Explore Complex Materials
with IR and THz near-field Microscopy and Spectroscopy

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ABSTRACT: In strongly correlated electron materials (SCEM), the delicate interplay between spin, charge, and lattice degrees of freedom often leads to extremely rich phase diagrams exhibiting intrinsic phase inhomogeneities. The key to studying and disentangling such complexities in SCEM usually lies in the characterization and control of the materials at fundamental energy, time and length scales. I will use this opportunity to report the recent advances in the near-field IR and THz spectroscopy and discuss their applications in the nanoscale electrodynamics in SECM. Specifically, I will discuss the details of modeling scanning near-field infrared microscopy with CST simulation and its application in understanding the mesoscopic insulator to metal phase transitions in VO_2 and Ca_2RuO_4 with over a broad spectral range (350 cm^{-1} to 2500 cm^{-1}). I will also discuss the future development of near-field scanning microscope including the cryogenic capabilities and its coupling to ultrafast pump-probe spectroscopy. These results set the stage for future spectroscopic investigations to access the fundamental properties of complex materials at the nanoscale.

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Mapping three-dimensional near-field responses with scattering-type scanning near-field optical microscopy"

Scattering-type scanning near-field optical microscopy (s-SNOM) enables mapping of nanoscale field distributions in two dimensions. However, the standard s-SNOM technique lacks direct resolving ability along the vertical direction, therefore unable to provide full three-dimensional near-field responses. Here, we develop a technique that enables s-SNOM to collect near-field responses at explicit tip-sample distance dependences. As a demonstration, spectral responses of boron nitride and silicon carbide are studied by the new s-SNOM method to reveal bound electric near-field of plasmonic structures, tip-induced spectral shift and modified relaxation dynamics of phonon polaritons. The new technique extends the capability of s-SNOM and is generally applicable for a wide range of nanoscale characterizations on plasmonic and phonon polaritonic nanostructures.

Scattering from singular surfaces, from AFM tip for NSOM to polygonal plates for Terahertz sensor

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We study the response of a conical metallic surface to an external electromagnetic (EM) field by representing the fields in basis functions containing integrable singularities at the tip obtained by conformal mapping between the cone and a round disk. We found the field-induced charge distribution to consist of localized terms at the tip apex and the base and an extended bulk term along the body of the cone far way from the tip. We apply our calculation to the scattering-based scanning near-field optical microscope (s-SNOM) and successfully quantify the elastic light scattering from a vibrating metallic tip over a uniform sample. In recent s-SNOM experiments at the optical range (< 1um) the fundamental is much larger than the higher harmonics whereas at THz range (> 1mm) the fundamental becomes comparable to the higher harmonics. We find that the tip charge dominates the contribution to the higher harmonics and becomes much bigger for the THz experiments, thus providing an explanation. Our calculation is orders of magnitude faster than current approaches. We demonstrate this by extracting a two dimensional dielectric constant map from the s-SNOM image of a finite metallic disk which suggests the possibility of mapping the charge density distribution of a finite metallic surface induced by an EM field.

Optical Study of Topological Crystalline Insulators and Graphene/BN Heterostructures

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Abstract: The surface states of topological crystalline insulators (TCI) arise from the topology of the bulk bands and are protected by crystalline symmetries. So far, the surface states remain mostly elusive in optical and transport experiments. We investigated the infrared (IR) reflectance spectrum of a TCI Pb1-xSnxSe in zero and high magnetic fields. Analysis of the interband Landau level transitions of the TCI phase shows that their bulk bands can be well described by massive Dirac fermions. Moreover, our optical data have revealed several signatures of the surface states in the TCI phase. We will discuss and compare the mobility and DC conductivity of the surface and bulk states. These findings provide new insights in the unique surface states of TCIs.

In the second half of the talk, we report our study of photocurrent in graphene/boron-nitride Moiré superlattice structures. A record-high zero-bias photoresponsivity of 0.3 A/W (equivalently, an external quantum efficiency exceeding 50%) is achieved using graphene's photo-Nernst effect, which demonstrates a collection of at least five carriers per absorbed photon. We reveal that this effect arises from the enhanced Nernst coefficient through Lifshtiz transition at low-energy Van Hove singularities, which is an emergent phenomenon due to the formation of Moiré minibands. Our observation points to a new means for extremely efficient and flexible optoelectronics based on van der Waals heterostructures.

