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GENERAL INFORMATION

Venue

Rm. S104, Teaching Building,
Zhong-Guan-Cun Campus, UCAS
Add: No.3, Zhong-Guan-Cun Nan Yi Tiao, Haidian, Beijing, China

Registration

The registration desk will be opened at the UCAS, Zhong-Guan-Cun Campus during the following hours:
08:30-16:00, 15 January 2020
08:40-10:30, 16 January 2020

Catering

Lunch
Lunch coupons are inside the package given to you when you register. You should present your coupon in order to obtain lunch.

Place: 4th Floor, Wuke Restaurant

Morning and Afternoon Tea Breaks
Tea breaks during the workshop will be served outside Rm. S104, Teaching Building

Nearby Cafes and Restaurants
There are numerous cafes and restaurants near Kavli ITS. Have fun with Chinese food and language!

The 2nd Kavli ITS Workshop on Magnetic Semiconductors

15-16 January 2020, Beijing, China

S104, Teaching Building, Zhong-Guan-Cun Campus, UCAS

No. 3, Zhong-Guan-Cun Nan Yi Tiao, Haidian, Beijing

PROGRAM

15 January (Wednesday)

8:30-16:00 Registration

08:50-09:00 Opening **Fu-Chun Zhang**, Kavli ITS, UCAS

Wednesday Session A

Chair: **Sadamichi Maekawa**, RIKEN/ Kavli ITS, UCAS

09:00-09:30 **Tomasz Dietl**, Institute of Physics, Pan
Phase separations and nematicity in dilute magnetic materials

09:30-10:00 **Masaaki Tanaka**, University of Tokyo
Fe-doped narrow-gap III-V ferromagnetic semiconductors and related heterostructures with high Curie temperature

10:00-10:30 **Alberta Bonanni**, Johannes Kepler University
Dilute magnetic systems: magnetic nitrides, ferromagnetic topological crystalline insulators and 2D antiferromagnetic transition metal phosphorus trisulphides

10:30-11:00 Photo & Tea Break

Wednesday Session B

Chair: **Chang Qin Jin**, Institute of Physics, CAS

11:00-11:30 **Laurens W. Molenkamp**, Würzburg University
Topological Physics in HgTe-based Quantum Devices

11:30-12:00 **Sang-Wook Cheong**, Rutgers University
Topological Entanglement in the Structural/Magnetic Textures of Chiral Magnets

12:00-12:30 **Pham Nam Hai**, Tokyo Institute of Technology
Giant spin Hall effect in BiSb topological insulator

12:30-14:00 Lunch Break

Wednesday Session C

Chair: **Gang Su,** UCAS

14:00-14:30 **Yasutomo J. Uemura**, Columbia University
Magnetism and Superconductivity of Transition Metal Di-Chalcogenides $MoTe_2$ and $NbSe_2$

14:30-15:00 **Dieter Weiss**, University of Regensburg
Spin injection/detection in two-dimensional electron systems

15:00-15:30 **Erjun Kan** Nanjing University of Science and Technology
Theoretical Investigations of Spintronics

15:30-16:00 Tea Break

Wednesday Session D

Chair: **Jian Hua Zhao,** Institute of Semiconductors, CAS

16:00-16:30 **Xiaohong Xu,** Shanxi Normal University
The emergent phenomena in the perovskite nickelates and manganites heterostructures

16:30-17:00 **Zhongyi Lu,** Renmin University
The melilite-type compound (Sr1-x,Ax)2MnGe2S6O (A=K, La) being a room temperature ferromagnetic semiconductor

17:00-17:30 **Zheng Deng**, Institute of Physics, CAS
Recent progresses of new types of diluted magnetic semiconductors with independently charge and spin doping

17:30-18:00 Poster Presentations

16 January (Thursday)

8:40-10:30 Registration

Thursday Session A

Chair: **Kaiyou Wang** Institute of Semiconductors, CAS

09:00-09:30 **Yu Ye,** Peking University
Quantum properties of 2D magnetic semiconductors revealed by optical spectroscopy

09:30-10:00 **Fanlong Ning**, Zhejiang University
The Synthesis and Microscopic Characterization of Series of Bulk Form Diluted Ferromagnetic Semiconductors

