OPTICAL AND ELECTRICAL CHARACTERISTIC OF VERTICAL-CAVITY SURFACE-EMITTING LASER FOR FREE SPACE OPTICAL COMMUNICATIONS

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Outline

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- What is the motivation?
- Research objectives
- Introduction to optical feedback
- Theoretical analysis
- Research results and measurements
- Contributions of the work
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- Conclusion

Introduction

Vertical cavity surface emitting lasers (VCSELs) **are relatively recent type of semiconductor laser** (SL) devices, which are attractive for a number of application from sensor to telecommunications systems

VCSEL properties

- VCSEL can operate at a **higher data rate up to 57 Gbit/s, low manufacturing cost**, **wavelength stability** (from infrared to visible light), **high reliability**, **small beam divergence**, **low threshold current, circular output beam**, which allows for good coupling efficiency with optical fibre, **small diverging angle**, single laser mode output, **High modulation bandwidth ,** Life time of the devices are several million hours under normal operating condition.

VCSELs present a number of shortcomings, including **polarization instability** also known as **polarization switching** (PS) and resistance heating, **nonlinearity behaviours**

One of the major limiting factors of optical devices when used in analogue communication systems is that the nonlinearity behaviours, which can significantly limit the device performances and ultimately the link performance

Research Motivation

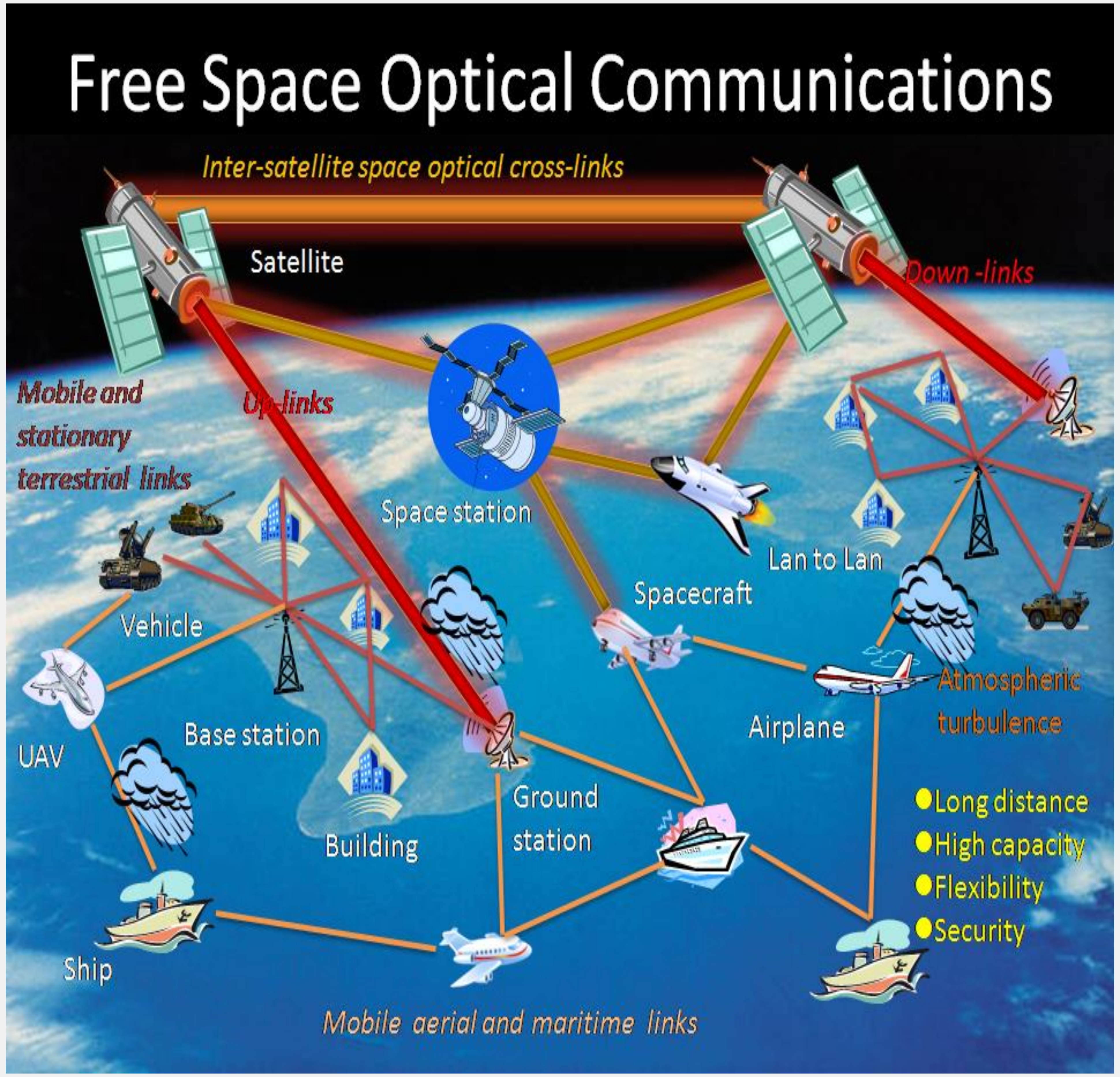
Free space optical (FSO) communication links need to provide;

- **High-speed**
- **Reliable wireless device**
- **Output-power stability**
- **Cost-effectively**

Security Issues in Communication Systems

A crucial issues in VCSELs are the need for ;

- **1- Improving the polarization modes properties** such as polarization switching, relative intensity noise, etc.
- **2- Control the output polarization instability** and **the nonlinearity** of the polarization modes
- **Generated and controlled the chaotic dynamics** through both synchronization phenomena and the polarization-rotated OF



Heterogeneous Communications Networks and Imaging

Research Objectives

- **VCSELs are sensitive to the optical feedback (OF**) and optical injection due to their higher mirror reflectivity inside the laser cavity

- **OF can lead to a number interesting complex dynamic behaviors in VCSELs** including **chaotic**, time-period pulsing dynamics and **polarization switching**.

- **Variable Polarization Optical Feedback** (VPOF) is used to characterised the polarization modes properties of VCSEL

- The VPOF is used with the modulation signal to investigate; **L-I characteristics**, **polarization switching**, **RIN**, **bi-stability**, **hysteresis properties**, **nonlinearity behaviours** and **chaotic dynamics**

