Experimental characterization of optical feedback and current modulation effects on the spatial coherence of a semiconductor laser

Maria Duque-Gijon, Jordi Tiana-Alsina, Cristina Masoller

Departamento de Fisica, Universitat Politecnica de Catalunya

Terrassa, Barcelona, Spain

UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

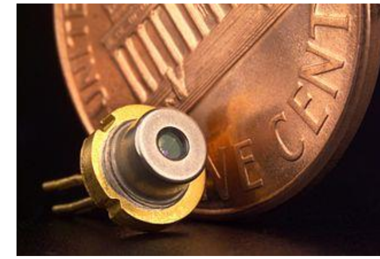
Campus d'Excel·lència Internacional

EOSAM 2025, Delft, The Netherlands, August 27, 2025

cristina.masoller@upc.edu @cristinamasoll1

Diode lasers (electrically pumped semiconductor lasers) play a key role in photonic technologies

- Inexpensive, compact, efficient.
- Wide range of wavelengths (optical communications, biomedical applications),
- Wide range of powers (μWs-KWs).



But they are highly sensitive to optical perturbations.

cristina.masoller@upc.edu @cristinamasoll1

Coherence Collapse in Single-Mode Semiconductor Lasers Due to Optical Feedback

DAAN LENSTRA, BASTIAAN H. VERBEEK, AND ARIE J. DEN BOEF

Abstract—Line broadening up to 25 GHz in a single-mode semiconductor laser with relatively strong optical feedback is reported and theoretically analyzed. Measurements of the coherence function were performed using a Michelson interferometer and demonstrate that the coherence length decreases by a factor 1000 (to approximately 10 mm) due to optical feedback. A self-consistent theoretical description is given, which is based on the view that coherence collapse is maintained due to optical-feedback-delay effects, in which quantum fluctuations play no role of importance. A connection with recently suggested chaotic behavior is made. The theoretical results obtained are in good qualitative and reasonable quantitative agreement with measurements.

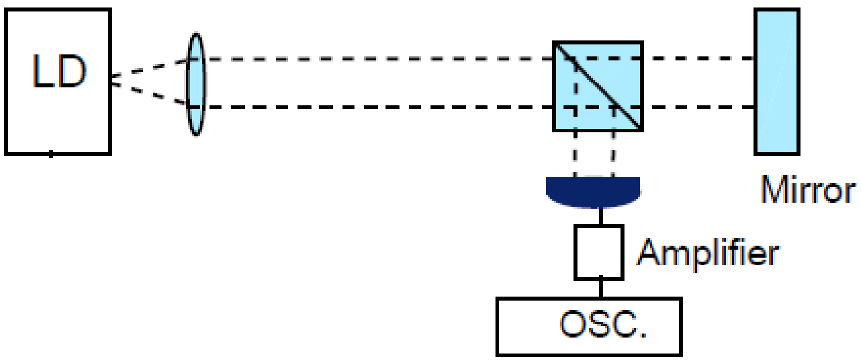
Manuscript received September 18, 1984; revised November 28, 1984.

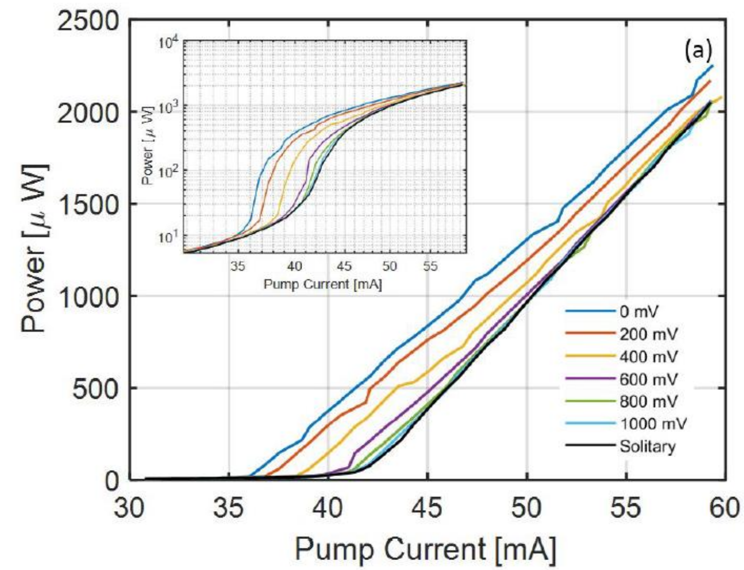
D. Lenstra was with the Department of Electrical Engineering, Delft University of Technology, Delft, The Netherlands. He is now with the Department of Physics, Eindhoven University of Technology, 5600 MB, Eindhoven, The Netherlands.

B. H. Verbeek and A. J. den Boef are with Philips Research Laboratories, Eindhoven, The Netherlands.

cristina.masoller@upc.edu @cristinamasoll1

Effects of optical feedback on semiconductor lasers



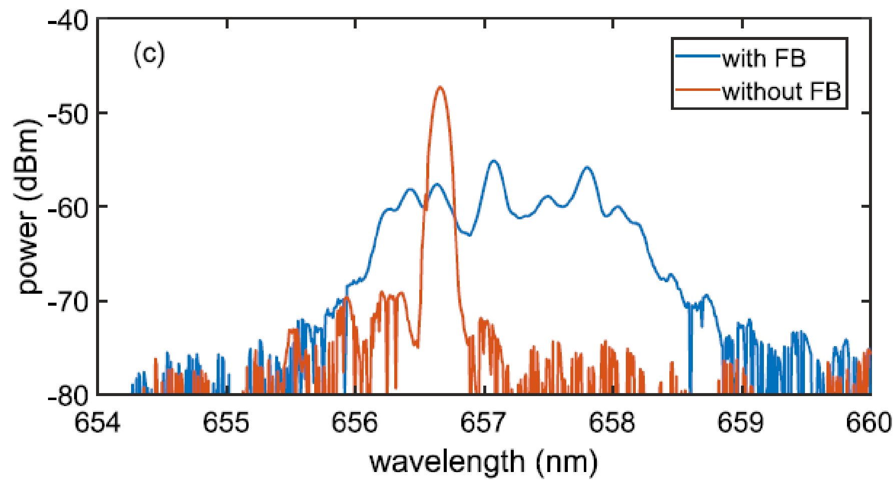


Well known:

