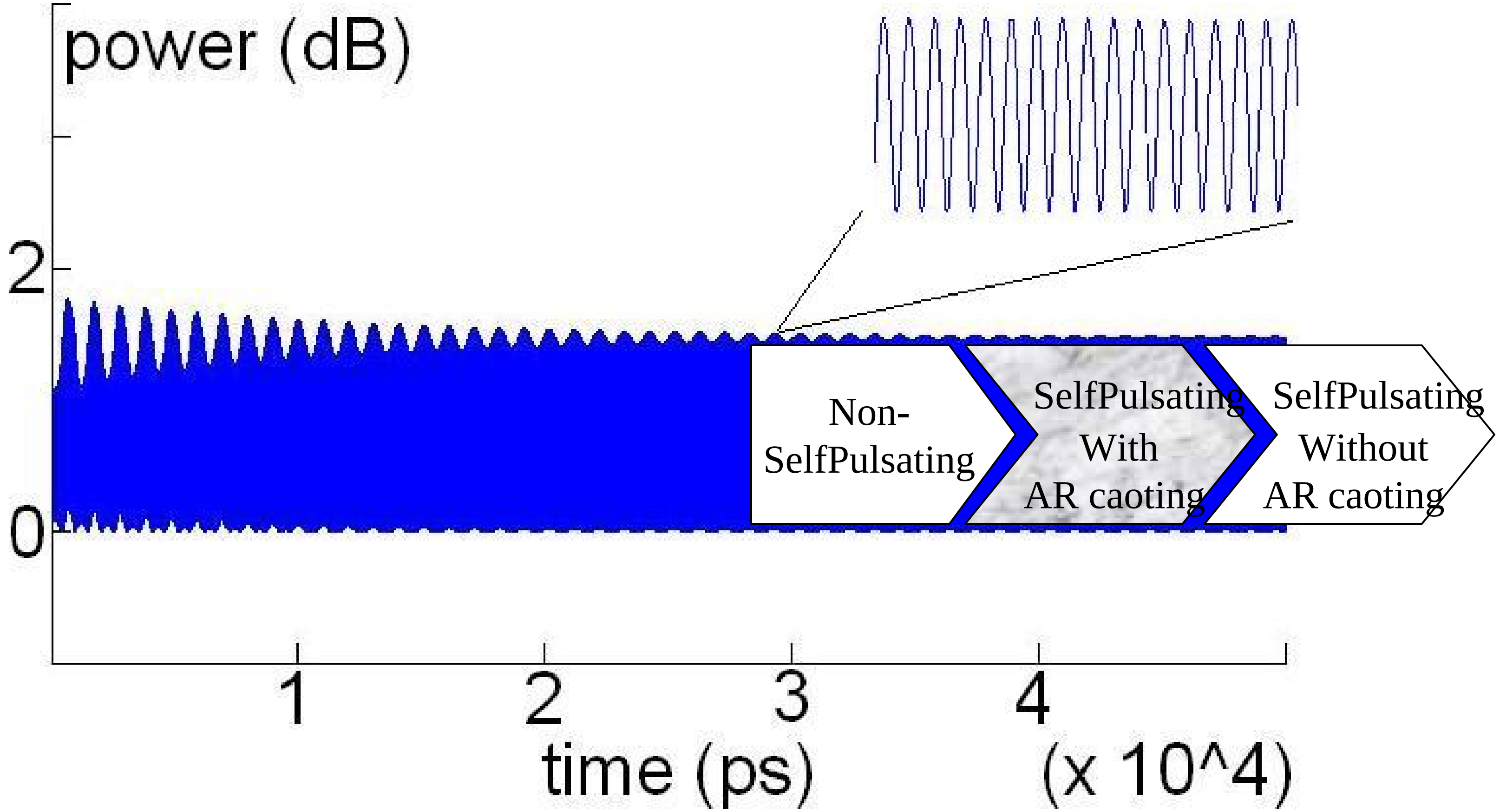
SelfPulsating With AR caoting

SelfPulsating Without AR caoting

mountain-peak-swinging

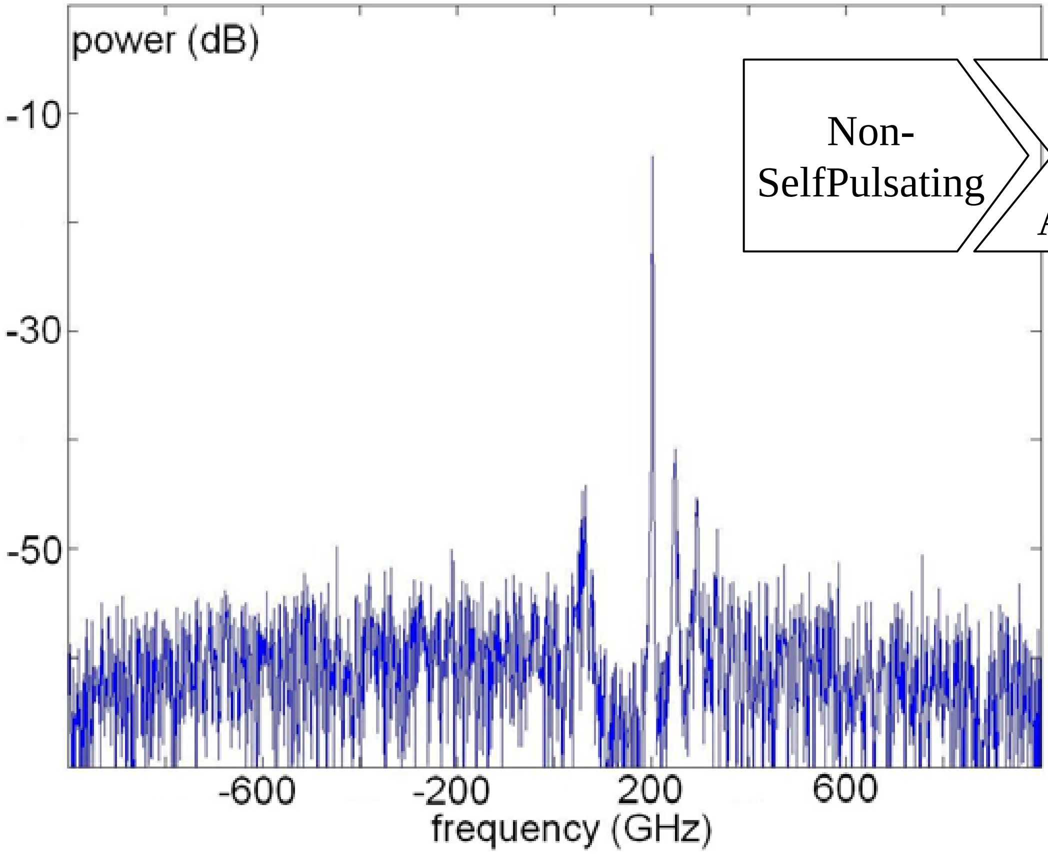
- Calculated normalized space optical sum field (normalized relative power) for TS-DFB including AR-coating, with mode-beating mechanism, and under self-pulsation **for long time simulation**. Two optical fields for “**mountain-peak-swinging**” could be observed.

Optical Field Analysis and Numerical Calculation **Case2**



- Calculated normalized periodic optical output waveforms and its detail for TS-DFB mode-beating mechanism, under self-pulsation **for long time simulation**. The pulsation period is **25ps (40GHz)**.

