Experimental study of the coherence of the light emitted by a semiconductor laser with optical feedback and current modulation

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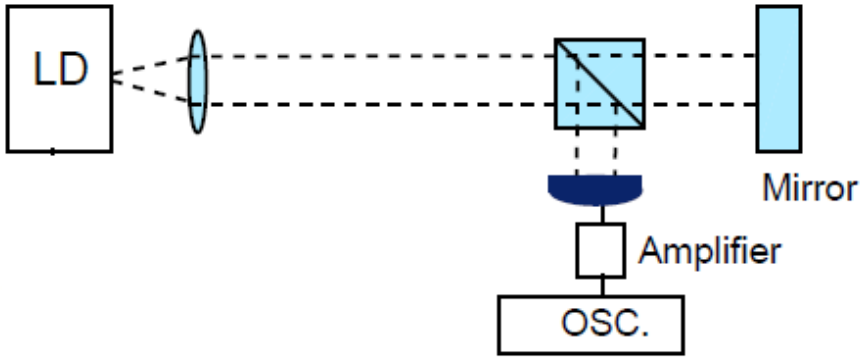
Optical feedback effects on semiconductor lasers

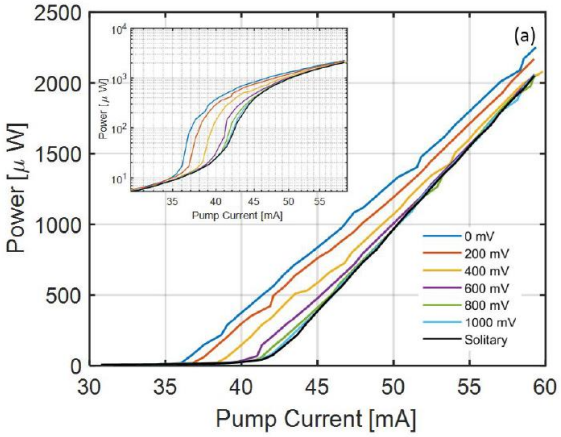
Well-known

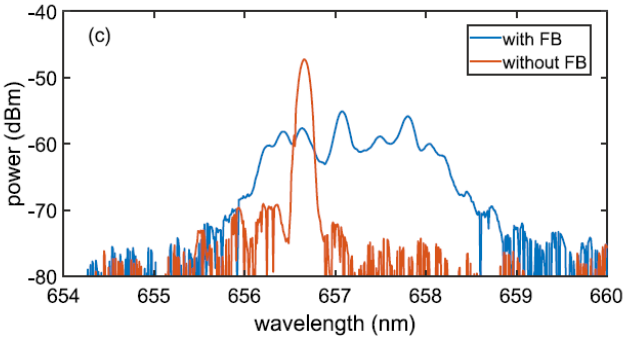
- reduce the laser threshold
- narrow its linewidth,

but also

- chaotic dynamics and broad-band emission







Optical feedback effects on the *spatial coherence*?

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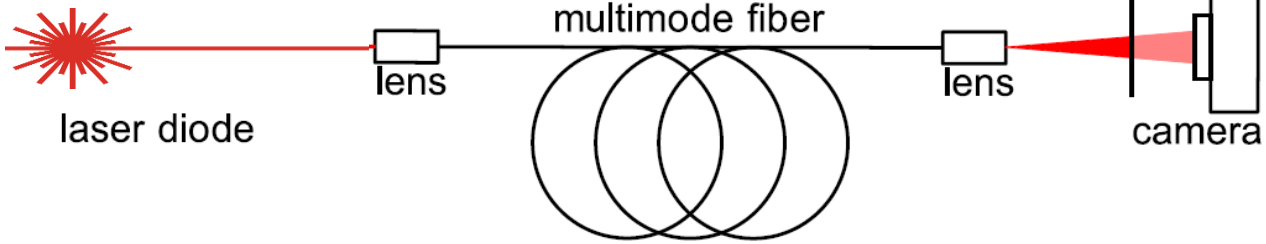
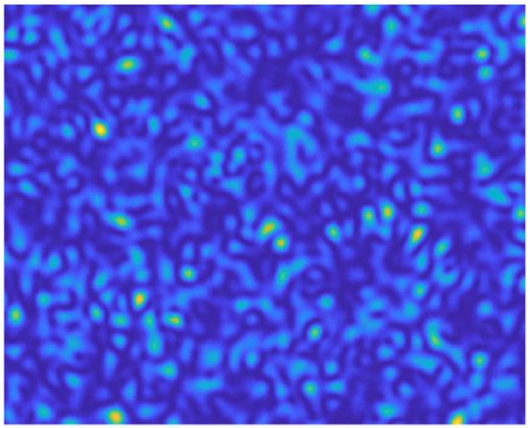
Speckle pattern: generated by random interference / scattering of coherent waves





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 application.