- reduce the laser threshold
- narrow its linewidth

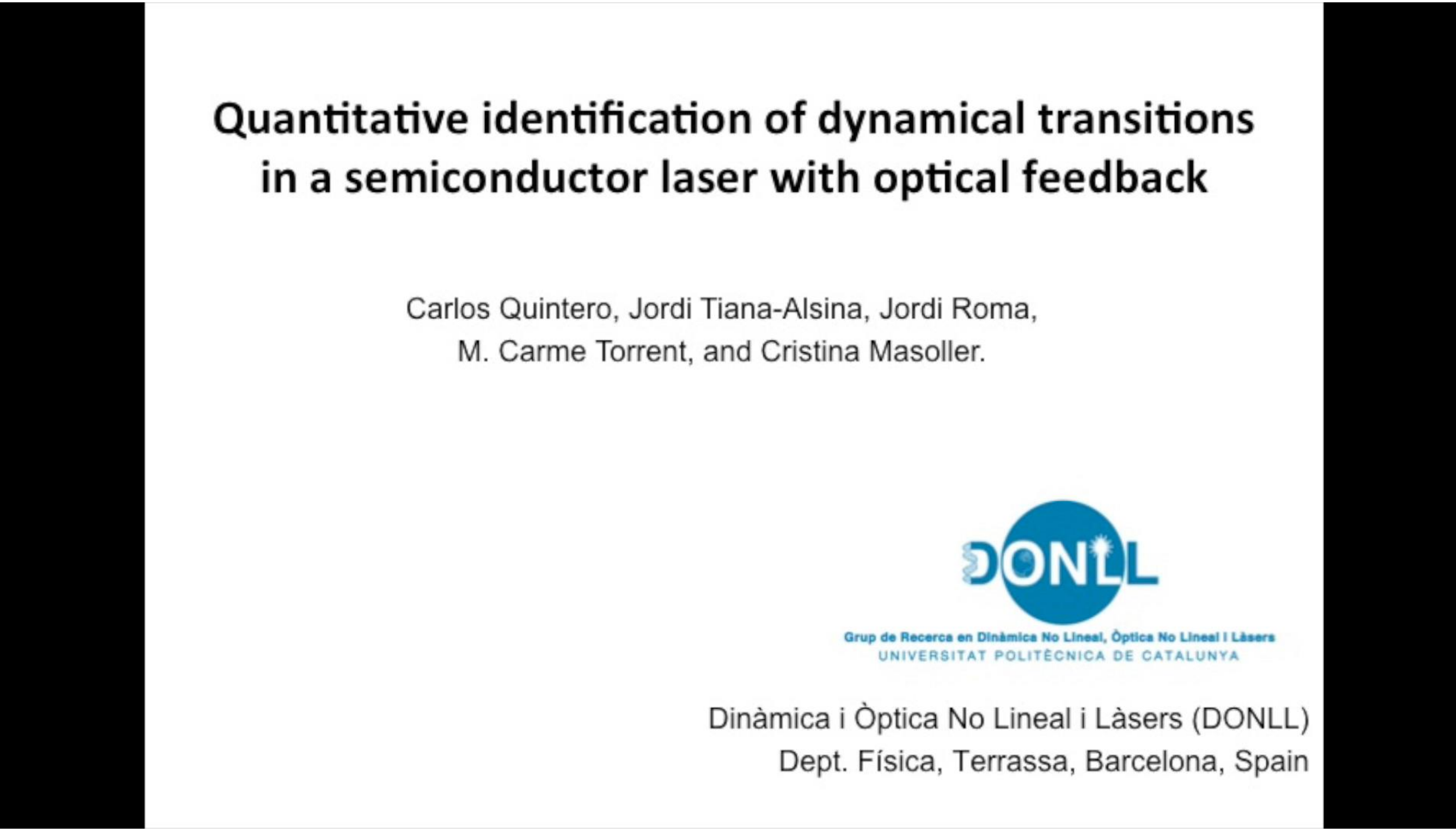
But also

- Induce chaotic dynamics and broad-band emission



cristina.masoller@upc.edu @cristinamasoll1

As the laser pump current increases, how a noisy output turns into a chaotic output?

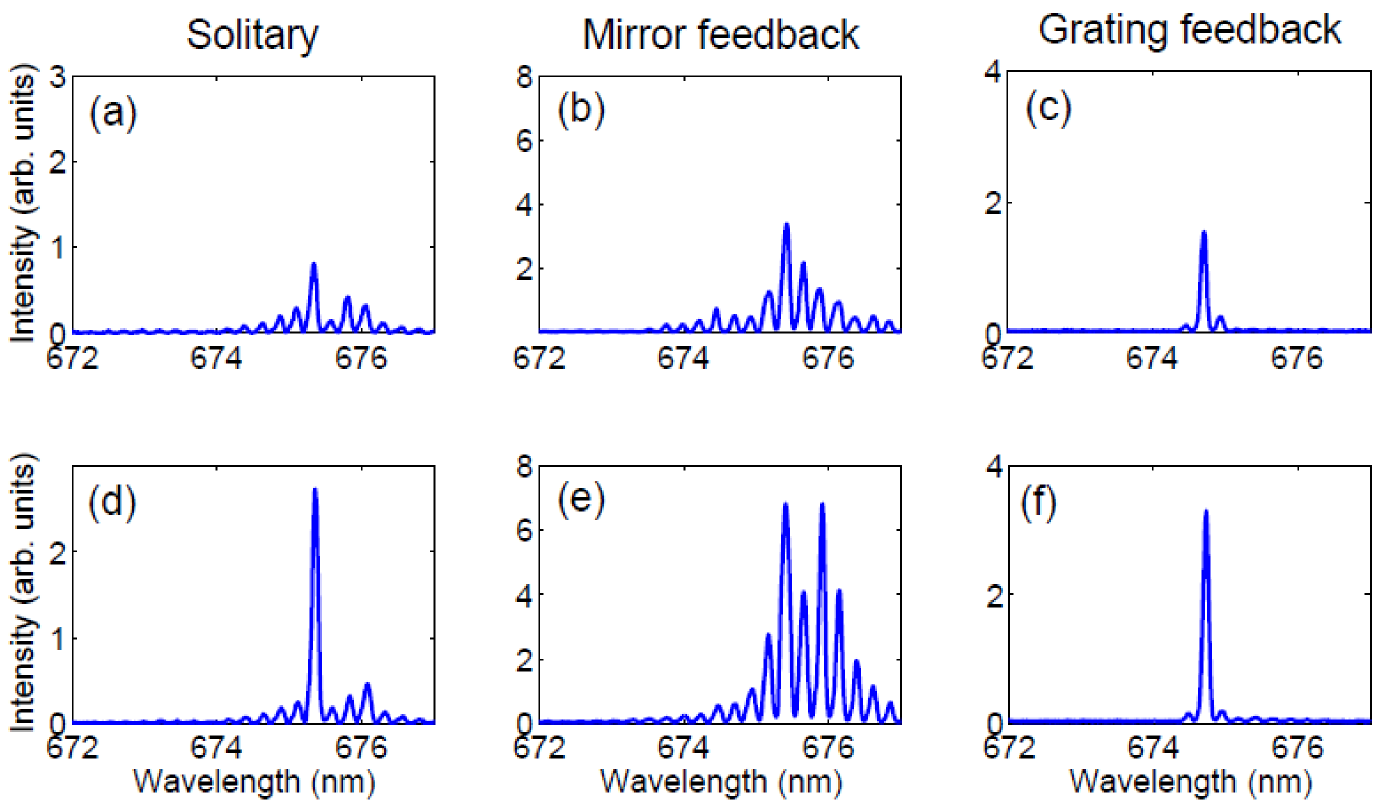


cristina.masoller@upc.edu @cristinamasoll1

Optical feedback excites additional modes

Close to threshold

Above threshold

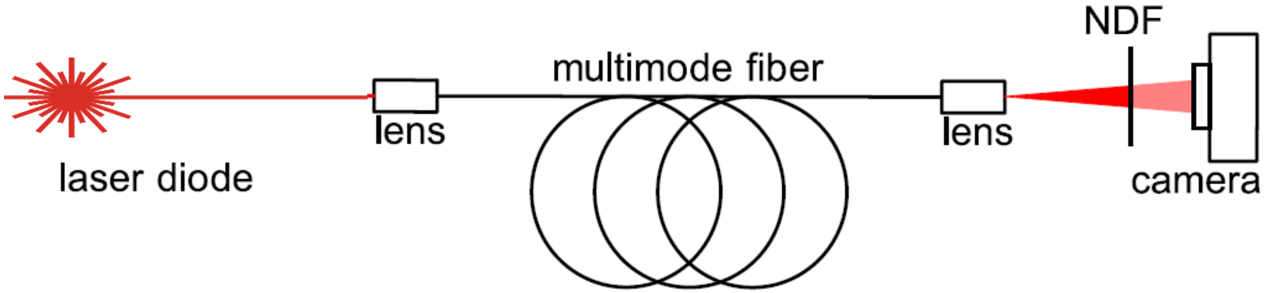


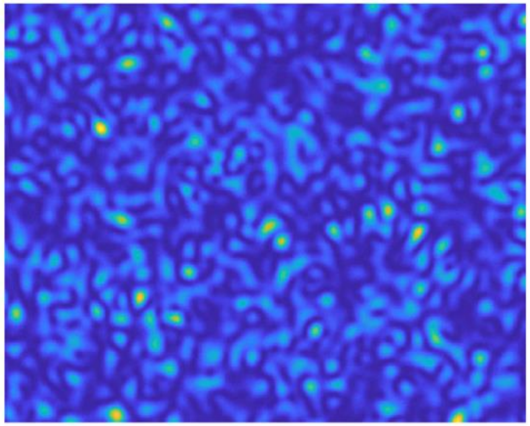
Andres Aragoneses PhD thesis (UPC 2014).

cristina.masoller@upc.edu @cristinamasoll1

Optical feedback effects on the *spatial coherence*?

