I-PHOQS

INTEGRATED INFRASTRUCTURE INITIATIVE IN PHOTONIC AND QUANTUM SCIENCES

Mid-term Review Meeting

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Book of abstracts

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Welcome message

This mid-term review meeting of our new Research Infrastructure, I-PHOQS, is a unique opportunity to meet colleagues from all the Infrastructure sites, to share experiences and to plan joint Projects and experiments. The new scientific and technological workforce, that includes colleagues with Temporary contracts, in addition to staff people, already having a position at CNR or Politecnico di Milano, will surely provide strong momentum to our Facilities and to our joint Research.

Considering this is the first large Facility for Photonics and Quantum Sciences, distributed all over Italy, that begins operation, it is necessary to know well what each area and each geographical site actually does, to start cross-disciplinary research, representing the true added value of I-PHOQS. Therefore, in-person meetings like this one can really make a difference for our work and for the years coming.

The Infrastructure Director

Paolo De Natale

I-PHOQS MID TERM REVIEW MEETING

High Efficiency GaAs/Si HJT Four-terminal solar cell systems

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By combining the low cost of silicon (Silicon Heterojunction) with the high efficiency of GaAs (Gallium Arsenide), the GaAs/Si Heterojunction (HJT) four-terminal (4-T) solar cell system is a promising advancement in photovoltaic technology. In this study we investigate 4T systems with dichroic mirrors and wedge dielectric prisms to optimize the spectrum splitting, to ultimately improve the energy conversion efficiency.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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Multi-pass Cell Design for Ultrashort Pulses

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Multi-pass cells (MPC) have become a widely used technique for compressing laser pulses, capable of reaching durations down to a few laser cycles. This technique can achieve good spatial quality and spatio-spectral homogeneity [1]. While there have been a few instances of compressing laser pulses of a few tens of femtoseconds with high pulse energy (above 1 mJ) [2], this area remains an active field of research. MPCs present challenges when operating at high energies since thermal effects, unwanted nonlinear optical processes (such as self-focusing or ionization), and material damage become more pronounced. Consequently, the mirror damage threshold, and therefore the energy of the pulses to be compressed, impose a minimum MPC length; this may involve large footprints, limiting its applicability in setups where space is a constraint.

This work presents a comprehensive theoretical study of two MPC geometries: concave-convex (Cv-Cx) [3] and concave-concave (Cv-Cv) [4] for 1-mJ, 30-fs a Ti:Sa laser systems. The minimum length, spectral broadening, and the Fourier-transform limited (FTL) duration for both configurations are investigated to identify the most suitable option for compressing high-energy pulses, thereby providing practical insights for laser pulse compression applications. Simulations show that both geometries allow for the achievement of pulses with FTL durations approximately between 3-8 fs, resulting in a compression factor of up to 10. Both geometries, Cv-Cx and Cv-Cv, are viable options for MPC configuration. However, the Cv-Cx geometry offers a more compact cavity due to the fact that this configuration results in a larger beam size, which in turn leads to a lower fluence on the mirrors. This prevents optical damage while maintaining sufficient intensity for Self-Phase Modulation (SPM). Therefore, the Cv-Cx configuration is a more practical solution for high-energy pulse compression, combining compactness with robust performance.

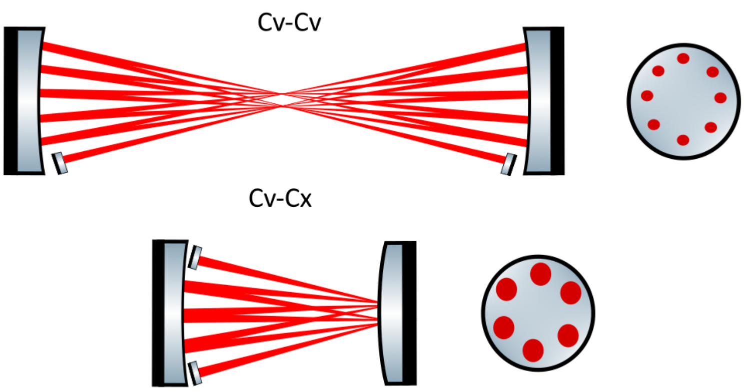

Figure 1. Schematic side view and dense spot pattern in the mirror of a Concave-Concave MPC above and of a Concave-Convex MPC below.

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This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Investigation on Laser Plasma Acceleration regimes at kHz repetition rate

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Nowadays compact laser-plasma accelerators (LPA) are being considered as novel sources for direct use of electrons in medical applications. In particular with the recent development and demonstration of laser systems capable of operating at 1 kHz rate [1], LPAs represent a potential solution for high dose rate irradiation in the context of FLASH-RT[2]. In this work we show, through a numerical investigation based on experimental conditions achievable by the 20 mJ, 1 kHz laser system at the Intense Light Irradiation Laboratory, the possibility to accelerate electrons from interaction with a sub-mm supersonic gas jet. According to the values of plasma background density we identify two acceleration regimes: at high densities $(1 \div 2 \times 10^{20} cm^{-3})$ electrons are accelerated through the Direct Laser Acceleration (DLA) mechanism while at lower densities $(\sim 8 \times 10^{19} cm^{-3})$ the Self Modulated-Laser WakeField Acceleration is predominant. In the latter case a fine tuning scan of the laser focus position in the plasma up-ramp is needed to optimize the acceleration.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, funded by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Ultrafast dynamics of strongly coupled bound state in the continuum in a WS_2 metasurface

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Metasurfaces are artificially structured materials that derive their optical properties from the control of the shape, size, orientation and arrangement of their subwavelength units, usually called "meta-atoms". They have been used as platforms for light-matter coupling applications, owing to their high optical signal contrasts and experimental robustness.