10:00-10:30 **Bo Gu**, Kavli Institute for Theoretical Sciences, CAS
Two-dimensional ferromagnetic semiconductors with room Curie temperatures

10:30-11:00 **Hailong Wang**, Institute of Semiconductors, CAS
High mobility Ni-doped topological Dirac semimetal Cd_3As_2 films

11:00-11:30 **Guoqiang Zhao**, Institute of Physics, CAS
Material systhesis and μSR research on Diluted Magnetic Semiconductor

11:30-11:45 Closing **Sadamichi Maekawa**, RIKEN/ Kavli ITS, UCAS

12:00-14:00 Lunch

ABSTRACT CONTENTS

Phase separations and nematicity in dilute magnetic materials

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Semiconductors [1] and topological materials [2] doped with magnetic impurities attract a considerable attention due to a fascinating physics and nonospintronic functionalities associated with exchange coupling between band carries and localized spins. However, there is a growing amount of evidences that *d*-shells of magnetic impurities contribute also to bonding, which can affect their spatial distribution and modify key properties, such as magnetic ordering temperature [3]. It has recently been experimentally demonstrated that the resulting phase separation (spinodal decomposition) can be anisotropic and result in the hitherto puzzling rotational symmetry breaking (*i.e.*, nematic characteristics) revealed in a certain class of dilute magnetic semiconductors [4]. This finding put in a new light a possible origin of nematicity in other systems, such as unconventional superconductors and modulation doped semiconductor quantum wells, in which rotational symmetry breaking has so far been assigned to unidirectional spontaneous ordering of spin, orbital or charge degrees of freedom.

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Acknowledgments: This work has been supported by the Foundation for Polish Science through the IRA Programme financed by EU within SG OP Programme.

Fe-doped narrow-gap III-V ferromagnetic semiconductors and related heterostructures with high Curie temperature

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Ferromagnetic semiconductors (FMSs) with high Curie temperature (T_C) are strongly required for spintronics device applications. So far, the mainstream study of FMSs is Mn-doped III-V FMSs; however they are only p-type and their T_C is much lower than 300 K. In this study, we present a new class of FMSs with high T_C, Fe-based narrow-gap III-V FMSs. Because Fe atoms are in the isoelectronic Fe^{3+} state in III-V, the carrier type can be controlled independently and thus both n-type and p-type FMSs are obtained. Using low-temperature molecular beam epitaxy, we have successfully grown both p-type FMS [(Ga,Fe)Sb [1], (Al,Fe)Sb [2]] and n-type FMSs [(In,Fe)As [3], (In,Fe)Sb [4]]. The most notable feature in these Fe-based FMSs is that the T_C value increases monotonically as the Fe content increases; and there is a tendency that T_C is higher as the bandgap is narrower, which contradicts the prediction of the mean-field Zener model (see Figure 1). Intrinsic room-temperature ferromagnetism has been observed in $(Ga_{1-x},Fe_x)Sb$ with $x \geq 23\%$ [1] and $(In_{1-x},Fe_x)Sb$ with $x \geq 16\%$ [4], which are promising for practical spintronic devices operating at room temperature.

We also present our findings on new magnetotransport phenomena in heterostructures containing these Fe-doped FMSs. In an Esaki diode composed of a 50 nm-thick n-type FMS (In,Fe)As (6% Fe) / 250 nm-thick p^+ InAs:Be, we found that the magnetic-field-dependence of the current flowing through the pn junction (magnetoconductance, MC) can be largely controlled, both in sign and magnitude, with the bias voltages V [5,6]: The diode shows small positive MC (~0.5%) at $V < 450$ mV, but the MC changes its sign and magnitude at $V > 450$ mV, reaching -7.4% (at 1T) at $V = 650$ mV. This bias-controlled MC originates from the change in the band components of (In,Fe)As that participate in the spin-dependent transport.