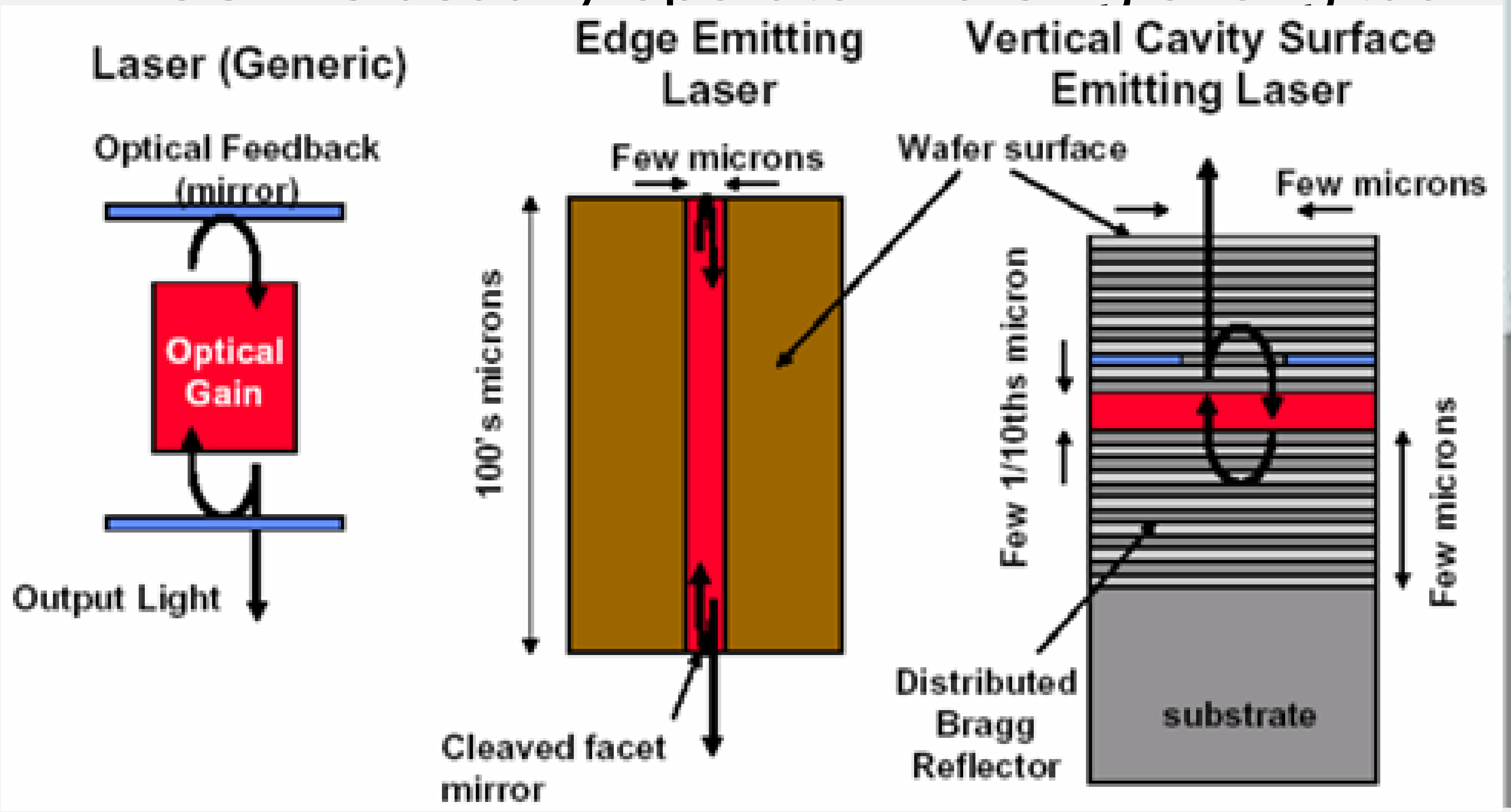
VCSEL concepts and operating principles

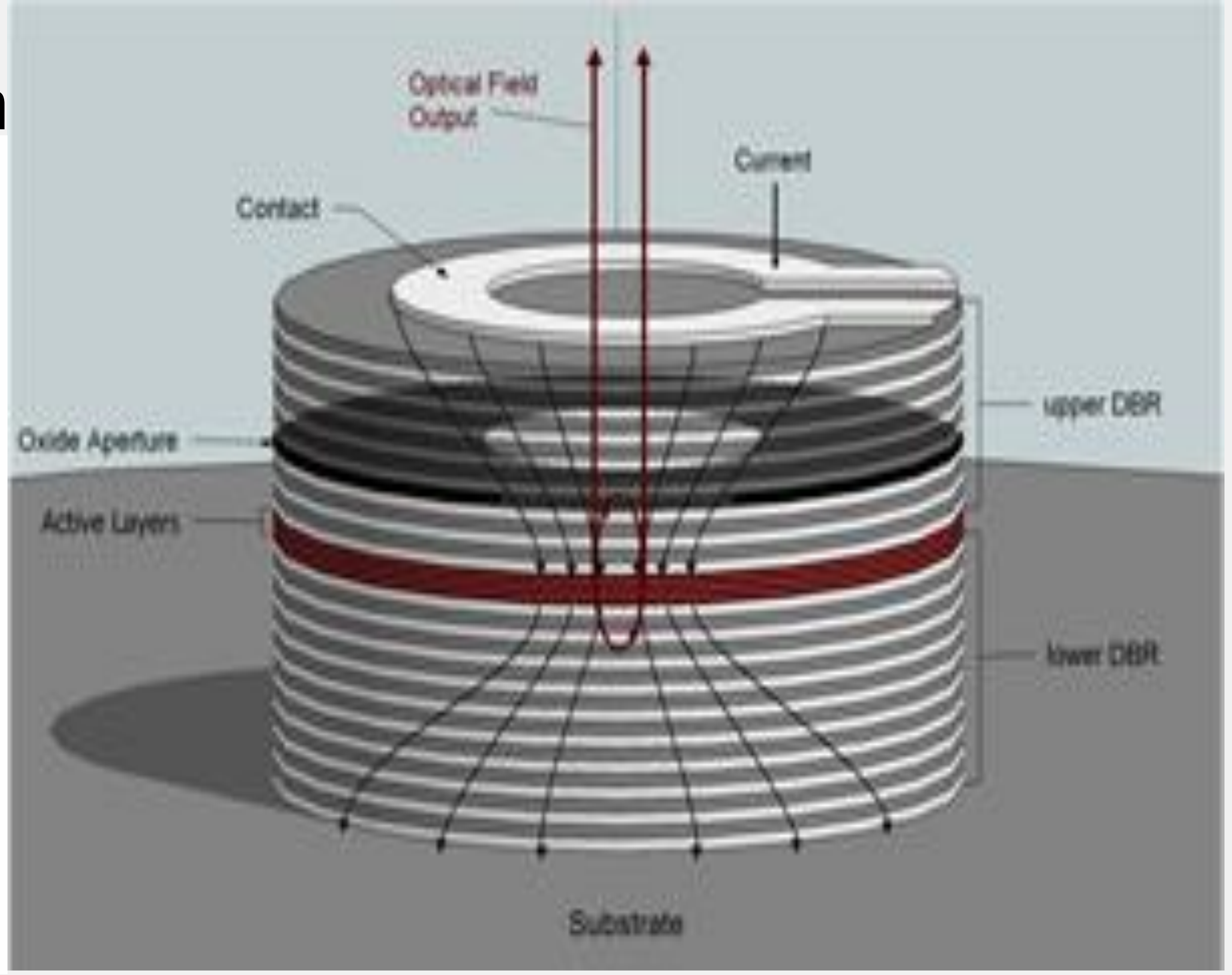
- VCSELs usually consist of Distributed Bragg Reflectors (DBRs)

- Active layer

- lasing activity in a VCSEL requires a DBR reflectivity exceeding 99 %.

- VCSELs usually operate in a single longitudin





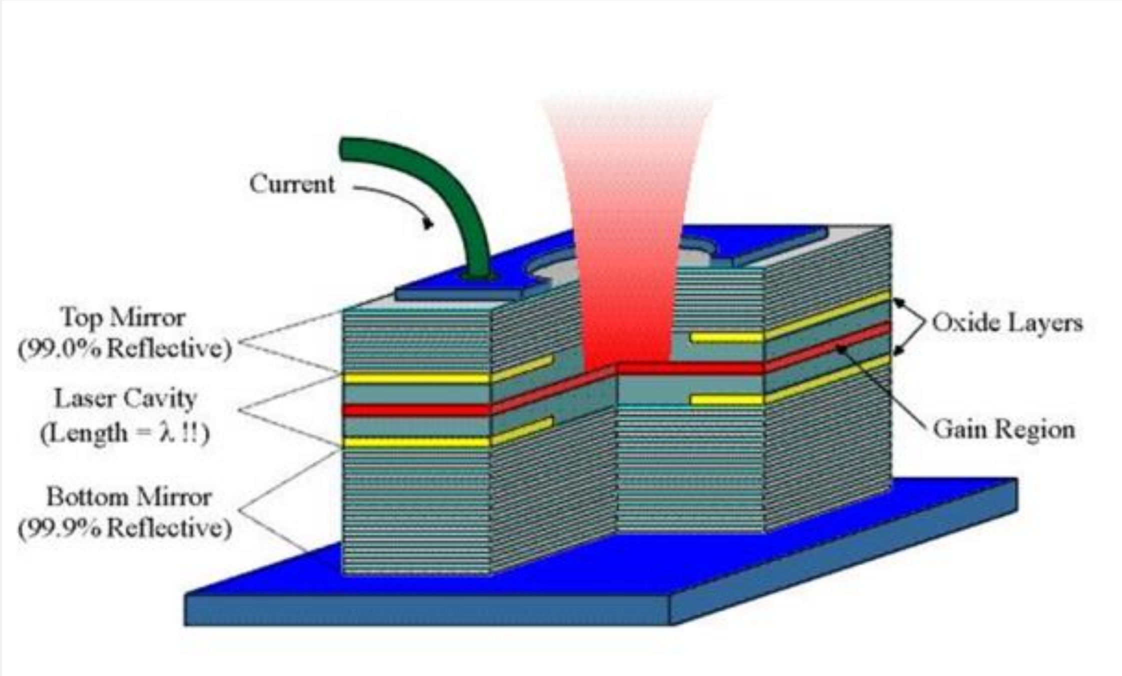
VCSEL structure & comparison with conventional lasers devices

- VCSEL offered many advantages compared with edge-emitting laser (EEL)

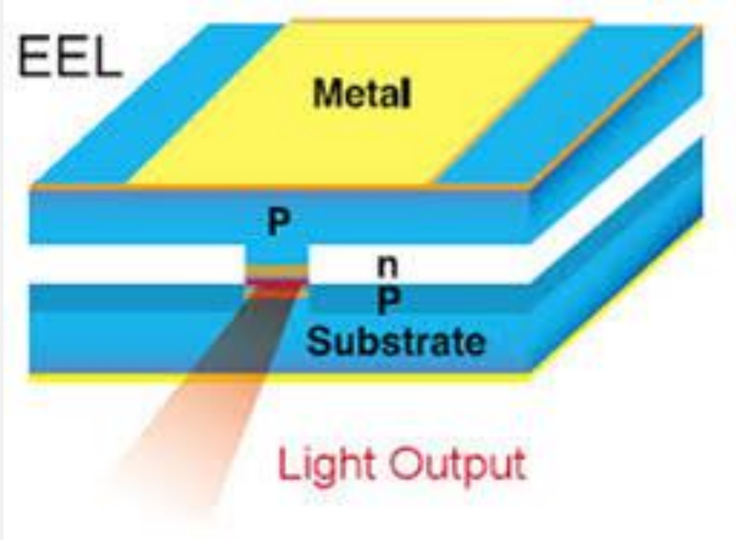
1. Lower manufacturing costs
2. Higher reliability
3. The lasing wavelength is very stable
4. The emission wavelength is ~5 times less sensitive to temperature variations than in EEL
5. VCSEL devices can be operated without refrigeration
6. VCSELs emit a circular beam

