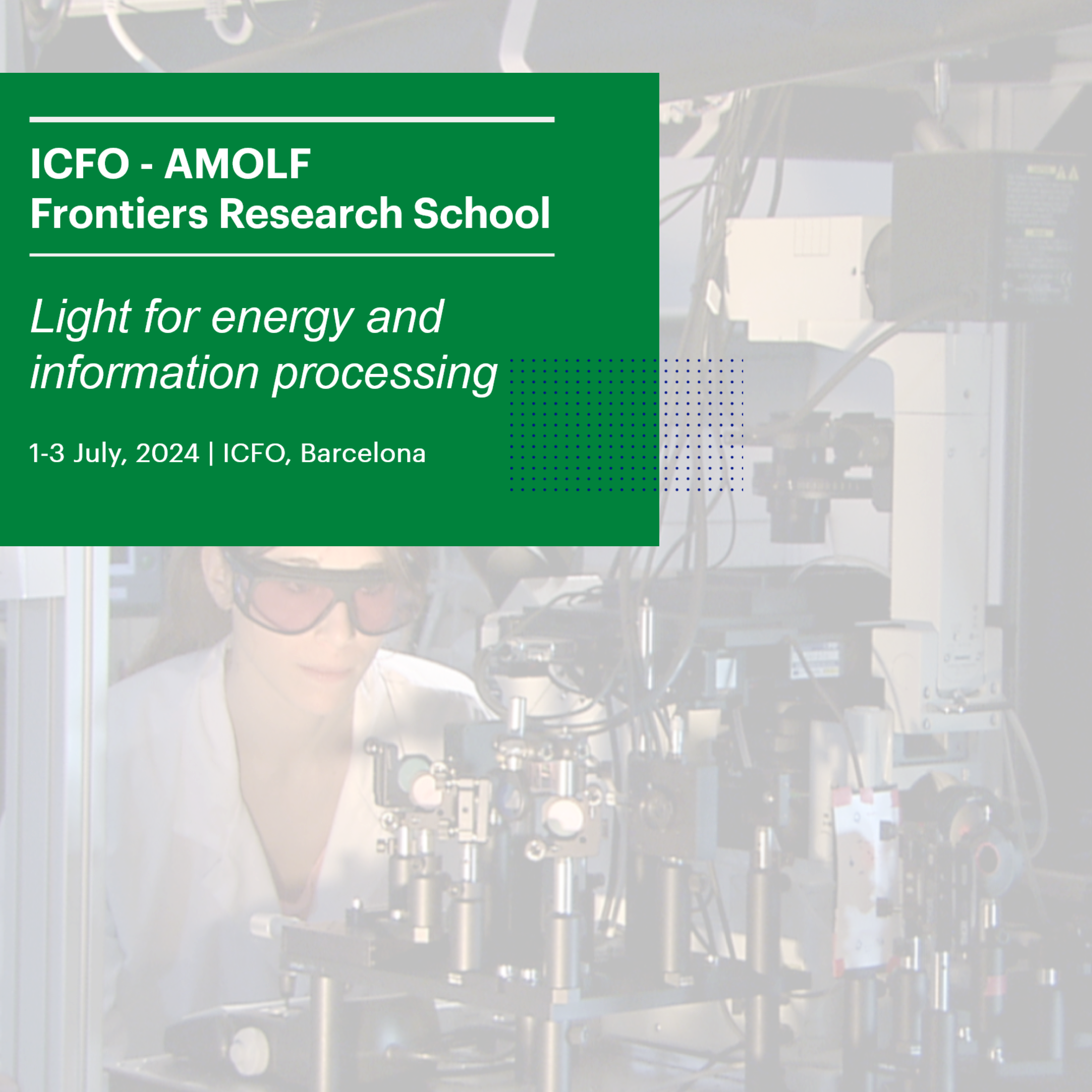

ICFO - AMOLF Frontiers Research School

Light for energy and information processing

1-3 July, 2024 | ICFO, Barcelona

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1. 3D Nanostructures for PVK Solar Cells

TO BE CONFIRMED

2. 3D Spatially Resolved PL Maps of Textured Perovskite-Silicon Tandem Cells

In recent years, perovskite-silicon tandem solar cells have shown their potential for photovoltaic systems, with the current research-cell record power conversion being 33.9%, which was achieved by LONGi Green Energy Technology. Surface texture is an important factor for reaching these high efficiencies, as the resulting increase in incoupling efficiency enhances light absorption. In collaboration with Fraunhofer ISE, we obtained a detailed understanding of the local light-matter interactions in textured perovskite-silicon tandem cells by studying 3D spatially resolved PL maps. With a confocal laser scanning microscopy setup at AMOLF, we were able to resolve spatial variations in PL intensity and center wavelength, providing information about the underlying origin of these variations, such as photon recycling, compositional variations and laser induced changes in the film. In order to isolate and study each factor independently, several changes in excitation conditions are necessary to exclude secondary effects, such as halide segregation by the light source.