Furthermore, we found that the current flowing in a nonmagnetic n-type InAs quantum well (QW) that is interfaced to an insulating p-type (Ga,Fe)Sb layer (20% Fe, $T_C > 300$ K) exhibits a giant change of approximately 80% at high magnetic field and that its magnitude can be controlled by ten-fold using a gate. The mechanism for this large magnetoresistance is attributed to a strong magnetic proximity effect (MPE) via the *s-d* exchange coupling at the InAs/(Ga,Fe)Sb interface. It was found that a spin splitting in the InAs QW is induced by MPE, which can be varied between 0.17 meV and 3.8 meV by the gate voltage [7]. Other studies on ferromagnetic semiconductor heterostructures are underway and novel phenomena and properties are being investigated [7-9]; these new properties of the Fe-doped FMS-based materials and devices provide novel functionalities for the future spin-based electronics.

This work was partly supported by Grants-in-Aid for Scientific Research (Nos. 16H02095, 17H04922, and 18H05345), CREST of JST (No. JPMJCR1777), and Spintronics Research Network of Japan (Spin-RNJ).

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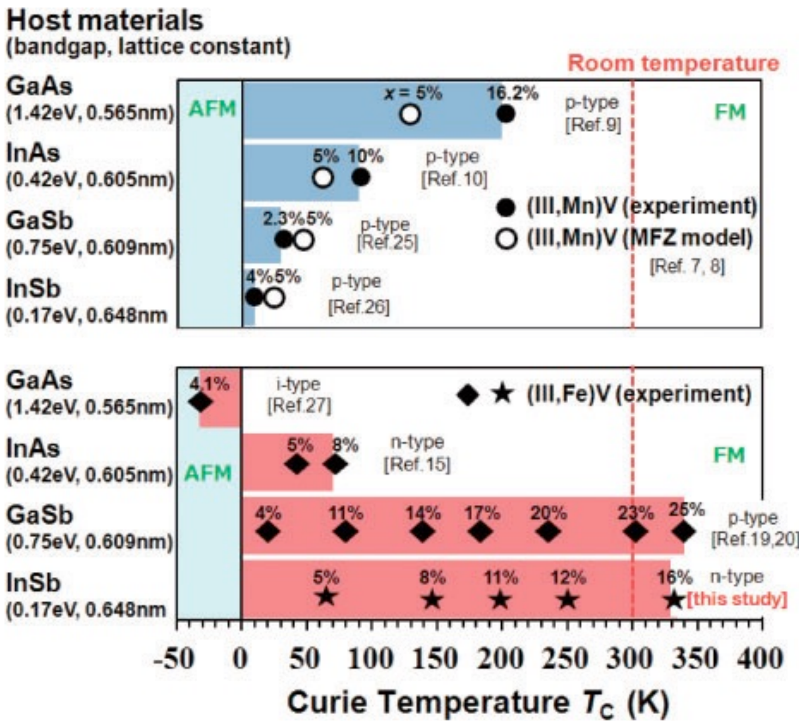

Figure 1: Highest Curie temperature (T_C) values of Mn-doped (blue bars) and Fe-doped (red bars) III–V FMSs reported so far. The black circles, diamonds, and stars show the experimental T_C values. The white circles show the T_C values of Mn-doped III–V FMSs calculated using the mean-field Zener model. Here, AFM and FM are the antiferromagnetic and ferromagnetic couplings between the magnetic dopants, respectively.

Dilute magnetic systems: magnetic nitrides, ferromagnetic topological crystalline insulators and 2D antiferromagnetic transition metal phosphorus trisulphides

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An overview is provided on how, by controlling the fabrication parameters and establishing a comprehensive protocol of characterization involving also synchrotron-radiation-based methods, we have unraveled and can now control a number of relevant features in semiconductor-based magnetic systems. Particularly significant in this context is the generation of pure spin current at room temperature in nitride-based bilayers, pointing at these systems as efficient spin current generators. We have proved, that the magnetization of dilute III-nitrides doped with transition metals may be controlled electrically, bridging the piezoelectricity of wurtzite semiconductors and electrical magnetization switching [1].