Princeton Optronics, Inc. Electronics Drive Mercerville, New Jersey 08619

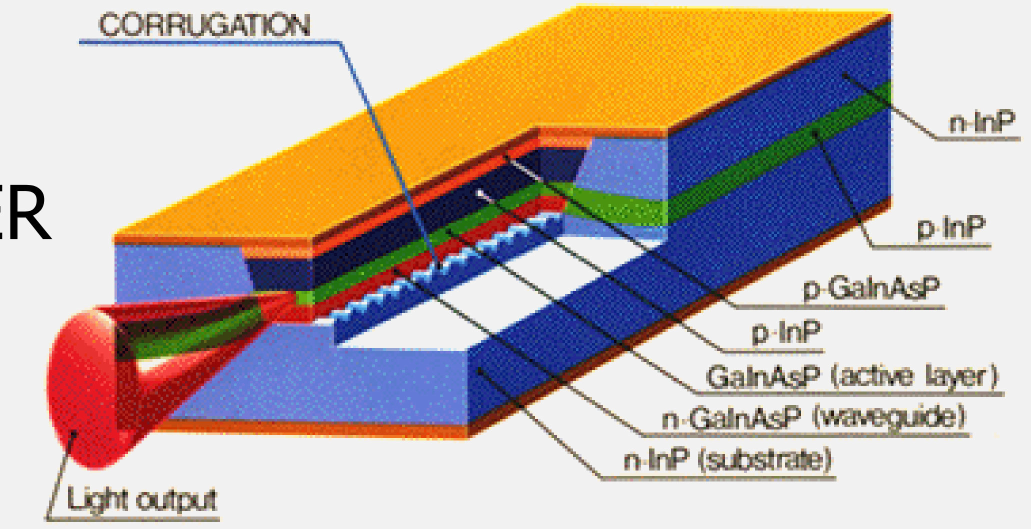
VCSEL



Edge Emitting LASER



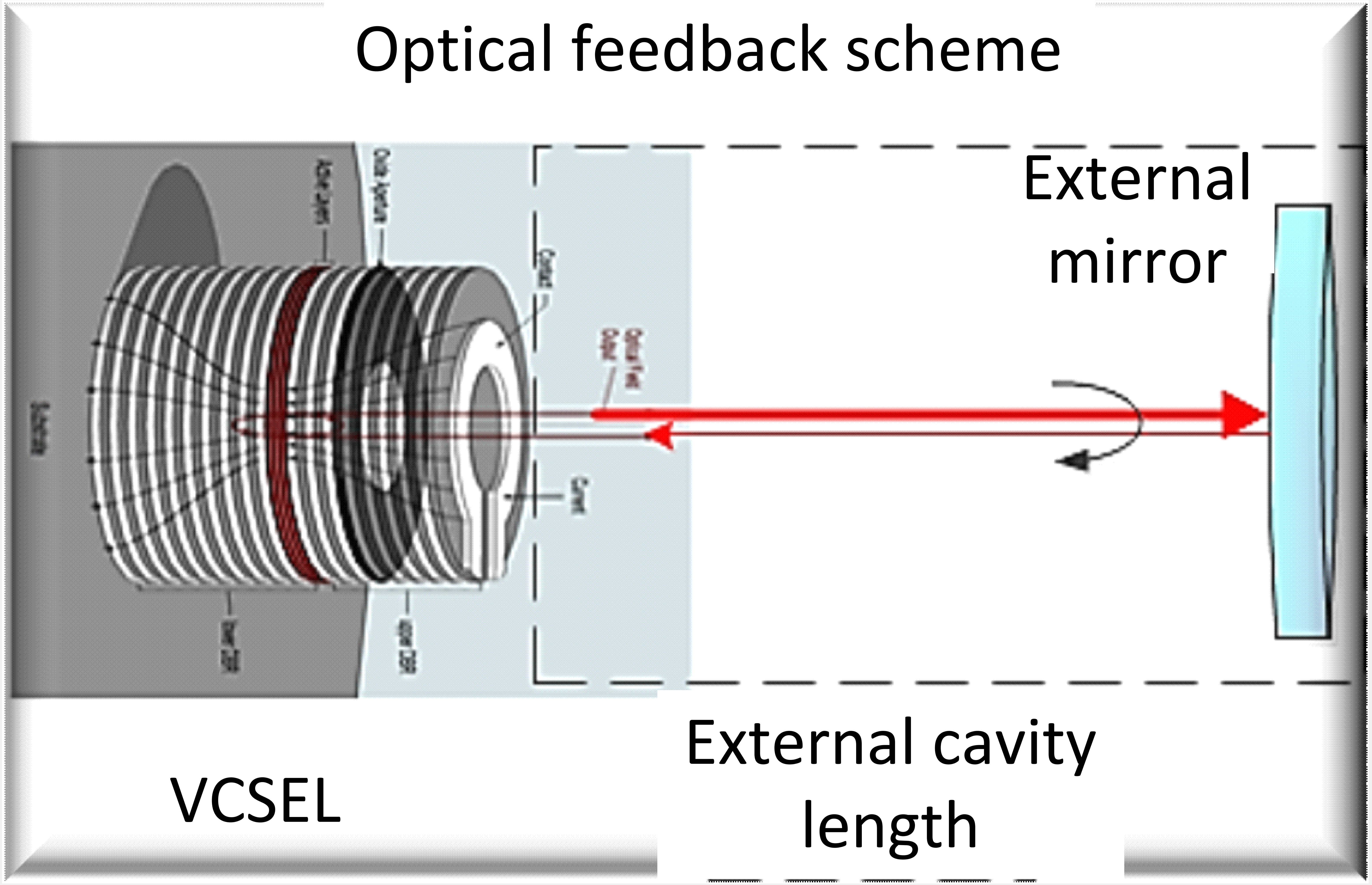
DFB LASER



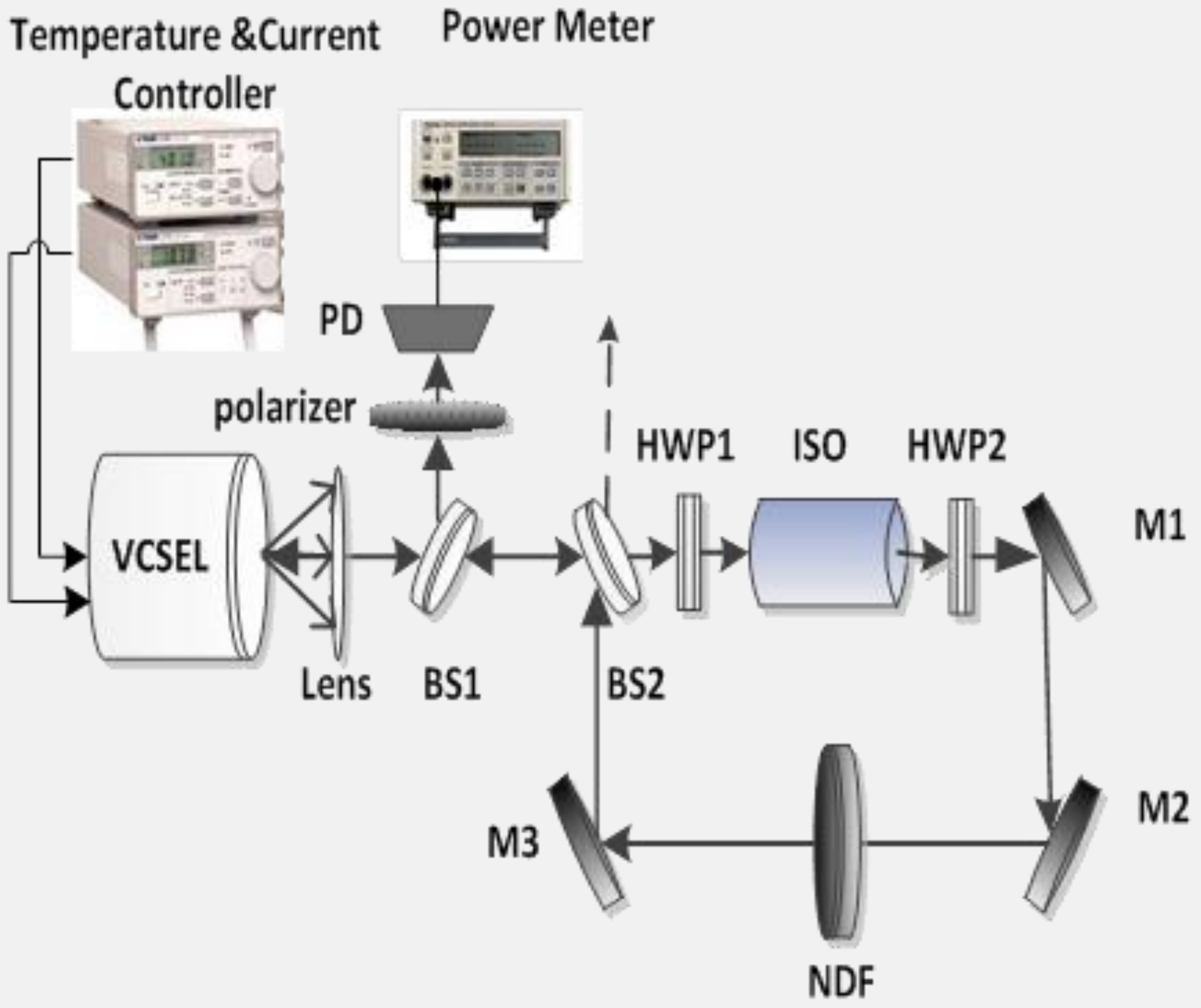
DFB LASER STRUCTURE

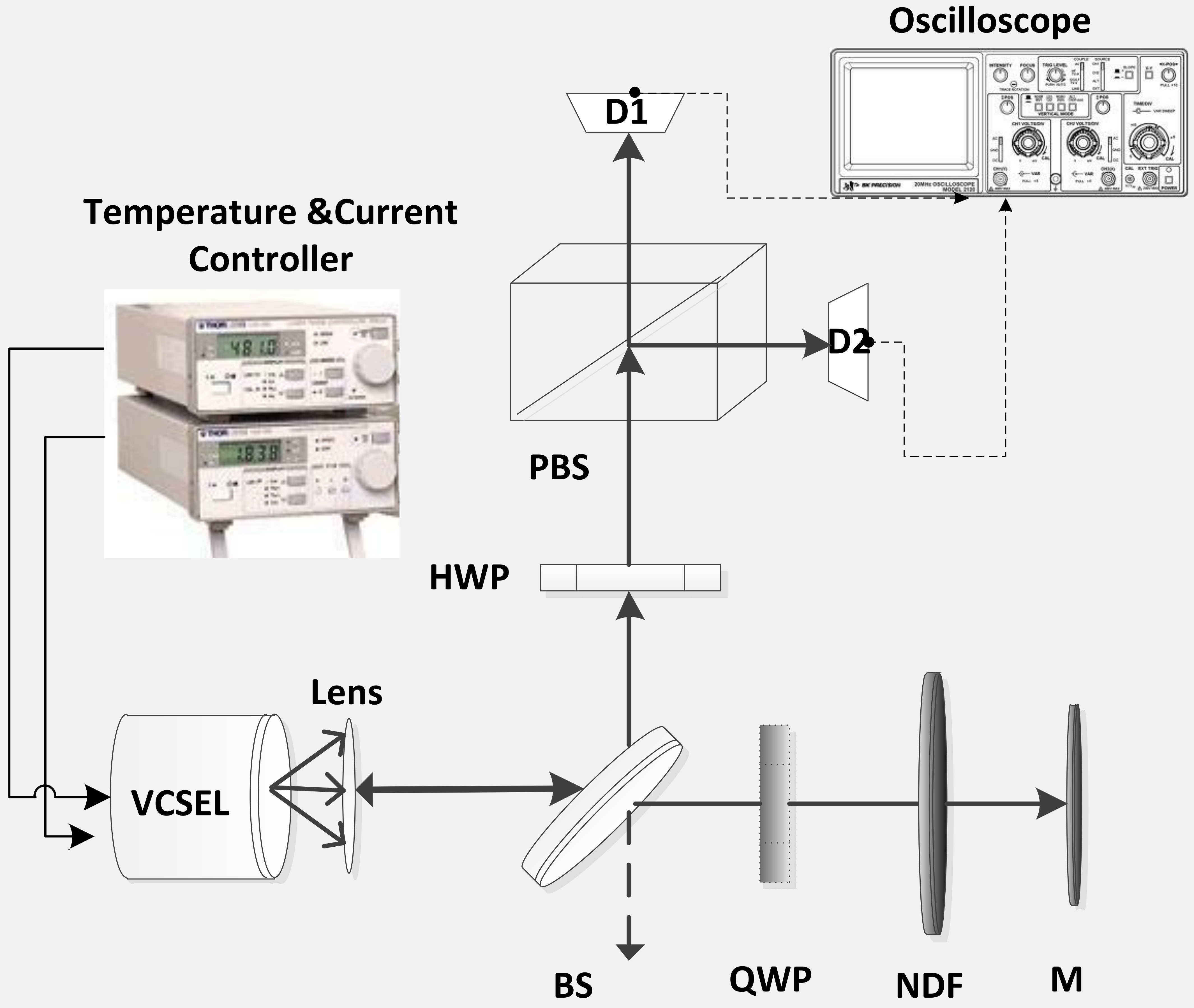
Optical feedback mechanism

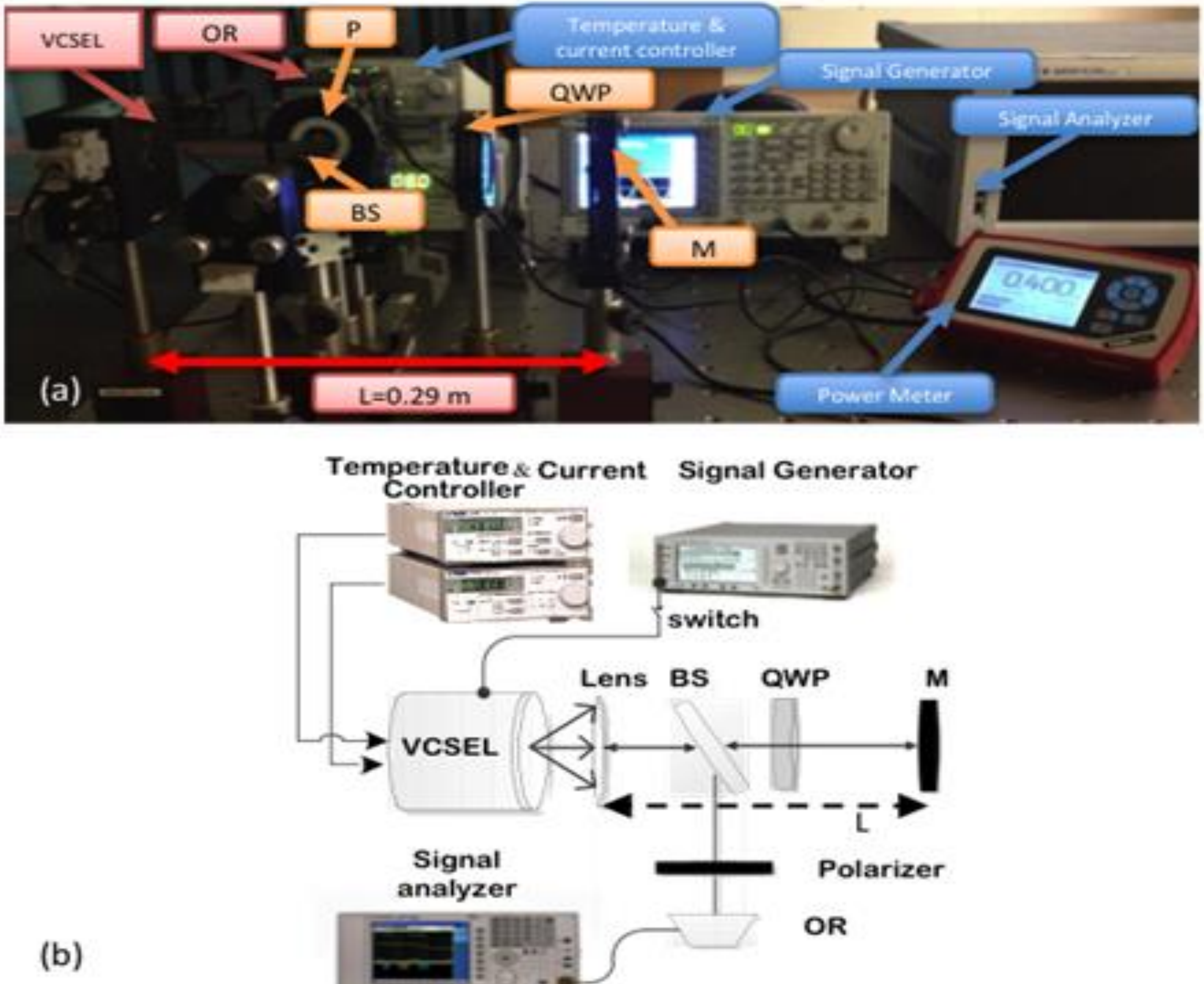
The reflected beam is called the optical feedback