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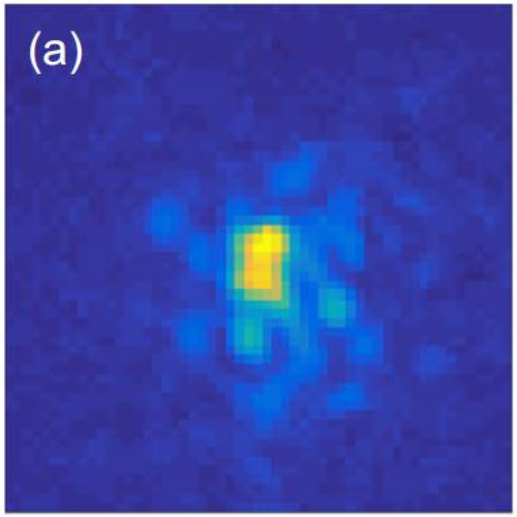
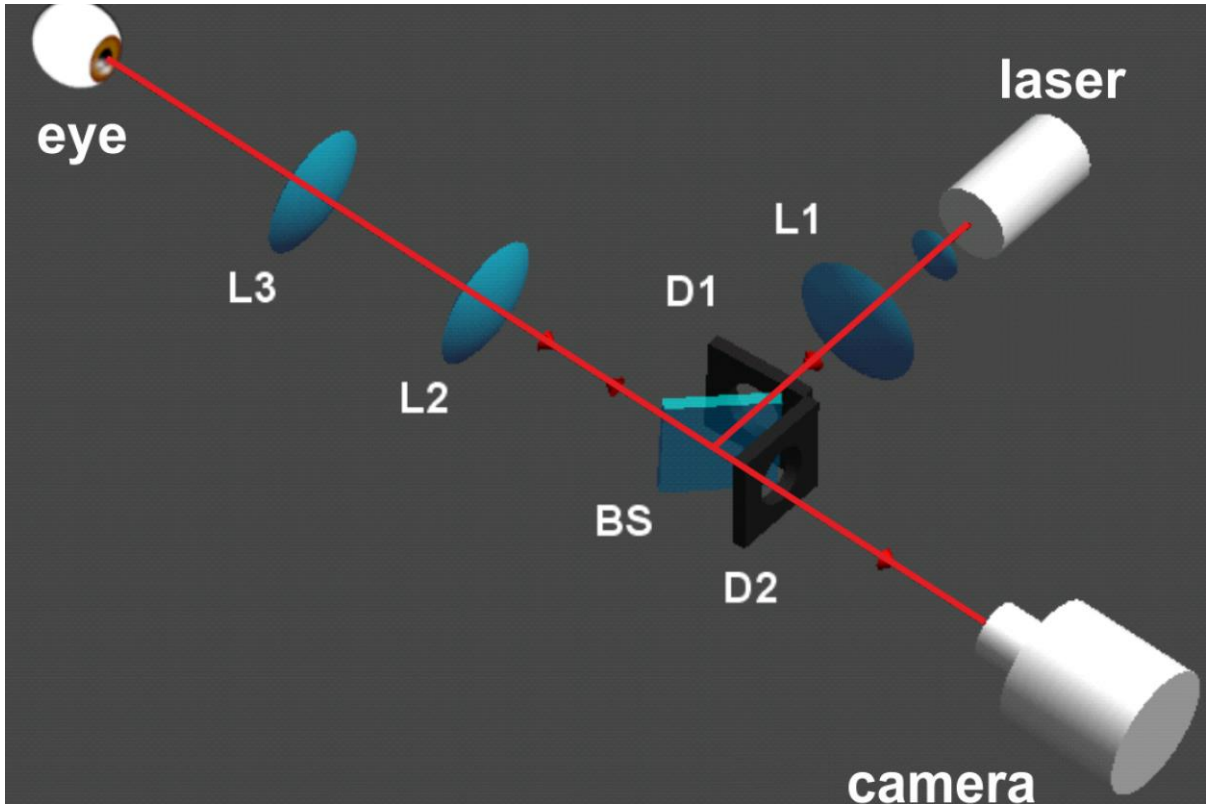
Speckle reduction in double-pass retinal imaging

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)

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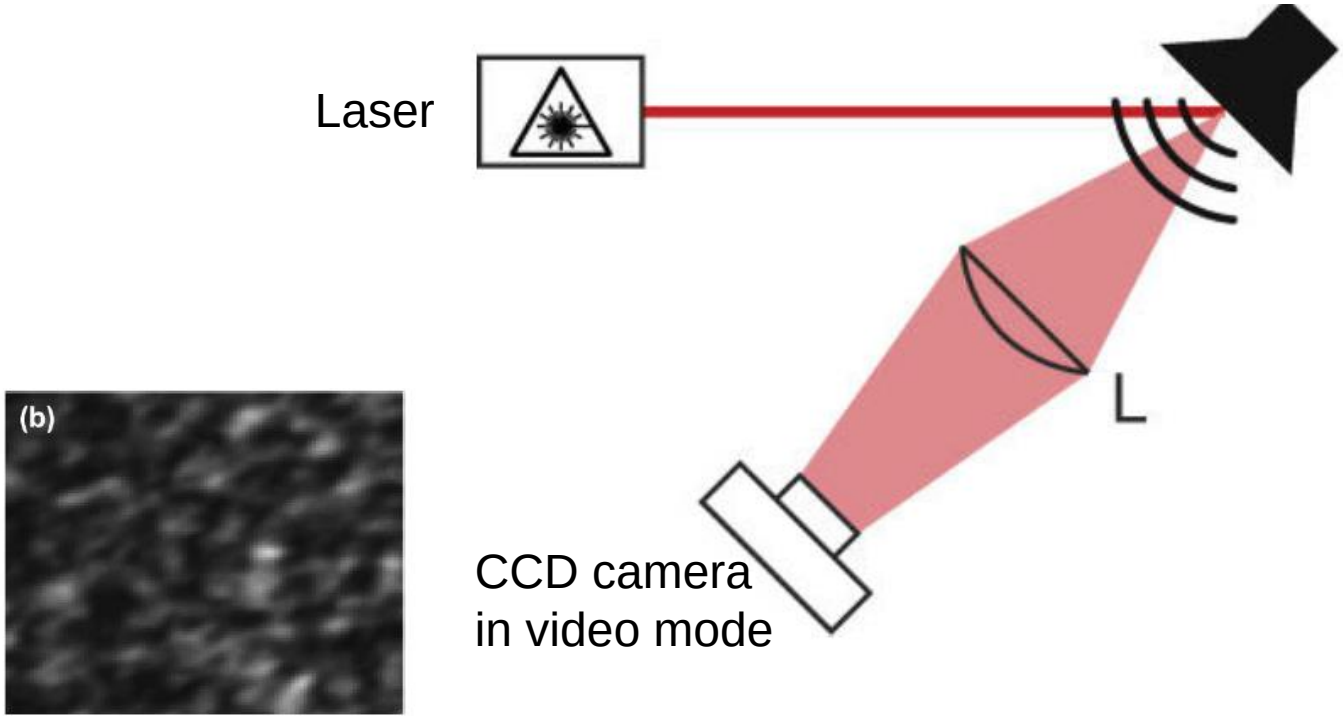
An example of application of speckle pattern analysis

Recovery of audio signals from silent videos of speckle patterns



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).