3. A hBN-based polaritonic lattice for probing and controlling 2D quantum materials

Van der Waals materials provide a unique platform to explore the effect of ultra-strong light-matter interaction on mesoscopic states. Indeed, it is possible to design and integrate, at the atomic level, various 2D materials showing emergent photonic and electronic phenomena.
In this work, we focus on the properties of hexagonal Boron Nitride (hBN) as a platform for deep subwavelength confinement of mid-infrared light, due to the formation of phonon-polariton states. We recently demonstrated the design of polaritonic cavities with a Purcell factor on the order of 10^8, by indirect patterning [1].
We show that, when probing a hBN/Graphene heterostructure in the quantum Hall regime, a lattice of polaritonic cavities is coupled to the inter-Landau level transitions (ILTs) of the system and this effect can be observed in photo-transport.
Furthermore, due to its extreme subwavelength confinement, our system stands as a promising candidate to push light-matter interaction to the regime in which mesoscopic phenomena in 2D materials can be engineered through cavity light.

[1]: Herzig Sheinfux et al. High-quality nanocavities through multimodal confinement of hyperbolic polaritons in hexagonal boron nitride. Nat. Mater. 23, 499–505 (2024).

4. A single shot polarimeter for Fourier imaging

Optically resonant nanoparticles are crucial building blocks for metasurfaces, nanosensors, and microscopic light sources due to their ability to control the amplitude, phase, directivity, and polarization of scattered light. Here, we show that a single-shot polarimeter coupled with a Fourier imaging system can recover all degrees of polarization information encoded in the far-field radiation pattern by a single nanostructure. We have built and calibrated such a set up that enables to capture the radiation pattern of a chiral scatterer in real-time (as opposed to sequentially rotating through polarizer settings as is standard in Fourier microscopy). We demonstrate that the set-up can be fully calibrated from pixel-to-pixel, reconstruct any unknown Stokes vectors, with a few degrees of deviation from the expected polarization sate on a Poincare sphere.

5. Advancing Photoelectrochemical Water Splitting and CO2 Reduction: Material's Engineering and Light Management to Enhance BiVO4 Photoanode's Performance

TO BE CONFIRMED

6. Arcsine laws and weak ergodicity breaking of light

Consider a laser-driven resonator operated as a sensor. The goal is to detect perturbations to its resonance frequency by monitoring the time-integrated transmitted or reflected intensity. Given a time budget to estimate the mean time-integrated intensity, we pose the question, what yields a better estimate: one measurement of duration τ, or m independent and identically distributed measurements of duration τ/m? For ergodic processes, both approaches are equally accurate. However, we have recently shown that the time-integrated intensity emitted by a linear resonator breaks ergodicity “weakly”. This effect is a consequence of Lévy's arcsine laws, which are a cornerstone of extreme value statistics. In this contribution, we present the first experimental demonstration that light in a coherently-driven resonator follows the arcsine laws. We elucidate how the arcsine laws imply a weak ergodicity breaking with important implications for optical sensing.

7. Influence of the particle size on the photoemission of plasmonic nanoparticles in electrolytic solutions

Plasmonic nanoparticles can amplify electric fields, generate localized heating, and produce charged species with a limited lifetime when exposed to light. These effects can be applied in many practical fields, including nanomedicine and photocatalysis. However, it is necessary to understand their underlying mechanism and which parameters are necessary to improve their efficiency and control them. Therefore, it is crucial to study the electrochemical activity of nanoparticles under illumination to better comprehend their enhanced plasmonic activity and associated processes.
This study explores the photoelectrochemical behavior of plasmonic silver nanoparticles under illumination. We observe the generation of solvated electrons from silver nanoparticles under plasmonic resonance conditions (λ = 385 nm) in sodium nitrate electrolyte. By varying the applied bias, we infer that the photocurrent response comes from electron photoemission as predicted by Brodsky-Gurevich theory. The influence of the nanoparticles' size on the photocurrent response was also investigated. Smaller particles exhibit higher photoemission efficiencies than larger ones, which is in line with the literature. Furthermore, through the Brodsky - Gurevich model this work showcases the possibility of using electrochemical methods to get information about the work function of the nanoparticles as well as the charge transfer at the interface of the nanoparticles, thus offering an alternative to spectroscopical methods to study this transfer.

8. Cathodoluminescence interferometry of plasmonic scatterers

High energy electrons in a SEM (2-30 keV) can excite resonances in plasmonic and dielectric nanostructures that radiate to the far field as cathodoluminescence (CL). The coupling between a free electron and a single scatterer is well understood and depends strongly on the electric near fields in the structure. Here, we study the sequential interaction of the electron with a plasmonic tip and a metallic planar surface, where it excites transition radiation. These two coherent excitations interfere in the far-field which creates a platform to study cathodoluminescence interferometry.