Photonic bound states in the continuum (BICs) have recently emerged as a new paradigm for achieving electromagnetic resonant modes in nanophotonic structures with controllable resonant frequencies and virtually infinite Q-factors, since they are completely decoupled from the radiating waves.

In recent works it has been shown that metasurfaces supporting quasi-BIC states can be strongly coupled to excitons in semiconducting transition metal dichalcogenides (TMDs) [1], where polaritons appear at room temperature. However, ultrafast studies of excitons and polaritons dynamics in such systems are still missing.

In this work, we study arrays of nanorod-type BIC unit cells made of bulk WS_2, where the asymmetry of the structure is controlled via the length difference of the rods, while the spectral tunability is controlled via the geometrical scaling factor S (Fig. 1a) of the nanostructure [1]. Acting on the scaling factor, the BIC resonances are tuned across the exciton energy of the WS_2, resulting in an anti-crossing with a Rabi splitting of 116 meV at room temperature for the metasurface with scaling factor S=1.11.

As shown in Fig.1b, we retrieved the polariton dispersion of the metasurfaces as a function of angle, wavelength and scaling factor. By increasing the scaling factor, we progressively observed the hybridization of the exciton (Ex, at 629 nm) and the BIC and the red shift of the lower polariton and upper polariton branches (LPB, UPB).

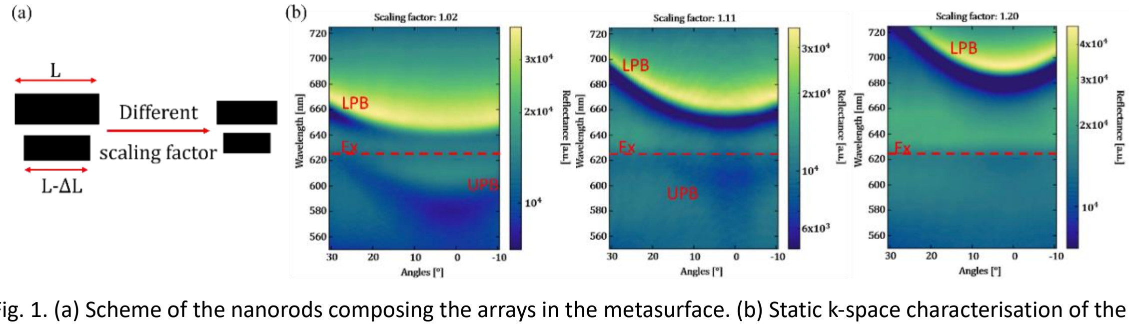

Fig. 1. (a) Scheme of the nanorods composing the arrays in the metasurface. (b) Static k-space characterisation of the metasurfaces with S=1.02, 1.11, 1.20. By increasing the scaling factor, the LPB and the UPB red shift

We also performed ultrafast spectroscopic measurements using broadband pulses tuned at 550 nm as pump and supercontinuum white light as probe. The pump pulses are pre-compressed by chirped mirrors, obtaining an overall temporal resolution of 50 fs.

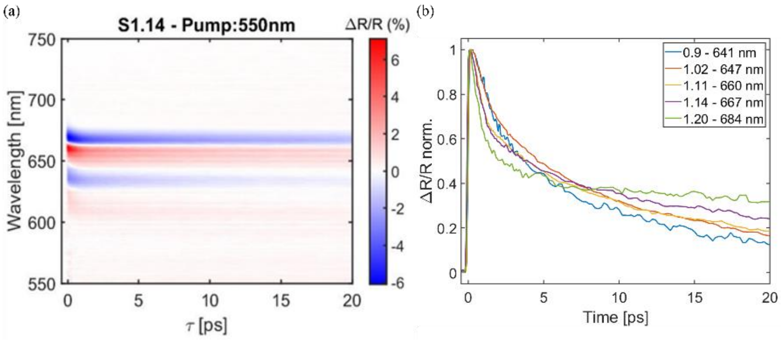

Fig. 2. (a) Transient reflectivity map versus probe wavelength and pump-probe delay time of the metasurface with S=1.14. (b) Normalized LPB dynamics for different S; by increasing S the first decay time decreases, while the second increases.

By changing the delay time between pump and probe, we retrieved transient reflectivity maps of the samples (see Fig. 2a) showing the appearance of the LPB, as the scaling factor is increased, as also observed in the k-space characterization. By extracting temporal cross-sections at the wavelength of the LPB, we can analyse the lower polariton ultrafast dynamics (Fig. 2b). As we increase the scaling factor, the first faster decay time tends to decrease, while the second slower decay time tends to increase. We argue that the first decay time τ_1 reflects the radiative relaxation of bright polariton states and its behaviour can be explained considering a balance between the photonic nature and the excitonic nature of the LPB, according to [2]: $\frac{1}{\tau_1} = p\frac{1}{\tau_p} + x\frac{1}{\tau_x}$. Where τ_p and τ_x are the relaxation times of the photon and the exciton respectively, while p and x are the Hopfield coefficients for the polariton states at different detunings. The behaviour of the second decay time, instead, might be related to a slow repopulation of these bright states from non-radiative channels: dark excitons can scatter down in energy into the polariton states, through phonon-assisted processes. Considering the negative dispersion of the LPB such process is not very efficient in our system, which can explain the much slower second decay time observed in the structures with higher scaling factor.