Thursday

Synthetic gauge potential in classical waves

C.T. Chan, Hong Kong University of Science and Technology

We show that a synthetic gauge potential in momentum space can be introduced by twisting the micro-structure of a classical wave system in real space. One example is the geometric phase mediated topological transport of sound vortices. It is well-known that geometric phase in light, as a vector wave, manifests through polarization (or spin) that is an intrinsic degree of freedom of vector waves. Such a degree of freedom is absent in scalar waves, such as airborne sound. We demonstrate that the propagation of airborne sound can also induce geometric phase if we create a sound vortex and the geometric phase arises from the propagation of the topological defect state associated with the sound vortex through a helical waveguide in which the 3D twisting bestows a nontrivial winding of the wave vector in momentum space. The effect can be interpreted as a twisting induced synthetic gauge potential that couples orbital angular momentum to the linear momentum. Another example is the control of the equifrequency surfaces at the long wavelength limit. All natural materials have their index ellipsoids centered at k=0. We will see that some metallic scaffolds with helical structures can possess multiple index ellipsoids centered at arbitrary nonzero k-points. The shifting of the equifrequency surfaces at low frequencies can again be interpreted as the consequence of a twisting induced gauge potential. Other examples include the realization of Weyl crystals. Weyl points, as monopoles of Berry curvature in momentum space, have captured much attention recently in various branches of physics. However, many Weyl photonic structures designed previously are probably too complicated for nanofabrication. We found that Weyl points can be found in metallic chiral structures. In the microwave regime, such structures can be fabricated using planar fabrication technology. In IR and optical frequency regimes, Weyl points can be found in chiral woodpile photonic crystals, which can be fabricated using current nanotechnology. When the constituent materials change from the air-in-metal to metal-in-air configuration, the sign of topological charge will change, leading to a topological phase transition and the bands change from topologically trivial to nontrivial. Gapless surface states exist in the latter cases and its robust transport property has been demonstrated.

Observation of optical vortices in momentum space

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Vortex, the winding of a vector field in two dimensions, has its core the field singularity and its topological charge defined by the quantized winding angle of the vector field [1, 2]. Vortices are one of the most fundamental topological excitations in nature, widely known in hair whorls as the winding of hair strings, in fluid dynamics as the winding of velocities, in angular-momentum beams as the winding of phase angle, and in superconductors and superfluids as the winding of order parameters [2]. Nevertheless, vortices have hardly been observed other than those in the real space. Although band degeneracies, such as Dirac cones, can be viewed as momentum-space vortices in their mathematical structures, there lacks a well-defined physical observable whose winding number is an arbitrary signed integer [3]. Here, we experimentally observed momentum-space vortices as the winding of far-field polarization vectors in the Brillouin zone of periodic plasmonic structures. Using a home-made polarization-resolved momentum-space imaging spectroscopy, we completely map out the dispersion, lifetime and polarization of all radiative states at the visible wavelengths. The momentum space vortices were experimentally identified by their winding patterns in the polarization-resolved iso-frequency contours and their diverging radiative quality factors. Such polarization vortices can exist robustly on any periodic systems of vectorial fields, while they are not captured by the existing topological band theory developed for scaler fields. This work opens up a promising avenue for exploring topological photonics in the momentum space [4], studying bound states in continuum (BICs) [5], as well as for rendering and steering vector beams and designing high-Q plasmonic resonances.

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Valley physics in phononic crystals

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Abstract:

Phononic crystals (PCs) are artificial periodical structures for acoustic waves with frequency bands in momentum space. Dirac conic dispersions can be found at the Brillouin zone of 2D PCs with hexagonal lattice. By breaking the symmetry of the PCs, the degeneracies at two Dirac points can be lifted and bandgaps open, resulting in two inequivalent valleys with states of opposite vortices. The valley vortex states which carry angular momentum can exert torque on particles through interacting with them. Breaking symmetry oppositely leads to two PCs with band inversion, and the one-way edge states emerge on the interfaces of the two PCS, as demonstrated in simulations and in experiments.

Manipulating electromagnetic wave propagating non-reciprocally by a chain of magnetic rods

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Abstract

We theoretically and experimentally demonstrated that non-reciprocal wave propagation could be manipulated by magnetic rod chains under bias DC magnetic fields. We show along the direction of the chain the wave propagation is non-reciprocal, however, the underlying mechanism may be different, One is related to the chiral edge state and the other related to the non-reciprocal bulk state of the rod array. The direction of the wave propagation can be tuned by the DC magnetic field or the symmetry to the chain. The unidirectional transmission makes the chain as one-way waveguide with minimized transvers dimension and flexible geometry. On the other hand, we show out of the chain plane the rod array also exhibits non-reciprocal wave propagation characteristics, showing almost a total reflection when the incident wave obliquely impinged on the rod chain, but nearly a total transmission when the wave reversed its propagation direction. The non-reciprocal wave propagation was directly observed by using the field mapping technique. We show the non-reciprocal wave propagation is due to the non-reciprocal diffraction of the rod chain for the orders 0 and ± 1. The unique non-reciprocal wave properties, along the magnetic rod chain and out of the rod strip plane, provide new ways to control the flow of EM waves.

