Università di Genova

Dipartimento di Fisica

ISTITUTO ITALIANO DI TECNOLOGIA OPTICAL NANOSCOPY

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Annual PhD Report
PhD Course in Physics and Nanosciences
Curriculum Bio-Nanosciences

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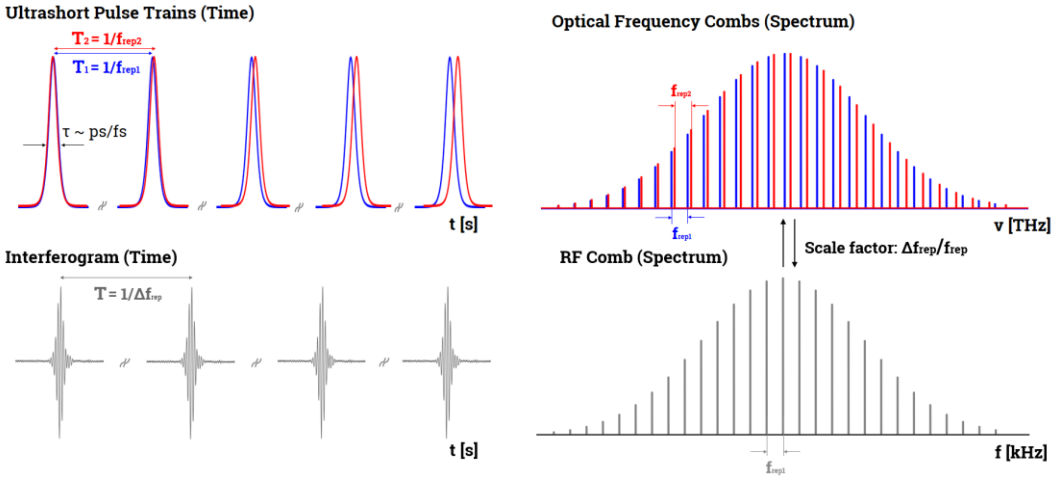
Research Activity

I am carrying out my PhD research activity in the Nanoscopy & NIC Lab @ IIT and my research project concerns the development of light sources whose properties are tailored to the requirements of optical microscopy. This work is being developed in the context of the MOMIX project, consisting in the design and realization of a versatile multi-modal optical microscopy platform, having tunable contrast mechanism and performances both based on fluorescence and label-free approaches. We already realized a Mueller Matrix microscope having a Zeeman Laser as core element to achieve a fast generation of different polarization states. The sample response to polarized light has been encoded in interferometric signals generated by the Zeeman Laser and it has been exploited to obtain label-free images. Now, we planned to use a Dual-Comb Laser (DCL) as an innovative and versatile illumination stage of a multimodal optical microscope, able to excite both linear and non-linear label-free imaging contrasts. I spent an abroad research stay at the ETH during my 3rd PhD year, hosted by the Ultrafast Laser Physics (ULP) lead by the Professor Ursula Keller. Here, I developed and characterized a solid-state DCL under the supervision of Dr. Christopher Phillips. Then we performed interferometric measurements of polarization properties of samples using the ultrashort pulse trains emitted by this new light source. A DCL is a mode-locked laser emitting two-twin trains of ultrashort pulses that are associated with two mutually coherent Optical Frequency Combs (OFCs) in the spectrum. The interaction between two OFCs leads to a strong interferometric signal in virtue of the mutual coherence of the two combs. The spectrum of this interferometric signal is a third comb in the Radio-Frequency (RF) range that is a rescaled replica of the optical output spectrum of the laser.



Our DCL laser oscillator is based on a Yb:CALGO crystal emitting around 1050 nm that is inserted in a ~15 cm cavity to achieve 1 GHz repetition rate. The oscillator is pumped by a multimode laser diode emitting at 980 nm. The generation of the ultrashort pulse train has been achieved by using a SEmiconductor Saturable Absorber Mirror (SESAM): this device is the key element to passively mode-locked the laser emission, thanks to its intensity-dependent nonlinear reflectivity. Moreover, the chromatic dispersion introduced by the optical elements in the cavity has been compensated by exploiting chirped mirrors to introduce some negative Group Delay Dispersion (GDD). The core element for the Dual-Comb operation is a biprism inserted in the cavity as a multiplexing element: it realizes a physical separation of the oscillating beam into two components, experiencing two slightly different optical paths in the cavity. Consequently, the two emitted beams will own different repetition rate values that are associated to the tiny frequency shift in the spectra of the two combs. So, this device emits two spatially separated but parallel beams, that are one almost the exact copy of the other: their main difference is lying in the repetition rate

that is the frequency spacing between two consecutive spectral lines (longitudinal modes). Our DCL emits an optical average power > 2 W for each comb, associated with 100 fs ultrashort pulses and 10 nm of bandwidth centered around 1053 nm. Their repetition rate is about 1 GHz and their difference can be tuned from few kHZ to some tens of kHz by moving the intracavity biprism. The two separated beams are both linearly polarized along the same oscillation plane and we modify this property outside the laser resonator to perform the polarization-resoved interferometric measurements. Then, we set the linear polarization states of the two different output combs in order to be orthogonal (H and V). Then we shined a sample with this cross-polarized light and its anisotropic signature is impressed in two interferograms. These signals form from the heterodyne mixing of the two comb that is the result of the interference between many pairs of discrete spectral lines of the two OFCs. So, the Dual-Comb emission realized with these laser sources can be used to detect the polarization-resolved spectral signature of samples encoded in the beating of several comb lines. The broadband OFCs are used to reconstruct the polarization signature of samples over a relatively wide spectral region, wider than 10 nm in our case. Finally, the high peak intensity could be exploited to trigger nonlinear optical interactions inside the sample. We are planning to integrate the novel DCL in our multimodal microscopy setup and use its optical properties to image optical anisotropies, such as dichroism and birefringence, and excite optical nonlinear processes as label free imaging methods.

Courses and Exams

3nd Year	Course	Organizer	Hours	State
extra	Multimodal And Nanoscale Optical Microscopy	SIF	> 30 h	DONE
extra	Summer School on Quantum Optical Technologies	UniBa & INFN	> 30 h	To be Done

Publications

- Callegari F, Le Gratiet A, Zunino A, Mohebi A, Bianchini P and Diaspro A (2021), "*Polarization Label-Free Microscopy Imaging of Biological Samples by Exploiting the Zeeman Laser Emission".* Frontiers in Physics. 9:758880. doi: 10.3389/fphy.2021
- A Mohebi, A Le Gratiet, A Trianni, F Callegari, P Bianchini, A Diaspro, *"Phasor map analysis to investigate Hutchinson–Gilford progeria cell under polarization-resolved optical scanning microscopy"*, Scientific Reports 12 (1), 1-10

Conferences and Workshops

- Frontiers in Optics and Laser Science 2021 (FiO+LS 2021), *"Polarization label-free microscopy imaging of biological samples by exploiting the Zeeman Laser emission",* Online Poster
- Focus On Microscopy 2022 (FOM 2022), *"Fast polarization-based label-free imaging in a scanning microscope utilizing the beating signal of a Zeeman Laser"*, Online Talk
- Società Italiana Di Biofisica Pura Ed Applicata (SIBPA) Congress 2022, *"Probing Of Optical Anisotropies Through The Dual-Frequency, Dual-Polarization Emission Of A Zeeman Laser",* Poster
- Società Italiana di Fisica Congress (SIF) 2022, *"Dual-comb laser as a versatile light source for multimodal optical microscopy"*, Oral Communication