

Symposium Designing Quantum Materials with Light: From Floquet to Cavity Engineering (SYFC)

jointly organised by
the Semiconductor Physics Division (HL),
the Surface Science Division (O), and
the Low Temperature Physics Division (TT)

Marcel Reutzel
Universität Marburg
Renthof 5
35032 Marburg
marcel.reutzel@uni-marburg.de

Michael Sentef
Universität Bremen
Otto-Hahn-Allee 1
28359 Bremen
sentef@uni-bremen.de

This symposium focuses on how tailored light fields and optical cavities can be used to design and control novel phases of quantum matter far from thermal equilibrium or even in the dark. Building on rapid progress in ultrafast experiments – including time-resolved momentum microscopy and high-quality 2D/3D materials – Floquet and cavity engineering now enable the creation of engineered band structures, correlated and topological phases, and emergent “polaritonic quantum matter.” In parallel, ab initio and advanced many-body theory have matured to the point of providing quantitative guidance and interpretation for these experiments. The symposium will bring together leading international experts from theory and experiment to discuss current breakthroughs and future directions towards optoelectronic and quantum-information devices based on light-designed quantum materials.

Overview of Invited Talks and Sessions

(Lecture hall HSZ/AUDI)

Invited Talks

SYFC 1.1	Mon	9:30–10:00	HSZ/AUDI	Subcycle videography of strong-field controlled band structures — ●RUPERT HUBER, MANUEL MEIERHOFER, ULRICH HÖFER
SYFC 1.2	Mon	10:00–10:30	HSZ/AUDI	Engineering Quantum Materials through Structured Cavity Vacuum Fluctuations — ●ANGEL RUBIO
SYFC 1.3	Mon	10:30–11:00	HSZ/AUDI	Floquet engineering of quantum materials: from semiconductors to semimetals — ●SHUYUN ZHOU
SYFC 1.4	Mon	11:15–11:45	HSZ/AUDI	(Quantum) Light Control of Materials — ●DANTE KENNES
SYFC 1.5	Mon	11:45–12:15	HSZ/AUDI	Lightwave-driven electrons in a Floquet topological insulator — DANIEL LESKO, TOBIAS WEITZ, WEIZHE LI, SELINA NÖCKER, CELINA HÜTTNER, TAMARA PRÖBSTER, SIMON WITTIGSCHLAGER, CHRISTIAN HEIDE, OFER NEUFELD, ●PETER HOMMELHOFF

Sessions

SYFC 1.1–1.5	Mon	9:30–12:15	HSZ/AUDI	Designing Quantum Materials With Light: from Floquet to Cavity Engineering
--------------	-----	------------	----------	---

SYFC 1: Designing Quantum Materials With Light: from Floquet to Cavity Engineering

Time: Monday 9:30–12:15

Location: HSZ/AUDI

Invited Talk

SYFC 1.1 Mon 9:30 HSZ/AUDI

Subcycle videography of strong-field controlled band structures — •RUPERT HUBER¹, MANUEL MEIERHOFER¹, and ULRICH HÖFER^{1,2} — ¹Department of Physics and Regensburg Center for Ultrafast Nanoscopy (RUN), University of Regensburg, Germany — ²Department of Physics, Marburg University, Germany

In lightwave electronics, the oscillating carrier field of intense light pulses has been utilized as an alternating bias to coherently accelerate electrons through solids [1]. Lightwave-driven closed quantum trajectories can lead to new eigenstates and tailored Floquet-Bloch band structures. We will first report how all-optical measurements can uniquely identify the presence of Floquet-Bloch states using high-order sideband generation [2]. A direct momentum-resolved observation of the formation and decay of Floquet-Bloch band structures on subcycle time scales has become available with ARPES-based band-structure videography [3]. While our lead-off experiments were limited to subcycle dynamics at small electron momenta, a novel approach using momentum microscopy with few-fs XUV pulses affords a panoramic view of strong-field dynamics throughout the first Brillouin zone. We will illustrate how this approach allows us to reveal the anatomy of strong-field light-matter interaction in quantum materials ranging from graphene to novel flat-band materials.

[1] Borsch et al., *Nature Reviews Materials* 8, 668 (2023); Kira et al., *Optics and Photonics News* 36, 28 (2025). [2] Freudenstein et al., *Nature* 610, 290 (2022); Kneller et al., in preparation. [3] Ito et al., *Nature* 616, 696 (2023); Reimann et al., *Nature* 562, 396 (2018).