Speckle pattern: generated by interference / scattering of coherent waves





Many applications. Two main types

- Extract information of the light (wavemeters)
- Extract information of the medium that generates the speckle (speckle-based spectroscopy)

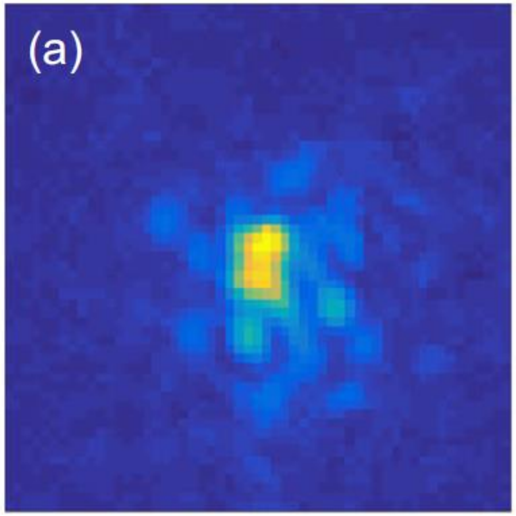
But

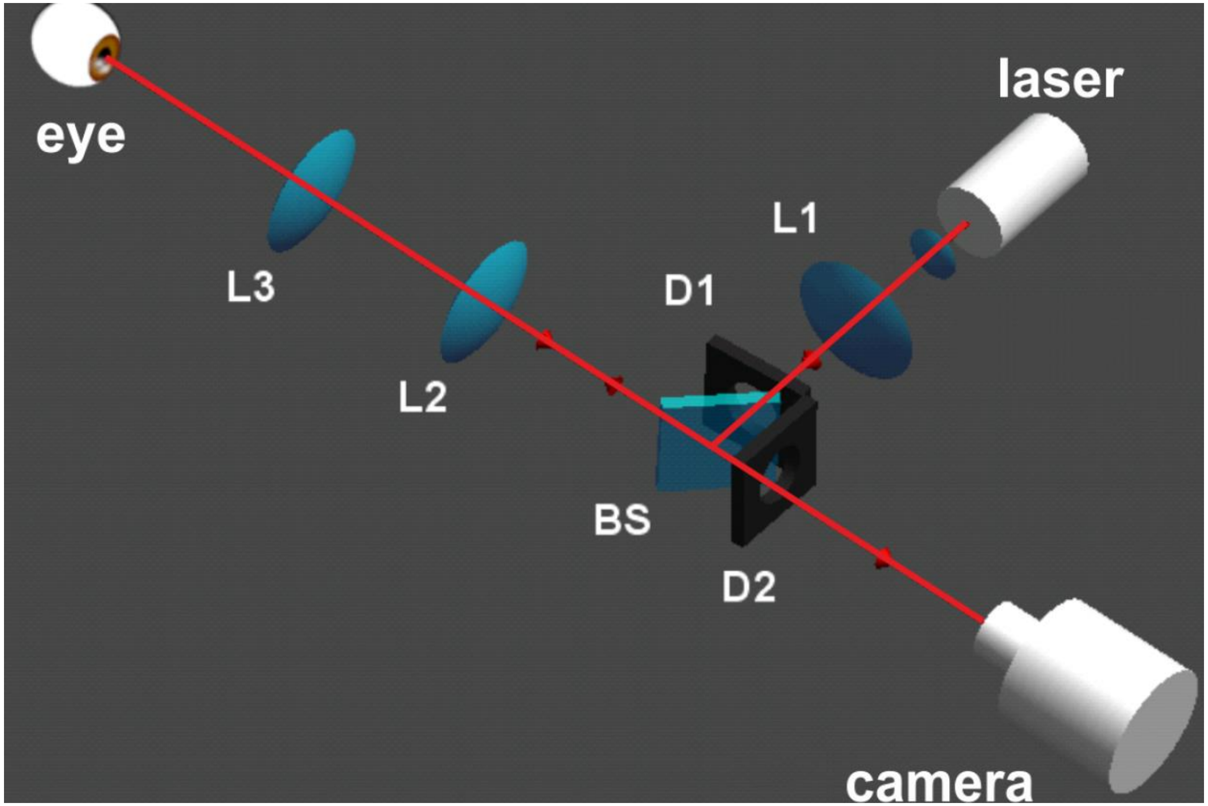
Speckle is a drawback in laser-based illumination and imaging applications.

cristina.masoller@upc.edu @cristinamasoll1

Speckle reduction in double-pass retinal imaging system (quantifies the optical quality of the eye by measuring its point spread function)

Problem:
The retina reflectivity is about 4%

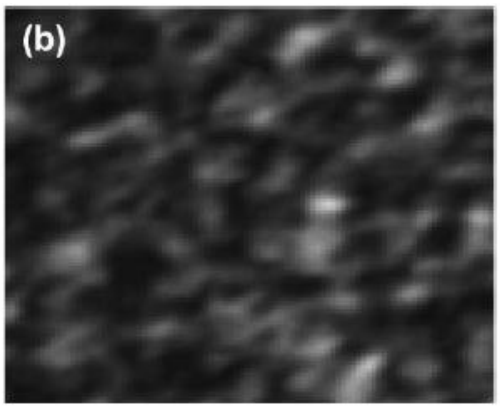


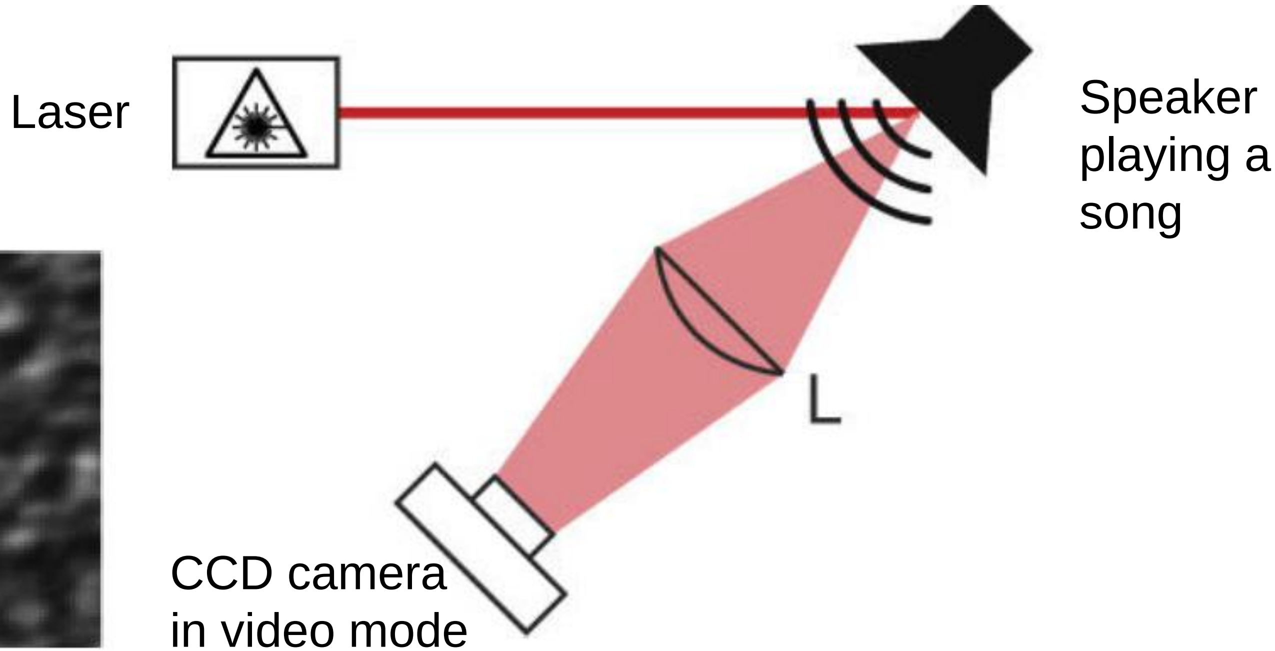


D. Halpaap, C. E. Garcia-Guerra, M. Vilaseca, C. Masoller, "*Speckle reduction in double-pass retinal images*", Sci. Rep. 9, 4469 (2019).

cristina.masoller@upc.edu @cristinamasoll1

Example of extracting information from speckles: Recovery of audio signals from silent videos of speckles