9. Cavity-Enhanced on-demand Quantum Memory for Quantum Repeaters

TO BE CONFIRMED

10. Considerations for Electromagnetic Simulations for a Quantitative Correlation of Optical Spectroscopy and Electron Tomography of Plasmonic Nanoparticles

The optical cross sections of plasmonic nanoparticles are intricately linked to the morphology of the particle. If this connection can be made accurately enough, it would become possible to determine a particle's shape solely from its measured optical cross sections. For that, electromagnetic simulations can be used to bridge the morphology and optical properties assuming that they can be performed in an accurate manner. In this paper, we study key factors that influence the accuracy of electromagnetic simulations. First, we compare several standard electromagnetic simulation methods and discuss in detail the effects of the meshing accuracy, choice of dielectric function and inclusion of a substrate for the boundary element method. To help the boundary element method's complex parametrization, we develop a workflow to be able to use electron tomography data as input for these simulations. In particular, we analyze how the choice of reconstruction algorithm and the intricacies of image segmentation influence the results of the electromagnetic simulations and correlate it to induced shape errors, which can be minimized in the case of optimal choices during the processing pipeline.

11. Detection of single ions in a nanoparticle coupled to a tuneable fiber cavity

Rare-earth ion-doped crystals constitute a promising platform for quantum information processing and networking. They feature exceptional spin coherence times to store information, narrow optical transitions to act as an interface to optical photons, and possibilities to realize quantum gates between single ion qubits. Coupling quantum emitters to optical cavities enables channeling the emission from the emitters into the cavity mode while decreasing their emission lifetime. This allows the realization of an efficient and high-rate spin-photon interface, while also increasing the indistinguishability of the emitted photons in the presence of dephasing.

In this work, by utilizing erbium-doped nanoparticles that emit at telecom wavelengths coupled to a fully tunable high-finesse fiber-based microcavity in a cryostat, we demonstrate an average Purcell factor greater than 100 for a very small ensemble of erbium ions (Purcell enhanced lifetime of 90 μs). Frequency selective excitation followed by fluorescence detection results in discrete features which indicate the sensitivity of the setup to few ions. Next steps involve isolating one such feature in a sparsely populated spectral region of the inhomogeneous line and measuring the auto-correlation function of the emitted photons. The presence of one or few ions can then be induced from the value of this function.

We have demonstrated with the previous version of our setup that we can control the Purcell factor and hence the emission rate of the ions on a timescale of hundreds of microseconds. Our current setup should enable us to reduce this time to a few tens of microseconds. If implemented at the single ion level, this ability will enable the generation of fully tunable narrowband single photons at telecom wavelengths, and quantum processing using single rare-earth-ions.

12. Cooling of sideband-unresolved mechanical modes using multimode optomechanical interactions

Optomechanical systems hold great promise for applications in quantum information transduction and routing. To be able to get the system in the required mechanical ground state using optomechanical cooling, the optical linewidth needs to be smaller than the mechanical frequency (the so-called resolved sideband condition), which avoids the detrimental heating by quantum backaction that gives rise to the Doppler limit in sideband-unresolved cavities.

However, by parametrically coupling a low frequency mechanical mode to an auxiliary high frequency mechanical mode, the low frequency mode can be efficiently cooled, even when the optical linewidth is larger than the mechanical frequency.

We realize an optomechanical device possessing mechanical modes in both the MHz and GHz range, coupled strongly to the same optical mode. In this device, the sideband-resolved GHz modes can be used to suppress the Stokes scattering into the sideband-unresolved MHz mode. We experimentally demonstrate linewidth broadening due to the induced interaction between the MHz and GHz modes indicating potential for cooling beyond the Doppler limit. Moreover, we show that this interaction can be used to reverse the effect of dynamical backaction, leading to amplification – and even self-oscillation – instead of cooling with a red detuned pump. This shows that parametric control in multimode optomechanical systems can dramatically alter the dynamics, and avoid conventional quantum limits to performance.