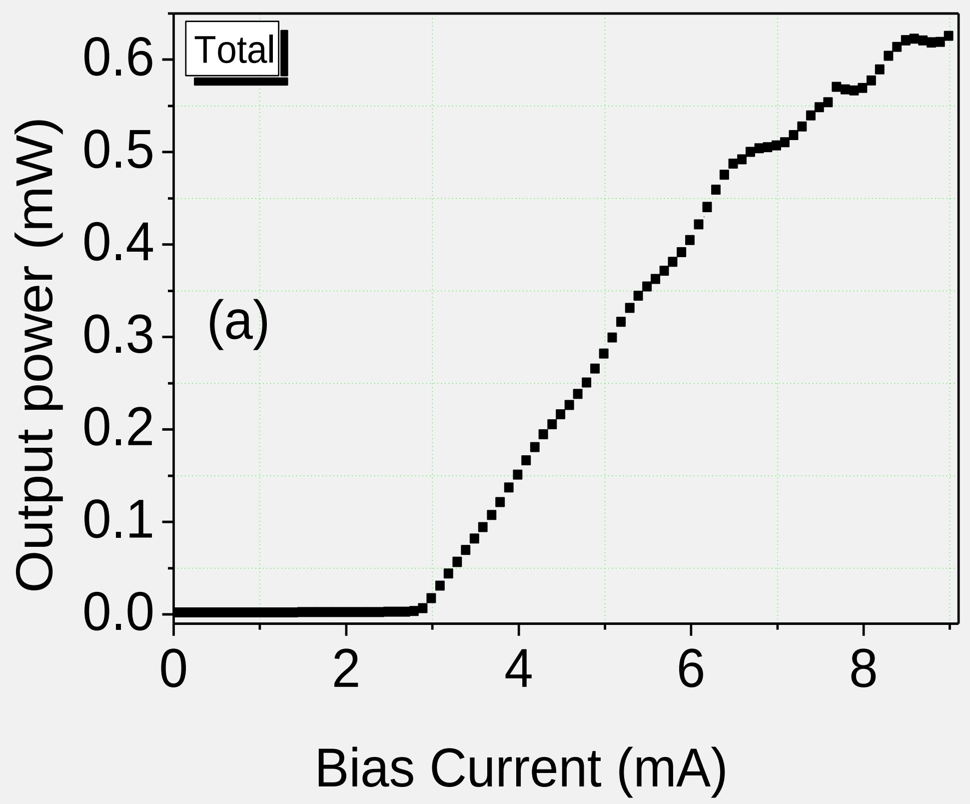
Optical Feedback Setup

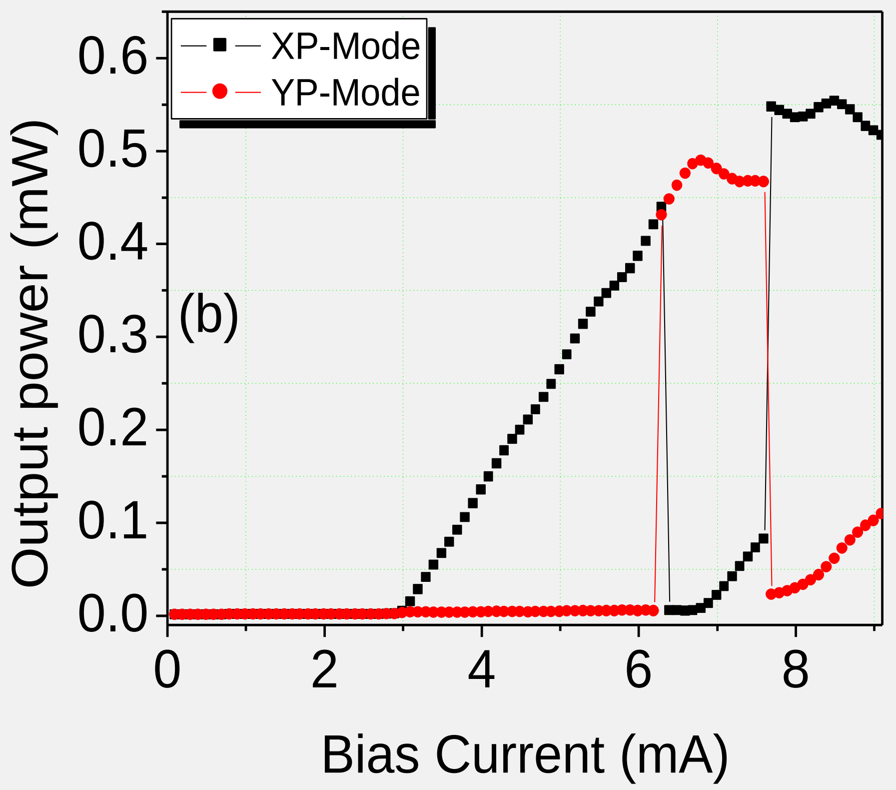





VCSEL
OR
P
Temperature &
current controller
QWP
Signal Generator
Signal Analyzer
BS
M
L=0.29 m
Power Meter
(a)
Temperature & Current
Controller
Signal Generator
switch
Lens
BS
QWP
M
VCSEL
L
Polarizer
Signal
analyzer
OR
(b)

Light-Current (L-I) Characteristics and Hysteresis Properties under VPOF





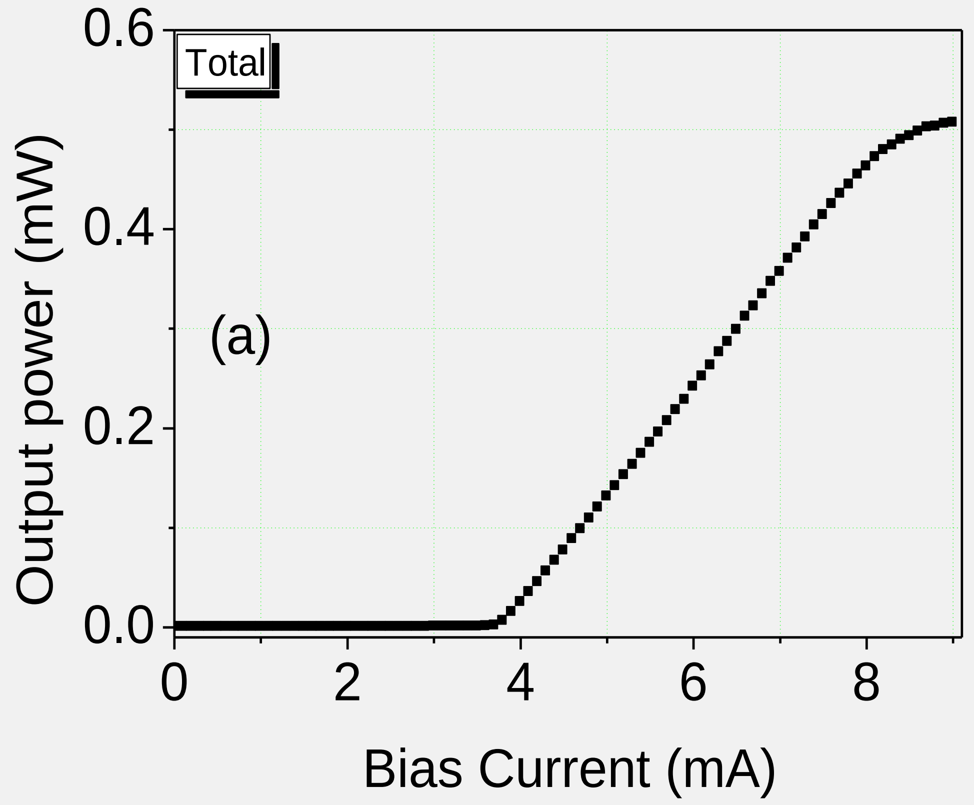
a) Nonlinearity in the total power of VCSEL

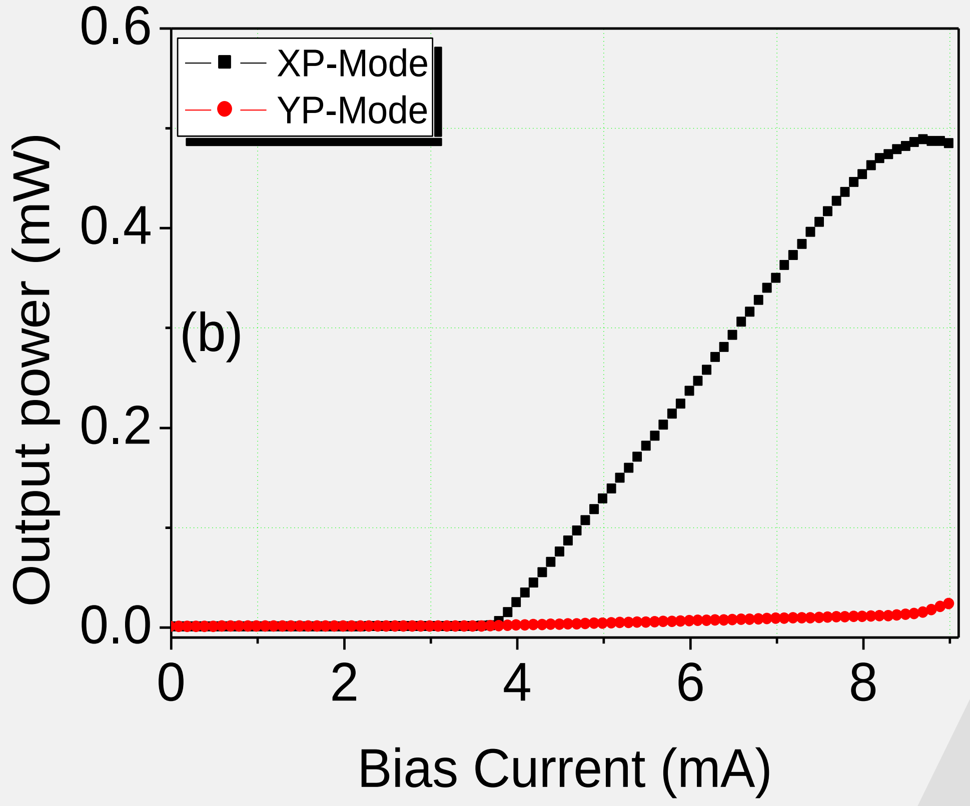
b) Polarization **instability or PS** of the polarization-resolved of VCSEL

Threshold current **reduction of** ~ 11.5% compared with that of standalone VCSEL with OF

VPOF induced Hysteresis cycles **beyond 45º of θ_p** with OF level greater than -8 dB

θ_{pd} of the PS was more sensitive to the feedback level than θ_{pu} of PS of the upward scan