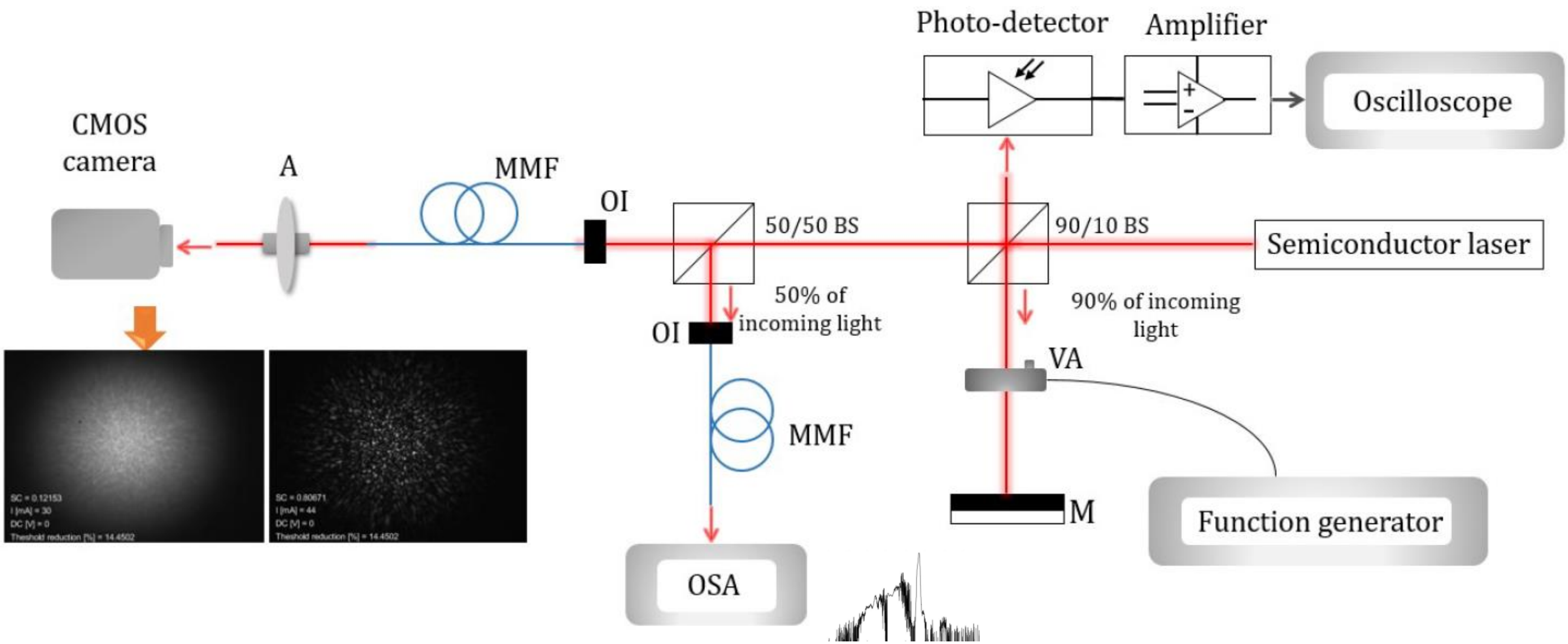




C. Barcellona, D. Halpaap, P. Amil, A. Buscarino, L. Fortuna, J. Tiana, C. Masoller, "*Remote recovery of audio signals from videos of optical speckle patterns: a comparative study of signal recovery algorithms*", Opt. Exp. 28, 8716 (2020).

cristina.masoller@upc.edu @cristinamasoll1

Experimental setup for studying the effect of optical feedback on the speckle pattern generated by a multimode laser

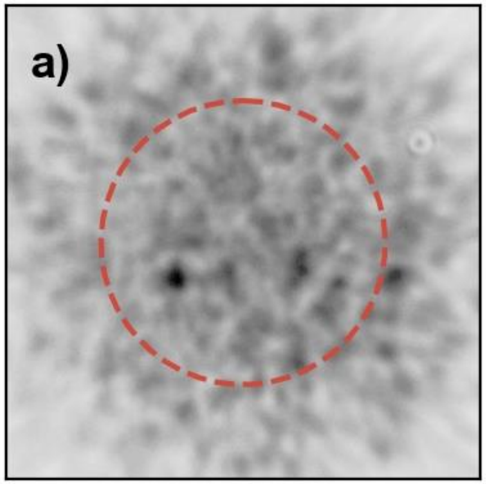


M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, “*Abrupt transition from low-coherence to high-coherence radiation in a semiconductor laser with optical feedback*,” Opt. Exp. 31, 3857 (2023).

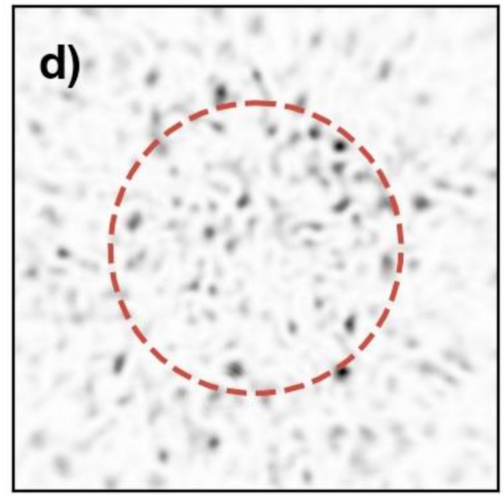
cristina.masoller@upc.edu @cristinamasoll1

Examples of speckle images

Below threshold



Above threshold

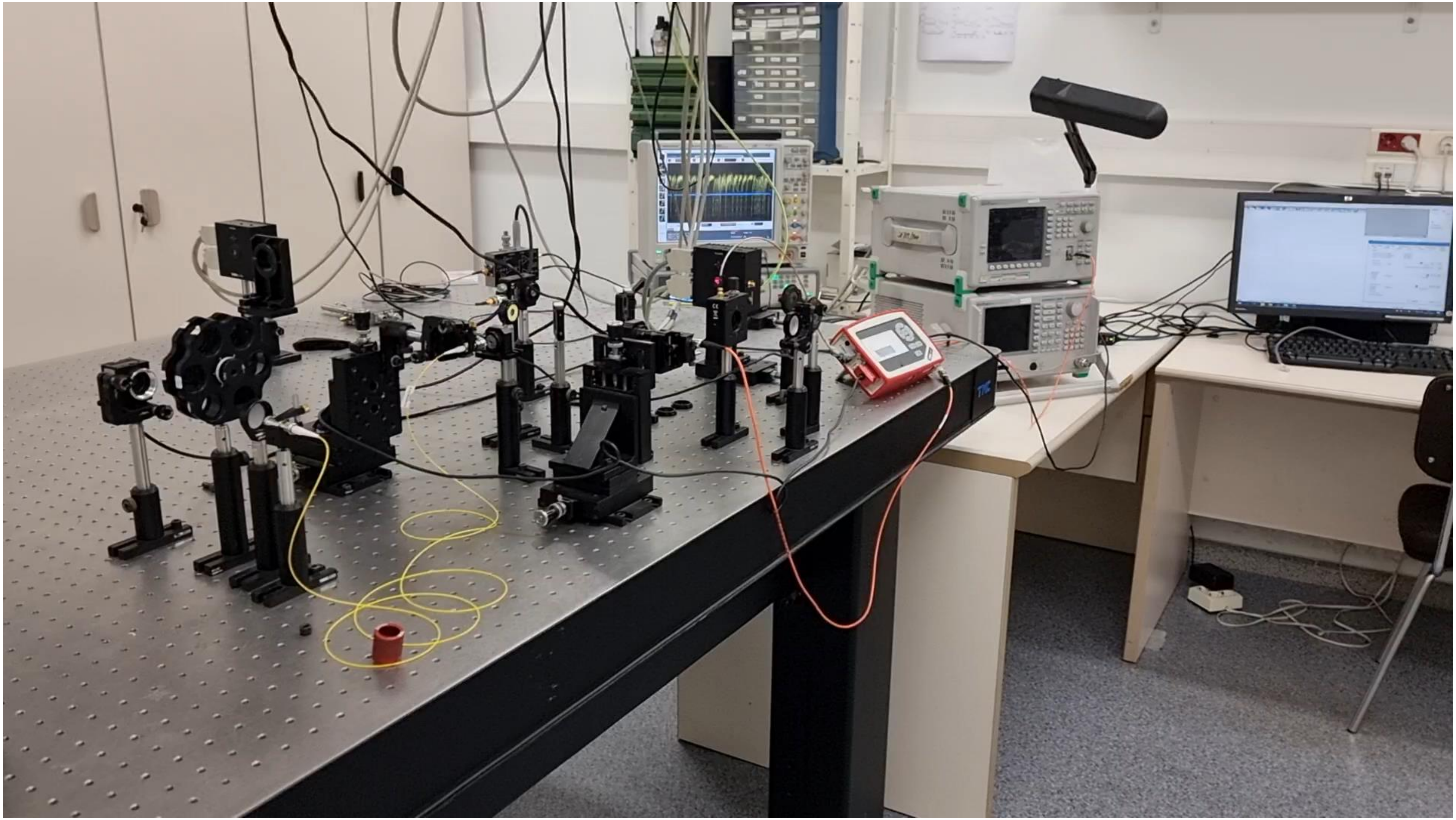


Quantification of speckle contrast: $SC = \sigma/\langle I \rangle$

cristina.masoller@upc.edu @cristinamasoll1

Three different diffusive media are used to generate speckle:

Multimode fiber --- Multimode fiber and diffuser --- Single mode fiber and diffuser