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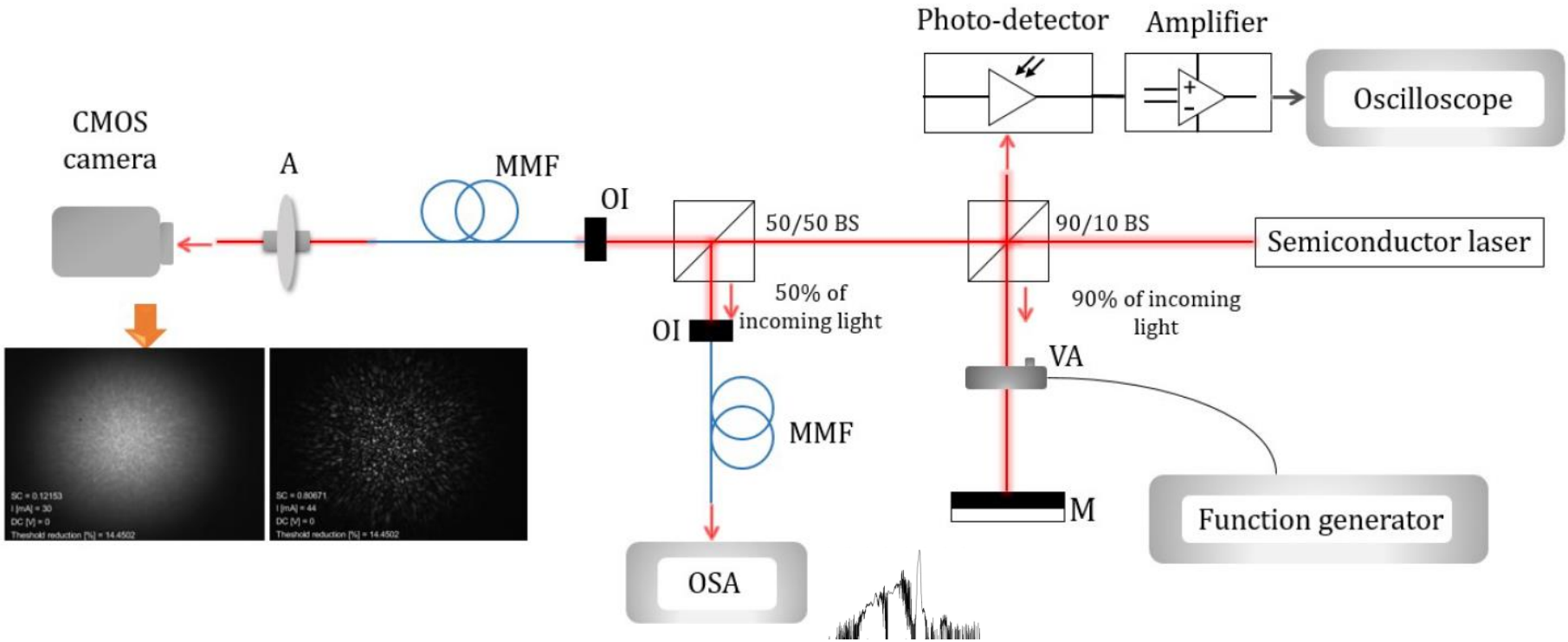
Experimental setup for studying the effect of optical feedback on the spatial coherence of the laser light



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).

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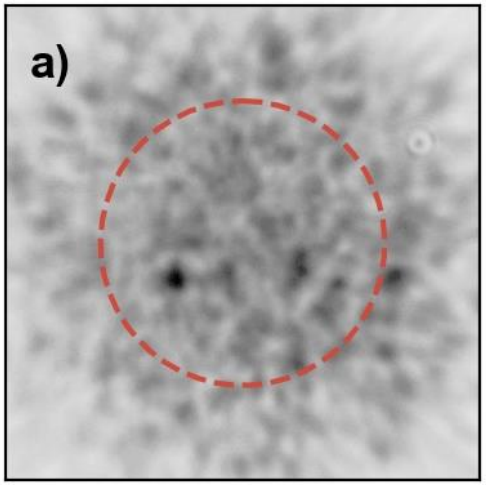
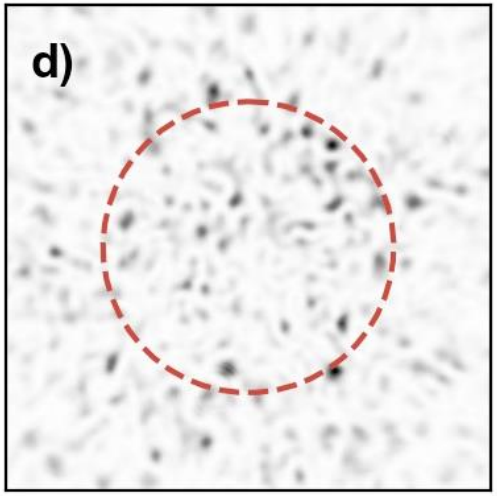
Examples of speckle images

Below threshold



Above threshold



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

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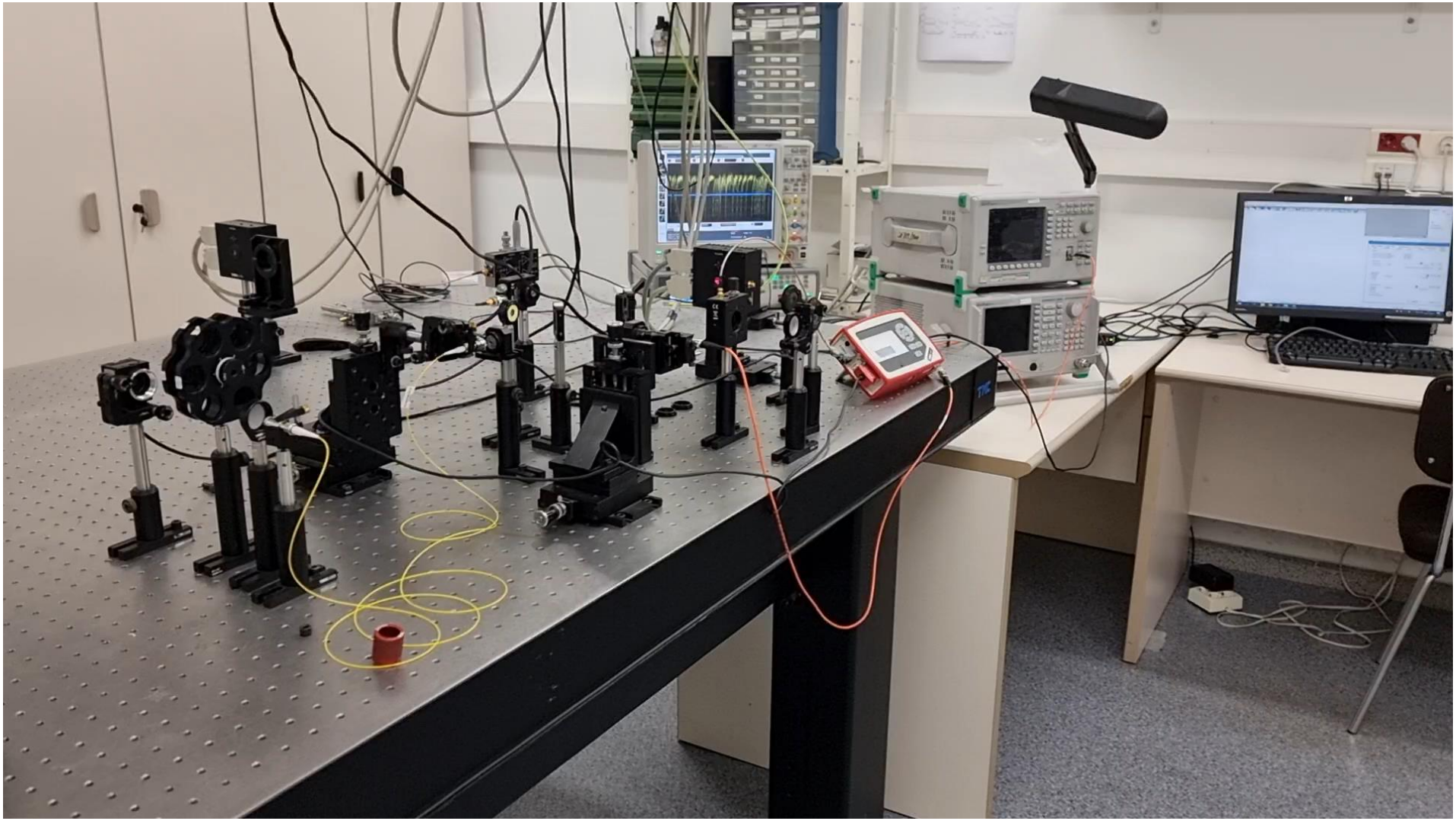
Three different diffusive media are used to generate speckle:

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



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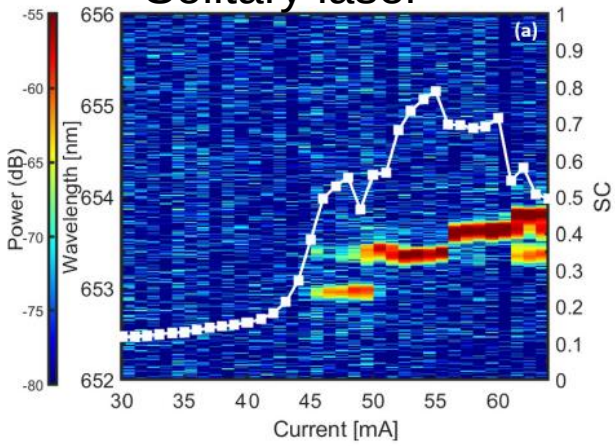
Spectral & speckle analysis, speckle generated by a MM fiber

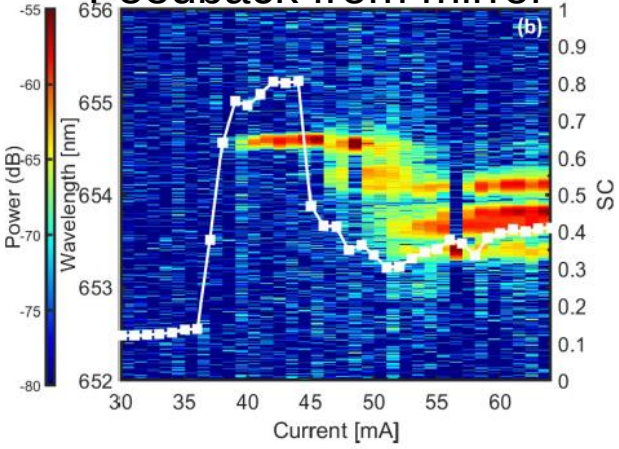
Speckle contrast (white) SC = $\sigma/\langle I \rangle$

Color code:
optical spectrum

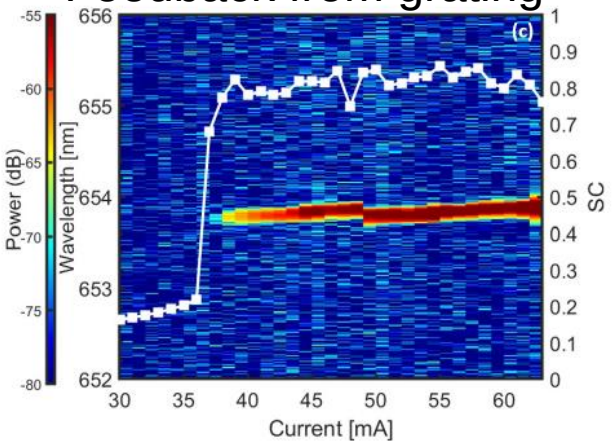
Solitary laser



Feedback from mirror



Feedback from grating



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)

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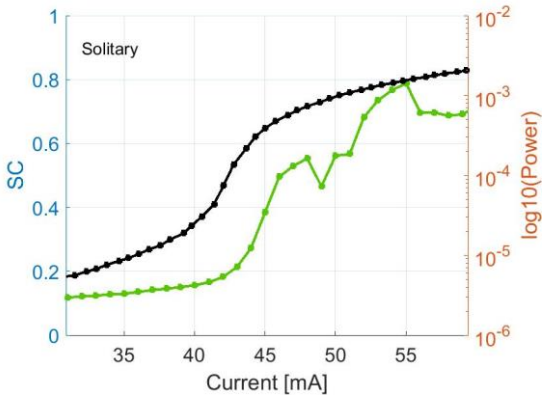
Speckle contrast and L-I curves