In conclusion, we retrieve the polariton dispersions of WS_2 metasurfaces as a function of the scaling factor, exhibiting a negative concavity. From the pump probe measurements, we obtained the ultrafast temporal behaviour of the samples from which we could observe the lower polariton population dynamics changing dramatically with the BIC-exciton detuning.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Quantum optics with organic molecules in solid-state matrices

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Besides emerging as excellent single photon emitters, organic molecules trapped in solid-state matrices are also promising candidates to be a new fertile and versatile complete quantum optics platform. Unlike atoms in optical tweezers, these quantum emitters face the complexity of existing in a structured solid-state environment, which strongly affects their behavior. Particularly striking is the effect of the matrix's phonons and intrinsic molecular vibrations, which are known to produce strong decoherence and dephasing in the optical emission properties. Additionally, positional disorder and matrix defects can generate significant inhomogeneous broadening and spectral diffusion. Through the most recent experimental and theoretical advancements, I will show in this talk that these features are not necessarily detrimental but can actually be a resource that brings technical advantages or even the possibility to address new physical phenomena.

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I-PHOQS MID TERM REVIEW MEETING

A novel multi-modal optical microscope: integrating Raman and photoluminescence spectroscopies with multivariate analysis

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Multimodal imaging is a rapidly emerging approach that integrates multiple imaging techniques to provide a comprehensive understating of a sample. By combining these methods with distinct sensitivities, it enables the acquisition of a complementary view of the sample under investigation.

Cultural Heritage (CH) artifacts are notably complex from a material standpoint due to the multiple chemical species present, which are heterogeneously distributed from the surface to the inner layers. Indeed, to evaluate their conservation status, a multi-analytical approach is commonly employed by collecting a variety of spectroscopy and imaging data of the artwork [1]. Specifically, CH micro-samples as pigments' powders, paint stratigraphies and other heterogeneously distributed compounds, often require different microscopy and micro-imaging techniques that are often sequentially employed. This sequential acquisition of information using different setup poses significant challenges in the superimposition of the images and the data integration.

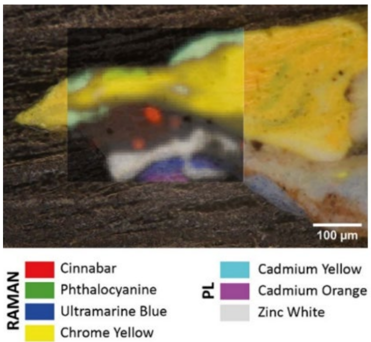

Figure 1: Analyzed stratigraphy from Larionov's painting with superimposed reconstructed image of Raman and photoluminescence measurements with a legend of the materials retrieved.

The aim of our work is to present the design and development of a novel multimodal optical microscope that combines Raman and laser-induced photoluminescence (PL) spectroscopy within the same set-up to achieve the chemical mapping of samples. Indeed, Raman and PL are highly complementary techniques, allowing comprehensive characterization of the different compounds present in a micro-sample. The exploitation of these techniques in a unique setup enables the easy integration of the acquired information. Additionally, we introduce a specialized analysis protocol designed to extract valuable information from the collected hyperspectral mapping datasets. This protocol employs a multivariate analysis approach based on spectral decomposition, named non-negative matrix factorization (NMF). Looking ahead, our setup, combined with NMF approach, promises potential applications in diverse research fields, including material science and biology.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Abstract for I-PHOQS Mid Term Review Meeting Poster Session

Separating single from multi photon events with a single detector in time correlated single photon counting

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The motivation behind this work is to explore the capabilities of a silicon photomultiplier (SiPM) in distinguishing single-photon events from multi-photon (specifically double-photon) events. By leveraging the unique properties of SiPM, the goal is to achieve precise multi-photon counting within a single detector, which is crucial for advancements in quantum optics. When laser pulses impinge on the detector, they trigger an avalanche of electron-hole pairs, resulting in an electrical signal. With a certain statistical probability, two photons may impinge on the detector within a very short time frame, causing associated avalanches that produce an electrical signal with double the amplitude. By setting a voltage threshold higher than the amplitude of a single avalanche event, we can selectively count only the multi-photon events. The experiment employs as photon source a 10 MHz pulse diode laser, fiber-coupled to the SiPM module. The electrical signal output is amplified, split using a radio frequency splitter, and sent to two separate channels of a MultiHarp DAQ board for parallel analysis. This board enables precise time-tagging of the photon events, and each channel can be configured with a different threshold voltage. After correcting the single-photon measurements for pile-up errors and estimating the percentage of optical crosstalk, the probability of multi-photon events was mapped. This data was compared with theoretical statistical models to validate the findings. The results demonstrate an impressive concordance up to a count rate of 30% of the laser repetition rate, significantly exceeding the single-photon statistics threshold of 5% as reported in the literature. This indicates that the setup is highly effective in distinguishing single-photon and multi-photon events even at high count rates, proving the robustness and reliability of the SiPM-based detection system. The ability to separate between single-photon and double-photon events is of immense value in the field of quantum optics, beneficial for techniques such as the Hong-Ou-Mandel effect among others. Further analysis will be conducted to understand the limits and range of applicability of this approach. This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Structural and Morphological thin film characterization facility

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The development of new optical components, devices, and detectors to support future optical, photonic, and quantum technologies requires a deep study and characterization of the employed materials. To pursue this objective, a set of new facilities and techniques devoted to frontier material studies is being acquired at the CNR-IFN laboratory in Padova as part of the I-PHOQS infrastructure. Four new primary instruments will be equipped: a Rigaku Smartlab X-ray Diffraction (XRD) Machine, a Park NX10 Atomic Force Microscope (AFM), a Horiba UVSEL+ UV-VIS-NIR Ellipsometer, and a custom-developed UV-XUV Reflectometer. Currently, the XRD and AFM machines are already installed and fully operational.
In this poster, we present the capabilities of the four instruments as well as presenting some first testing measures made with both the XRD and AFM.