Moreover, from magnetotransport measurements on topological crystalline insulator (TCI) $Sn_{1-x}Mn_xTe$ ($0.00 \leq x \leq 0.08$)(111) epitaxial thin films grown by molecular beam epitaxy on BaF_2 substrates, we have observed hole mediated ferromagnetism in samples with $x \geq 0.06$ and the highest $T_C \sim 7.5$ K is inferred from an anomalous Hall behavior in $Sn_{0.92}Mn_{0.08}Te$. The sizable anomalous Hall angle ~0.3 obtained is one of the greatest reported for magnetic topological materials. The ferromagnetic ordering with perpendicular magnetic anisotropy, complemented by the inception of anomalous Hall effect for a thickness commensurate with the decay length of the top and bottom surface states, points at $Sn_{1-x}Mn_xTe$ as a preferential platform for the realization of quantum anomalous Hall states in ferromagnetic TCIs [2].

Finally, we give a summary of preliminary studies of 2D transition metal phosphorus trisulphide ($TMPS_3$) semiconductors, where the distribution of magnetic moments is found to depend on the transition metal involved. While antiferromagnetic ordering is well established for these systems in the bulk phase, a systematic in-depth analysis of magnetism and electronic states in 2D layered arrangement is in its infancy [3].

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Topological Physics in HgTe-based Quantum Devices

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Suitably structured HgTe is a topological insulator in both 2- (a quantum well wider than some 6.3 nm) and 3 (an epilayer grown under tensile strain) dimensions. The material has favorable properties for quantum transport studies, i.e. a good mobility and a complete absence of bulk carriers, which allowed us to demonstrate variety of novel transport effects.
A novel development is the use of wet etching technologies to fabricate HgTe based nanostructures. This approach allows a much higher transport quality in nanodevices. We have fabricated quantum point contacts, which show remarkable spin selective transport behavior. Additionally, we have developed a gate-training technique, which pushes the scattering length for the quantum spin Hall effect well above 100 μm. A further recent development is the realization that van Hove singularities in the valence band may give rise to remarkable transport effect, such as e.g. the realization of a n=-1 quantum Hall plateau at fields as low as 20 mT.

Another regime we can study is topological superconductivity, achieved by proximity-inducing superconductivity in the topological surface states. Special emphasis will be given to recent results on the ac Josephson effect. We will present data on Shapiro step behavior that is a very strong indication for the presence of a gapless Andreev mode in our Josephson junctions, both in 2- and in 3-dimensional structure. An additional and very direct evidence for the presence of a zero mode is our observation of Josephson radiation at an energy equal to half the superconducting gap.

Controlling the strain of the HgTe layers strain opens up yet another line a research. We have recently optimized MBE growth of so-called virtual substrates ((Cd,Zn)Te superlattices as a buffer on a GaAs substrate), that allow us to vary the strain from 0.4% tensile to 1.5% compressive. While tensile strain turns 3-dimensional HgTe into a narrow gap insulator, compressive strain turns the material into a topological (Dirac/Weyl) semimetal, exhibiting clear signs of the Adler-Bell-Jackiw anomaly in its magnetoresistance. In quantum wells, compressive strain allows inverted energy gaps up to 60 meV.

Topological Entanglement in the Structural/Magnetic Textures of Chiral Magnets

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Transition metal dichalcogenides (TMDs) have been extensively investigated as 2D materials last decade. A large amount of transition metals (M) can be intercalated into the van der Waals gaps of a wide range of TMD materials, but a limited recent studies in intercalated TMDs have been reported. The limited examples include FexTaS 2 crystals with x=1/4 and 1/3, which exhibit intriguing configurations of antiphase and/or chiral structural domains related to the ordering of intercalated M ions with 2a×2a and √3a×√3a superstructures, respectively. In addition, Cr1/3NbS 2 undergoes helical spin order below 133 K, and shows an interesting soliton-lattice behavior when in-plane magnetic fields are applied in the helical spin state. We have explored a series of chiral M1/3Ta(Nb)S(Se) 2 to investigate the topological correlations among chiral structure, magnetic helicity/spirality and their physical properties. These results as well as Moire patterns with self-twisted TMDs induced by intercalation will be discussed.