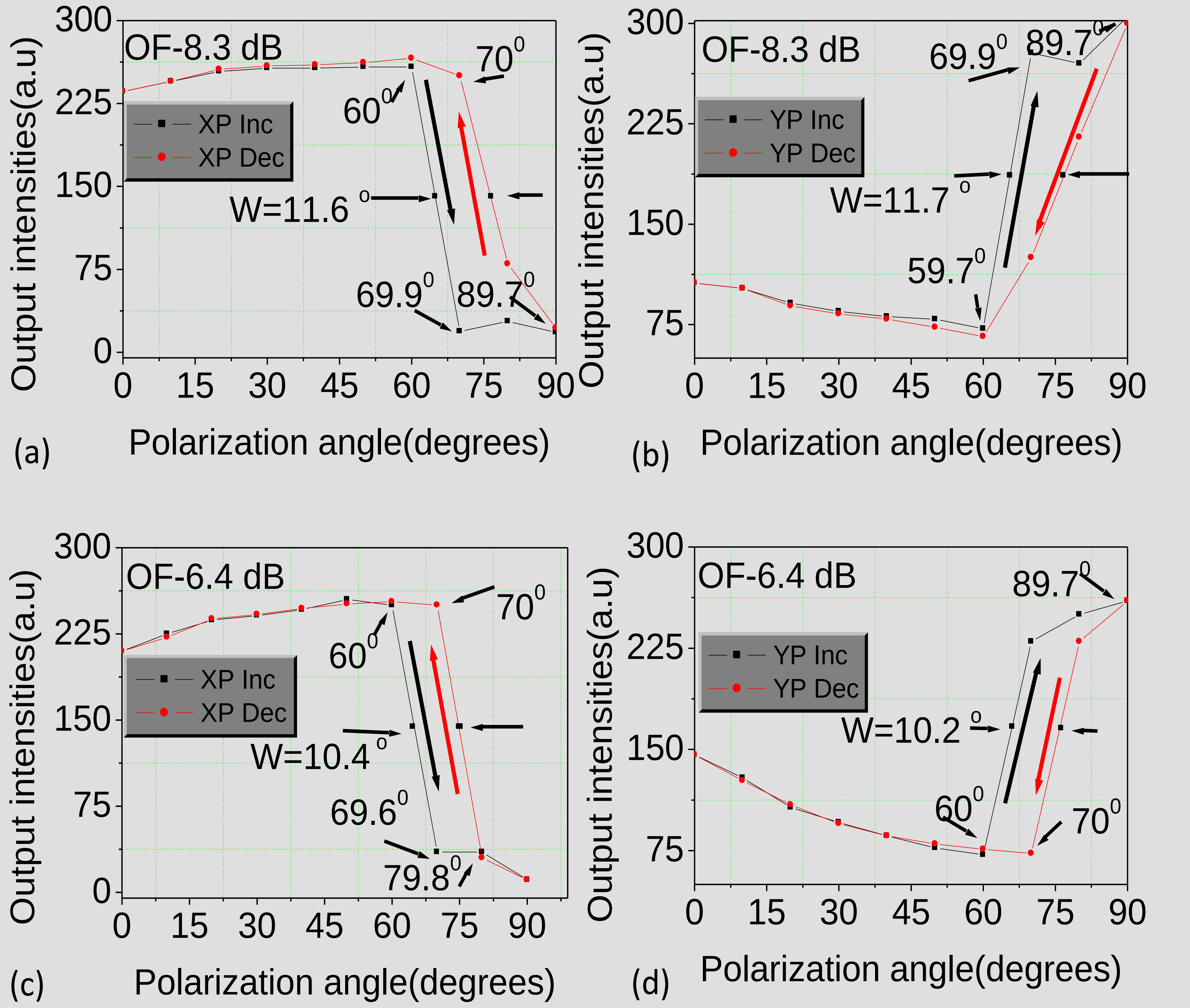




a) Total power of VCSEL

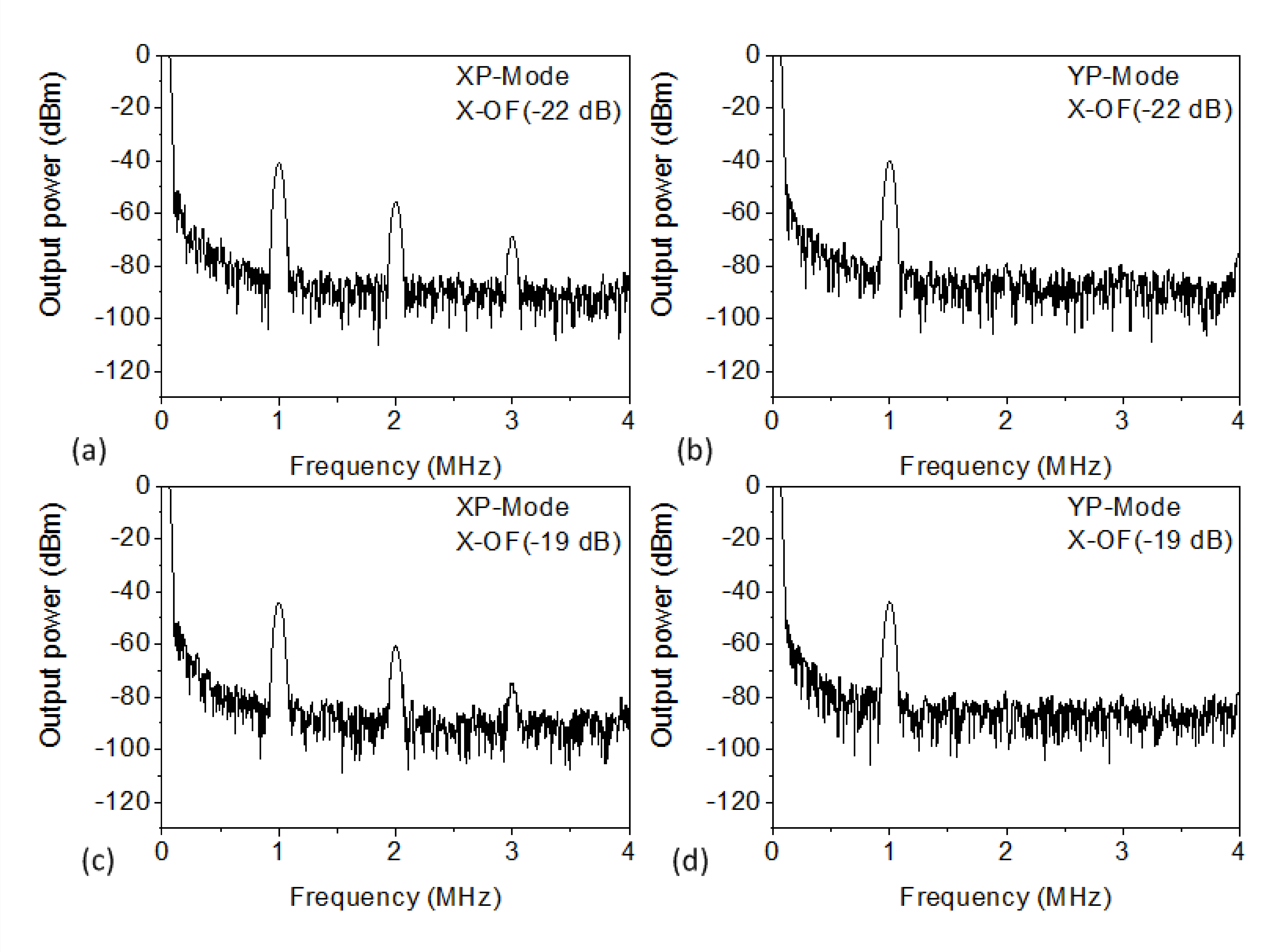
b) Polarization **stability** of the polarization-resolved of VCSEL

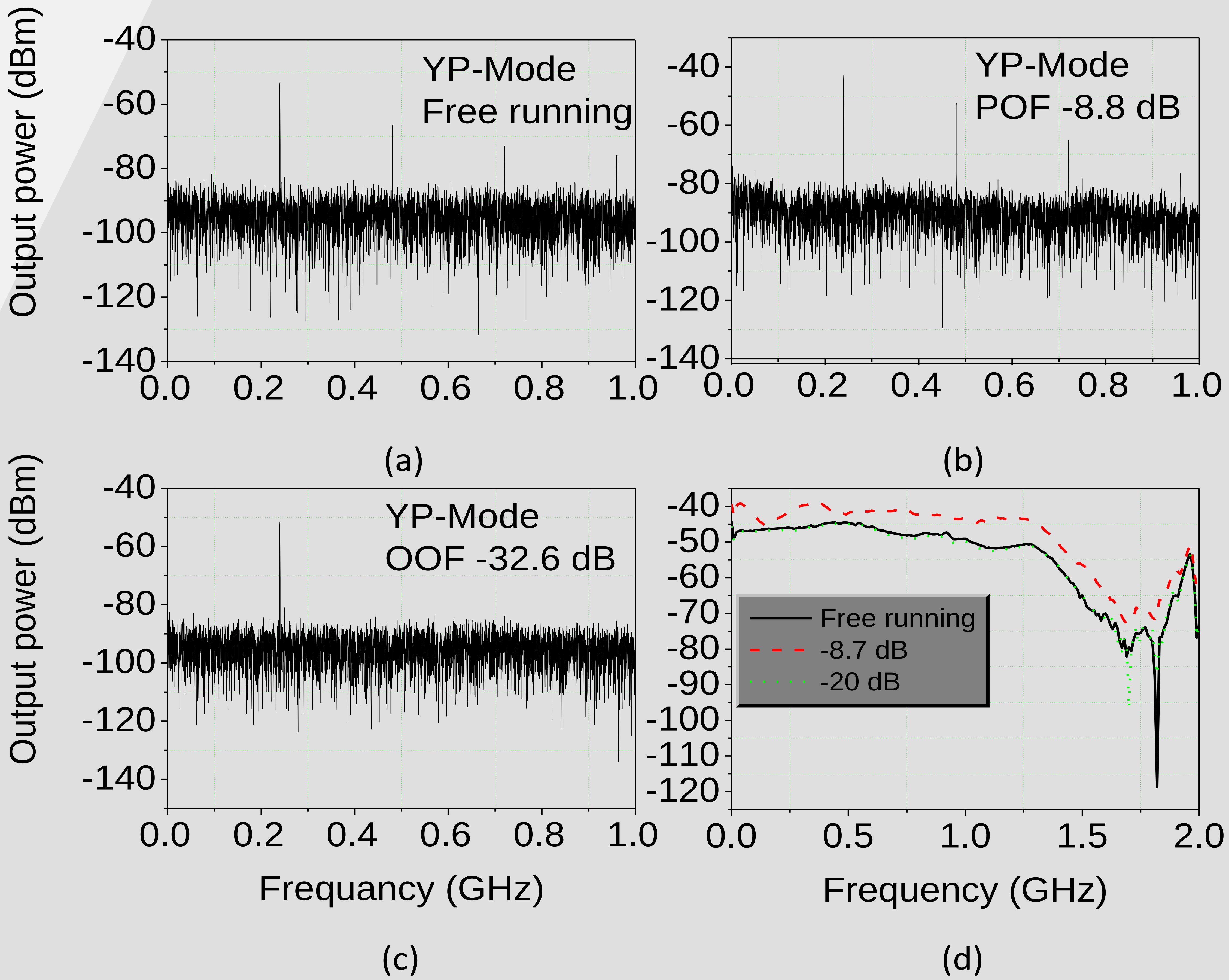
The **narrow** HL takes place at **higher OF level** and **wide** HL with **lower levels of OF**



Polarization-resolved intensities as a function of polarization angle, (a) , (c) the Xp mode, (b) and (d) the YP mode at -8.3 and -6.4 dB, respectively . The arrow down (up) corresponds to increasing (decreasing) θ_p

Nonlinearity behaviour and relative intensity noise investigation of VCSEL with VPOF