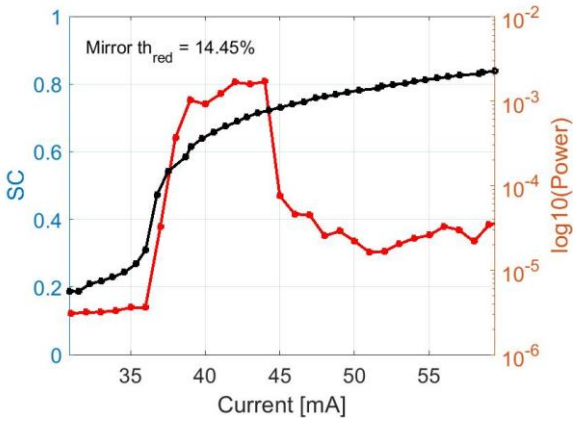
L-I curves: black, log scale

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

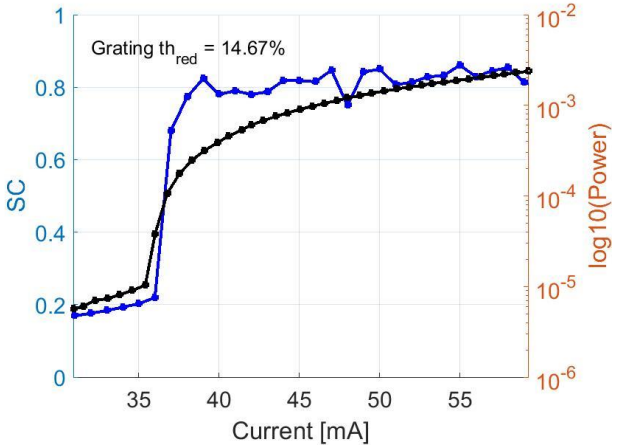
Solitary laser



Feedback from mirror



Feedback from grating



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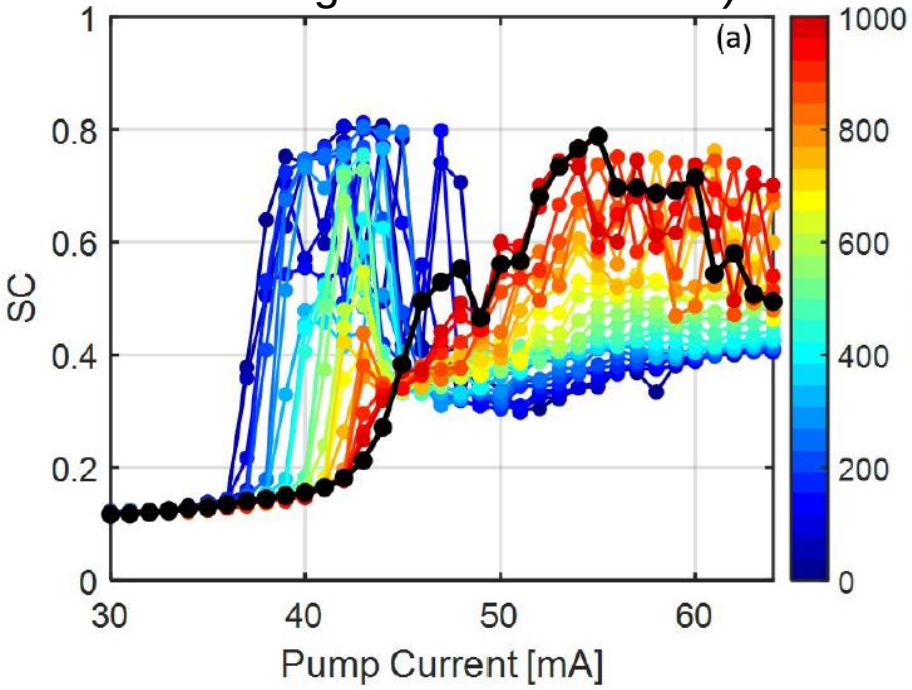
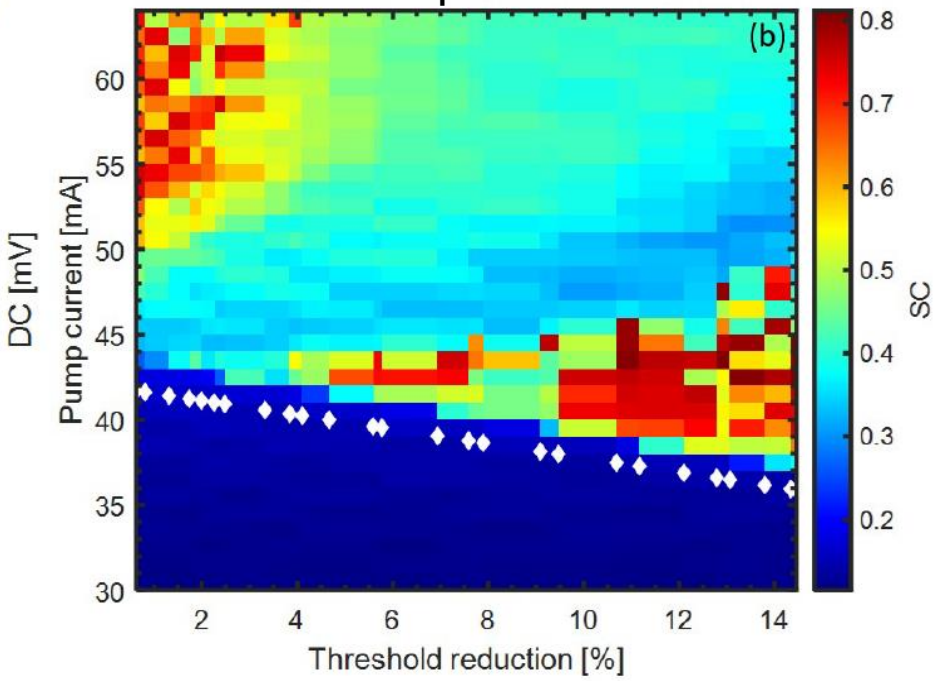
Influence of the feedback strength

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



Color code: speckle contrast



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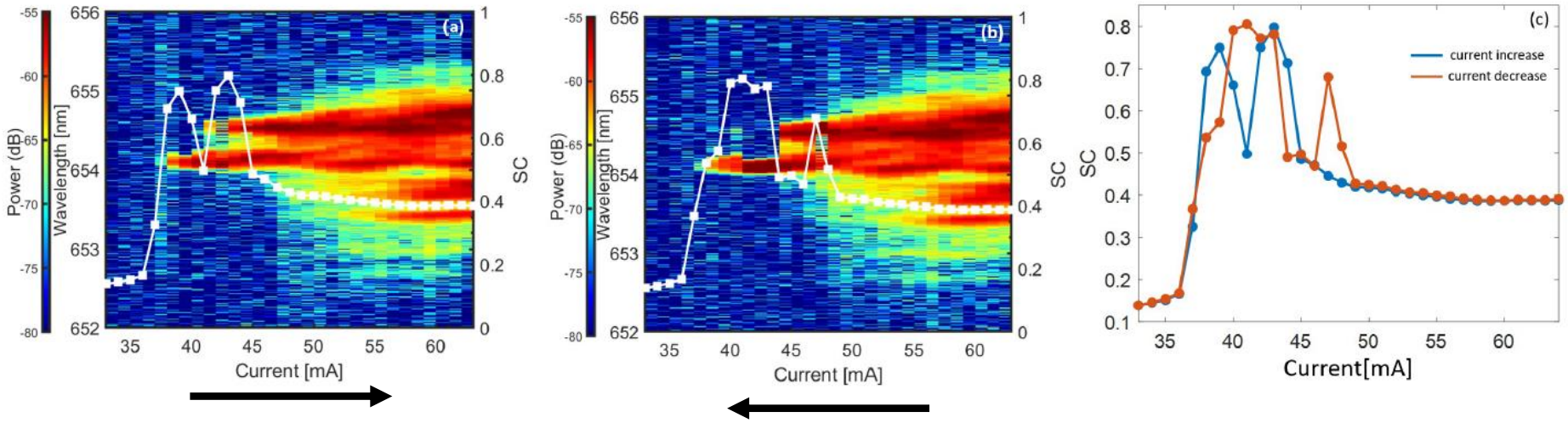
Hysteresis?



