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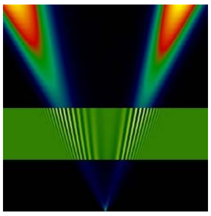
IFISC

NONLINEAR OPTICS AND DYNAMICS OF OPTOELECTRONIC DEVICES



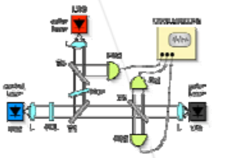
The general topic of this line is the study of the light-matter non-linear interaction and its consequences towards applications in emerging photonics technologies. We study emitter systems (lasers, mainly semiconductor ones) as well as systems subject to optical injection (semiconductor optical amplifiers, Kerr media, parametric oscillators). Most of the research carried out on this line can be classified in two complementary categories: the study of temporal evolution (dynamics) and the generation of non homogeneous light distributions (pattern formation).

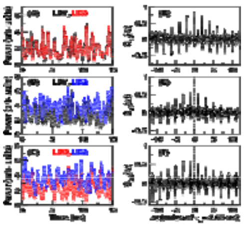
DYNAMICS OF SEMICONDUCTOR LASERS

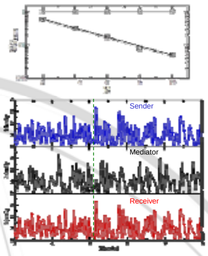
We study the dynamics and nonlinear effects of edge emitting and ring lasers and the mechanisms for selection, destabilization and switching of the polarization state in vertical cavity lasers, with the perspective of possible applications in information and communication technologies. The use of chaotic lasers to increase the security in optical communications is investigated focusing on the chaotic dynamics in presence of optical or electro-optical feedback, and on the synchronization of chaotic lasers.

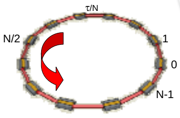
• *Synchronization of delay coupled lasers*

Mutually delay-coupled semiconductor lasers gives rise to collective dynamical behavior and synchronization with potential functional roles in complex systems. Interestingly, isochronal synchronization (without lag) can occur between widely separated laser diodes.





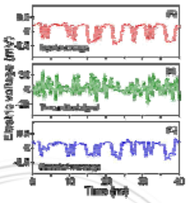


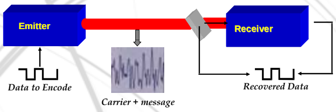


A ring of unidirectionally delay-coupled semiconductor lasers generates chaos and cross correlations that exponentially decay with the number of elements. When attaching a linear chain, identical synchronization via an uncorrelated signal can be obtained

• *Chaos-based communications*

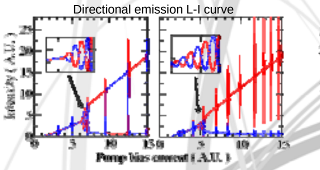
The output of chaotic lasers has been proposed as broadband information carrier with the potential of providing a high level of robustness and privacy in data transmission. The first field experiment over a commercial fiber-optic channel was reported in 2005. An optical carrier generated by a chaotic laser was used to encode a message for transmission over 120 km of installed optical fiber belonging to the metropolitan area network of the city of Athens, Greece. Transmission rates in the gigabit/s range were achieved, with corresponding bit-error rates below 10^{-7}. The system used matched pairs of semiconductor lasers as chaotic emitters and receivers, and off-the-shelf fiber-optic telecommunication components.

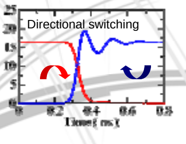


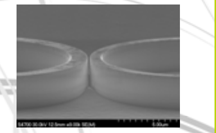


• *Ring lasers*

Ring lasers are potential universal building blocks for future all-optical digital and logic functional sub-systems. Their strong and robust directional optical bi-stability can be exploited as a fundamental mechanism for all-optical digital building blocks -from which digital functions of all types can be synthesized. The central concept is that the switching between two digital logic states within an semiconductor ring laser (the two possible directions of operation) can be triggered by an external optical signal - and can occur at ultra-high speeds. The innovation lies in the development of technologies that enable the progressive down-scaling of the dimensions of micro-SRLs to less than 20 microns, thus allowing optically induced switching times of 10 ps.