I-PHOQS MID TERM REVIEW MEETING

Femtosecond Switching of Strong Light-Matter Interactions in Microcavities with Two-Dimensional Semiconductors

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Monolayers of Transition Metal Dichalcogenides (TMDs) show excitons with high binding energies and large oscillator strengths, stable up to room temperature [1]. Intense Coulomb interactions arise among TMD excitons, leading to enhanced nonlinear effects. Such strong interactions can be exploited to achieve high polariton nonlinearities, when TMDs are in strong coupling (SC) with light in optical microcavities. Harnessing polariton nonlinear interactions is paramount for coherent optical processes (e.g. lasing, optical parametric scattering, Bose-Einstein condensation), or optical logic gates and networks [2]. However, explorations and exploitation of such nonlinearities in TMDs on the ultrafast time scale remain elusive. We performed broad-band pump-probe spectroscopy experiments at 8K in a microscopy setup to study hBN-encapsulated bilayers (BLs) of MoS_2 placed in optical microcavities (Fig.1, inset). Both intra- and interlayer excitons in MoS_2 BL can be strongly coupled to resonant cavity, resulting in enhanced nonlinear interactions [3]. We probed the ultrafast dynamics of exciton-polaritons in such systems by resonantly exciting the cavities with femtosecond pulses and measuring the transient reflectivity, R(τ). Our experiments revealed a complete switch off and recovery of the strong coupling regime in less than 1 ps (Fig. 1). The dynamics of exciton-polaritons investigated in our study showcase a new paradigm for all-optical switching and open access to the exploitation of strong nonlinear phenomena in TMD systems on ultrafast time scales.

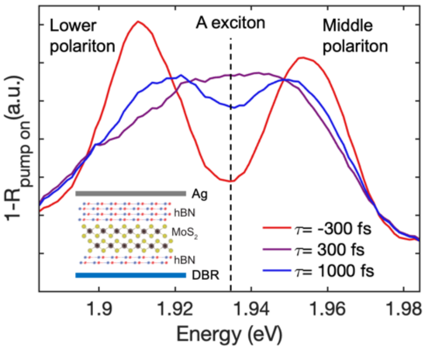

Figure 1: 1-R(τ) spectra of a MoS_2 BL microcavity as a function of the pump-probe delay time showing the collapse and recovery of the SC regime. Inset: scheme of the TMD heterostructure embedded in the microcavity.

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I-PHOQS MID TERM REVIEW MEETING

Evidence of a bright-dark exciton transition in anatase TiO_2

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Anatase TiO_2 is a well-known indirect bandgap transition metal oxide, featuring high photocatalytic activity and excellent photoelectric properties, together with chemical stability and wide bandgap [1]. Very recently, bright and strongly bound excitons across the direct bandgap of the material has been predicted theoretically and observed experimentally [2].

Given the indirect bandgap of anatase TiO_2, momentum-indirect dark excitons were predicted theoretically in a recent work [3]. Such excitons are characterized by longer lifetimes compared to their bright counterpart, making them a possible platform for quantum information, Bose-Einstein condensation, and energy harvesting [3]. The existence of momentum indirect excitonic states in TiO_2 is still without experimental confirmation.

This study reports the first experimental evidence of a strongly bound, momentum-dark exciton at the indirect bandgap of anatase TiO2. Using deep-UV pump-probe spectroscopy in transient reflectivity (TR) with 20 fs time resolution, we populate the bright excitonic state (3.8 eV) near the direct bandgap and collect TR responses over a photon energy range of 3.1 to 4.85 eV. The TR spectra show a clear signal of the bright exciton and a weak spectral feature around 3.4 eV, consistent with theoretical predictions of the dark exciton. The rise time of the feature (200 fs) matches an ultrafast decay component of the TR bright exciton signal, indicating a transition to the dark, momentum-indirect exciton due to carrier-phonon scattering. The experimental timescale of the process aligns well with theoretical predictions [3].

In conclusion, using a high sensitivity setup for ultrafast spectroscopy in the deep UV spectral range, with a sufficiently high temporal resolution, we are able to detect the predicted dark exciton of anatase TiO_2. We thus shed light on the properties of this physically and technologically relevant material. This result also contributes to the general understanding of excitonic states in transition metal oxides, and wide bandgap indirect semiconductors.

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Development of a Novel Multichannel Approach for Time-Resolved Photon Counting Applications

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The time-correlated single-photon counting (TCSPC) is a precise technique for recording the arrival times of single photons and is utilized in different areas of applied physics, e.g. for determining fluorescence lifetimes or reconstructing DTOF curves [1]. Exploiting recent developments with time-tagged time-resolved data collection, our research investigates a multichannel approach to increase the number of effective channels in time-resolved applications, such as Raman spectroscopy with detector arrays and diffuse optical tomography.