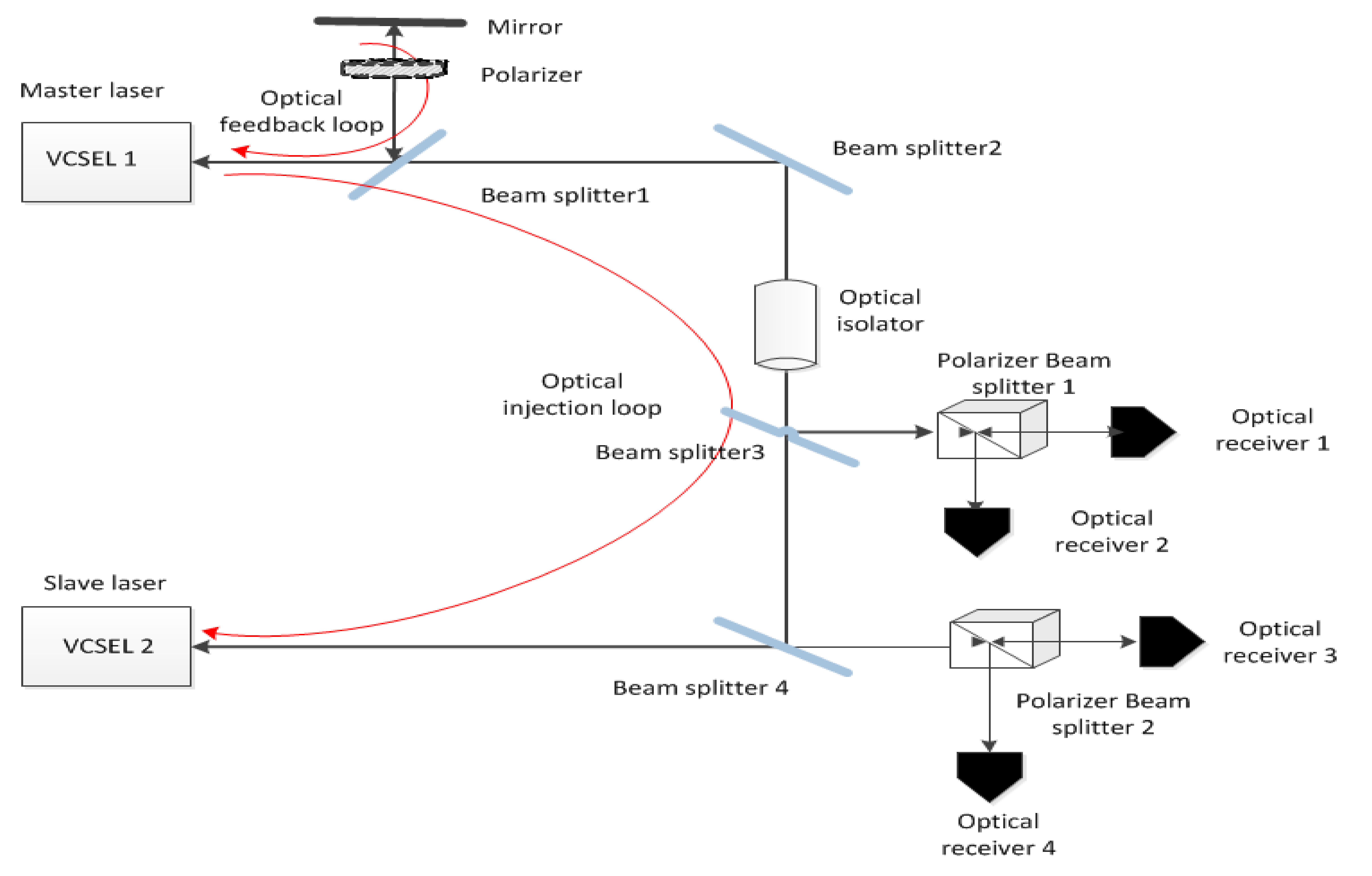


The frequency spectrum of the YP mode of VCSEL for: (a) free running, (b) POF of -8.8 dB, and (c) OOF of -32.6 dB. (d) The frequency response of the YP mode at a bias current of 3.6 mA with OOF.

- The 2nd, 3rd, 4th harmonics were completely suppressed and reached the noise floor when using the **orthogonal optical feedback**
- The modulation bandwidth is **enhanced by ~140** MHz compared with that of the free running VCSEL

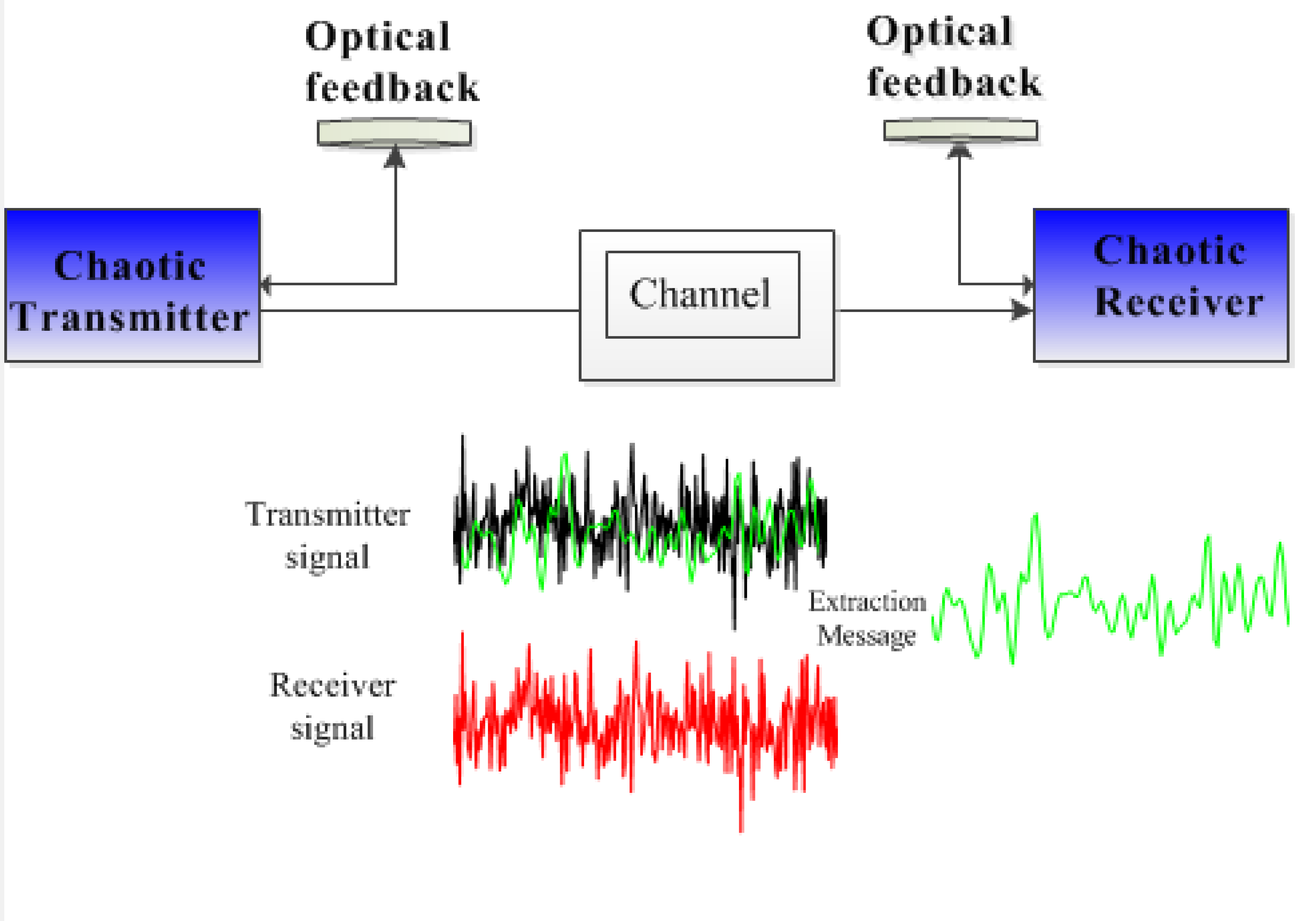
Based on the results of published papers in PTL /IEEE & applied physics Journals 2015, 2016

Chaos communication system



Transmitter-Receiver Laser chaotic communication Configuration

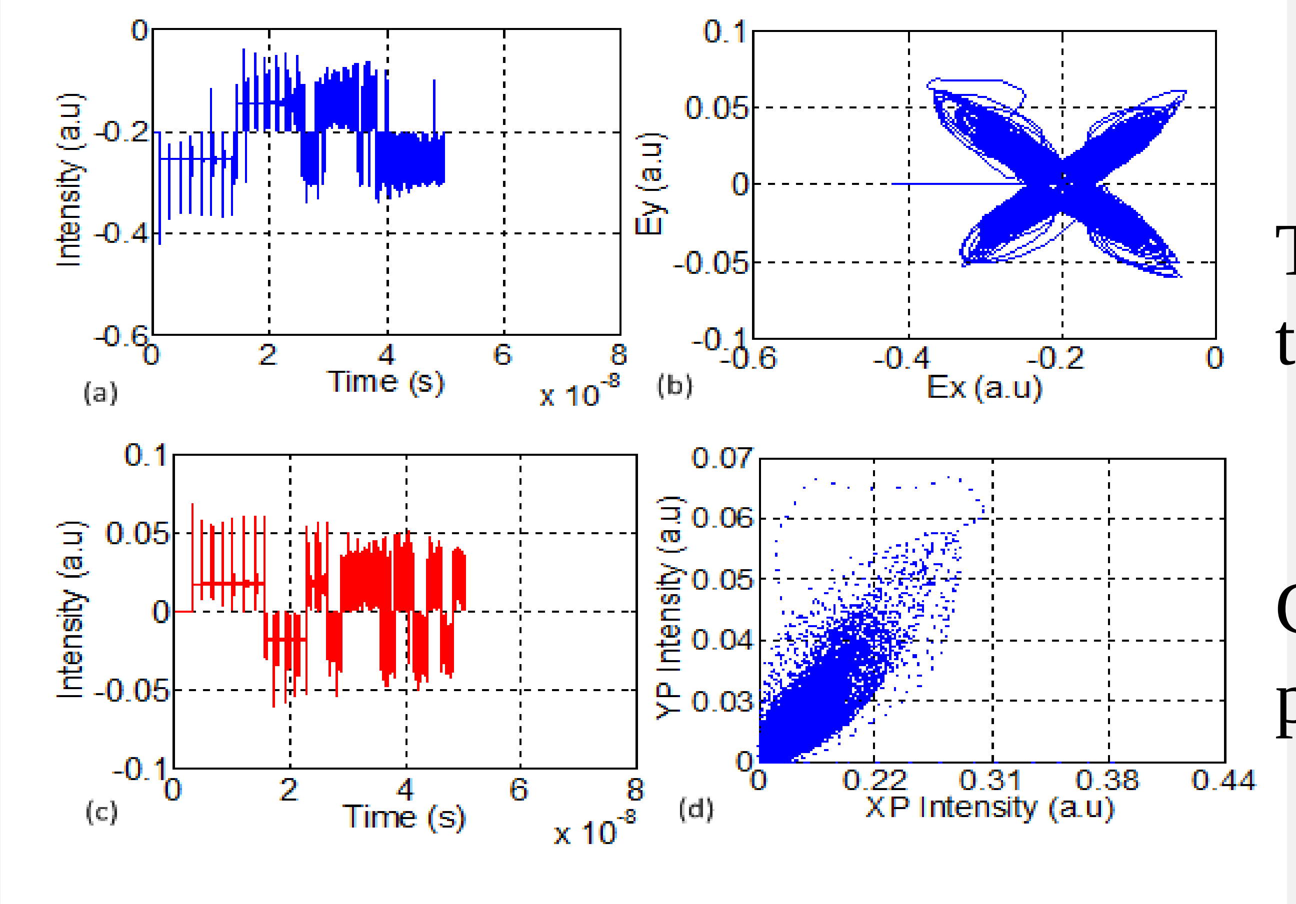
Chaos synchronization



Using the PROF setup the emission of the laser is split into its two linearly polarized components but only one is fed back into the laser after being rotated in the orthogonal polarization direction.