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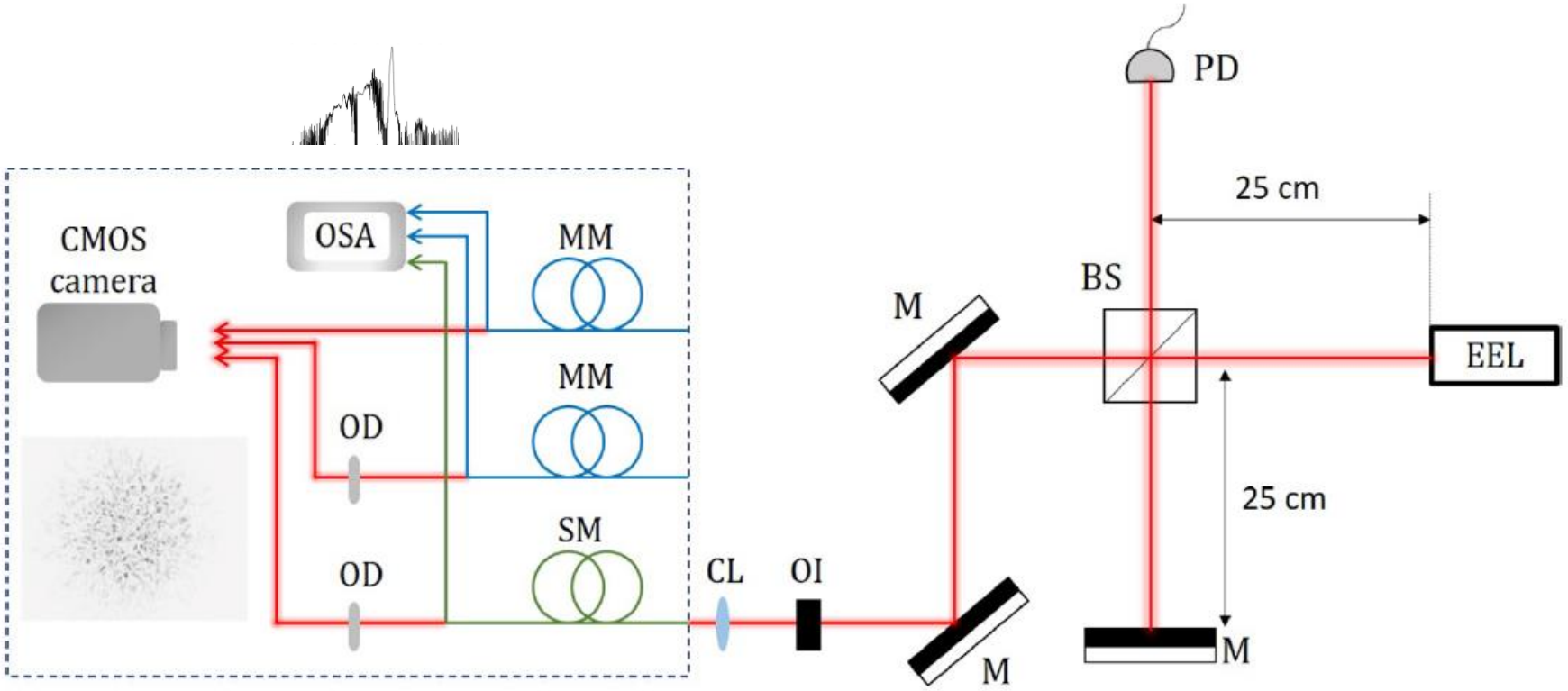
Role of the medium that generates the speckle pattern?



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)