Giant spin Hall effect in BiSb topological insulator

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Topological insulators (TIs) are novel materials with insulating (semiconducting) bulk states and metallic surface (edge) states. The electron spin on the surface of TIs is locked to its momentum, resulting in many novel physics. These include the quantum spin Hall effect in two-dimensional TIs, the quantum anomalous Hall effect in magnetic TIs, and Majorana Fermions at TI/superconductor interfaces. So far, those novel physics have been observed in TI-based heterostructures at extremely low temperatures, making them less attractive for device applications at room temperature. Here, we present our recent results on the giant spin Hall effect at room temperature in a conductive topological insulator, BiSb. We show that BiSb have both high electrical conductivity [1] and giant spin Hall angle at room temperature [2], which are very promising for applications to ultralow power spin-orbit torque magnetoresistive random access memory (SOT-MRAM). Evaluation of spin-orbit-torque in epitaxial BiSb/MnGa bi-layers reveals a colossal spin Hall angle of 52 and a spin Hall conductivity of $1.3*10^7$ $\hbar/2e$ $\Omega^{-1}m^{-1}$ at room temperature, which are two orders of magnitude larger than those of heavy metals. We demonstrate that epitaxial BiSb(012) thin films can generate a colossal spin-orbit field of 2.3 $kOeMA^{-1}cm^2$ and a critical switching current density as low as 1.5 $MAcm^{-2}$ in BiSb/MnGa bi-layers. Our quantitative analysis shows that the surface current is dominant in thin BiSb, and that the giant SHE in BiSb is governed by the Berry phase of the topological surface states. We further demonstrate robust ultralow-power spin-orbit-torque switching of perpendicularly magnetized ferromagnets by non-epitaxial BiSb deposited on silicon substrates, underlying its potential as the spin current source in realistic SOT-MRAM.

Acknowledgment: this work was supported by JST-CREST (Grant No. JPMJCR18T5)

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Magnetism and Superconductivity of Transition Metal Di-Chalcogenides $MoTe_2$ and $NbSe_2$

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Transition-Metal Di-Chalcogenides (TMDC's) are very interesting and promising systems for basic research and device formation due to several features: (1) easily cleavable for formation of exfoliated devices; (2) availability of various ground states, including charge density wave, semiconducting and superconducting states, and (3) relevance to topological effects due to Dirac dispersion from honeycomb lattices. The most recent progress on TMDC's includes a discovery of possible signatures of superconductivity in twisted bi-layer WSe_2 by a group of Columbia University [1]. In this talk, I report our recent MuSR studies of TMDC's and show (a) static magnetic order in 2H-$MoTe_2$ [2] which adds a magnetically ordered state to the above-listed variety of ground states, and (b) nearly linear correlations between the superconducting Tc and the superfluid density in 1T'-$MoTe_2$ and 2H-$NbSe_2$ in ambient and applied hydrostatic pressure. We also show the results of semiconductor-metal transition in 2H-$MoTe_2$ tuned by pressure studied at IOP. These features make TMDC's as a new family of unconventional strongly correlated superconductors in addition to high-Tc cuprates, iron-based systems, and twisted-bilayer graphene. We will discuss commonalities of TMDC with these other unconventional superconductors and Mott transition oxide systems, and consider possible effect of competing order and multi-band features in understanding correlations between the superfluid density and T_c [4].

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Spin injection/detection in two-dimensional electron systems