The experimental setup is based on a pulsed diode laser (PDL 800-D) operating at a wavelength of 683 nm. The attenuated laser light illuminates two silicon photomultipliers (SiPMs). The electronic signal from the detectors is split into two and combined using a specialized system. Delay lines are added at the connections from the splitters to the combiners demonstrating the delayed effect. The outputs from the delay line combiners are fed into two channels (Signal and Reference) of the time-counting electronics (Multiharp 160, Picoquant), which are synchronized with the laser.

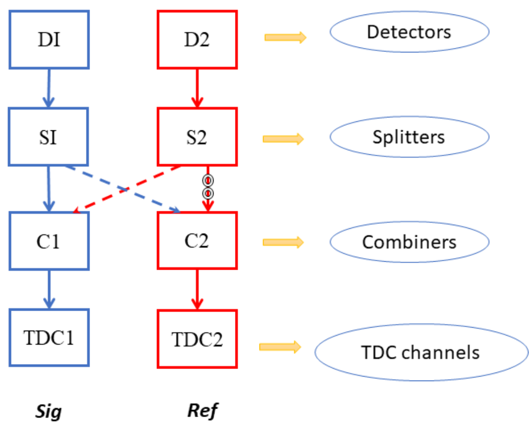

Figure 1. Electrical scheme of the detection chain

Knowing the added delays between the detectors, analyzing the data from both channels, we aimed to identify which detector was illuminated and reconstruct the signals coming from each detector. This initial effort aims to pave the way for the future development of a system capable of managing up to 100 detectors.

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I-PHOQS MID TERM REVIEW MEETING

Abstract for I-PHOQS Mid Term Review Meeting Poster Session Improvement of accuracy and precision in quantum-enhanced differential measurements in presence of correlated noise

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Atom interferometers can be used to measure accelerations with a wide spectrum of possible applications[1-3]. In this kind of set-up, absolute measurements can be significantly limited by vibration noise. Conversely, acceleration gradients can be measured in a differential configuration by two interferometers that share a common reference frame. Vibration noise, affecting the two phase shifts equally, can thus be efficiently rejected[4-5]. It has also been demonstrated that very large phase fluctuations can be tamed by applying ellipse-fitting techniques to coupled fringe data[6]. Ellipse fitting's immunity to correlated phase noise and its lack of requirement for a detailed noise model are two highly crucial advantages. On the other hand, one disadvantage of the method concerns its precision, which is currently limited by classical shot noise. Entangled states, which are typically linked to sub shot-noise sensitivities, operate best around some phase optimal working point; therefore, their compatibility with fitting techniques and noisy environments is doubtful and has up to now been matter of discussion[7]. Moreover, conic fitting has the drawback of producing biased estimates[8-9], an effect that is hardly eliminated by increasing the number of measurement repetitions. Here, we show that entangled input states created by a spin-squeezing dynamics can be combined with data-fitting techniques in presence of arbitrary large, correlated phase noise leading to an improvement in both accuracy and precision. By simulating state evolution and data acquisitions numerically and supported by analytical calculations, we prove that different fitting procedures all lead to bias and uncertainty reduction around a specific optimal value of the squeezing strength. Interestingly, we find that the squeezing strength required is moderate and smaller than those commonly considered as optimal for other estimation protocols[10]. For what concerns improvement in precision, we find a gain over the shot noise limit which follows the scaling ~ N^(1/6), with N the atomic population in each interferometer. For what concerns bias reduction, we single out two fitting procedures which, combined with an optimal squeezing strength, can remove the bias completely. We

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interpret this last result, which cannot be reproduced by simply increasing the atom number in a classical state, in terms of the unique statistics of the state obtained from a spin-squeezing dynamics. Our work has reconciled the use of entangled states, needed for high-sensitivity measurements, with a technique that is uniquely robust against phase noise, thus paving the way for the full exploitation of entanglement in precision measurements in a strong noise scenario.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

SERS detection of Biomolecules in Hydration Condition Using Ag-Dendrites Platform

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We report on the highly sensitive spectroscopic detection of biomolecules via Surface-Enhanced Raman spectroscopy (SERS), that exploits the peculiar plasmonic properties of a silver (Ag) dendrite layer. This 3D material is generated as a by-product in the metal assisted chemical etching (MACE) synthesis of silicon nanowires, when silver nitrate salts serve as precursors of metallic Ag. The unique hierarchical structure effectively traps light in micro and nanocavities of varying dimensions where *hot-spot* regions form, enhancing SERS detection performance and broadening the range of excitation wavelengths. Moreover, the sponge-like behavior of this platform promotes the encapsulation and confinement of very small liquid sample volumes, enabling proteins in solutions to maintain their natural hydration shell and move freely within the liquid environment. This offers a great advantage as it allows to analyze biomolecules in their biologically active conformation [1]. Among various biomolecules, a particular interest has been focused on the SERS identification of the SARS-CoV-2 virus, especially the Omicron variant [2]. The technique provided, for the first time, a detailed spectral fingerprint of nucleobases, suggesting potential applications for rapid genome identification under physiological conditions. Further efforts were directed towards characterizing three different allergenic proteins from *Parietaria judaica* pollen (*Par j 1, 2 & 4*), triggering severe respiratory diseases. The "blinking" effect of SERS was utilized to gain valuable insights into the vibrational modes of the analytes, allowing rapid identification of the subtle differences in their structures [3].