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

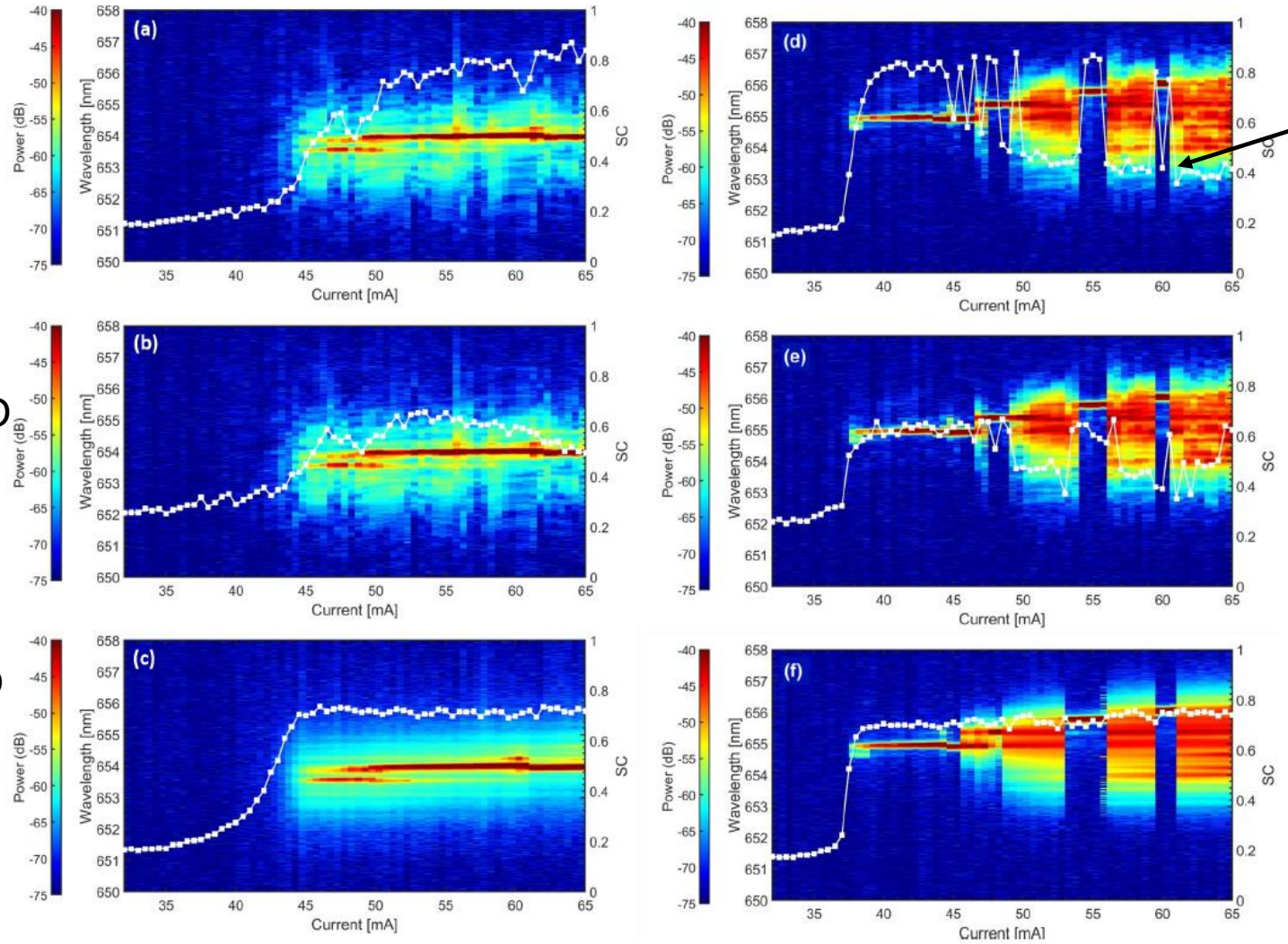
Solitary laser

Laser with optical feedback

MM

MMD

SMD



High spectral coherence but low speckle contrast

Low spectral coherence but high speckle contrast

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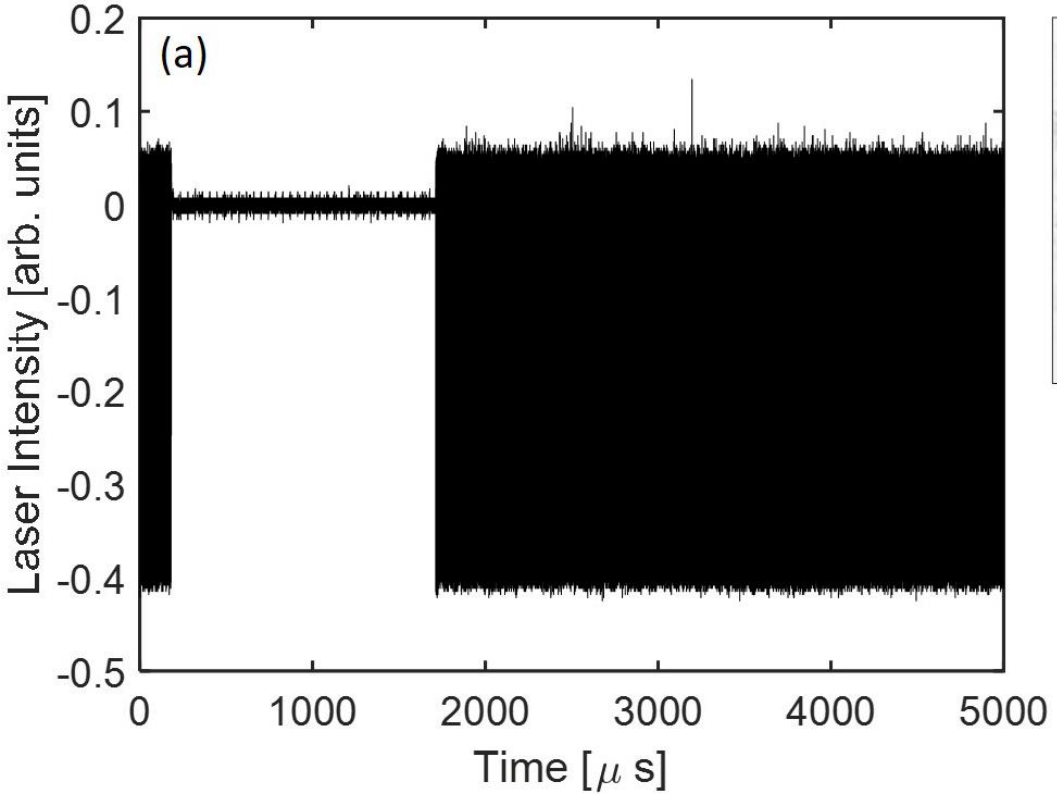
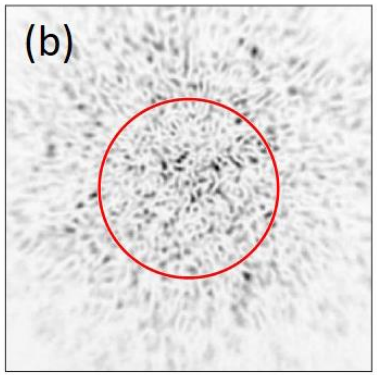
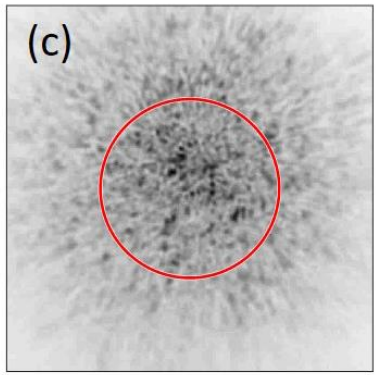
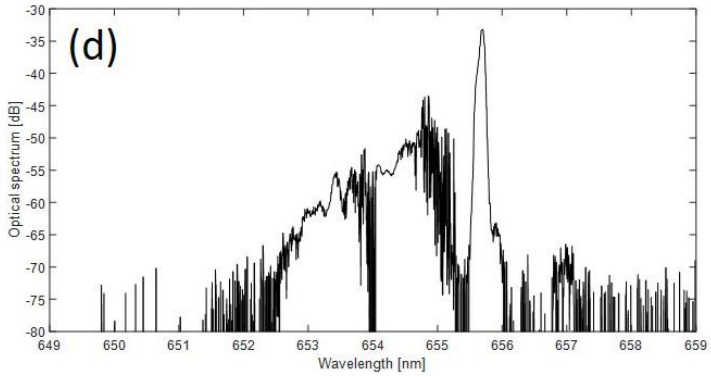
Alternation of stable and unstable emission