Directional emission L-I curve


Directional switching

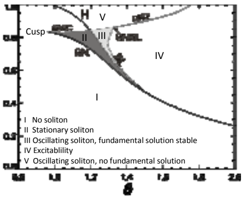


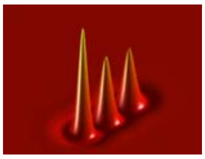
FORMATION OF SPATIAL STRUCTURES

The study of the formation of spatial structures and its dynamics in optical cavities filled with nonlinear media (Kerr, optical parametric oscillators, second harmonic generation) has implications that range from fundamental aspects such as the effects of different nonlocal couplings to potential applications for all optical processing of information. The possibility of using nonlinear optical cavities to perform all-optical contrast enhancement and contour recognition of images has also been studied.

• *Cavity solitons*

Cavity Solitons (CS), bright spots of finite size that appear in the transverse plane of nonlinear optical cavities, have been proposed as bits for fast and reconfigurable all-optical memories. At IFISC we showed that these structures can exhibit excitable behavior as an emergent property. This opens the possibility to use these structures not only to store information but to process optical signals.

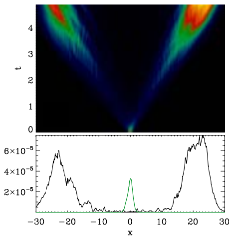


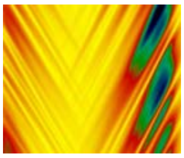


The figure on the top shows a phase diagram of all the dynamical regimes of CS in a self-focusing Kerr cavity. The figure on the right shows the implementation of a logical gate using three excitable CS. The two outer structures receive the input and the one in the middle will produce the output. The first structure has just received a signal, producing an excitable excursion.

• *Nonlocal interactions*

Diffraction is typically modeled by a Laplacian. However some optical systems include interactions not only at first neighbors but with a finite region around it, or even with more complicated motifs such as a *two-point nonlocality*, as in presence of a misaligned feedback loop. This leads to new dynamical regimes, such as the noise sustained pattern shown below. Due to the two point nonlocality positive and negative wave-numbers travel apart leading to a spatio-temporal "thread".

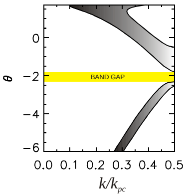


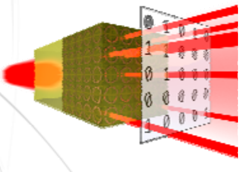


Furthermore, small localized signals can be strongly amplified while the background radiation in other region of the system remains very low. Surprisingly, the signal moves across the cavity with transverse phase and group velocities that are easily managed to have the same or opposite signs. In the above picture a laser is shown operating as a signal splitter, dividing a local spot into two copies traveling apart.

• *Photonic crystals and metamaterials*

Photonic crystals, artificial materials structured with a periodic modulation of the refractive index, allow to control light in ways that are not possible with conventional optics. We propose using these materials to control non desired spatial instabilities in broad area photonic devices. This has been now demonstrated experimentally and could allow a substantial improvement in the quality of the beams of broad area lasers. The Figure on the right shows the band-gap opened by a photonic crystal in the dispersion relation of a nonlinear cavity, inhibiting any spatial instability.





Metamaterials are artificially structured in such a way that they can exhibit a negative refractive index. Introducing a layer of such a material in a cavity the strength of diffraction can be reduced. This potentially allows the creation of sub-diffraction-limited cavity solitons for ultra-compact optical memories. The figure on the left shows an art work illustrating one of this devices using intracavity metamaterials.