Optical Field Analysis and Numerical Calculation **Case3**



Non-SelfPulsating

SelfPulsating With AR caoting

SelfPulsating Without AR caoting

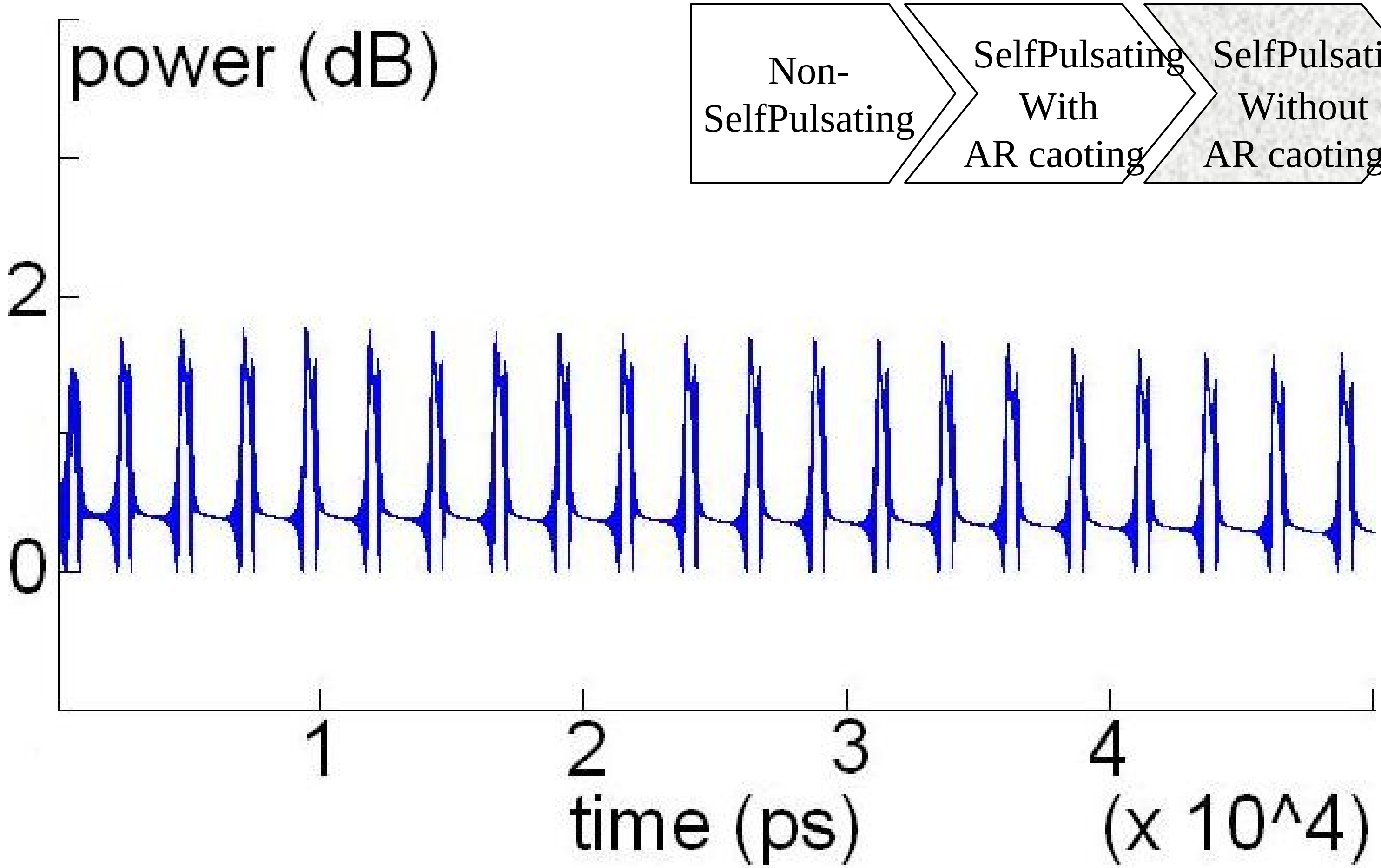
- Calculated normalized optical power spectrum for TS-DFB (with natural facets) under self-pulsation **for long time simulation**.