Invited Talk

SYFC 1.2 Mon 10:00 HSZ/AUDI

Engineering Quantum Materials through Structured Cavity Vacuum Fluctuations — •ANGEL RUBIO — Max Planck Institute for the Structure and Dynamics of Matter

Structuring the photon density of states in optical cavities enables control of material properties through strong light-matter coupling. Quantum Electrodynamical Density Functional Theory (QEDFT) extends TDDFT by incorporating quantized electromagnetic fields into electronic structure theory, providing an ab initio framework for predicting cavity-induced phenomena. Experiments such as photon-mediated superconductivity and optically engineered topological phases show that vacuum fluctuations, rather than classical light, can reshape material ground states and drive new quantum phases.

We present an ab initio approach to study cavity effects in two-dimensional materials. Using QEDFT, we show how vacuum fields modify van der Waals systems, inducing charge localization, tunable band gaps, and interlayer spacing that alter ferroelectric and optical responses. A non-perturbative Hartree-Fock framework further reveals cavity-mediated electron interactions in graphene and dichalcogenides, where anisotropic photon modes open Dirac gaps while isotropic ones renormalize the Fermi velocity. Cavity photons thus emerge as a new control parameter for correlated quantum states.

Invited Talk

SYFC 1.3 Mon 10:30 HSZ/AUDI

Floquet engineering of quantum materials: from semiconductors to semimetals — •SHUYUN ZHOU — Department of Physics, Tsinghua University

Time-periodic light-field can dress the electronic states of quantum materials, providing a fascinating controlling knob for transient modifications of the electronic structure with versatile light-induced emergent phenomena. In this talk, I will present our recent experimental progress on the Floquet engineering of quantum materials using time- and angle-resolved photoemission spectroscopy (TrARPES). In particular, experimental progress on the Floquet engineering of semiconductors and semimetals. Experimental insights on Floquet engineering and light-matter interactions in quantum materials will also be discussed.

15 min. break**Invited Talk**

SYFC 1.4 Mon 11:15 HSZ/AUDI

(Quantum) Light Control of Materials — •DANTE KENNES — RWTH Aachen University, Germany — MPSD Hamburg, Germany

Light offers a versatile handle for tailoring quantum materials. I will outline two complementary examples focusing on their theoretical and computational nonequilibrium quantum many-body descriptions: (i) Ultrafast optical drives can transiently reshape a solid's symmetry and electronic structure, where for the latter Floquet engineering provides the framework for accessing and stabilizing novel non-equilibrium phases [1]. (ii) Embedding a material in an optical cavity couples it to quantized photon modes, unlocking new many-body phenomena in the realm of cavity quantum electrodynamics [2]. I will close with an outlook on merging these strategies with the flexibility of two-dimensional heterostructures to enable on-demand design of quantum functionalities [3].

[1] *Rev. Mod. Phys.* 93, 041002 (2021)

[2] *Appl. Phys. Rev.* 9, 011312 (2022)

[3] *Nat. Phys.* 17, 155 (2021)

Invited Talk

SYFC 1.5 Mon 11:45 HSZ/AUDI

Lightwave-driven electrons in a Floquet topological insulator — DANIEL LESKO^{1,2}, TOBIAS WEITZ^{1,2}, WEIZHE LI¹, SELINA NÖCKER^{1,2}, CELINA HÜTTNER¹, TAMARA PRÖBSTER¹, SIMON WITTIGSCHLAGER¹, CHRISTIAN HEIDE^{1,3}, OFER NEUFELD⁴, and •PETER HOMMELHOFF^{1,2} — ¹Department Physik, Friedrich-Alexander-Universität, Erlangen — ²Fakultät für Physik, Ludwig-Maxilians-Universität, München — ³University of Central Florida, Orlando, FL, USA — ⁴Technion, Haifa, Israel

Topological insulators enable novel quantum and electronic phenomena but are limited by material constraints. Floquet topological insulators (FTIs), created by time-periodic driving, promise tunable topological properties and petahertz operation. We demonstrate optical control of photocurrents in light-dressed graphene, where circularly polarized pulses induce an FTI state and phase-locked second-harmonic pulses drive electron dynamics. This enables measurement of all-optical anomalous Hall and valley-polarized photocurrents, revealing sub-cycle phase sensitivity and dynamical symmetry selection rules. Supported by ab-initio and analytical theory, our results establish a bridge between Floquet and topological physics, attosecond science, and valleytronics, advancing ultrafast topotronic control beyond static band engineering.