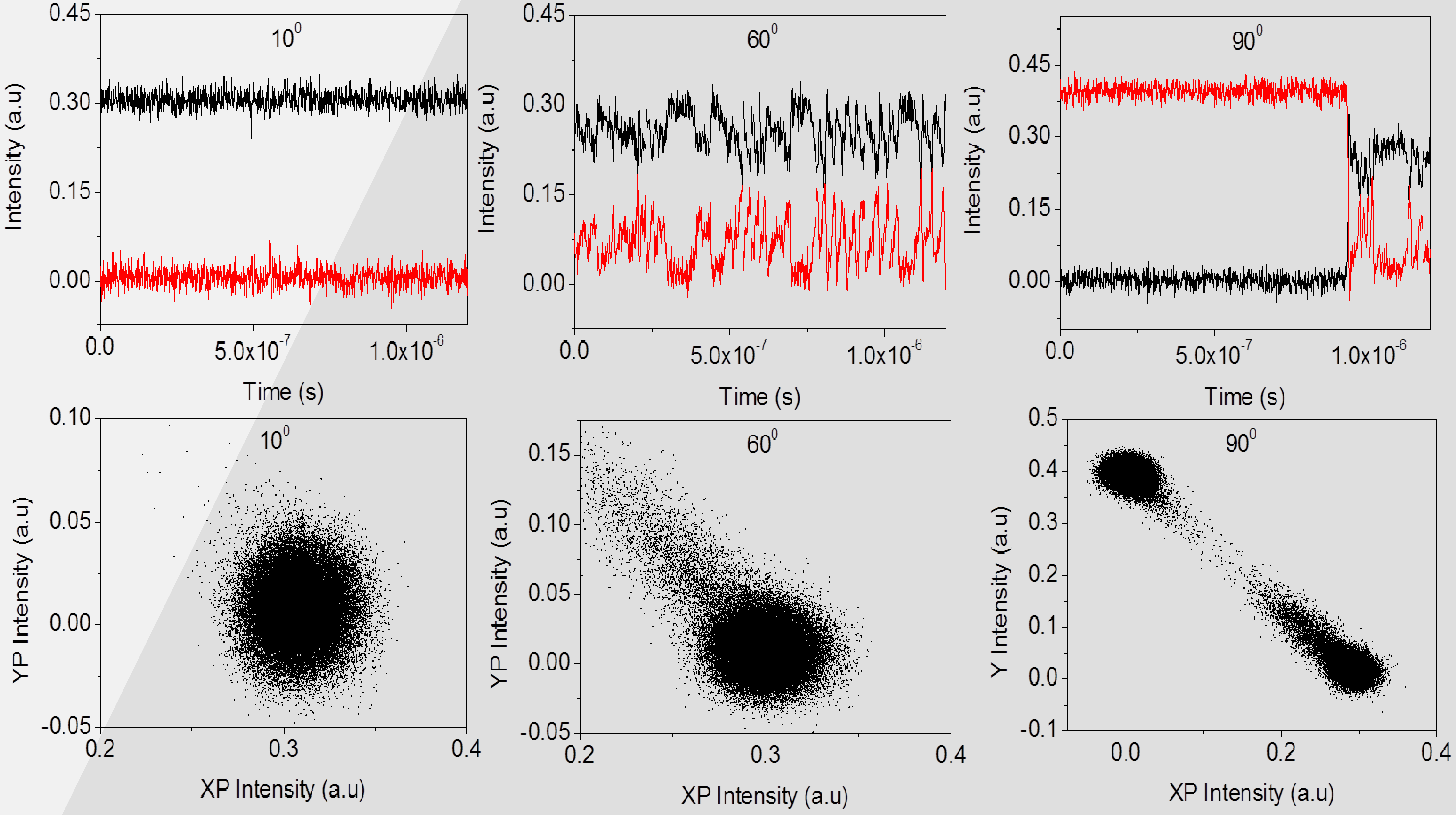
Experimental results/ chaotic Synchronization

- The **anti-phase chaotic synchronization** gradually increased with θ_p
- The **anti-phase correlation** is increased beyond 45° , which increase modes fluctuation and fast polarization switching between the polarization modes of the VCSEL
- Similar finding of the experimental measurements were demonstrated numerically



Trajectory attractor of the polarization modes

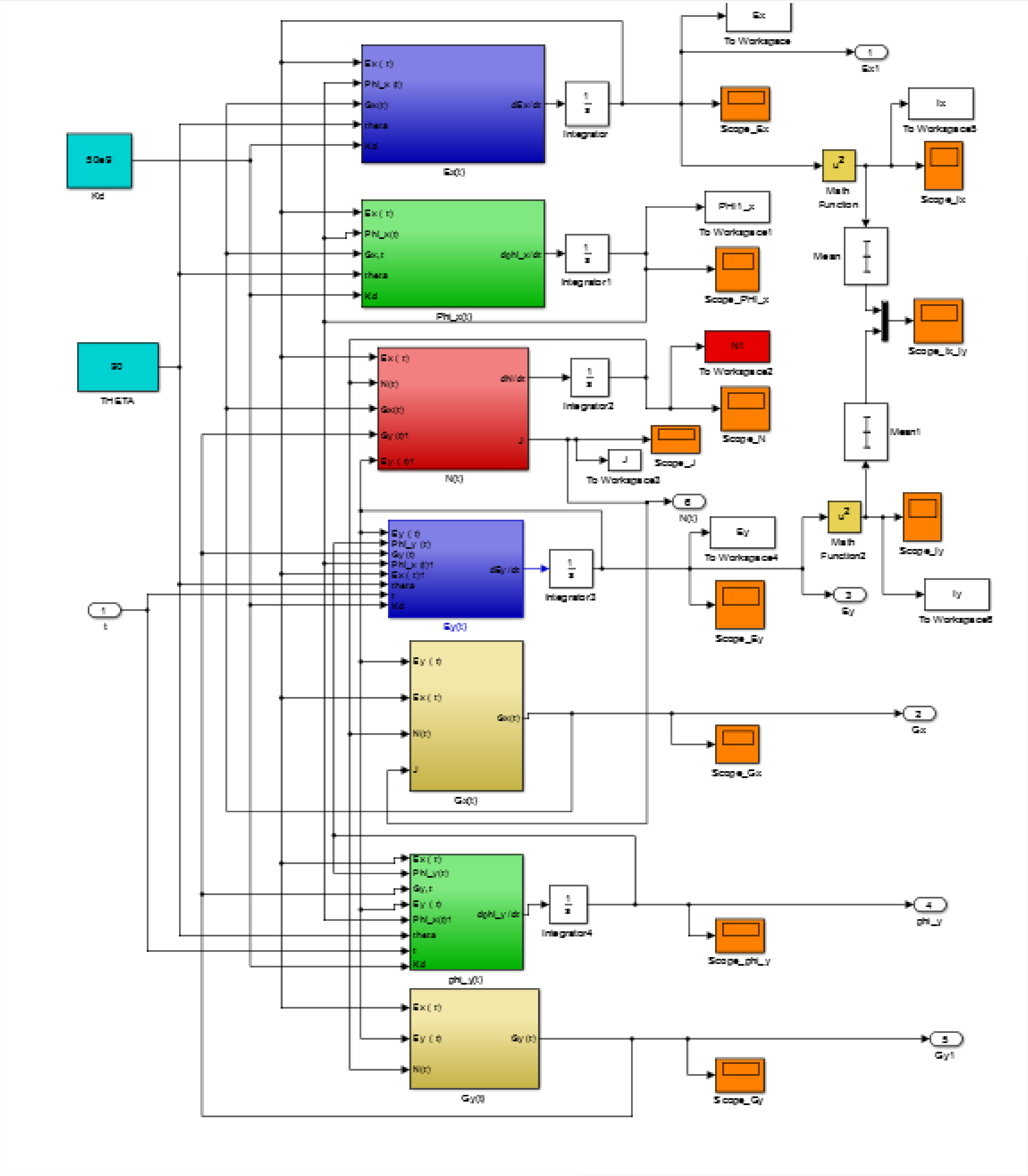
Correlation plot of the polarization modes