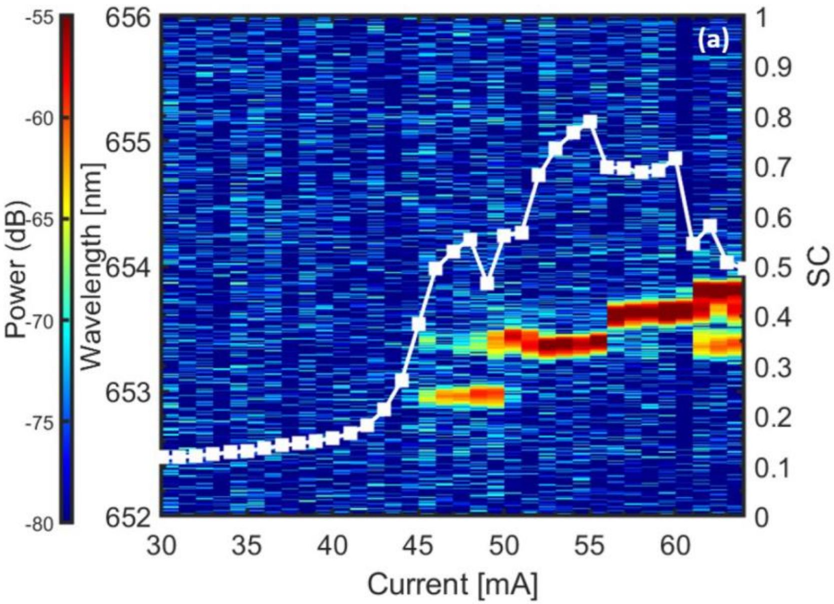
cristina.masoller@upc.edu @cristinamasoll1

Spectral & speckle analysis, speckle generated by a MM fiber

Speckle contrast (white) SC = $\sigma/\langle I \rangle$

Solitary laser (no feedback)

Color code: optical spectrum



High spectral coherence ⇔ high speckle contrast
Low spectral coherence ⇔ low speckle contrast

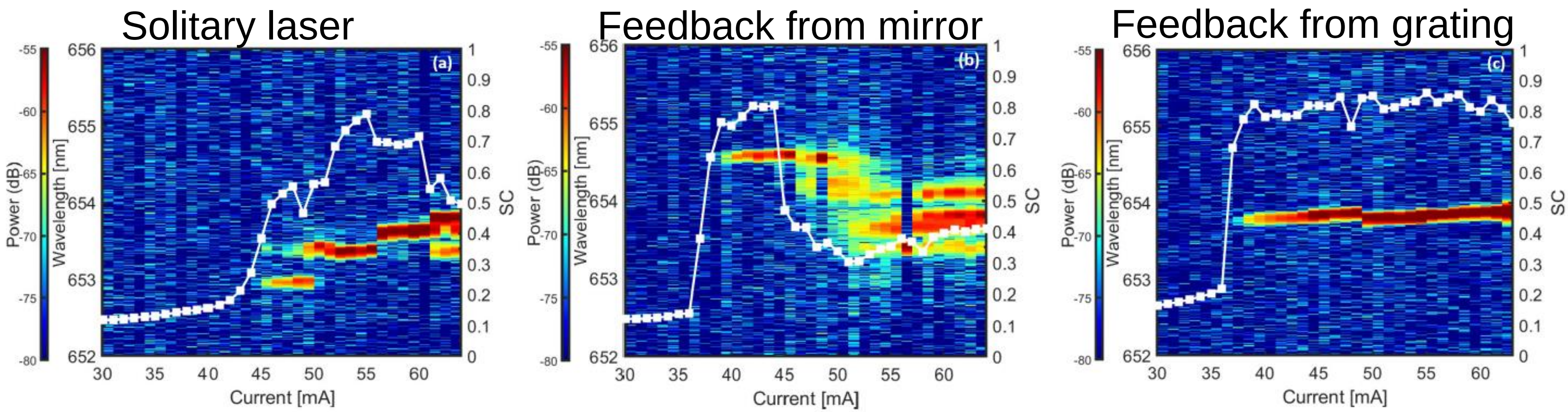
M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, Opt. Exp. 31, 3857 (2023)

cristina.masoller@upc.edu @cristinamasoll1

Spectral & speckle analysis, speckle generated by a MM fiber

Speckle contrast (white) SC = $\sigma/\langle I\rangle$

Color code:
optical spectrum



High spectral coherence ⇔ high speckle contrast
Low spectral coherence ⇔ low speckle contrast

M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, Opt. Exp. 31, 3857 (2023)

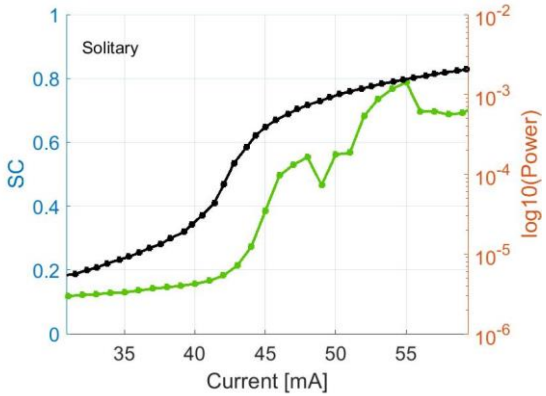
cristina.masoller@upc.edu @cristinamasoll1

Speckle contrast and L-I curves

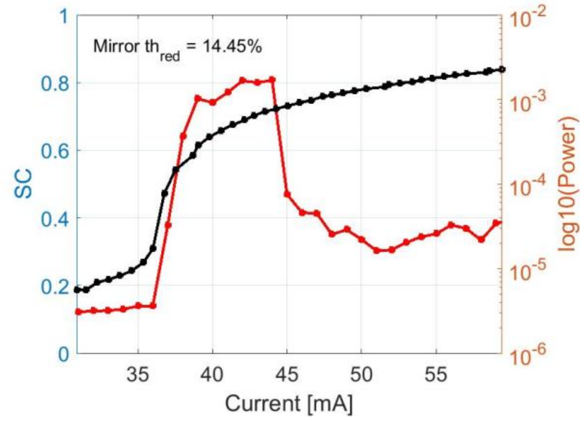
L-I curves: black, log scale

Speckle contrast curves (color) $SC = \sigma/\langle I\rangle$

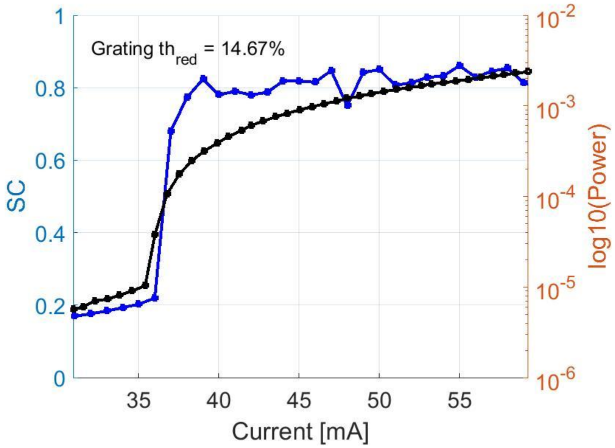
Solitary laser



Feedback from mirror



Feedback from grating



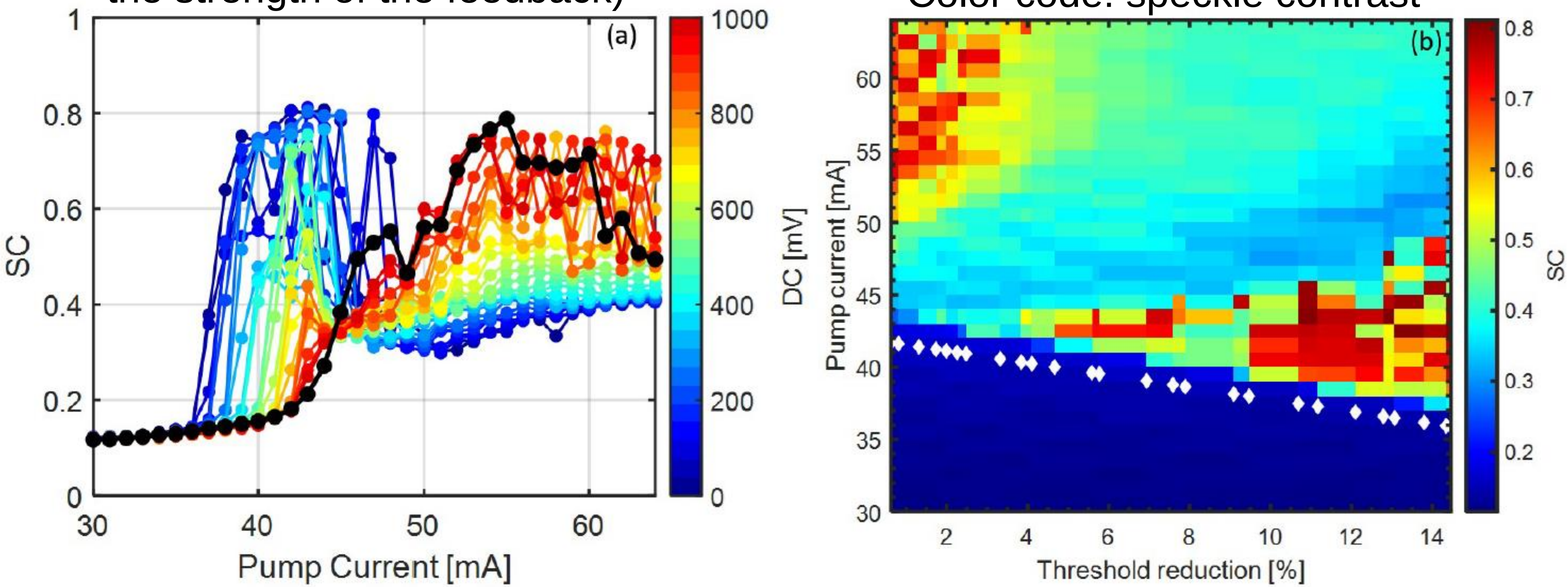
M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, Opt. Exp. 31, 3857 (2023)

