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Research Statement

Professional Biographical Sketch

Dr. Greg Jenkins is an experimental Associate Research Scientist studying condensed matter physics at the University of Maryland (UMD) College Park campus and a member of the Center for Nanophysics and Advanced Materials (CNAM). He joined UMD in 1994 as a graduate student after working at the research and development branch of Dasibi. At UMD with Prof. Richard A. Webb and thesis advisor Prof. H. Dennis Drew, research included development of novel single-electron tunneling devices and several studies of high-temperature cuprate superconductors using a variety of optical techniques. He earned a PhD in 2003, performed as a jazz pianist for four years, returned to the University of Maryland in 2007 as a Research Associate, and promoted to Assistant Research Scientist in 2011 and Associate Research scientist in 2017. In 2009, he independently collaborated with the NIST metallurgical team, and taught two undergraduate courses at UMD, Physics 142 and 270. In 2016, he advised the Institute for Research in Electronics and Applied Physics (IREAP) on the design and installation of a multi-laboratory helium recovery system.

Summary of accomplishments since 2009

Since 2009, accomplishments include publishing 10 first-author papers (20 total) and collaboratively writing 10 proposals, 5 of which were awarded totaling $2.6 million. He is Co-PI of three basic research programs awarded by DoE and NSF, and currently manages two of these programs awarded in 2016 at the one million dollar level. Collaborations include many theoretical and experimental groups spanning 18 national universities, 5 national laboratories, and 9 international universities and laboratories. At the University of Maryland, collaborators include members of the Condensed Matter Theory Center, Joint Quantum Institute, IREAP, and CNAM. Eight undergraduate students, one graduate student, and four research associates were mentored.

Since 2009, experimental studies have mainly focused on the electronic properties of various condensed matter systems including Weyl and 3D Dirac semimetals, 3D topological insulators, the 2D topological insulator (quantum spin Hall effect) InAs/GaSb inverted double-quantum well, the quantum Hall effect at THz frequencies in graphene and GaAs heterostructures, and n- and p- type cuprate high temperature superconductors. Work also includes the study and development of carbon nanotube and graphene photo-thermal THz detectors and emitters, high resolution imaging using quantum optics (N00N states), study of excitons in double-gated high mobility graphene, and photocurrent measurements in GaAs (110) quantum well stacks. The feasibility of utilizing anti-ferromagnetic resonance to detect and quantify the oxidation of ferrous material (primarily rebar) in re-enforced concrete structures as an *in situ* technique was investigated. Instrumentation development and implementation includes a THz Kerr rotation and circular dichroism measurement system, gate-modulated magneto-optical and FTIR techniques that greatly enhance sensitivity to surface effects, a polarization-modulation technique to measure polarization-sensitive photocurrents, a highly automated helium recovery system that spans five laboratory areas, and full laboratory automation of all magneto-optical measurements. The pioneering polarization-modulation complex Kerr and Faraday angle measurement instrument has been duplicated by multiple condensed matter laboratories. The design of the helium recovery system was adopted as a model for a larger installation lead by Prof. Dan Lathrop at IREAP.

Selected work from three research areas are highlighted for brevity.

1. High temperature cuprate superconductors (HTSCs)

Of the many peculiar properties exhibited by these materials, the anomalous Hall effect is one of the strangest and earliest observed phenomena. By extending dc Hall measurements to THz frequencies, crucial information was garnered to help solve this long standing problem.