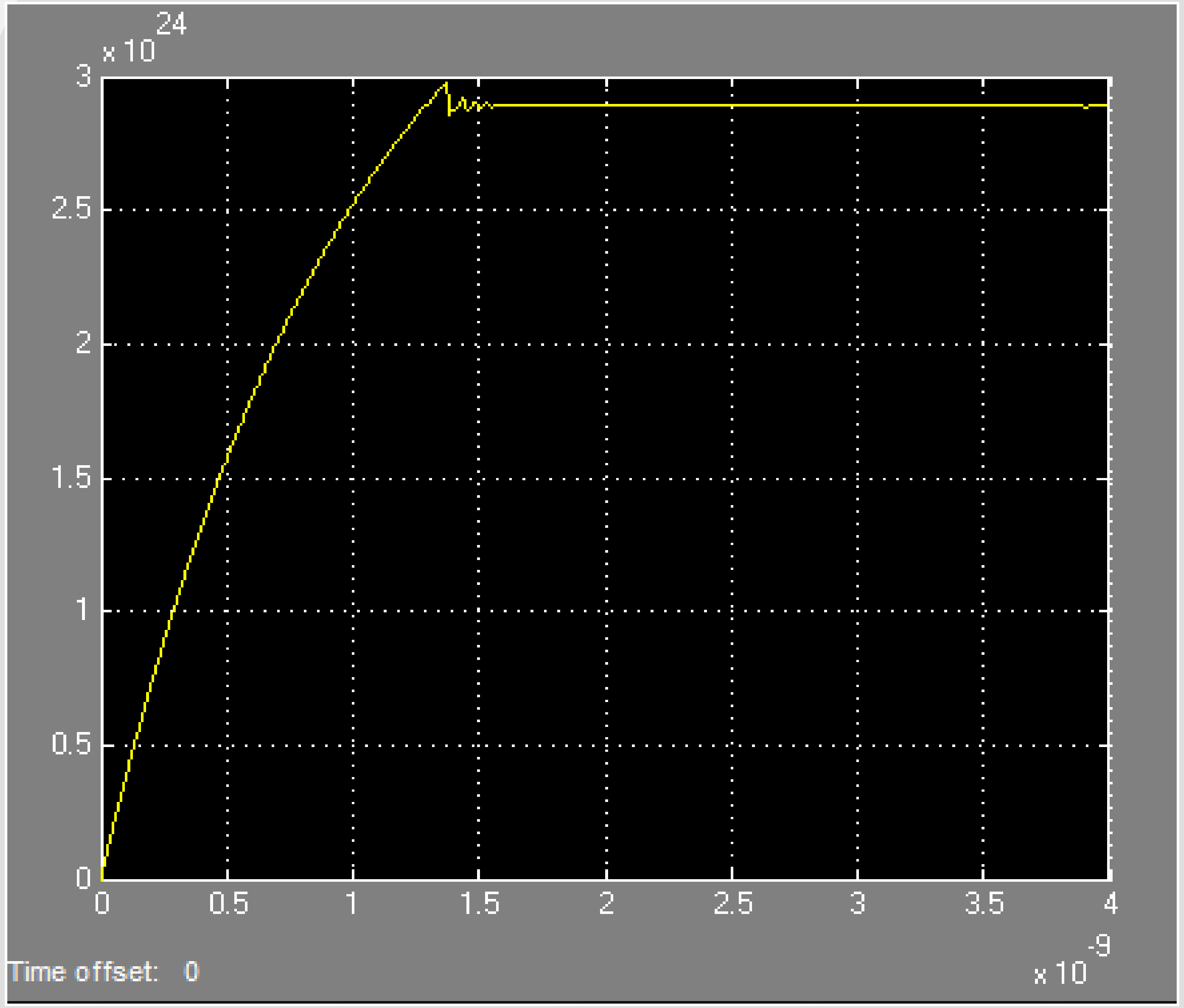


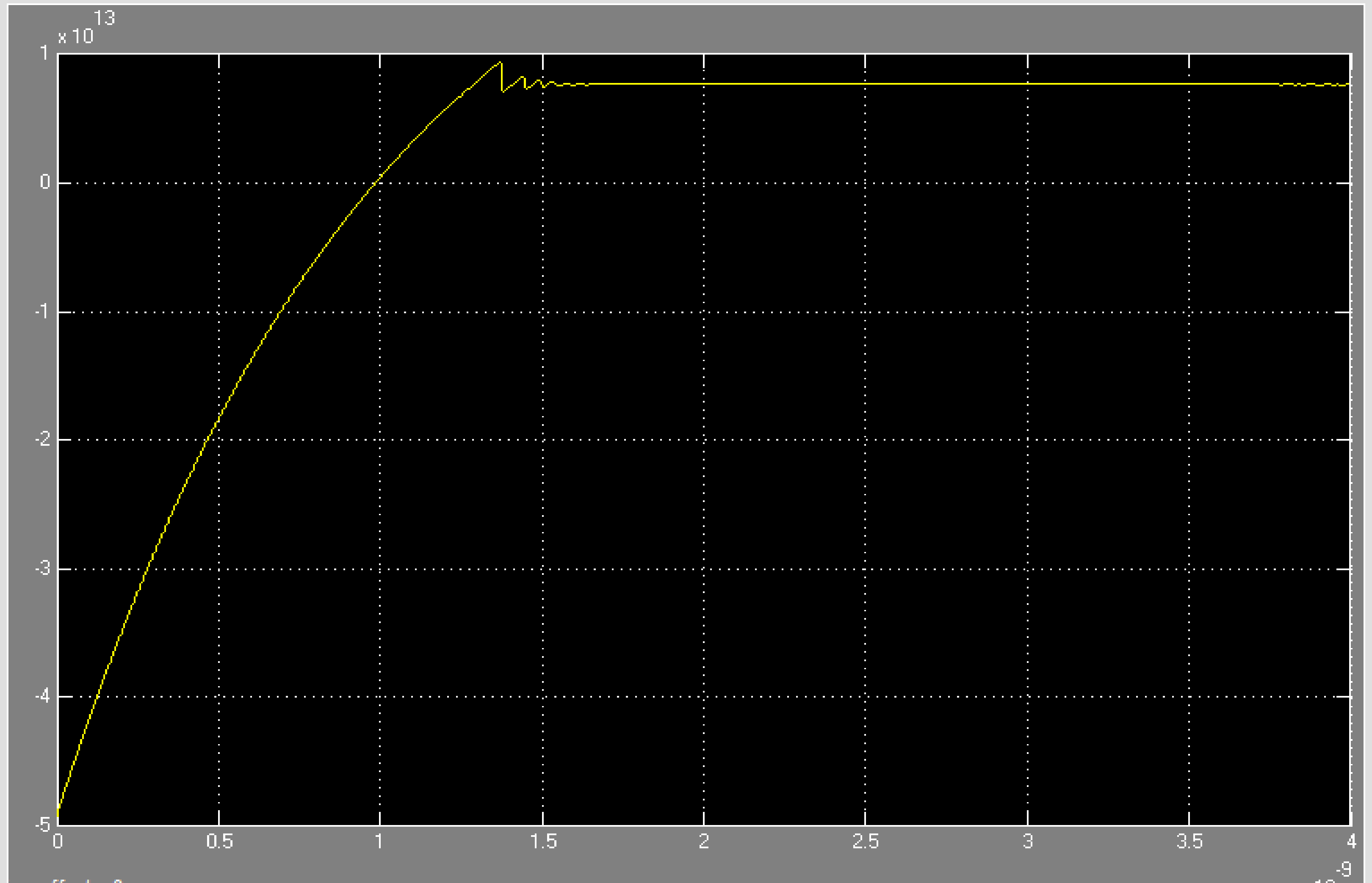
Polarization-resolved time series of the VCSEL modes, XP (black) and YP (red), and the corresponding correlation plots

Based on the results of published paper in Chaos /AIP Journal 2016

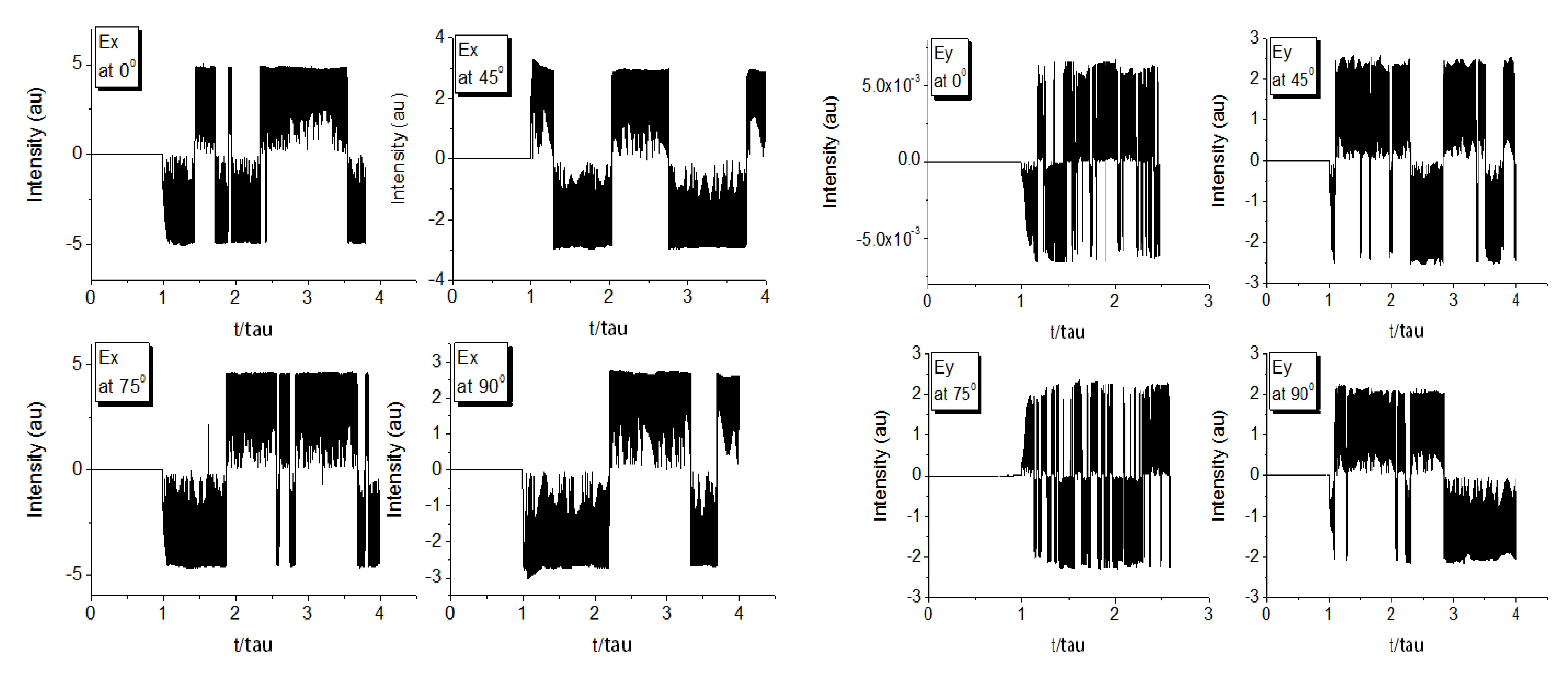
Simulink configuration







Simulation results



Contributions of the work

- **Suppressed the nonlinearity of the VCSEL** that associated with the modulation signal by employing orthogonal polarization optical feedback.

- **Generate high-quality chaotic synchronization dynamics** between the polarization modes, where obtain correlation coefficient value of -0.99 with a zero time delay between the polarization modes.

- **Provide a new tools** , modulation signal parameters, to **improve and control the polarization switching** properties of the VCSEL with the modulation signal.
-
- **Demonstrating** a **hysteresis loop** (HL) with the determining the dependency conditions in the polarization mode properties with VPOF.

- **Reduced the threshold current of VCSEL and determining the optimal condition** to achieve a minimum values of the relative intensity noise (RIN).

list of publications;

Journal Papers

1- Salam Nazhan, Z. Ghassemlooy, K. Busawon, and A.Gholami. " Investigation of Polarization Switching of VCSEL subject to Intensity Modulated and Optical Feedback" Optics and Laser Technology, JOLT, Volume 75, PP 240-245.

2- Salsm Nazhan, Z. Ghassemlooy, Krishna Busawon, and Asghar Gholami. **"**Suppressing the Nonlinearity of Free Running VCSEL using Selective-Optical Feedback**"** Photonic technology letter, IEEE Journal, Volume: PP, Issue:99, 2015

3- Salsm Nazhan, Z. Ghassemlooy and Krishna Busawon "Chaos synchronization in vertical-cavity surface-emitting laser based on rotated polarization-preserved optical feedback" CHAOS, 26,000000, 2016.

4- Nazhan, Salam, Ghassemlooy; Zabih and Busawon, Krishna **"**Harmonic Distortion-Dependent on Optical Feedback, Temperature and Injection Current in Vertical Cavity Surface Emitting Laser**" JPhysD, 2016**

Conference Papers

4 Salam Nazhan, Z. Ghassemlooy , Krishna Busawon and Perez, J. "Hysteresis properties induced by variable polarization angle in the polarization switching of VCSELs," 9th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP), 2014, Manchester, UK, pp. 325 – 329

5- Salam Nazhan, Z. Ghassemlooy , Krishna Busawon and Stanislav Zvanovec " Relative Intensity Noise of Vertical-Cavity Surface-Emitting Lasers Subject to Variable Polarization-Optical Feedback" IWOW 2014, 17-19 September - 7th Opticwise MC/WG Meeting & 3rd International Workshop on Optical Wireless - Funchal, Madeira Island, Portugal.

6- Salam Nazhan, Z. Ghassemlooy and Krishna Busawon. "Investigation of current modulation effects on threshold current of an 850nm single-mode VCSEL," Proceeding of the Northumbria Research Conference, Newcastle, UK, 21-22 May 2014.

7- Salam Nazhan, Z. Ghassemlooy, K. Busawon and A.Gholami "Variable-Polarization Optical Feedback Induced High-Quality Polarization-Resolved Chaos Synchronization in VCSEL" Science and Information Conference 2015, July 28-30, London, UK. (paper in press)

8- Salam Nazhan, Josep pericas, Zabih Ghassemlooy and Krishna Busawon "Chaotic regime modulation in VCSEL based on Rotated Polarisation-Preserved Optical Feedback" photonics global conference 2015, (PGC), 28 June to 03 July, Singapore.(Abstract)

9- Salam Nazhan, Z. Ghassemlooy and Krishna Busawon "High-quality Chaos Synchronization in VCSEL polarization modes under Optical Feedback" Proceeding of the Northumbria Research Conference, Newcastle, UK, 21-22 May 2015 (poster)

10- Salam Nazhan, Z. Ghassemlooy, K. Busawon and Joaquin Perez "Polarization Resolved Intensity Noise of VCSEL Subject to Modulation Signal with Variable Polarization Angle of Optical Feedback" 4th International Workshop on Optical Wireless Communication, 07-08 September 2015, Istanbul, Turkey

11- Salam Nazhan, Z. Ghassemlooy, K. Busawon and Joaquin Perez "VCSEL under selective optical feedback for chaotic-optical wireless communication" UKSim-AMSS 9th European Modelling Symposium on Mathematical Modelling and Computer Simulation, Madrid, 6 – 8 October 2015 (paper accepted)

12- Salam Nazhan, Z. Ghassemlooy and K. Busawon "Polarization properties of Vertical-Cavity Surface-Emitting Lasers subject to variable polarization angle of optical feedback" Second Scientific Conference, Diyala, Iraq, 16 – 17 December 2015

Conclusion

•A novel way was proposed to **suppress the nonlinear behaviours** of the polarization modes of VCSEL, where the irregular dynamics of the VCSEL with modulation signal was drastically modified using the selective-optical feedback, which **improve the dynamic range** of the laser for communication system

• **Generate chaotic signals and identified the optimal operating conditions** for the chaotic synchronization between the orthogonal polarization modes of VCSEL with VPOF, which offers an improvement in terms of the synchronization dynamics for secure communication

•The thesis works devoted **to study and expand understanding** of the polarization modes properties of VCSEL with the VPOF effects to give more insight and potential practical applications of such devices to use in FSO system

•**Improving the polarization modes properties** of VCSEL under VPOF for instance; **reduce the threshold current** and **suppresses the output power polarization instability**

Future work

- Expanded the nonlinearity investigation to **several GHz** of the modulation signal

- Extended the chaos synchronization investigations of the VCSELs' polarization modes to include some factors such as **frequency detuning** and optical feedback **phase effect**

- Applied the chaotic oscillation with the high dynamic synchronization in the transmitter and receiver sides for FSO systems

Thank you!

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