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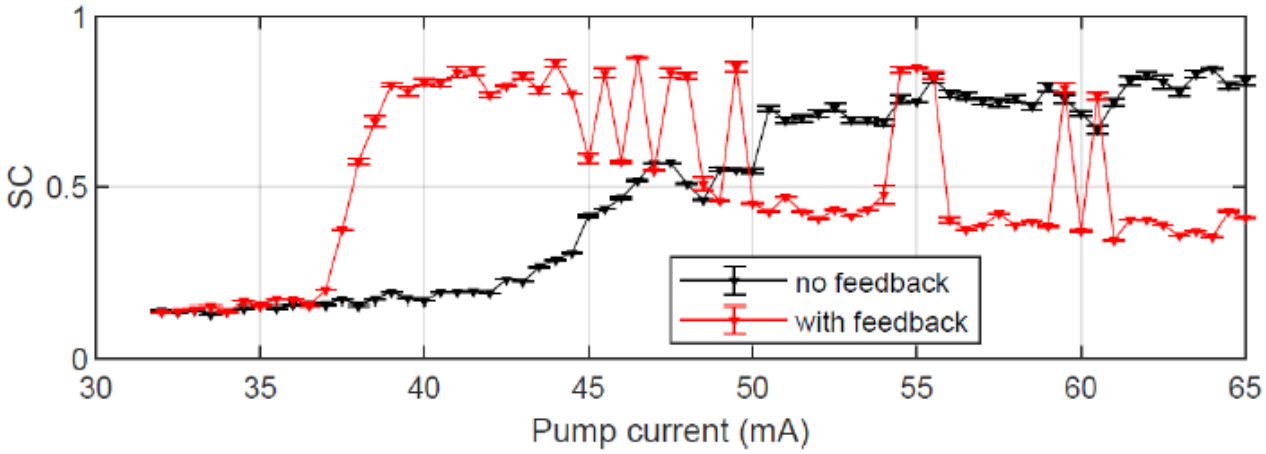
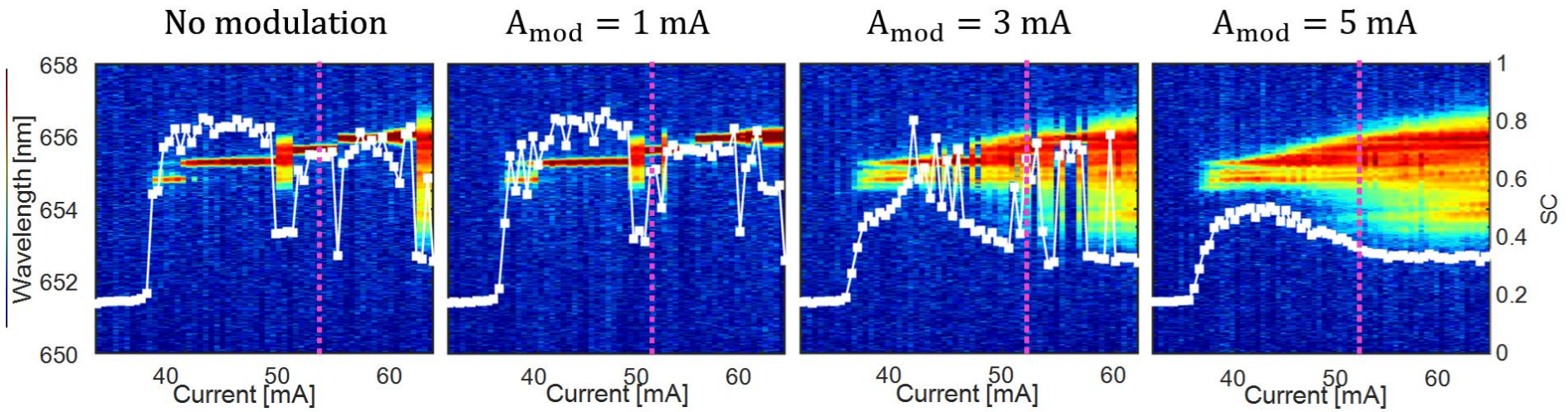
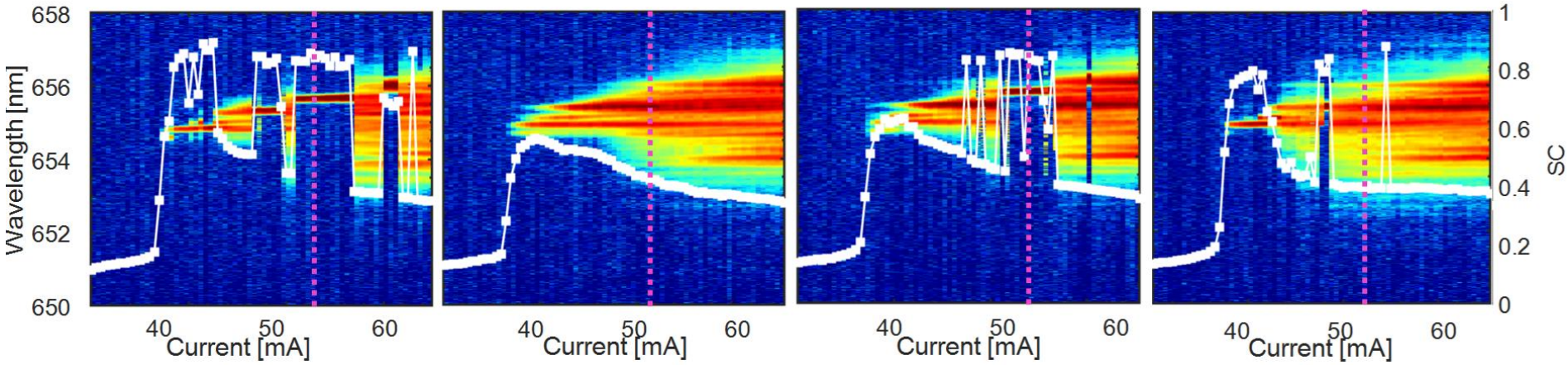


Research question: can we further decrease the coherence of the light by direct current modulation?

ν_{mod} = 1 MHz



A_{mod}= 2 mA (I_{DC}= 52 mA)



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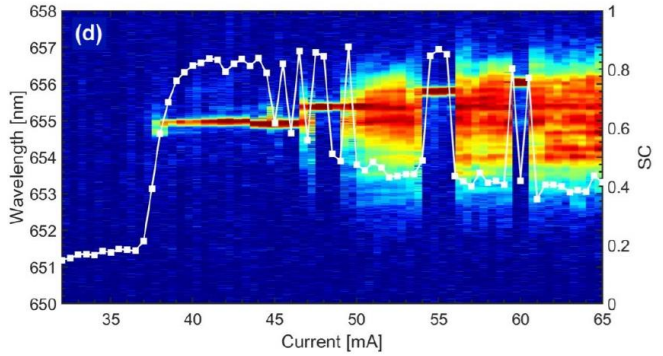
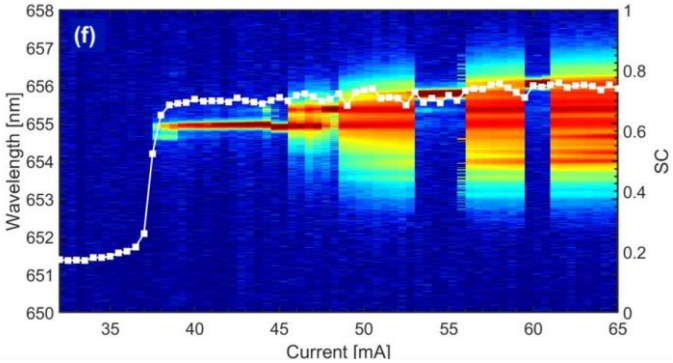
Take home messages

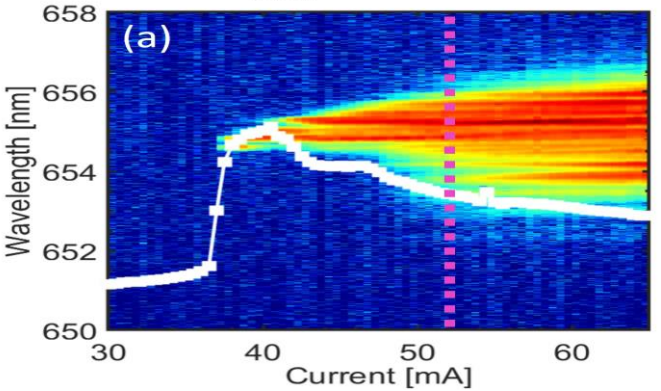
1. Strong enough optical feedback induces an abrupt transition to coherent emission.

2. Combining speckle and spectral analysis we can differentiate spatial and temporal coherence.

3. With appropriate modulation parameters, the regions of high speckle contrast are suppressed.







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

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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!

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