13. Determining instability causes at a highly efficient organic photoanode

Solar synthetic fuels, based on the photoelectrochemical (PEC) conversion and storage of sunlight in the chemical bonds of molecules such as H_2 or other CO_2-based fuels, allow for long-term storage and distribution of energy, and CO_2 recycling. The generation of these fuels takes place via water splitting and CO_2 reduction reaction (CO_2RR), respectively. PEC structures have been widely researched during the last decade, but large bandgaps and high recombination rates of metal oxide photoelectrodes (i.e. $BiVO_4$, WO_3, TiO_2) limit their output photocurrent to < 5 mA/cm2 still far from the target of 10 mA/cm2 for H_2 production. Organic PEC (OPEC) devices consist a promising alternative to reach the required potential needed for the electrochemical reactions to occur. Organic polymers are free of critical materials, and compatible with high throughput fabrication processes, resulting in flexible and lightweight products. This work is focusing on the stability of a highly efficient organic photoanode for the photoelectrochemical oxygen evolution reaction (OER). The group has explored and found that top-performing OPV blends like PM6:Y6, where PM6 is an organic polymer donor and Y6 an organic small molecule that is the non-fullerene acceptor, can be used in OPEC devices with very high performance (16.8 mA/cm2 at 1.23 VRHE), partially achieving OPV's performance (23.9 mA/cm2 at 1.23 VRHE). Changes in the morphology of the ETL ZnO and the possible degradation of the AL PM6:Y6 are investigated, as detecting the layer where degradation, delamination or formation of voids occur, is very important for achieving a stable device. The results indicate that the cause of instability is the ETL, as the roughness decreases, and it seems to disappear after its immersion in the electrolyte, while the AL seems to maintain its composition. Therefore, the careful selection of the fabrication method or parameters of the ETL could lead to the more stable performance of organic photoanodes.

14. Design and characterize photonic crystal for pulse sensing

TO BE CONFIRMED

15. Engineering high quality graphene superlattices via ion milled ultra-thin etching masks

Moiré superlattices in graphene have attracted a tremendous amount of attention, due to the observation of Hofstadter butterflies [1], and more recently, the discovery of superconductivity [2]. However, moiré systems are difficult to control and tune. An alternative, more versatile, approach is to engineer superlattices is by applying a periodic electrostatic potential, so both the lattice geometry and period can be designed as needed. Despite an extensive effort to push nanofabrication techniques in order to engineer electrostatic graphene superlattices, achieving periods below 40 nm remains an extreme challenge [3-4], making it impossible to explore the most exciting aspects of superlattice physics.
Here, we demonstrate a new nanofabrication technique able to pattern periodic structures with sub-20 nm pitch, approaching the moiré length scales [5]. Our technique combines He focused ion beam (FIB) indirect milling of ultrathin suspended hard masks with reactive ion etching (RIE), achieving ultimate FIB resolution and relatively damage free patterning. This allows us to generate clean and low-disorder lattices and avoid inducing damage in the gate material, allowing the graphene device to retain high mobility. Furthermore, by engineering a non-bipartite superlattice (here Kagomé), we observe electron-hole symmetry breaking in single layer graphene. Our technique opens the path to engineer exotic phenomena in single layer graphene, with symmetries not accessible in Moiré superlattices and dimensions well below the state of the art in nanofabrication.

References
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16. Diffraction imbalance from a nonlinear metasurface

The field of nanophotonics has created a diverse range of tools for controlling the optical properties of resonant scattering structures, that depend strongly on intricate details at the nanoscale [1]. The abundant and customizable mode structure, resulting from strong multiple scattering and near-field effects, provides flexible means to manipulate and govern nonlinear light processes, including efficient frequency conversion and nonlinear wavefront shaping [2]. To facilitate nonlinear processes, it is crucial to have greatly enhanced electric fields, achievable through sharp resonances in nonlinear metasurfaces [3]. In this study, we investigate the remarkable sensitivity of nonlinear scattering processes to geometric alterations in nanostructured surfaces.

17. Effects of electron cascade and lamella preparation on InGaN quantum wells recombination dynamics

InGaN/GaN quantum wells (QWs) have garnered significant attention for LED applications due to their high quantum efficiencies in the ultraviolet/visible range and emission tunability with indium content, among other factors. However, the growth of QWs with high indium content encounters issues with indium phase separation, resulting in structural changes and inhomogeneous light properties. This can be controlled via growth stopping, forming quantum dot like islands that behave as localized emitters. Furthermore, subsequent etching reduces the strain-induced quantum Stark effect present in majority of such structures. Due to its deep subwavelength spatial resolution and broadband frequency components enabling coupling to high-energy optical transitions, cathodoluminescence nanoscopy (CL) has emerged as the ideal tool to study such high-bandgap semiconductor systems and characterize their nm-scale features and defects. Despite it being a popular characterization technique, the impact of the electron cascade on the sample, as well as the optoelectronic effects of thinning bulk samples into lamella, as is commonly performed for studies in a transmission electron microscope, have hitherto not been studied systematically. In this work we aim to confront this using a comprehensive study comparing time-resolved scanning electron microscope-based CL.