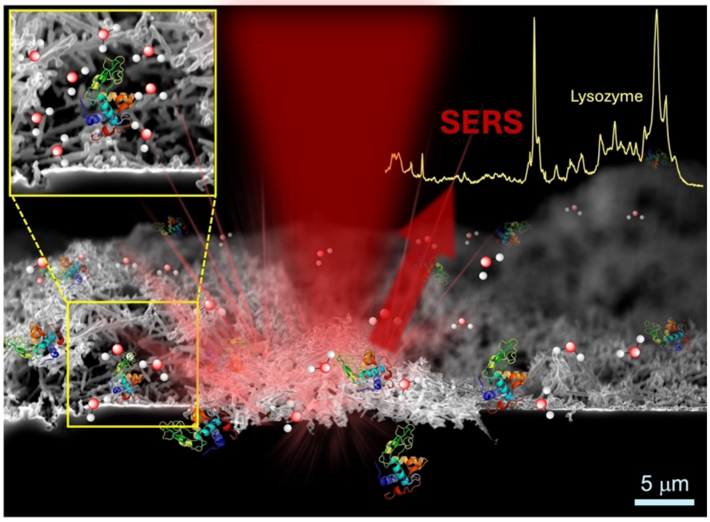

Figure 1. 3D SERS Platform based on Ag dendrites. This fractal material confines the biomolecules (lysozyme) in liquid environment in very small cavities. The red laser beam is focused onto the sensing platform enhancing the Raman spectrum of the biomolecules in their biological conditions.

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I-PHOQS MID TERM REVIEW MEETING

Development of germanium NIR detectors for biomedical optics: latest advances

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Single Photon Avalanche Diodes (SPADs)[1,2] for the near-infrared (800-1500 nm) wavelengths can be fabricated both in InGaAs/InP and in Germanium [3]. InGaAs/InP SPADs are commercially available, having, in general, good performances but with the intrinsic drawback of large afterpulsing limiting its application to low/medium frequencies. To overcome this limitation, germanium SPAD has been suggested as a viable solution [3,4]. However, Ge technology must still be fully exploited for single-photon detection [4]. In this work, we will present our effort and preliminary results in developing planar Ge SPAD technology for medium/large-scale fabrication.

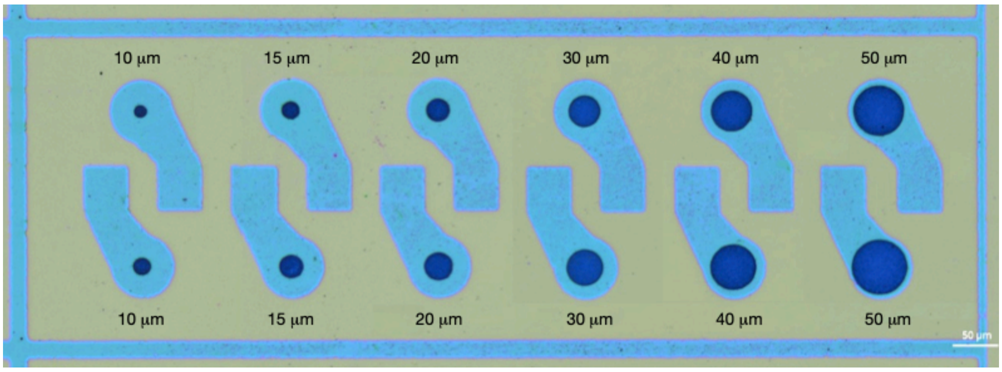

Figure 1. Microscope image of the 1st generation of Ge SPADs developed at the CNR-IMM Catania, showing devices with different size,

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I-PHOQS MID TERM REVIEW MEETING

Abrupt Breakdown in industrial grade Silicon monocrystalline PERC and HJT Solar Cells

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Hot spots in a photovoltaic module, caused by partial or complete shading of cells, are a significant factor in decreasing module performance and reliability [1,2]. This study involves detailed investigations of industrial monocrystalline silicon solar cells of two different technologies: passivated emitter and rear contact (PERC) [3] and amorphous-silicon/silicon heterojunction (HJT) [4]. The cells were fully experimentally characterized, and the main degradation mechanisms were explained through in-depth TCAD simulation.

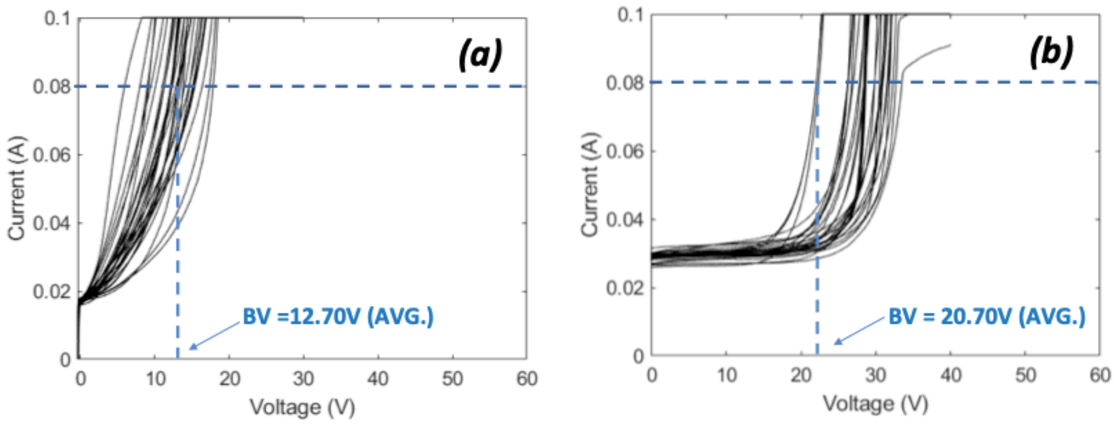

Figure 1. Reverse VI of monocrystalline Si Solar Cell, showing the Breakdown knee for (a) PERC and (b) HJT technologies.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Multipass Amplifier Development For The 2-μm 1-kHz ILIL Beamline