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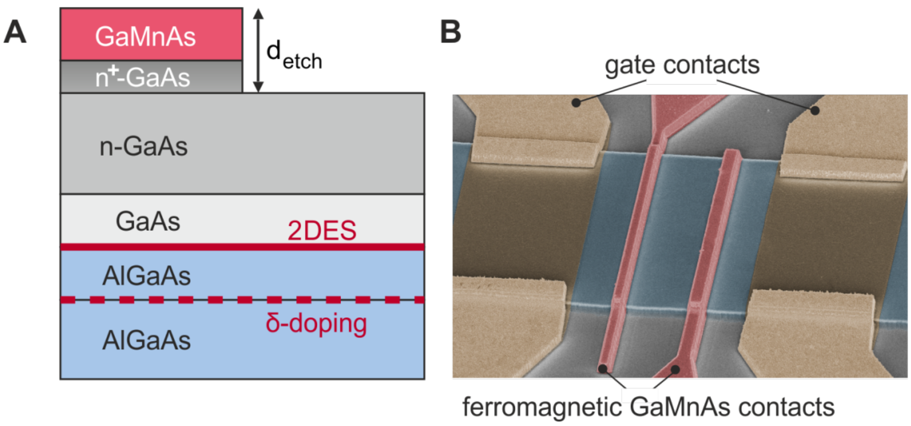
Ferromagnetic contacts of the diluted magnetic semiconductor (Ga,Mn)As turn out to be very effective spin injectors and detectors for (Al,Ga)As/GaAs based high mobility two-dimensional electron systems (2DES) [1]. As (Ga,Mn)As is a degenerately doped p-type semiconductor, epitaxially grown on n-type GaAs, the (Ga,Mn)As/GaAs interface forms an Esaki diode with high spin injection efficiency between 70% and 90%. The combination of epitaxial interface, high spin injection efficiency and non-recifying contacts enables two-terminal spin-valve experiments with large spin signals ΔR/R (ΔR= spin dependent resistance change, R = spin independent two-terminal resistance) of up to 80% [2]. 2DES with (Ga,Mn)As injector/detector contacts are thus perfectly suited to seek for the Datta-Das spin transistor functionality [3]. Besides first experiments, using gates to tune the spin signal I will report a significantly increased spin relaxation length in devices with reduced transport channel width.



A) Layout of the heterojunctions used for spin-injection/detection. Etching of the highly doped (Ga,Mn)As and n+-GaAs layers depletes the bulk of electrons, thus enabling exclusive spin and charge transport in the 2DES. B) Device with ferromagnetic leads and gate contacts.

Work done in collaboration with Mariusz Ciorga, Franz Eberle, Martin Oltscher, Thomas Kuczmik, Andreas Bayer, Martin Utz, Dieter Schuh, & Dominique Bougeard.

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Theoretical Investigations of Spintronics

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Spintronics have been recognized as the most promising candidate for next-generation low-cost, high-performance and nano-scale spintronic applications such as spin field-effect transistors and quantum computation/communication. However, how to achieve a feasible ferromagnetic semiconductor with high Curie temperature is still a long-standing challenge despite of tremendous efforts have been devoted in this field since 1960s. Here, in this talk, we will introduce our progress in this field, which includes half-metal and ferromagnetic semiconductors. Based on first-principles calculations and model analysis, we will explore how to enhance the spin-spin interaction in semiconductors, and how to coexist with the ferroelectricity.

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The emergent phenomena in the perovskite nickelates and manganites heterostructures

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Abstract: Transition metal oxides have attracted a lot of attetions in condensed matter physics and material science over the last two decades. This is due to the strong correlation effects result in many novel physical properties, such as, high-temperature superconductivity, magnetoresistance, multiferroic, and metal-to-insulator transition [1]. The significant characteristics of perovskite rare-earth nickelates (except for $LaNiO_3$) are the sharp metal-to-insulator transition and the irregular antiferromagnetism state as the temperature decrease. The electrical transport behavior of nickelates is insulator-to-metal transition as the temperature increase rather than metal-to-insulator transition in manganites. Therefore, the perovskite nickelates are typical Mott insulator materials [2]. Moreover, the least distorted member of the nickelate family, $LaNiO_3$, is an exception since it only exhibits metallic paramagnetic behavior over all temperatures [3]. Perovskite manganites also have much of abundant physical properties, such as, charge-spin-orbital order, metal-to-insulator transition, phase separation, and giant magnetoresistance effect. Thus, the high-quality heterostructures composed of these two materials have been grown in our group. The emergent phonomena, such as, insulator-to-metal transition, robust exchange coupling effect and superconductivity properties, have been observed in these heterostructures. Furthermore, the internal mechanisms of these novel phenomena also have been revealed by our experimental designs. Our findings will provide important foundation for the research of perovskite nickelate-based heterostructures.