18. Heat generation in gold nanorods under pulsed laser illumination

Gold nanorods (GNR) are interesting morphologies for photothermal heat generation. In fact, they have larger absorption cross sections compared to spheres and their optical properties can be conveniently tuned by changing their aspect ratio. In this poster presentation, I will discuss the temperature that can be reached by photothermally exciting GNRs under different conditions, which I numerically determined by finite element simulations in COMSOL. Modelling of the temperature increase was performed by implementing the two temperature model and explicitly including cooling of the nanoparticles for different environments. The final goal of the project is to develop an optimal excitation workflow for achieving high local temperatures while keeping the nanorod shape preserved.

19. Holographic amplitude and phase imaging for characterization of ultra-thin and 2-D materials

We present a “lateral-shearing interferometric microscope” (LIM) for characterization of ultra-thin and 2-D materials by imaging the phase and intensity of transmitted or reflected light. The technique’s common-path interferometric scheme, based on birefringent Savart plates and phase-shifting, makes it highly stable and works with low coherence light sources, with a variety of wavelengths, over a large spectral range and with a wide range of sources. Measuring the optical response in intensity and phase, i.e. the complex field with both amplitude and phase, and over several wavelengths, enables in-depth characterisation and modelling of light-sample-interactions, allowing to infer sample properties such as layer thicknesses or refractive indices. The technique therefore could become a valuable tool in the design and verification process of nano-optoelectronic devices using thin films and 2D materials, such as meta-surfaces and -lenses, diffractive optical elements, or plasmonic devices.

20. How sticky are the electrochemical interfaces?

The electrified solid-liquid interface (SLI) is a dynamic few-nanometer layer that dictates the nature of electrochemical processes. Understanding the structure of the SLI, including water layer density, water arrangement, and ions at the interface, is crucial for designing better electrocatalytic systems. Local differences at the SLI, sometimes even across a single crystal plane, can lead to different catalytic hotspots across the studied single crystal plane. Therefore, it is vital to probe the SLI structure at the nanoscale (spatially) and to understand the molecular SLI structure evolution over time (temporally) at different applied potentials.

In this work, we investigate the use of an in-situ electrochemical atomic force microscope (EC-AFM) to understand the spatio-temporal structure of the SLI by mapping the interfacial adhesion forces. The interfacial adhesion forces, obtained during the retraction of the AFM probe from the interface, provide insights into the interfacial energy of the SLI. As the SLI evolves under different applied potentials, the interfacial energy of the SLI changes, thereby modulating the measured adhesion forces.

In this contribution, I will discuss the potential and time-dependent evolution of the SLI structure in a polycrystalline platinum electrode in sulfate-based electrolytes under neutral and acidic pH conditions. We apply different potential steps, corresponding to various electrode processes (H+ adsorption/desorption, double layer, Pt-oxidation/reduction) to the platinum electrode for 30 seconds. During the experiment, the adhesion forces are mapped as line scans of the same area. We observe a clear time dependence of the measured mean adhesion force during each applied potential pulse. We also note a fast and slow restructuring of the interface at potentials corresponding to the H+-adsorption/desorption and Pt-oxidation reactions, respectively. In addition to adhesion, we also observe a potential-dependent response in platinum grain heights, which can be attributed to oxide formation at the electrode interface.

Our work demonstrates that EC-AFM can be used to understand the time-dependent nature of SLI structure in-situ under different applied biases. We highlight the local differences in SLI structure both spatially and temporally when a potential is applied to the electrode.

21. Non-Gaussian states of light provide an advantage for precision energy storage

We study how to perform work on a microscopic system using quantum states of the electromagnetic field. We prove that if we restrict ourselves to Gaussian distributions the signal-to-noise ratio of the energy stored in the system is independent from the correlations present among the light modes. We show example where non-Gaussian operations among multimode quantum optical fields can provide an advantage in energy charging.

22. Hyperuniform disordered light-trapping structures for solar applications

Current industry's crystalline silicon solar cells rely on fossil fuels for wafer production and require too much high-quality silicon per watt-peak and are thus unsuitable to meet climate goals. Substantially reducing the absorber thicknesses will not only allow to save silicon, but also to avoid the wasteful Czoralski process, use lower quality poly-silicon, expand the application of c-Si cells to light-weight, semi-transparent, flexible, and wearable photovoltaics.

In order to overcome the shortcoming of poor absorption in thin silicon layers, we present light-trapping patterns based on hyperspectral uniformity to achieve unprecedented absorptance values. We experimentally demonstrated beyond 65% sunlight absorption in one micron thick free-standing silicon membranes and developed an analytical model based on temporal coupled-mode theory to find optimum Fourier-space profiles.

We recently fabricated ultra-thin silicon solar cells of less than five micron thickness by molecular beam epitaxy that have shown over 16 % power conversion efficiencies when our patterns were applied, while flat silicon-nitride-coated references only achieved about 10%. We furthermore give reasonable indication that efficiencies beyond 20 % are achievable already below 10 micron silicon thicknesses.

