scientific issue targeted

In order to deepen the understanding of the common requirements of the magneto-optical materials for the transmission magneto-optical modulation function, to carry out the research of transmissive magnetochromism, and to realize the magneto-modulation of optical polarization state and spectrum simultaneously distinguishing from the traditional magneto-optical effect, here are a few key problems this project aims to solve:

1. The contradiction between high optical absorption of two-dimensional magneto-optical materials and long optical paths required by transmissive magneto-optical modulation.

At present, the birefringence of two-dimensional magneto-optical materials based on graphene oxide is relatively low. Therefore, to achieve a substantially continuously adjustable optical phase difference, a long optical path is required. However, the optical absorption of the graphene magneto-optical material is strong, which must limit the range of the optical path to a great extent. To this end, this project will systematically study low-optical absorption two-dimensional materials, and strive to screen out wide-band gap two-dimensional materials in the existing two-dimensional material library. Such two-dimensional magneto-optical new material will provide long optical range and further enhancement of magneto-optical modulation capability by doping to regulate the bandgap and magnetic properties under the premise of ensuring low absorption.

1. How to enhance the magnetic properties of two-dimensional materials without changing their large anisotropy, electrical, optical and chemical properties.

The magnetic source of graphene oxide has been in dispute that whether it is from defects or magnetic element doping avoidable during synthesis. Also, the magnetic properties of graphene oxide are very different under different experimental conditions. The uncontrollability of magnetism is bound to cause uncontrollable magneto-optical modulation performance. In addition, confirming the magnetic anisotropy of two-dimensional materials in dispersions remains a challenging challenge. Therefore, it is necessary to dope the controllable magnetic elements in the material preparation process, and prepare a sample similar to the orientation distribution of the two-dimensional material in the dispersion for magnetic anisotropy characterization, in order to provide mechanism guarantee for obtainment of the complete material magnetic information and final realization of controllable magneto-optical modulation.

(3) The competition between layer-layer magnetic moment coupling of two-dimensional materials and the magneto-optical effect

Under the action of an external magnetic field, the two-dimensional magneto-optical material generates an induced magnetic moment. The interaction between the magnetic moments causes agglomeration of the two-dimensional material. On the one hand, the optical anisotropy of the material itself is reduced, and on the other hand, the precipitation occurs after the agglomeration of the material. Therefore, this project will try to introduce surface charge on the surface of two-dimensional material which generates electrostatic repulsion between the layers to solve the possible agglomeration problem.

(4) The realization and explanation of transmissive magnetically controlled continuous change of the structure color.

Although magnetochromism has been achieved in only a few materials, all of the reported magnetochromisms are based on Bragg's law and can be classified as reflective magnetochromism. Considering that most of the light modulation is carried out in the transmission mode, the fact that traditional magnetochromic material itself absorbs strongly and the transmitted color is the color of the material itself directly affects the important application of magnetochromism in the field of light modulation. Since Bragg's law is used in the reflection mode and the realization of transmissive magnetochromism cannot be achieved with this mechanism, a mechanism innovation is required.

Proposed methodologies

This project is a crossover of multidisciplinary fields such as materials science, magnetism, optics, chemistry, and theoretical physics. It combines the research of major basic scientific problems of low-dimensional materials science with its optical applications, conventional material characterization methods with the unconventional characterization of the materials' own special magneto-optical properties, the optically-dependent steady-state characterization with the dynamic-state characterization of the material's directional alignment under magnetic field, and the analysis of magnetic properties of the materials at the atomic scale with the exploration of the behavior under the magnetic field. The comprehensively and deeply understanding and mastery of the basic mechanism of new magneto-optical two-dimensional materials optical modulation will provide important technical support and theoretical support for the development of new two-dimensional magneto-optical materials in optical, sensing and other fields.