Both n- and p-type HTSCs in the normal and superconducting state were studied. In overdoped $Pr_{2-x}Ce_xCuO_4$, an electron doped (n-type) HTSC, the THz complex Hall angle, extrapolated to low temperatures, shows inelastic scattering introduces electron-like contributions to the Hall response. Calculations of the complex Hall angle that include current vertex corrections (CVCs) induced by electron interactions mediated by magnetic fluctuations reproduce the temperature, frequency, and doping dependence of the experimental data. The results show that CVC effects are the source of the anomalous Hall transport properties in overdoped n-type cuprates. In underdoped $Pr_{2-x}Ce_xCuO_4$, strong deviations are found between transport data, both THz and dc Hall measurements, and the predictions of transport theory within the relaxation time approximation (RTA) based on angular resolved photoemission (ARPES) data. Furthermore, the Hall mass remains negative with no signature of a change in Fermi surface topology at or above the Neel temperature and the characteristic temperature at which the optical gap fully closes. In the paramagnetic state this behavior of the Hall mass may be qualitatively understood by the same mechanism found in overdoped $Pr_{2-x}Ce_xCuO_4$, namely CVCs to the Hall conductivity due to magnetic fluctuations. Above Tc in optimally doped $Bi_2Sr_2CaCu_2O_{8+x}$, a hole doped (p-type) HTSC, the expected THz Hall response calculated within a Boltzmann formalism using ARPES measured parameters was significantly larger than the measured THz Hall response. This is the THz manifestation of the well-known anomalous dc Hall effect where dc-R_H enhancements are much larger than the value expected from Luttinger's thereom as well as the expected value calculated directly from ARPES data analyzed within the RTA. These enhancements as well as the frequency and temperature dependence of the dc and THz Hall response are also well described by the same mechanism, CVCs to the conductivity due to electron-electron interactions mediated by antiferromagnetic fluctuations.

2. 3D Topological Insulators

Three dimensional topological insulators have two-dimensional surface states that exhibit Dirac-like dispersion similar to graphene, but the spins of the quasiparticles are locked perpendicularly to the surface current. Manipulating the current (electric field) effects the spins (magnetic field) and vice versa. This and other emergent exotic properties (like the Majorana fermion) may have far reaching implications ranging from quantum computing to spintronics. Prior to 2013, the unambiguous detection of the surface states by transport measurements was confounded by large bulk conduction. A UMD collaborative effort published optical and dc transport properties of Bi_2Se_3 bulk crystals reporting that the surface state was not observable and therefore the surface state carrier scattering rate may be high. A new THz complex Kerr angle (circular dichroism and polarization rotation) measurement scheme was implemented to resolve the surface state, but the high surface state scattering rate broadened the cyclotron resonance hindering unambiguous detection.

A new gate-modulated THz Kerr and Faraday polarization-modulation measurement instrument was devised and implemented with concurrent dc-gate tunability. The instrument is two orders of magnitude more sensitive than any other THz polarimetry measurement scheme. New gate fabrication methods were developed to uniformly apply electric fields over large areas (~cm^2) on highly irregular surfaces of as-grown bulk crystals. The gate-modulated measurement technique spatially resolves surface from bulk conductivity contributions, and spectroscopically resolves carriers by their cyclotron frequency (mass). The surfaces of all measured Bi_2Se_3 bulk crystals, grown under a variety of conditions, were highly accumulated with large scattering rates. However, Bi_2Se_3 films with a thin passivation layer of In_2Se_3 permitted gating the surface Fermi level to the Dirac point, and up through the conduction band edge. The unambiguous small cyclotron mass associated with the surface Dirac cone carriers was observed. A Dirac-like cyclotron mass and evidence of puddling in the vicinity of the Dirac point was observed similar to graphene. A large sudden increase in the topological surface state scattering rate occurs when the surface state Fermi level becomes degenerate with bulk states, which opens new scattering channels. Since the surface is buried beneath the trivial insulator In_2Se_3, the topological surface interface state is different than the vacuum interface state, and shows a large shift of the Dirac point towards the conduction band edge. This shift of the Dirac point is tunable through the material properties of the trivial insulator offering new routes to tailoring the surface. An extremely wide quantized Faraday-rotation plateau was discovered, the finite-frequency analogue of a quantized Hall plateau, which involves both the surface and accumulated bulk carriers near the surface. The effect is not currently understood.