23. Inverse design of photonic structures for enhanced performance of transparent organic solar cells for agrivoltaics applications

Flat agricultural lands are among the most suitable sites for photovoltaics (PV) installations. For a sustainable exploitation of such grounds, solar-to-electrical energy conversion has to be compatible with plant growth and food production. Plants require a specific wavelength range of the solar spectrum (400-700nm), called action spectrum, to regulate their growth and photosynthesis. The action spectrum describes the efficiency with which a photochemical reaction is produced at certain wavelengths. Up to date, research in the field has concentrated mainly on developing wave-selective transparent solar cells, with a high transmission in the active spectrum range, to be placed on structures such as greenhouses. A good transparency in that part of the spectrum limits the final performance of the PV cell, because it requires a large reduction in thickness for the back electrode of the PV cell. Consequently, IR photon harvesting is also reduced. By incorporating photonic back structures to organic solar cells with different binary blends, we show that the PV cell transmission can be tuned to the shape of action spectrum and enhance at the same time the photon absorption of the cell in the IR region. Using an inverse design approach, we target an optimized structure of the organic PV cell with an efficiency approaching 10% and a crop growth factor (an indicator relating the cell transparency to the action spectrum) of at least 40%. We also investigate how the variation of angle of incidence of the sun radiation along the year would impact the cell performance.

24. Machine learning for the free-form inverse design in nanophotonics

We present our approach utilizing deep neural networks for both the prediction of optical properties of nanostructures and their inverse design. First, we demonstrate the feasibility of employing neural networks to accurately predict the optical properties of nanostructured materials, with a particular emphasis on metasurfaces. Subsequently, we present methodologies to achieve inverse design of metasurfaces, guided by specific desired optical attributes and fabrication constraints. This is achieved through neural network design and the generation of training data, labeled with corresponding optical characteristics and manufacturability constraints. We implemented a conditional generative adversarial network comprised of five synergistic neural networks. This approach effectively mitigates challenges related to design non-uniqueness, mode collapse, and experimental feasibility.

25. Real-time measurements of a carbon nanotube electromechanical system hosting a double-quantum dot

Mechanical resonators are systems which present high quality factors and can easily couple to a wide range of forces rendering them excellent candidates for sensing and quantum information. In particular, carbon nanotubes (CNT) have been exploited in many fields such as a mechanical oscillator due to their interesting proprieties. Quantum dots (QD) have been defined in nanotubes to read out and control the mechanical motion electrically. One of the main difficulties in quantum dots defined in a carbon nanotube is to measure the system's dynamics when the electrons are bounded in the quantum dot, where common techniques based on conductance measurements are not applicable. This state is however interesting for the realization of electro-mechanical qubits, ultraprecise sensors, and quantum simulators. The target is to employ CNT-based sensing dots to carry out real-time measurements of a carbon nanotube electromechanical system hosting a double quantum dot at a timescale faster than the mechanical period.

26. Optical management for the open-circuit voltage enhancement in single-junction organic solar cells

This study introduces an optical approach to enhance the open-circuit voltage (Voc) in organic solar cells (OSCs). By exploring various one-dimensional structurations of the OSC device, we reduce Boltzmann losses arising from the mismatch between absorption and emission cones. This innovative method leads to a significant Voc enhancement, achieving an increase of approximately 30 mV through optical means. Furthermore, our findings establish a novel route in the development of planar geometry single-junction solar cells, surpassing the power conversion efficiency values set by the Shockley-Queisser limit.

27. Silver telluride colloidal quantum dot infrared photodetectors and image sensors

Photodetectors that are sensitive in the shortwave-infrared (SWIR) range (1–2 μm) are of great interest for applications such as machine vision, autonomous driving and three-dimensional, night and adverse weather imaging, among others. Currently available technologies in the SWIR range rely on costly epitaxial semiconductors that are not monolithically integrated with complementary metal–oxide–semiconductor electronics. Solution-processed quantum dots can address this challenge by enabling low-cost manufacturing and simple monolithic integration on silicon in a back-end-of-line process. So far, colloidal quantum dot materials to access the SWIR regime are mostly based on lead sulfide and mercury telluride compounds, imposing major regulatory concerns for their deployment in consumer electronics due to the presence of toxic heavy metals. Here we report a new synthesis method for environmentally friendly silver telluride quantum dots and their application in high-performance SWIR photodetectors. The colloidal quantum dot photodetector stack employs materials compliant with the Restriction of Hazardous Substances directives and is sensitive in the spectral range from 350 nm to 1,600 nm. The room-temperature detectivity is of the order of 1012 Jones, the 3 dB bandwidth is in excess of 0.1 MHz and the linear dynamic range is over 118 dB. We also realize a monolithically integrated SWIR imager based on solution-processed, toxic-heavy-metal-free materials, thus paving the way for this technology to the consumer electronics market.