Guided by scientific theory and based on exploratory experiments, this project will conduct multi-angle and multi-method research on new two-dimensional magneto-optical materials. This research work will focus on exploring new two-dimensional magneto-optical materials directed against the application bottlenecks of existing magneto-optical materials, carrying out the analysis of magneto-optical anisotropy in the transmission mode of new magneto-optical materials and the study of unique magneto-optical modulation functions. It will not only reveal the basic source of magnetic properties of new two-dimensional materials, but also aim at achieving high transmission of materials, controllability of magnetic properties, and large modulation of transmission magnetism. Based on the unsolved key scientific problems in the application of existing magneto-optical materials, combining with the future requirement for new functions of magneto-optical modulation, in-depth research will be carried out, from new materials to new performance, from new characterization to application development.

The specific research plan and technical route are as follows:

(1) In view of the key problems of existing magneto-optical materials faced by the field of magneto-optical modulation, the common requirements of new magneto-optical materials are clarified, chemically doping of magnetic atoms and green liquid phase exfoliation method are adopted to control the magnetic properties of two-dimensional materials.

Specific plan:

Under the guidance of theory, explore the chemical doping of magnetic elements in the existing wide band gap layer precursor materials, and combine the two-dimensional material liquid phase exfoliation methods accumulated in the laboratory to prepare a single layer or few layer new two-dimensional magneto-optical material dispersion. The aforementioned methods include: electrochemical intercalation, electrochemical bubbling, shear force assisted liquid grinding and sugar assisted grinding. In the preparation of the magnetically doped metal oxide two-dimensional material dispersion, lithium ion intercalation, hydrogen ion replacement, and organic alkali expansion can exfoliate the single-layer two-dimensional material in a liquid phase in different solvents. For the magnetically doped III/V two-dimensional materials, by changing the concentration or the sort of sugar in combination with a low-temperature grinding new process, a non-destructive, high-quality single-layer or few-layer material dispersion is prepared.

Regarding the precise regulation of the number and size of the layers in the dispersion, this project will further separate the prepared dispersions in combination with the Density Gradient Ultra-centrifugation method widely used in the biological field. Under ultra-high-speed centrifugation, two-dimensional materials of different layers and sizes will be dispersed in pre-formed different density gradient layers, and optical dispersion experiments will be used to characterize dispersions of two-dimensional materials of different sizes and thicknesses. High-resolution imaging (HRTEM), spherical aberration-corrected atomic resolved imaging, selected area electron diffraction (SAED) and electron energy loss spectroscopy (EELS), elemental composition analysis imaging, etc. will be adopted to characterize and analyze structure and composition and the proportion of magnetic element doped into the crystal lattice for the dispersion of new magnetically doped two-dimensional materials..

(2) Synchronous research on magnetic and optical properties of materials for new two-dimensional magneto-optical materials.

Specific plan:

In the process of optical characterization, the incident light is with different polarization states, the birefringence medium is the new two-dimensional material under the action of magnetic field and the detection devices are photodetector and polarization spectrometer. By changing the strength and direction of the magnetic field, the two degrees of freedom, the system reveals the optical anisotropy of the new material, focusing on the quantitative law of the birefringence and dichroic absorption of the material as a function of the external magnetic field.

In the process of magnetic characterization, the magnetic properties of the materials at each stage of the synthesis process are monitored strictly, and the influence of the exfoliation process on the magnetic properties of the material is analyzed. Combined with theoretical calculations and simulations, the magnetic properties of the material are given (magnetic, superparamagnetic, ferromagnetic, ferrimagnetic, etc.) to determine the quantitative relationship of magnetization change caused by magnetic atom doping and to achieve final magnetic controllability.