cristina.masoller@upc.edu @cristinamasoll1

Influence of the feedback strength

Color code: voltage in the variable attenuator (mV, controls the strength of the feedback)

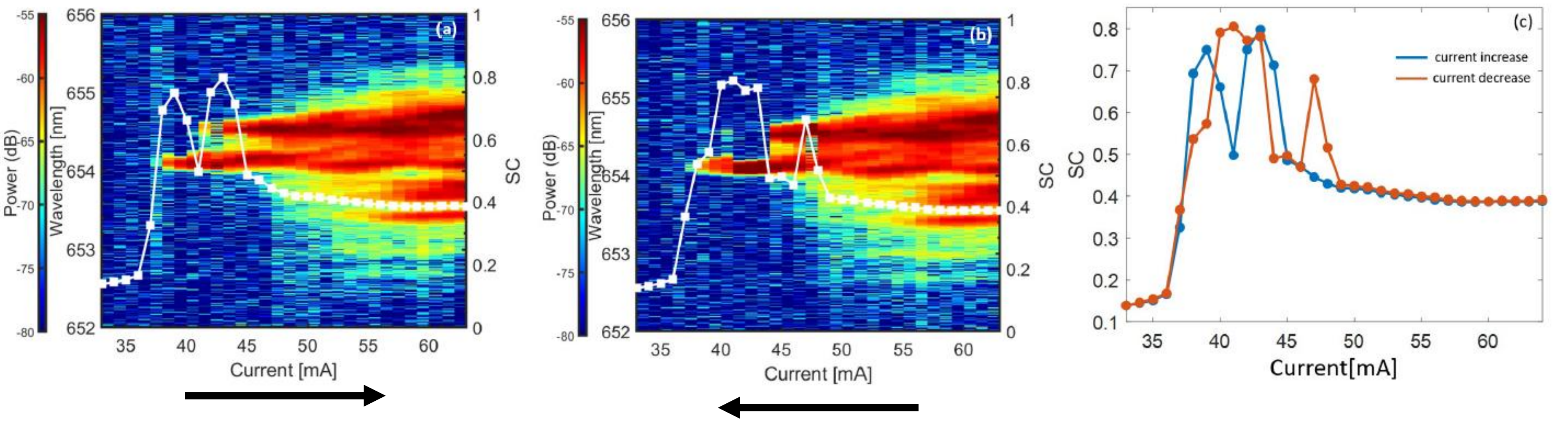
Color code: speckle contrast



M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, Opt. Exp. 31, 3857 (2023)

cristina.masoller@upc.edu @cristinamasoll1

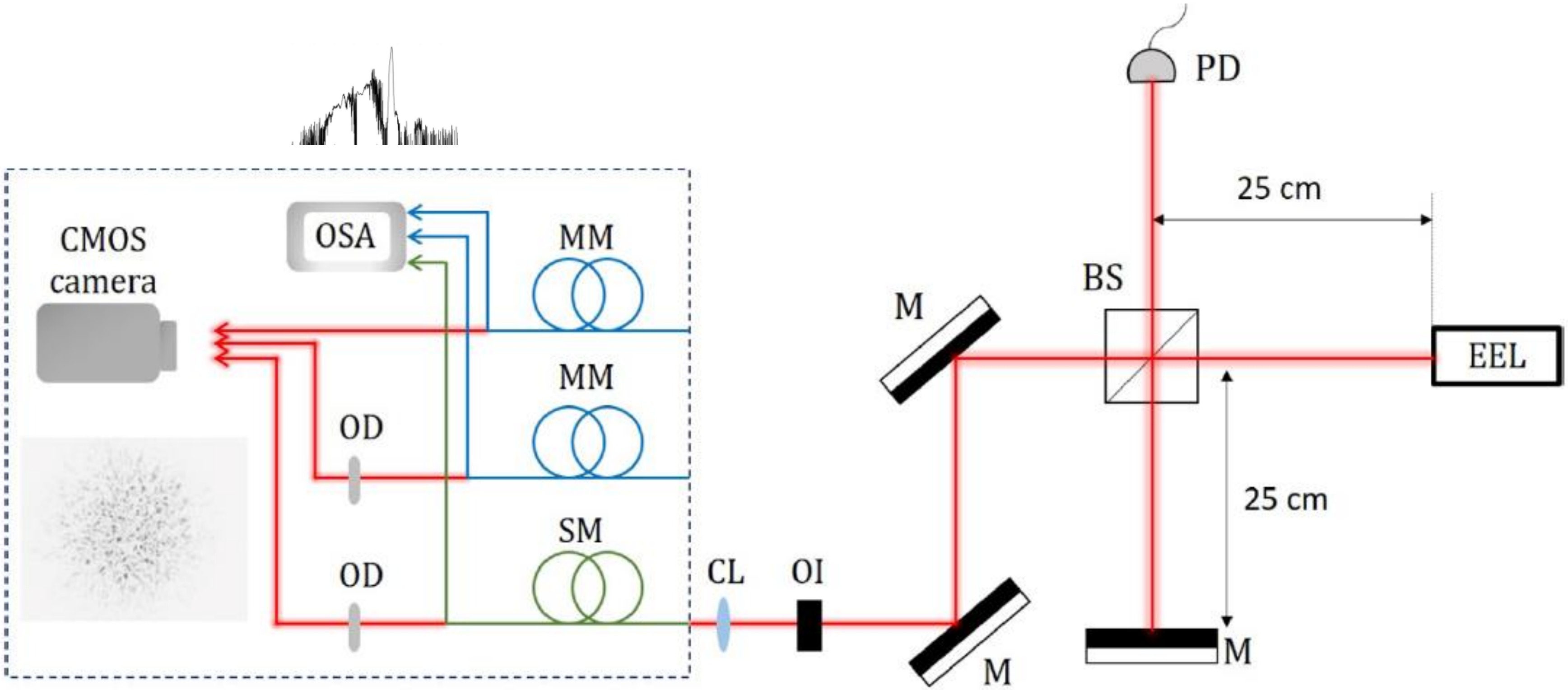
Hysteresis?