JunJie Du,

Shanghai Normal University,

Title:Anomalous Dipole-like Multipole in Homogenous Dielectric Rods

Abstract：
Localized optical scattering behavior might determine the properties of the artificially structured optical materials. Typically, in metamaterials locally resonant units are the basis of metaatoms or metamolecules[1], and in metasurfaces the antenna dispersion and the Pancharatnam-Berry phase of scatterers are the necessary condition to introduce abrupt phase changes[2]. In this report, we show that circular silicon rods can support an anomalous dipolelike multipole. Similar to an electronic dipole, the radiation fields from the rod are located in the forward and backward directions , but the phase is different from that of an electric dipole. The formation of the dipolelike multipole is also unique, resulting from the interplay between an electric quadrupole and a magnetic dipole excited simultaneously in a dielectric rod. Recently it has been shown that an EM counterpart of anapoles can be similarly obtained by the interplay between a toroidal dipole and an electric dipole. We will show that such silicon rods with the anomalous localized property are able to produce some unexpected results. The compatibility of the designed optical units with complementary metal-oxide semiconductor technologies might make it easily find useful applications in the fields of photonics, optical manipulation.

Friday:

Powerful spintronic THz emitters based on the ultrafast spin-to-charge conversion". I will try to give the abstract asap.

Jingbo Qi, University of Electronic Science and Technology of China

Terahertz photonic devices for frequency comb operation and fast detection

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Abstract

The terahertz wave with the frequency defined between 0.1 and 10 THz is of great interest due to its unique properties such as transparency for papers and plastic materials, abundant absorption "fingerprints" of various chemicals, and potential large communication bandwidth. The development of the terahertz technology is strongly dependent on the advances of terahertz sources and detectors. In our laboratory, we have been working on the semiconductor photonic devices employing the intersubband transitions, quantum cascade laser (QCL) and quantum well photodetector (QWP), for terahertz generation and detection, respectively. Here in this work, we report the homogeneous spectral spanning of terahertz QCLs for comb operation and fast terahertz QWP for detection of gigahertz modulated terahertz radiation.

Due to the long cavity geometry that results in a smaller inter-mode beat note frequency and then stronger mode coupling, we can efficiently modulate the long cavity laser and broaden the terahertz emission spectra utilizing a radio frequency modulation technique. The modulated spectra can homogeneously span 330 GHz frequency range, which is approximately 8% of the central frequency. Using the long cavity laser comb with homogeneous spectral spanning, GaAs etalon transmission and ammonia gas (NH_3) absorption measurements are successfully demonstrated.

Concerning the terahertz detection, by carefully designing the device structure and the microwave transmission line, we first demonstrate the fast detection of terahertz light using a terahertz QWP with a device area of 400x400 μm^2. The electrical rectification measurements reveal that the QWP device has a modulation response bandwidth upto 4.3 GHz. As a proof for the fast detection, a 6.2 GHz modulated terahertz light emitted from the 6-mm long terahertz QCL is successfully detected in terms of inter-mode optical beat note spectrum using the fast terahertz QWP.

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Quantum behaviors of graphene plasmons

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Discovering exotic quantum effects of plasmons and their coupling with other quasiparticles in solids may help to understand such collective excitations at the fundamental level, and further offer quantum-mechanical solution to design future quantum devices with optimized functionalities. In this talk, I will present our recent progress on the quantum behaviors of pasmons in graphene. In particular, I will show the control of plasmon excitation and propagation by tuning the quantum transmission at Heaviside step-like potentials. Moreover, I will also demonstrate that when the electron-plasmon coupling is introduced, the quantum coherence of electrons in graphene is substantially enhanced.

Nonlocal metamaterials and metasurfaces

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Abstract – We discuss possible interesting consequences when the material parameters of metamaterials / metasurfaces exhibit wave-vector-dependence, which is also known as nonlocality or spatial dispersion. One interesting possibility is the realization of ultratransparent materials [1], which could reach the ultimate transparency beyond any natural materials. Another interesting consequence is a new approach of cloaking via nonlocal metasurfaces, which may lead to much simpler and thinner cloaking shells than those based on transformation optics. Our work shows great potential in exploring the nonlocal degree of freedoms in metamaterials and metasurfaces.

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