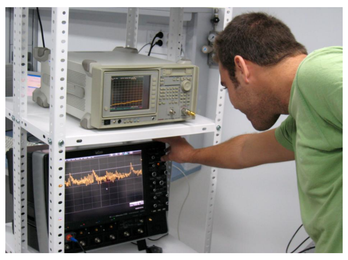
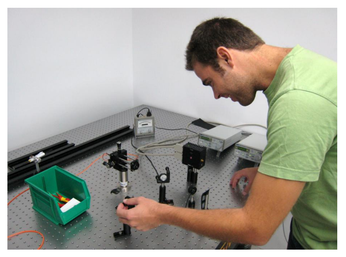
Nonlinear Photonics Lab
From Fundamental Interactions Towards Complex Networks

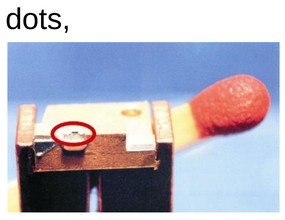
Lab Responsible:
Ingo Fischer
Office: 217
Phone : 971 25 98 78
email: ingo@ifisc.uib-csic.es





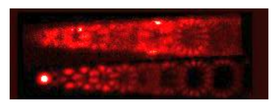
Semiconductor Lasers (SL)

- versatile and modern photonic sources
- interesting physics: laser and cavity physics, nonlinear (semiconductor) optics, complex dynamics, ...
- small size, electr. pumping, high efficiency
- multitude of structures, materials, wavelengths, power ranges
  - structures: Fabry-Perot, DFB, DBR, VCSEL, multi-section, µ-cavities, Photonic Crystal cavities, Photonic Integrated Circuits, .
  - active media: quantum wells, quantum dashes, quantum dots, quantum cascade structures
  - wavelengths: UV .. FIR (THz)
  - power ranges: µW .. kW
- particularities
  - fast time scales of the dynamics (ns..ps)
  - semiconductor band structure high gain bandwidth, high gain
  - strong nonlinearities in the interaction light - semiconductor medium



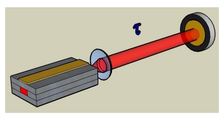
Experimental / Characterization Methods

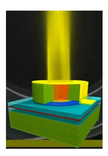
- modern photonics lab
  - multitude of photonic sources
  - various characterization techniques
- temporal characterization of emission dynamics
  - multichannel16GHz real-time acquisition (funded by CSIC and FEDER)
- spectral characterization of emission dynamics
  - real-time spectrum analysis with 14 GHz bandwidth (funded by Govern Balear and FEDER)
  - spectral analysis with 30 GHz bandwidth
- optical characterization
  - grating spectrometers
  - Fabry-Perot spectrometers
- spatio-temporal characterization with
  - picosecond resolution
  - polarization resolution
  - spectral resolution

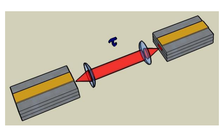


Main Research Activities

- nonlinear semiconductor laser emission properties
  - fundamental emission properties
  - semiconductor lasers as complex systems lab
- controlling and tailoring SL emission properties
  - controlling dynamical instabilities and synchronization
  - controlling temporal and spatial coherence
- dynamics of (delay-)coupled SL systems
  - dynamical instabilities
  - synchronisation properties
- utilization of complex dynamics, functional chaos
  - communication using chaotic carriers, key exchange
  - random number generation
  - Information processing
  - optical coherence tomography



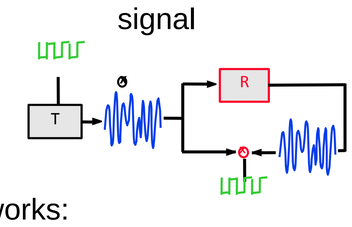


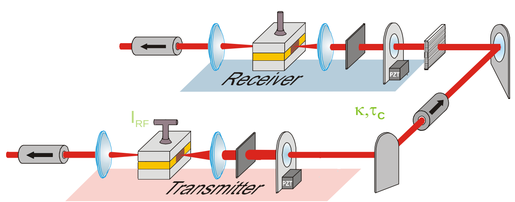


Utilization of Complex Dynamics

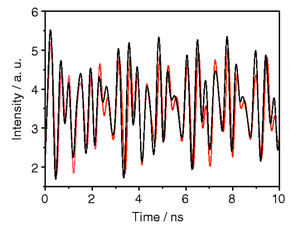
communication using chaotic carriers / key exchange