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Thin disks are an effective solution for high average power laser amplifiers with cooling achieved in the active mirror configuration. In this case, edge pumping can be used to efficiently couple the diode energy to the gain region, while leaving free access to the gain region for complex multi-pass amplifier geometries.[1].
Here we present the development[2] of a multipass amplifier to be integrate in the APOLLO laser at ILIL (Intense Laser Irradiation Laboratory) in Pisa. The amplifier input is characterized by an eye-safe 2-μm laser pulse with >1 mj energy and a repetition rate of 1 kHz. The ceramic active medium disk Tm^{3+}:Lu_2O_3 is direcly pumped at 800 nm, using diodes operating in (quasi) CW mode. The gain factor is 10, for a final energy >10 mj. The scalability of the design allows to consider further amplification stages with the same geometry up to >500 mj while maintaing the same repetition rate of 1 kHz. Multi-pulse extraction combined with cross-relaxation, diode pumping and high absorption of the active medium also ensure an high efficiency of whole the system.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Levitated quantum optomechanics

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Levitated optomechanics explores interactions between optical fields and mechanical oscillators obtained by trapping mesoscopic nanoparticles in external fields. These systems are seen as optimal candidates to explore quantum mechanics in this high mass regime and have the potential to explore the quantum nature of gravity in future laboratory tests.

In our system, silica nano-spheres with radius ~50nm are trapped in an optical tweezer which provides a 3D confining potential. Once trapped, the particle is positioned at the center of a high finesse Fabry-Perot cavity. The resulting coupling between the intracavity field and the particle motion allows to reach the motional ground state [1,2,3].

We report on the current stage of the design of an upgraded experimental setup featuring high precision nano-positioning stages with ~1nm resolution, a high-power infrared laser with quickly variable intensity and a large tuning range. Finally, a high-speed pumping system for an increased experimental duty-cycle. These upgrades will allow us to push past the current state-of-the-art and add capabilities necessary for more advanced experimental quantum protocols.

We will also present preliminary results in the development of a polychromatic optical tweezer exploiting chromatic aberration. We demonstrated the generation of two distinct trapping sites which allowed us to study particle-particle interactions through direct Coulomb coupling as well as cavity mediated coupling.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Contrast enhancement of high intensity laser pulses by second harmonic generation for ion acceleration

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Modern laser systems exploiting Chirped Pulse Amplification ensuring high peak power and short pulse duration are widely used to obtain accelerated ion beams by means of laser-plasma interaction. Proton acceleration is routinely implemented exploiting Target Normal Sheath Acceleration (TNSA) mechanism, the latter benefitting from the interaction of the laser with a sharp density gradient [1]. Therefore, among the key factors influencing the interaction between high-intensity laser pulses and solid targets, laser contrast is particularly important. Indeed, laser light preceding the main pulse can induce plasma formation prior to the arrival of the main pulse or even target disruption. Different approaches have been developed to enhance the laser contrast, one of which being frequency doubling the laser. This method exploits the non-linear dependence on intensity of the conversion efficiency, which drops for low laser intensities, resulting in a cleaning of the laser temporal profile. The shorter wavelength also grants that the laser couples at higher plasma density, making the interaction less sensitive to density gradients. Here we discuss the effect on the TNSA acceleration mechanism comparing the results obtained irradiating solid targets of various material and thicknesses employing both fundamental frequency pulses and frequency doubled pulses. The latter were produced exploiting the second harmonic generation process taking place in a 10 cm diameter, 0.8 mm thick KDP non-linear crystal positioned in the laser beam path.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Ultrafast electronic properties of $ZnAs_2$, an anisotropic semiconductor

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Comprehension of anisotropic materials is crucial for developing polarization-sensitive photodetectors and polarizers[1]. Binary II-V semiconductors are among the most promising candidates for this goal, exhibiting anisotropic optical and electronic responses[2]. This family includes $ZnAs_2$: its energy absorption edge varies by more than 30 meV when light polarization is rotated from parallel to orthogonal to the crystallographic c-axis. At the same time, reflectivity is 1.5 times larger when the electric field is parallel to the c-axis, both in the region of transparency [1.2 um - 20 um] and at energies larger than the optical gap[2,4,5].
What gives rise to these properties is still an open question. To address this inquiry, we have mapped the band structure of $ZnAs_2$ using angle-resolved photoemission spectroscopy (ARPES): the different effective masses of the valence band along ΓB and ΓZ directions of the Brillouin zone are the clear fingerprint of the optical anisotropy previously outlined.