28. Smith-Purcell metagratings for the generation of polarisation-tunable free-electron radiation

Merging metasurface design concepts with free-electron radiation phenomena presents a powerful approach to investigate and shape the interaction between light and electrons. As an electron passes a nanostructure, its evanescent field couples to a broad range of electromagnetic modes, emitting cathodoluminescence (CL) into the far-field. Grazing excitation schemes offer enhanced electron-light coupling via coherent excitation of multiple emitters, which enables phase-matching between light and electrons. One such example is the Smith-Purcell (SP) effect, where electrons grazing a periodic grating induce far-field emission with a characteristic, discrete scattering pattern. In this work, we propose a metagrating to generate polarisation-tunable SP emission. First, we perform finite-difference-time-domain simulations, demonstrating control over the polarisation state of SP emission via spatially selective excitation of different plasmonic modes within anisotropic Au nanostructures. Then we optimise the design for 30 keV electrons and develop a fabrication approach based on focused ion beam milling, exploring the potential of this technique for optical-fibre-integrated metasurfaces. Finally, we investigate the angular, spectral, spatial and polarisation properties of these structures through hyperspectral angle-resolved CL spectroscopy with polarimetry imaging, exploring on the nm-scale how the SP dispersion depends on grating pitch, nanostructure geometry, and electron position.

29. Stability Studies of Organic Solar Cells: A Path Towards Commercialization

Organic solar cells (OSCs) have gained attention over the last few decades due to the prospect of manufacturing highly efficient, semi-transparent, and large flexible solar panels via affordable solution processing methods. Currently, the power conversion efficiency (PCE) can reach up to 20% and despite a relevant gap with silicon or perovskite solar cells (PCE ~25%), OSCs have the potential to be produced in large quantities using roll-to-roll printing techniques, significantly reducing production costs and increasing the range of applications.

Currently, most high-efficiency OSCs use a blend composed of one polymer donor and Y-family non-fullerene acceptors (NFAs). They exhibit low voltage losses contributing, together with high absorption, electron mobility, and compact molecule packing, to reach high power conversion efficiencies.

However, the stability of high-performance NFA-OSCs remains the major barrier toward the commercialization of the technology.

One of the main factors affecting the stability is the penetration of oxygen in the active layer, it reacts with the organic materials and damages the conjugated structures through photo-oxidation reactions. This problem can be solved by appropriate encapsulation of the devices but stability is also affected by many other elements such as morphology of the active layer, diffusion of the electrode, mechanical stress, water, irradiation, and heating. In the case of irradiation the reasons for instability are photochemical and photophysical degradation of the active layer, hole/electron transporting layer and active layer/electrode interface. These can reduce the exciton generation and mobility, increase the energetic disorder and trap density, leading to a decrease in device stability. Regarding the thermal stability, the main cause is the physical degradation of organic materials induced by the heat and it can be improved in an effective way with the addition of a third component to the active layer.

In order to study the contribution of these factors and to compare the lifetime measurement results with the results of other devices, it is important to have a standardized method of reporting data. For this purpose, different categories of test protocols (ISOS) have been defined and are implemented at ICFO in collaboration with the spin-off company Vitsolc to understand the phenomena affecting the OSCs stability and find solutions that can allow commercial viability.

30. Time-resolved nanothermometry in a SEM

Cathodoluminescence spectra are used as sensitive temperature indicators. By studying the changes in the peak position, as well as the relative amplitude between peaks, we can tailor the ideal thermometer particle and unravel the mechanisms behind plasmonic heating. Furthermore, by using an advanced synchronized detection scheme, we can track the time evolution of the heat diffusion process whilst overcoming the diffraction limit of light using electrons as a probe.

31. Tracking Energy Transfer: Spatiotemporal Microscopy with a Near-Field Design

Spatiotemporal microscopy is an essential technique for the study of solar cells materials. Providing a picture of both the exciton spatial dynamics and its temporal decay, it opens the door to improvements in photovoltaic technology through a better understanding of the physics of light-to-charge transport. Typically used spatiotemporal microscopy configurations are sensitive to nanoscale diffusion, but they are essentially diffraction limited, averaging over micrometer spot sizes. While not a drawback in homogeneous organic semiconductor (OSC) materials like Y6, it is an impediment for the study of more complex disordered systems, such as natural light-harvesting (LH) membranes and perovskites.

To address this shortcoming and access the 10 nm scale of energy transfer we propose the integration of a background free nano-localized excitation and highly localized detection spots with a point-scanning pump-probe microscope. We nanostructure the microscope coverslip with nanoslits on a metal film combined with rod-shaped nanoantennas. The incident pump beam will largely screen the nanoslit. Light transmitted through the slit will create an initial exciton population on the sample. By tuning the antenna's resonance to the probe beam wavelength and creating many slit-antenna distances we plan to visualize the rate at which the exciton size increases on a 10-100nm scale.