M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, Opt. Exp. 31, 3857 (2023)

cristina.masoller@upc.edu @cristinamasoll1

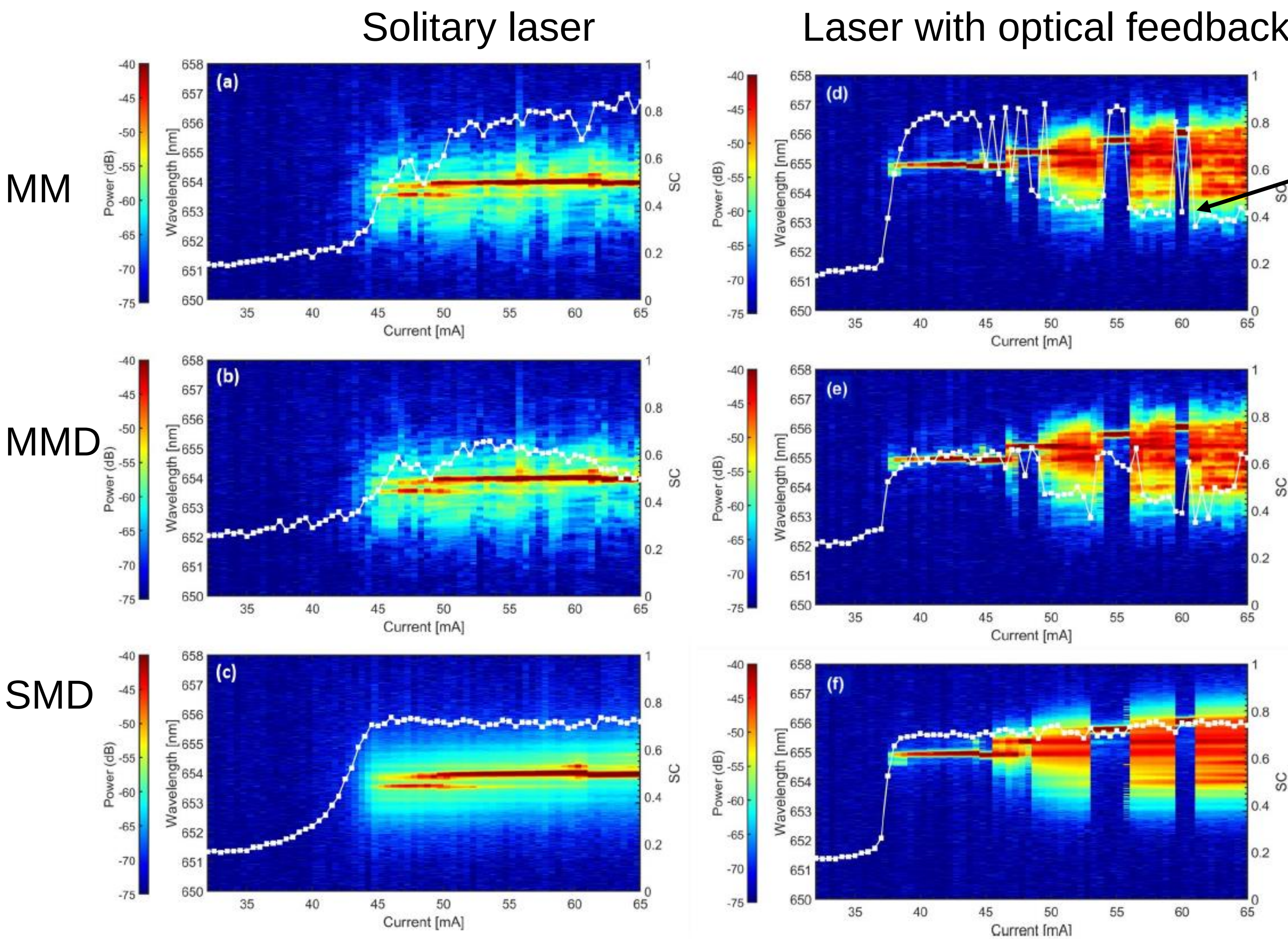
Role of the medium that generates the speckle pattern?



M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, “*Experimental study of spatial and temporal coherence in a semiconductor laser with optical feedback*,”
Optics Express 31, 21954 (2023)

cristina.masoller@upc.edu @cristinamasoll1

Comparison: multimode fiber, MM fiber and diffuser, single-mode fiber and diffuser

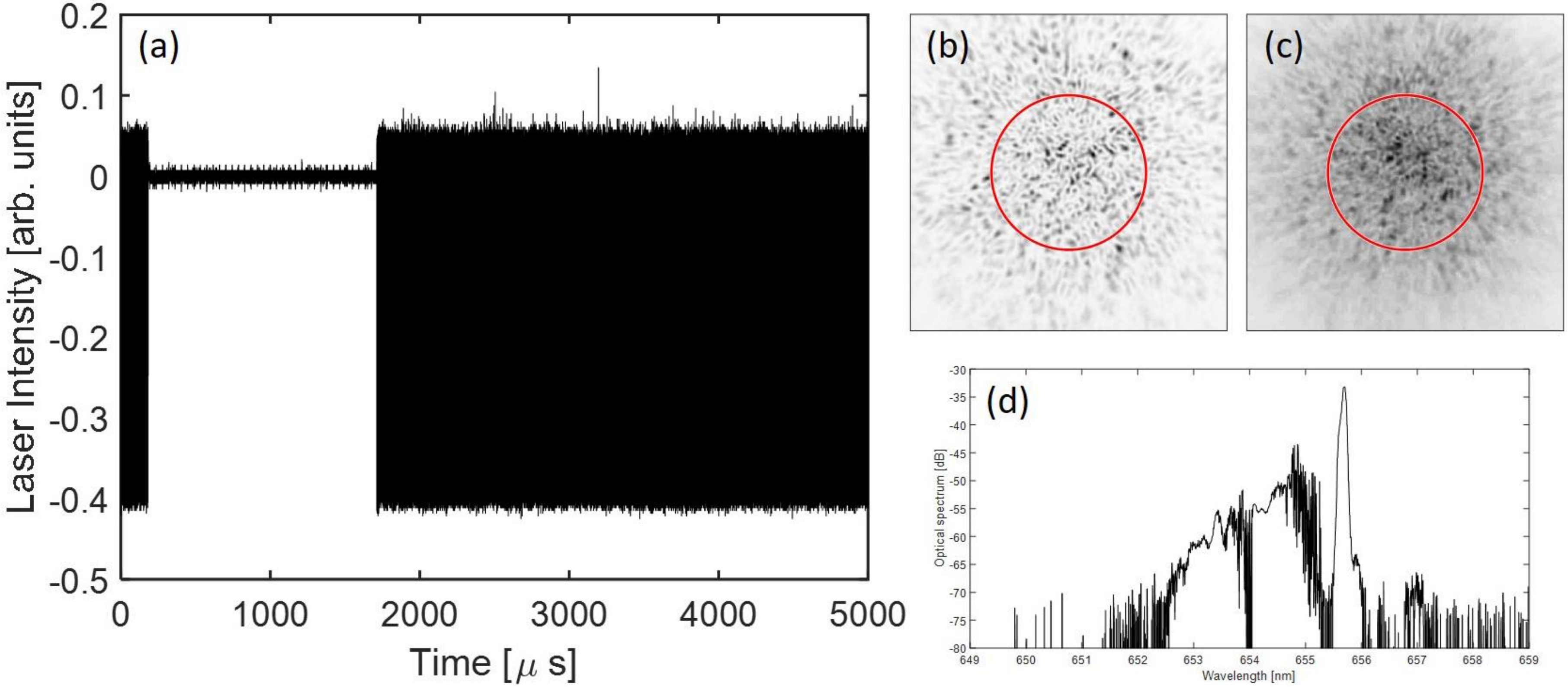


High spectral coherence but low speckle contrast

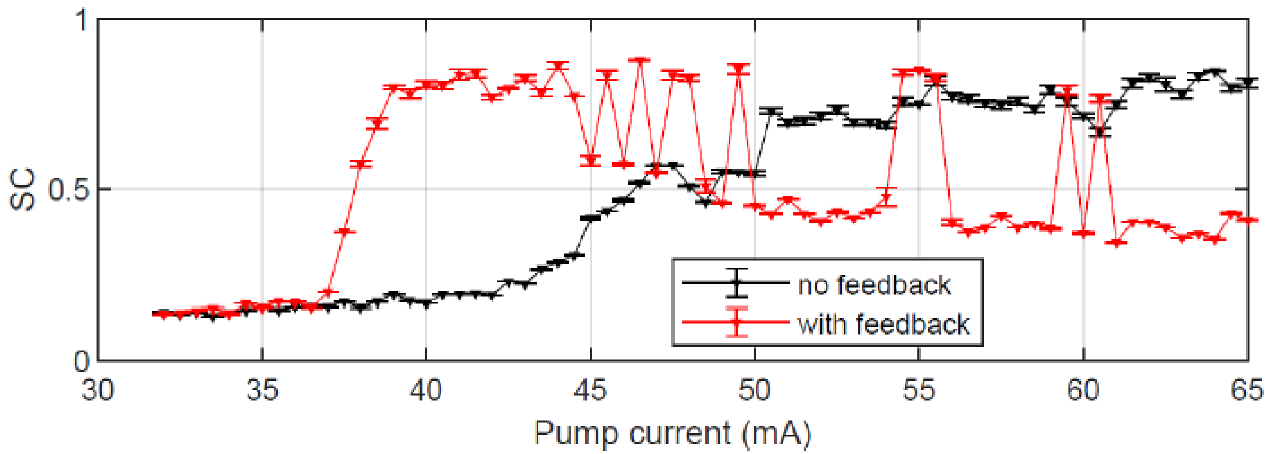
Low spectral coherence but high speckle contrast