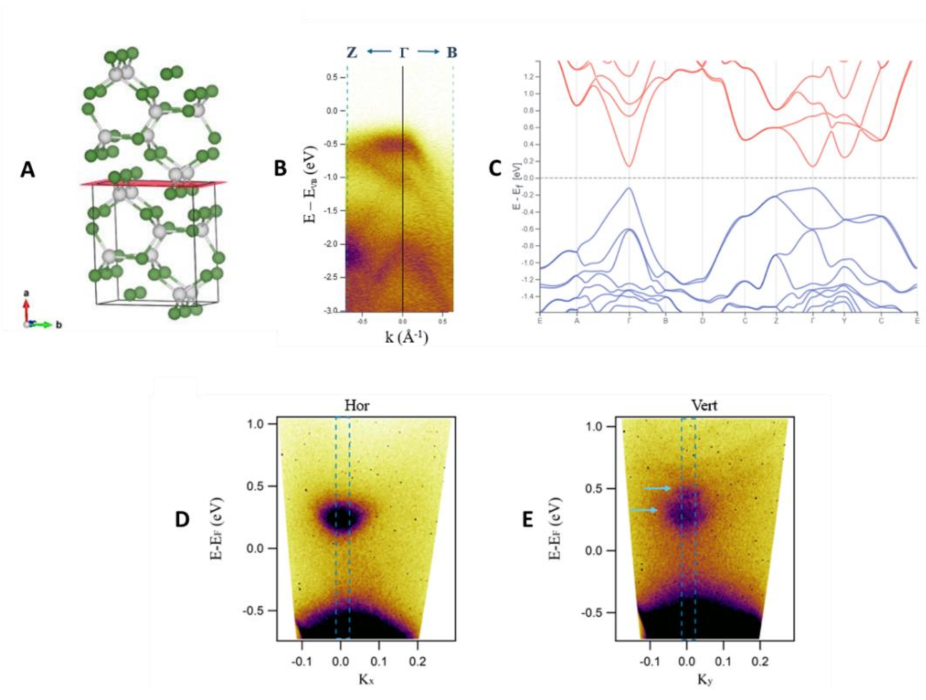

Figure 1. (A) Crystal structure of ZnAs2 showing in red the cleave plane [3]. (B) Occupied valence band structure measured with 56 eV photon energy, the zero energy scale is set to the maximum of the valence band (VB). (C) Calculated band structure adapted from [6]. (D) and (E) Conduction band transiently populated by an above gap (1.8 eV) optical excitation (pump). The polarization of the probe, with an energy of 6 eV, is horizontal (D) and vertical (E), respectively.

I-PHOQS MID TERM REVIEW MEETING

Furthermore, to disclose the unoccupied states, we have carried out time-resolved ARPES measurements, revealing lifetimes of several hundreds of picoseconds and a unique splitting in the transiently populated conduction band while probing with vertical polarization that cannot be reproduced by ab initio calculations. The goal of our activity is to clarify the origin of this behavior in the conduction band which may pave the way to the use of $ZnAs_2$, and II-V semiconductors, in optoelectronic devices, leveraging their large anisotropic properties, and the long-lasting charge populations induced by light absorption in the visible spectral range.

This work was supported by the PNRR MUR project IR0000016-I-PHOQS, financed by the European Union – Next Generation EU.

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I-PHOQS MID TERM REVIEW MEETING

Wavefront sensors design for large and XUV beams

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Large beams characterization is extremely important to monitor and control beam quality, especially for high power laser where thermal effects compromise [1, 2, 3]. We here present a first study of feasibility for a wavefront sensor for large beams without the need of a large optical relay for the beam resizing, which is always a disadvantage both in terms of space and cost, and still an open problem. The design is based on a combination of an array of zone plates, an objective and a sensor. A scaled prototype for a 12 mm beam has been realized, and tested to understand the critical issues and future improvements.
In recent years the presence of radiation in the XUV range has grown in various fields of the research: laser interferometry [4], photoelectron spectroscopy [5],pump-probe spectroscopy [6], diffractive imaging [7]. Because of the high absorbance of the materials for radiation in the XUV range, temperature changes can impose distortions in the optics materials and give origin to aberrations in the beam wavefront, therefore compromising the performances of the system [8]. We here present the first studies for the design of an Hartmann sensor for XUV light (from about 90nm to 250nm) with light propagation simulations and a first mechanical design.

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Upgraded “Pointing Lanex” spectrometer with signal weighting and collimator acceptance for Laser Wakefield Acceleration

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Accelerating electrons via laser-plasma interactions can pose a challenge in accurately measuring their energy spectra. Typical spectrometers use a magnetic dipole to scatter the incoming electron beam, which then impinges on a calibrated Lanex screen, and the emitted light is imaged by a charged coupled device camera. The entrance angle of electrons inside the dipole can however result in significant miscalculations of energy. Placing a second Lanex before the magnets, can be a compact and non-invasive method of correcting the energy [1,2]. Here, we provide an upgraded version of this “Pointing Lanex” spectrometer by adding a collimator in front of the dipole and considering its acceptance range. Depending on the pointing angle of the electron beam and the light emitted by the second Lanex, the final spectrum is energy-corrected and signal-weighted. In our setup, we show that for a $\pm 5\ mrad$ pointing angle, the energy misread is $+30\ MeV$ and $-20\ MeV$ respectively for electrons of peak $150\ MeV$. We simulate collimators of circular and rectangular shape with acceptance of $\pm 4.5\ mrad$, which further increases the error. Improvements can be made by calculating the increase of beam divergence due to scattering caused by the “Pointing Lanex” [3]. The focusing effect of the magnets should also be considered in the case of uncollimated electrons, as it results in crossing or overlapping trajectories.

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