Being sensitive to a few nanometers transfer distance we expect to better quantify diffusion constants, to resolve the diffusion length, and to be able to identify directional diffusion and even trapped sub-diffusion regimes.

Here we will present the current state of the project, showing the nanostructured surfaces and some preliminary signals from their integration with the setup. We will also describe the roadmap of the project, from the proof-of-concept and technique validation in Y6 to a more challenging experiment with LH membranes.

32. Waveguide-Particle Excitation for Photocatalysis

Interaction of resonant particles with the nearfield at a photonic waveguide offers the “remote” excitation of localized plasmons or Mie resonances. Distributing localized light along the waveguide has great potential in many applications, such as photocatalysis, plasmonic catalysis. This study focuses on the light distribution in the system to optimize the parameters for oxygen evolution reaction.

33. Non-singular near-touching plasmon modes in nanocube dimers

We investigate plasmons in dimers of fluorine-doped indium oxide nanocubes near the transition from touching to non-touching configurations. Through spatially resolved electron energy-loss spectroscopy, we reveal a non-singular transition, in which plasmon modes in separated dimers evolve in a continuous way to those of touching dimers. These results are in excellent agreement with simulations for the observed spectra and energy-filtered maps of the structures. When theoretically examining different types of geometries near touching conditions, we find that the presence of a finite two-dimensionality touching area makes the transition non-singular, while a zero-dimensionality or one-dimensionality touching region produces a singular behavior.

34. Radiative loss of coherence in free electrons: a long-range quantum phenomenon

We reveal a manifestation of quantum mechanics that involves macroscopic distances and results in a nearly complete depletion of coherence associated with which-way free-electron interference produced by electron–radiation coupling in the presence of distant extended objects. We illustrate this effect through a rigorous theoretical analysis of a two-path electron beam interacting with a semi-infinite metallic plate and find the inter path coherence to vanish proportionally to the path separation at zero temperature and exponentially at finite temperature. The investigated regime of large distances involves the coupling of the electron to radiative modes assisted by diffraction at material structures but without any involvement of material excitations. Besides the fundamental interest of this macroscopic quantum phenomenon, our results suggest an approach to measuring the vacuum temperature and nondestructively sensing the presence of distant objects.

35. Low-Energy Photocurrent Probe of Local Symmetries and Quantum Geometry in Magic-Angle Twisted Bilayer Graphene

One of the primary interests of modern condensed matter physics is to understand, predict and ultimately control many-body and topological quantum phases. Moiré 2D materials have emerged as a pivotal platform for such investigation, where atomically thin 2D layers are assembled twisted relative to each other, producing peculiar arrangements of atoms not found in any other solid-state system. Since the first realization of correlated phases in Magic-Angle Twisted Bilayer Graphene (MATBG) [1,2], a plethora of quantum phases ranging from superconductivity [1] to the recent discovery of anomalous fractional quantum hall states [3] have been demonstrated in moiré crystals. Despite considerable effort in the field, however, predicting the actual response of these materials remains challenging, and experimental results are often device-dependent.

In these cases, the understanding of the exotic phenomena of the system is driven by the identification of its symmetries. This is extremely challenging for moiré crystals, because, in addition to the intrinsic properties of the electronic system, many external factors can influence the final ground state [4]. In fact, not only they are intrinsically more sensitive to the dielectric environment due to their 2D nature, but also, they are more prone to strain and spatial inhomogeneities, suffering from the “tear and stack” fabrication technique.

In this context, second-order bulk photocurrents [5] are emerging as an exciting tool complementary to quantum transport or all-optical experiments. Their nonlinear nature makes them extremely sensitive to crystal/electronic symmetries offering unique insights with respect to pure optical experiments locking to the electronic degrees of freedom. Additionally, even when the photoexcitation is global, the response from local photoactive regions can still be observed since the non-photoactive regions act as current-collecting leads, making photocurrent a potentially more sensitive probe of local electronic order [6]. Furthermore, optical selection rules for photocurrent generation are tightly bounded to nontrivial quantum geometry, offering direct insight into the symmetries of electronic wavefunctions.
In this work we investigate MATBG with the use of polarization-resolved photocurrents at Mid-Infrared and Terahertz frequencies at cryogenic temperatures. We show how this technique can be used to detect local spatial symmetries of the crystal. We further demonstrate how the density dependence of the polarization axes of the photocurrent provides information on the interplay between quantum geometry and the many-body renormalization of single-particle properties in MATBG.

35. Optomechanical computation

TO BE CONFIRMED