Optical Field Analysis and Numerical Calculation **Case3**

Non-SelfPulsating

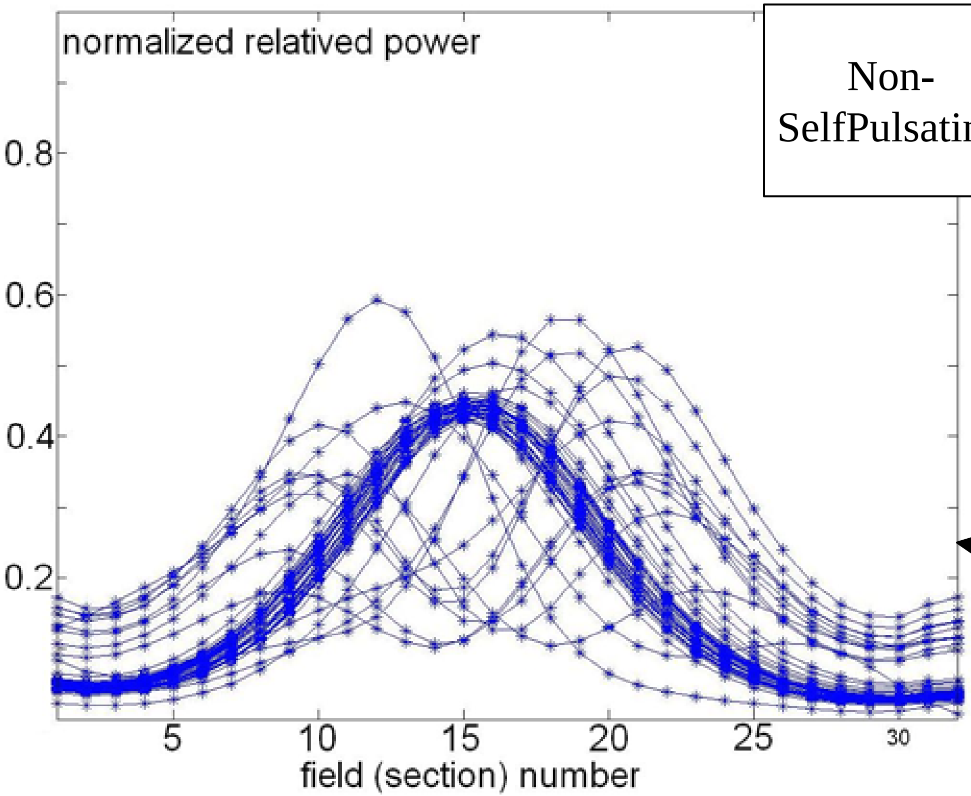
SelfPulsating With AR caoting

SelfPulsating Without AR caoting



- Calculated normalized periodic optical output waveforms for TS-DFB (no AR-coating) , under self-pulsation **for long time simulation**.

Optical Field Analysis and Numerical Calculation **Case3**



Non-SelfPulsating

SelfPulsating With AR caoting

SelfPulsating Without AR caoting

Mixing (Combination)

- Calculated normalized space optical sum field (normalized relative power) for the TS-DFB **including natural facets**, under self-pulsation **for long time simulation**. **Mixing “almost over-lapped” and “mountain-peak-swinging” could be observed**.

Conclusion

- We first apply the Finite-Difference method to DFB internal optical field patterns to study the stable output case.
- Then we analyze the internal optical field patterns of TSDFB under self-pulsation; and our results show that the field patterns also vibrate between two peaks from run-to-run.
- Finally, the difference effect between AR-coating and the natural facets also has been studied.
- In short, **the relationship between output waveform and internal optical field pattern** has been studied.

Reference

- *Sartorius.B, et.al,.*"Dispersive self-Q-switching in self-pulsating DFB lasers," IEEE Journal of Quantum Electronics, *Vol.33, No.2, pp.211-218, Feb 1998.*
- *Marcenac.D.D, et.al,.*"Distinction between multimoded and singlemoded self-pulsations-in DFB lasers," IEEE Electronics Letters, *Vol.30, No.14, pp.1137-1138, July 1994.*
- *John Carroll, et. al.. 'Distributed Feedback semiconductor lasers', chap.7 (1998).*

Appendix: Model Math Equations

$$\frac{1}{\upsilon_g}\frac{\partial F}{\partial t}+\frac{\partial F}{\partial z}=j\kappa R+(g-j\delta)F+i_{spf}$$

$$\frac{1}{\upsilon_g}\frac{\partial R}{\partial t}-\frac{\partial R}{\partial z}=j\kappa F+(g-j\delta)R+i_{spr}$$

$$\begin{bmatrix} F\{(T+1),(Z+1)\} \\ R\{(T+1),Z\} \end{bmatrix}=\exp\{(g-j\delta)s\}\begin{bmatrix} \cos\theta & j\sin\theta \\ j\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} F\{(T,Z)\} \\ R\{T,(Z+1)\} \end{bmatrix}$$

$$\approx\left(\frac{2+gs-j\delta s}{2-gs+j\delta s}\right)\begin{bmatrix} \sqrt{1-\kappa^2 s^2} & j\kappa s \\ j\kappa s & \sqrt{1-\kappa^2 s^2} \end{bmatrix}\begin{bmatrix} F\{(T,Z)\} \\ R\{T,(Z+1)\} \end{bmatrix}$$

$$\sin\theta=\frac{\kappa s}{1+\frac{1}{4}\kappa^2 s^2}\approx\kappa s \quad \cos\theta\approx\sqrt{1-\kappa^2 s^2}$$