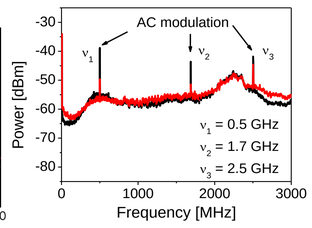
- principle:
  - generation of **suitable chaotic carrier** by the Transmitter
  - **encryption** of message by mixing it within the chaotic carrier of the Transmitter
  - **transmission** of entire signal to (matching) Receiver
  - **chaos synchronisation** if, and only if, Receiver is a “Twin system”
  - **extraction** of data via comparison of Transmitter and Receiver signal





- it works:
  - chaos generation and synchronisation
  - signal extraction





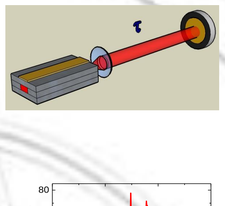
- field experiment
- in the Metropolitan Area Network of Athens
- 100 km fibre
- transmission at λ = 1552 nm
- BER: 10^{-7} for 1.0 Gbit/s transmission with NRZ PRBS

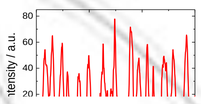
Nonlinear SL Emission Properties

- SL exhibit dynamical instabilities under various conditions
  - current modulation, light injection, or delayed optical feedback
  - high-power edge emitters (broad area lasers)
  - broad area VCSEL

semiconductor lasers as complex systems lab

- study of delayed feedback instabilities

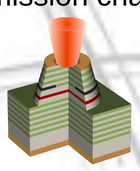


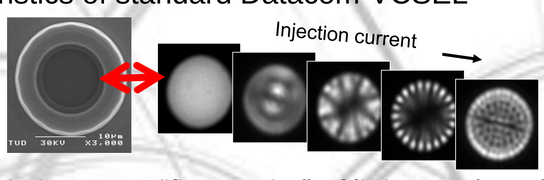


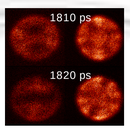
- instabilities in several applications due to delayed feedback from fibre or CD, DVD,..
- delay renders the system dynamically infinite dimensional
- aspects: dynamics, bifurcations, mechanisms, chaos-control, interaction with noise
- excellent testbed, has boosted studies of delay-systems

characterizing picosecond spatio-temporal emission

- emission characteristics of standard Datacom-VCSEL







- emission characteristics are a “fingerprint” of light-semiconductor interactions: spatial hole burning, spectral hole burning, temperature effects,..
- interactions lead to complex dynamical behaviour

Utilization of Complex Dynamics II

Generation of random bit sequences

- principle:
  - utilize unpredictability of chaotic laser dynamics
  - continuous dynamical system with noise avoids periodicities and recurrences
- advantages:
  - high bit-rate sequences
  - optical implementation

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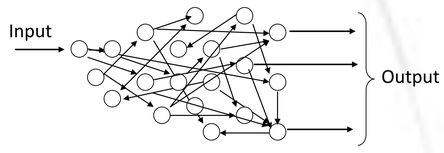
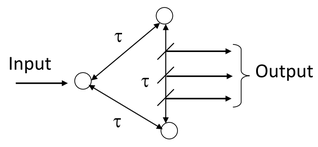
Information processing

- principle:
  - photonic implementation of a Liquid State Machine
  - information processing based on classification
  - utilizing delay-coupled elements to obtain high-dimensional state-space projection



traditional approach



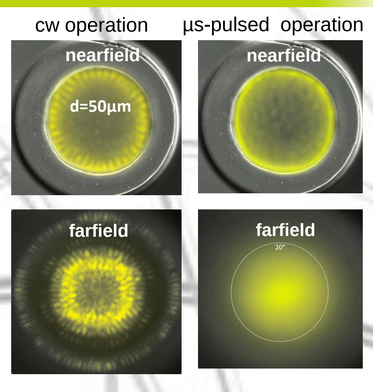
our approach

Controlling and Tailoring SL Emission

tailoring spatial coherence

broad area VCSEL

- cw operation:
  - emission in large number of transverse modes
- µs-pulsed operation
  - only slightly blurred nearfield, but
  - drastically changed farfield! (Gaussian)
- origin: breakdown of modal emission
- possible applications: speckle-reduced source, projection



Current Goals & Future Perspectives

- tailor emission properties using nonlinear physics
- benefit from modern photonic sources
- towards networks of delay-coupled lasers
- develop novel applications based on complex behavior
- bio-mimetic photonic architectures