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Probing Longitudinal Plasma Waves in Layered Cuprates through Optical Absorption in Tilted Geometries

Siyuan Wen*

Department of Mechanical and Materials Engineering, University of Turku, Turku, Finland

Introduction

Layered cuprates are a class of materials that exhibit high-temperature superconductivity and have been extensively studied due to their complex electronic properties. One of the fundamental phenomena in these materials is the behavior of longitudinal plasma waves, which are collective oscillations of charge carriers that play a crucial role in the understanding of their electronic properties, especially in relation to superconductivity and charge density waves. Investigating these longitudinal plasma waves in layered cuprates has proven to be a challenging task due to the intricate nature of the materials and the difficulty of directly measuring these waves. One promising method for studying longitudinal plasma waves is through the optical absorption in tilted geometries, a technique that allows for the indirect measurement of these waves. This method has shown significant potential in providing valuable insights into the dynamic behavior of the charge carriers in cuprates and their interactions with the underlying lattice. Optical absorption spectroscopy is a well-established technique that has been used to probe the electronic properties of various materials, including cuprates. The technique involves shining light on a material and measuring the amount of light absorbed at different wavelengths, which provides information about the electronic excitations within the material. In the case of layered cuprates, the optical absorption spectrum contains important information about the energy gaps, the density of states, and the collective excitations, such as plasmons and longitudinal plasma waves. The challenge, however, lies in the fact that these materials are highly anisotropic, with different electronic properties along the different crystallographic axes. As a result, conventional optical absorption measurements may not be sufficient to probe the longitudinal plasma waves directly, especially in the presence of multiple competing excitations and complex material behavior.

Description

To overcome these challenges, researchers have developed the technique of probing optical absorption in tilted geometries. This method involves tilting the sample at a specific angle relative to the incident light, allowing for the selective enhancement of certain electronic excitations and interactions. By carefully choosing the angle of incidence, the optical absorption process can be sensitively tuned to enhance the coupling between the light and the longitudinal plasma waves. This approach is particularly useful for layered cuprates, where the electronic properties are highly dependent on the direction of the light and the polarization of the incident photons. In a typical experiment, a sample of layered cuprate is positioned at a specific angle relative to the light source, and the optical absorption is measured across a range of wavelengths. By tilting the sample, the orientation of the crystal axes with respect to the light is changed, and this allows for the separation of different electronic excitations. The longitudinal plasma waves, which are collective oscillations of the charge carriers along the direction of the material's layers, are expected to be most strongly excited under specific geometric conditions. These waves can be characterized by their dispersion relations, which describe the relationship between the frequency and wavevector of the excitations. The optical absorption spectrum provides indirect information about the dispersion of these waves by capturing the resonant interactions between the longitudinal plasma waves and the incident light [1].

One of the key advantages of this technique is its ability to isolate the contribution of longitudinal plasma waves from other competing excitations, such as transverse plasmons, charge density waves, and spin fluctuations. In layered cuprates, where these phenomena often occur simultaneously and interact with each other, distinguishing the longitudinal plasma waves becomes a non-trivial task. The use of tilted geometries in optical absorption measurements helps reduce the overlap between these excitations, making it easier to isolate the signature of longitudinal plasma waves. The tilted geometry enhances the sensitivity of the measurement to these specific excitations, allowing researchers to observe subtle features in the absorption spectrum that would otherwise be difficult to detect. The interaction between the longitudinal plasma waves and the light field is governed by the dielectric function of the material, which encodes the response of the system to external electromagnetic fields. In layered cuprates, the dielectric function can be highly anisotropic due to the layered structure and the direction-dependent properties of the electronic states. The dielectric function at different wavelengths determines the extent to which the light is absorbed, and changes in this function can reveal information about the plasma frequency, the damping of the waves, and the nature of the charge carrier interactions. By measuring the optical absorption at different angles, researchers can obtain a detailed map of the dielectric function and its dependence on the orientation of the material [2].

The technique of optical absorption in tilted geometries has been successfully applied to various cuprate materials, including high-temperature superconductors like YBCO (Yttrium Barium Copper Oxide) and La2CuO4 (Lanthanum Copper Oxide). These materials exhibit a range of interesting electronic phenomena, such as superconductivity, charge density waves, and spin excitations, all of which interact with the longitudinal plasma waves. The ability to probe the longitudinal plasma waves in these materials is crucial for understanding the nature of the electronic ground state and the mechanisms that govern high-temperature superconductivity. The experimental results obtained from optical absorption in tilted geometries have provided valuable insights into the dispersion relations of the longitudinal plasma waves and their coupling with other excitations in the system. In addition to providing information about the dispersion of longitudinal plasma waves, optical absorption measurements in tilted geometries can also shed light on the interaction between these waves and other collective excitations in cuprates. For example, recent studies have suggested that the longitudinal plasma waves in cuprates may interact strongly with charge density waves, leading to a hybridization of the excitations. This interaction can result in the formation of new collective modes, which are detected in the optical absorption spectrum. By analyzing these hybrid modes, researchers can gain insights into the underlying mechanisms of charge order and the role of longitudinal plasma waves in the electronic structure of cuprates.

Furthermore, the technique can also be used to study the effects of external factors, such as temperature, pressure, and doping, on the longitudinal plasma waves in cuprates. These materials exhibit a range of phase transitions as they are tuned through various control parameters, and the longitudinal plasma waves are sensitive to these changes. For instance, the doping of cuprates can induce changes in the charge carrier density and the nature of the excitations, which in turn affect the plasma wave properties. By monitoring the changes in the optical absorption spectrum under different conditions, researchers can

***Address for Correspondence:** Siyuan Wen, Department of Mechanical and Materials Engineering, University of Turku, Turku, Finland, E-mail: wensiyu@gmail.com*

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track the evolution of the longitudinal plasma waves and their role in the phase transitions of the material. The technique of probing longitudinal plasma waves in cuprates via optical absorption in tilted geometries offers several advantages over other experimental methods. Unlike techniques such as electron energy loss spectroscopy (EELS) or inelastic X-ray scattering (IXS), which require large experimental setups and can be sensitive to sample quality, optical absorption measurements are relatively simple and can be performed in situ under controlled conditions. The ability to tune the incident light and vary the tilt angle provides a high level of flexibility in the measurement, allowing for the exploration of a wide range of excitation modes in cuprates. Additionally, the non-destructive nature of optical absorption makes it an attractive tool for studying the evolution of longitudinal plasma waves under different experimental conditions.

Conclusion

Despite its advantages, there are also some challenges associated with this technique. One of the main difficulties is the interpretation of the optical absorption spectra, as the presence of multiple competing excitations can make it challenging to isolate the contribution of the longitudinal plasma waves. The analysis of the data often requires careful modeling of the dielectric function and the dispersion relations of the waves, which can be complex in the case of layered cuprates. Moreover, the sensitivity of the technique to small changes in the material's electronic structure means that high-quality samples and precise experimental setups are necessary to obtain accurate results. In conclusion, optical absorption in tilted geometries provides a powerful method for indirectly probing longitudinal plasma waves in layered cuprates. By using this technique, researchers can gain valuable insights into the dynamic behavior of the charge carriers and their interactions with the lattice. The ability to isolate the longitudinal plasma waves from other competing excitations in cuprates makes this technique an effective tool for studying the complex electronic properties of these materials. With continued advancements in experimental techniques and theoretical models, optical absorption in tilted geometries will likely play an increasingly important role in the study of cuprates and other complex materials with collective excitations. This approach holds the potential to deepen our understanding of high-temperature superconductivity and the fundamental interactions that govern the behavior of charge carriers in strongly correlated systems.

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