In the process of studying the distribution state of new two-dimensional materials in the magnetic field, due to the high transmittance and small size of the two-dimensional materials, it is very difficult to observe the rotating state of the two-dimensional materials under the action of the magnetic field through the microscope directly. The optical scattering method dependent on the direction of the magnetic field is used to confirm whether the distribution state of the two-dimensional material is the parallel or vertical to the magnetic field by detecting the increase or decrease of the light scattering intensity in the parallel and vertical direction. On the other hand, in-depth magnetic characterization studies are conducted on the kinetic origin of two-dimensional materials rotation in a magnetic field. Considering the difficulty of magnetic characterization in liquids, effectively avoiding the influence of magnetic measurements caused by flow and solvent in the liquid, firstly, the two-dimensional materials in the new dispersion are effectively deposited to prepare a layered oriented distribution film similar to the state of arrangement under the action of a magnetic field. Magnetic anisotropy characterization is used to study its relationship with the geometric anisotropy of two-dimensional materials, revealing that the easier magnetization direction is in-plane or out-of-plane. Combining with the dynamic behavior of the macroscopic magnetic anisotropic film in the magnetic field, the distribution of two-dimensional materials in liquid dispersion under magnetic field is finally confirmed.

(3) Real-time monitoring of optical intensity, polarization and transmission spectrum is adopted to achieve the tracking of monochromatic and continuous light modulation for new two-dimensional magneto-optical material. Combining with theoretical calculations, the dynamic mechanism of transmission magneto-optical modulation is clarified.

Specific plan:

Firstly, for the modulation of monochromatic light, a 532 nm laser is chosen as incident light of a new two-dimensional magneto-optical material dispersion. Under different magnetic fields, the polarization information of the light is detected in real time by a polarization spectrometer. Combined with the principle of polarized optics, the quantitative relationship between magnetic field and phase difference can be speculated. Secondly, through the linear analyzer, the photodetector is used to record the change of the intensity of the emitted light with the magnetic field, the quantitative relationship between the magnetic field and the phase difference can be speculated again with the optical interference principle. Finally, we compare the two data, analyze the influence of dichroism on the measurement error, systematically reveal the basic principle of monochromatic light modulation of polarization and strength based on birefringence and dichroism caused by magnetic field.

Based on the 532 nm monochromatic light modulation, the wavelength of monochromatic light is extended to 450, 520, 589, 635, 671, 780, 808 nm, etc. and the quantitative relationship between phase difference and wavelength, that is, the dispersion of birefringence, under the same magnetic field is studied. Combined with the Cauchy dispersion equation, fits the optical phase difference at continuous wavelengths, and derives the modulation performance of the magneto-optical material on the continuous transmission spectrum. The white continuous light source is used to verify the modulation performance, and the relationship between the transmission spectrum change and the transmission structure color change are clarified. Observe the new phenomenon of transmissive magnetochromism, and understand the new mechanism of transmissive magnetochromism.

(4) Based on the new function of monochromatic light and continuous light magneto-optic modulation, assisting with photo-sensitizer curation method, a new type of transmissive magneto-optical modulation (transmission magneto-chromism) different from the traditional reflective magneto-optical modulation is explored. Combined with theoretical calculations, the magneto-optical modulation function is modularized.

Specific plan:

Since the magneto-optical modulation function of the two-dimensional material in the dispersant is affected by magnetic field strength, maintaining the magneto-optical modulation function needs to provide a stable magnetic field continuously. This project intends to add a photosensitizer into the solvent of the new two-dimensional magneto-optical material, and combine the ultraviolet light curing effect under magnetic field to realize the stable magneto-optical modulation function without magnetic field maintenance. the following three new applications different from the traditional magneto-optical modulation function will be the focuses on exploring (but not limited to):

For different single wavelength source, a polarization spectrometer is used to observe the evolution of the polarization state, and a series of continuous optical phase retarders are prepared by fixing the alignment of two-dimensional magneto-optical material in magnetic field assisting with UV curation of photo-sensitizer.

For the continuous wavelength source, by calculating the required optical path difference of the two-dimensional magneto-optical material, a series of films with different transmission spectra can be prepared by using a light curing device, which can be used as structural color films with sharp color and as optical filters.

For the dependence of the transmissive magnetochromism on the strength and direction of the magnetic field, by characterizing the relationships between the shape and magnetic field direction, between the color and magnetic field strength, combining with the principle of three-dimensional imaging, the three-dimensional spatial distribution of the magnetic field is drawn. This new function of the magneto-optical material will be applied to important fields such as three-dimensional panoramic imaging of non-uniform magnetic fields.