cristina.masoller@upc.edu @cristinamasoll1

Alternation of stable and unstable emission



cristina.masoller@upc.edu @cristinamasoll1



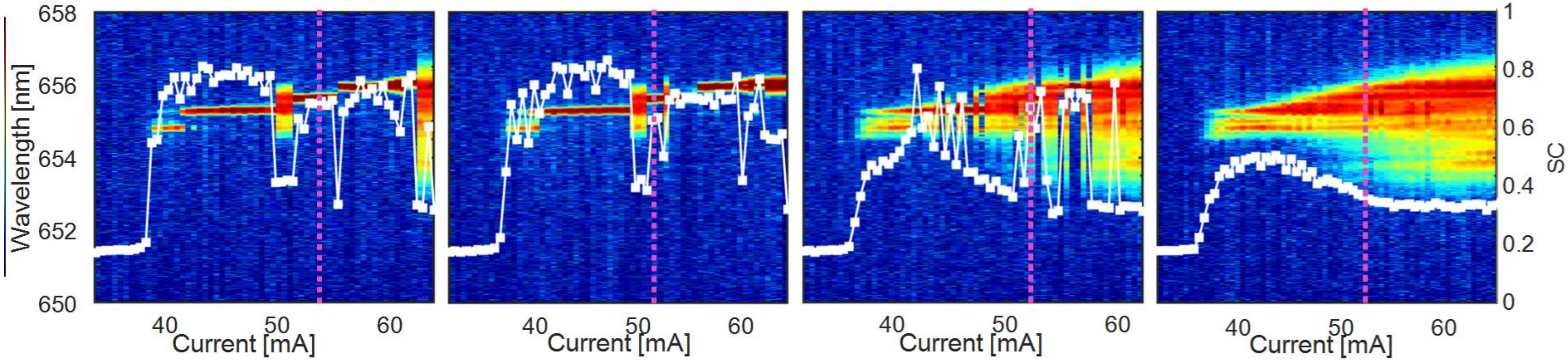
Research question: can we further decrease the coherence of the laser light by direct current modulation?

UNIVERSITAT POLITÈCNICA
DE CATALUNYA
BARCELONATECH

Campus d'Excel·lència Internacional

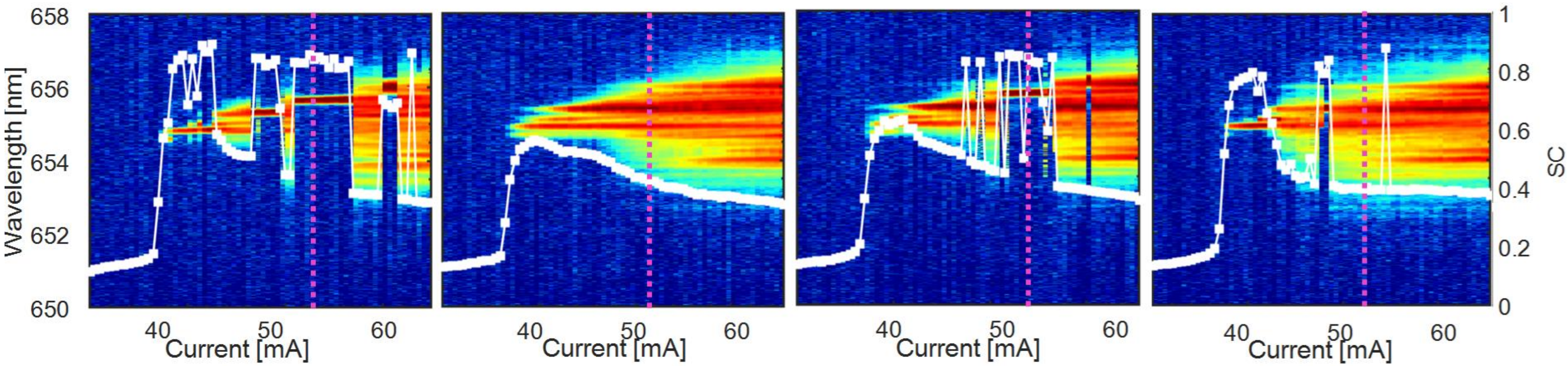
ν_{mod} = 1 MHz

No modulation | A_{mod} = 1 mA | A_{mod} = 3 mA | A_{mod} = 5 mA



A_{mod}= 2 mA

No modulation | ν_{mod} = 0.10 MHz | ν_{mod} = 1 MHz | ν_{mod} = 100 MHz



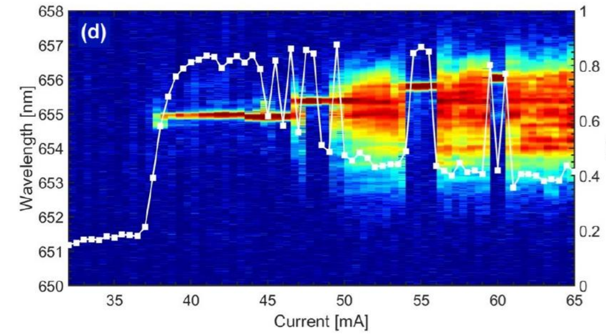
cristina.masoller@upc.edu @cristinamasoll1

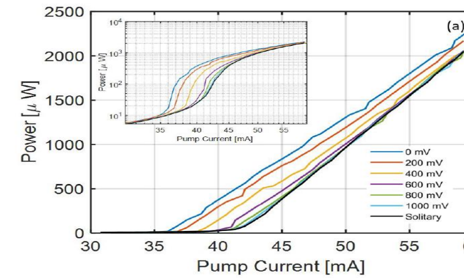
Take home messages

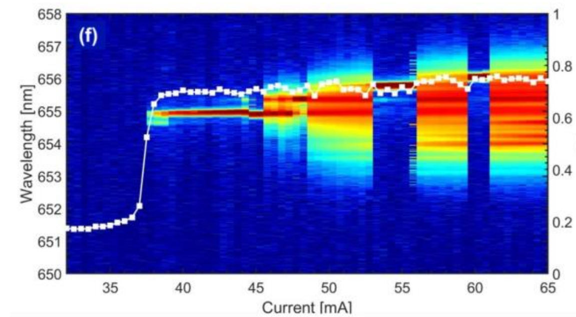
1. Strong enough optical feedback induces an abrupt transition to coherent emission—not seen in the LI curve that only reveals the threshold reduction.

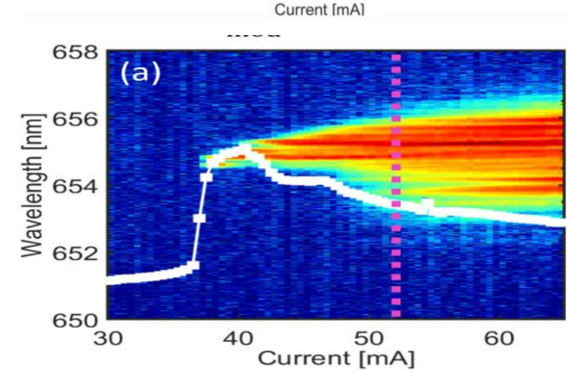
2. Combining speckle and spectral analysis we differentiate feedback effects on spatial and temporal coherence.

3. Under current modulation, with appropriate parameters, the current regions where speckle contrast is high are suppressed.









cristina.masoller@upc.edu @cristinamasoll1

VII "Rio de la Plata" Workshop on Optics and Photonics

December 15 – 17, 2025

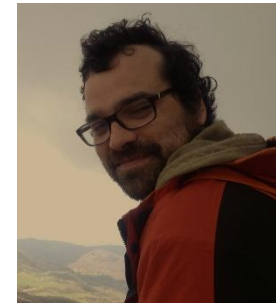
Punta del Este, Uruguay

The workshop will bring together researchers working on both fundamental and applied aspects of optics and photonics to foster cross-disciplinary discussions and collaborations.

https://workshopriodelaplata.org/

Funding, co-authors and references

Dra. Maria Duque-Gijon



Dr. Jordi Tiana-Alsina

- M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, “*Abrupt transition from low-coherence to high-coherence radiation in a semiconductor laser with optical feedback*,” Optics Express 31, 3857 (2023).
- M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, “*Experimental study of spatial and temporal coherence in a semiconductor laser with optical feedback*,” Optics Express 31, 21954 (2023).
- M. Duque-Gijon, C. Masoller, J. Tiana-Alsina, “*Effect of current modulation on the coherence of a semiconductor laser with optical feedback*,” Optics Express 32, 34721 (2024).

Thank you for your attention!

cristina.masoller@upc.edu @cristinamasoll1