3. Weyl and 3D Dirac

In condensed-matter systems, Dirac fermions exist in the valence and conduction bands that touch at a pair of points and disperse linearly away from the nodes. These bands are protected against gapping by crystal symmetry. If either crystal inversion or time-reversal symmetry is broken, each Dirac node splits into a pair of opposite chirality Weyl nodes, topological objects that act as a source or sink of Berry's phase curvature. This topological band structure effect is analogous to opposite-polarity magnetic monopoles residing at the nodes in momentum space, which fundamentally alter the semiclassical equations of motion and Maxwell's constitutive relations. The repercussions include new unique electronic properties like Fermi-arc surface states, chiral pumping effects, and magnetoelectric-like effects in plasmonics detectable by optical probes even in the absence of an applied field.

Optical spectroscopic measurements were performed on the 3D Dirac semimetals Na_3Bi and Cd_3As_2 as well as the time-symmetry broken Weyl material $Eu_2Ir_2O_7$ and inversion-symmetry Weyl material TaAs. In all systems, signatures of the Dirac dispersion are encoded in optical data through the temperature dependent chemical potential affecting the Drude free carrier response and interband transitions. The effects allow extraction of parameters like the Fermi velocity, Fermi surface anisotropy, Lifshitz gap characteristics, extrinsic doping level, and interaction energy.

In the pyrochlore $Eu_2Ir_2O_7$, the onset of semimetallic behavior below the magnetic transition temperature and Dirac-like behavior of conductivity at low frequency provides optical evidence that $Eu_2Ir_2O_7$ (at a specific off-stoichiometry) is a Weyl state system. Since Na_3Bi is highly reactive with air, performing measurements is sufficiently challenging that this was the first optical characterization. A few discoveries were made: a bulk plasmaron mode exists near the plasma edge, the ground state crystal symmetry is likely P3c1, the optical matrix elements are zero at the Lifshitz (saddle point) gap at the Γ-point, and a non-monotonic strongly temperature dependent plasma edge is indicative of the temperature dependence of Dirac free carriers.

Gate-modulation techniques were incorporated into FTIR continuous-scan spectroscopy to measure the transport properties of the Fermi arc surface states of Cd_3As_2. The gate is modulated at a high frequency compared to the bandwidth of the FTIR modulations. Strong (high order) bandpass filtering results in an interferogram that encodes only the modulated surface signals. The sensitivity to surface signals of the new gate-modulation measurement method is enhanced by 2-order of magnitude compared to dc-gating, allowing surface properties to be measured as a function of Fermi level. Similar to early measurements of bulk crystals of Bi_2Se_3, the experiments so far show a surface feature that is tunable with a dc-gate, but the surface is heavily accumulated and therefore at a very high Fermi level (100 meV larger than the bulk).

A Voigt geometry magneto-optical reflectance measurements scheme was designed and built to study TaAs. Full laboratory automation of magneto-optical experiments was implemented that allow (overnight) unattended data acquisition. The automation, together with the laboratory helium recovery system, allowed much more complete data sets with enhanced signal-to-noise. A B-field dependent enhancement of the optical spectral weight was observed for the first time allowing study of the chiral pumping mechanism arising from the underlying Berry's phase of the Weyl states. The chiral pumping was studied in the semiclassical and quantum limit of the Weyl state.

Current research summary

Research in Weyl and 3-D Dirac systems focus on probing the underlying Berry-phase curvature effects leveraging magneto-optical measurement schemes. Current work also includes fabricating plasmonic elements from Weyl state materials to probe magnetoelectric-like effects in zero applied field. Recently grown Na_3Bi is doped very near the Dirac point allowing optical study of the anomalous chiral n=0 Landau Level in the quantum limit. Work in the near future includes various gating methods (different crystals, chemical doping, electrolytic gating, surface passivation) that lower the Fermi level of the surface to the vicinity of the bulk node allowing gate-modulated optical techniques to measure the transport properties of the surface arcs.