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The melilite-type compound $(Sr_{1-x},A_x)_2MnGe_2S_6O$ (A=K, La) being a room temperature ferromagnetic semiconductor

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The seeking of room temperature ferromagnetic semiconductors, which take advantages of both the charge and spin degrees of freedom of electrons to realize a variety of functionalities in devices integrated with electronic, optical, and magnetic storage properties, has been a long-term goal of scientists and engineers. Here, by using the spin-polarized density functional theory calculations, we predict a new series of high temperature ferromagnetic semiconductors based on the melilite-type oxysulfide $Sr_2MnGe_2S_6O$ through hole (K) and electron (La) doping. Due to the lack of strong antiferromagnetic superexchange between Mn ions, the weak antiferromagnetic order in the parent compound $Sr_2MnGe_2S_6O$ can be suppressed easily by charge doping with either p-type or n-type carriers, giving rise to the expected ferromagnetic order. At a doping concentration of 25%, both the hole-doped and electron-doped compounds can achieve a Curie temperature (Tc) above 300 K. The underlying mechanism is analyzed. Our study provides an effective approach for exploring new types of high temperature ferromagnetic semiconductors.

Recent progresses of new types of diluted magnetic semiconductors with independently charge and spin doping

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We report our recent work on a new type of diluted magnetic semiconductors (DMSs). With independently charge and spin doping, these so-called I-II-V and II-II-V types DMSs can control charge doping and spin doping independently.[1-7] In I-II-V type Li(Zn,Mn)As a very low coercive field (~30Oe) is promising for spin manipulations. The Curie temperature in II-II-V type (Ba,K)(Zn,Mn)2As2 (230K) is higher than that of typical (Ga,Mn)As, making room-temperature ferromagnetism within reach. Large size single crystals of (Ba,K)(Zn,Mn)2As2 have been grown and Andreev reflection junctions based on the (Ba,K)(Zn,Mn)2As2 single crystals have been fabricated. A plorization of 66% was obtained with the Andreev reflection junction.[8]

We recently successful synthesized $(Ca,Na)(Zn,Mn)_2Sb_2$ as a new DMS. This feature of independently charge and spin doping allows us to separately investigate the effect of carriers and of spins on the ferromagnetic properties of this new DMS alloy, and particularly of its critical ferromagnetic behavior. We use modified Arrott plot analysis to establish critical exponents β, γ, and δ for this alloy. We find that at low Mn concentrations (< 10 at.%), it is governed by short-range 3D-Ising behavior, with experimental values of β, γ, and δ very close to theoretical 3D-Ising values of 0.325, 1.24, and 4.815. However, as the Mn concentration increases, this DMS material exhibits a mixed-phase behavior, with g retaining its 3D-Ising characteristics, but β crossing over to longer-range mean-field behavior.

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Quantum properties of 2D magnetic semiconductors revealed by optical spectroscopy

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Spectroscopy is one of the most powerful technique to reveal electronic structures and magnetic properties of 2D materials. We performed spectroscopic studies on layered chromium thiophosphate ($CrPS_4$), a ternary antiferromagnetic semiconductor with photoluminescence in near-infrared wavelength region and observed Fano resonance when $CrPS_4$ experiences phase transition into the antiferromagnetic state below Néel temperature (838 K). The temperature and external magnetic field dependences of the Fano resonance provide insights into the photon-emitting coherent electronic transition of $CrPS_4$ and their connection to the magnetism related broken symmetry. Using magnetic circular dichroism, we measured the thickness-dependent magnetic properties of the quaternary van der Waals ferromagnetic semiconductor $AgVP_2Se_6$. When the thickness of the $AgVP_2Se_6$ flakes is reduced, enhanced out-of-plane magnetic anisotropy is observed. For a few-layer $AgVP_2Se_6$ with an atomic thickness of 6.7 nm, hard ferromagnetism with large coercivity and an undiminished T_C of 19 K is observed, which makes the semiconducting transition metal thiophosphate a promising prospect for exploring low-dimensional magnetism and enriching the rare 2D ferromagnet family.

The Synthesis and Microscopic Characterization of Series of Bulk Form Diluted Ferromagnetic Semiconductors

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In past decade, our collaboration team extended the research from Fe-based superconductors into diluted ferromagnetic semiconductors (DMS). We have successfully synthesized a series of bulk form DMS materials that have the advantages of decoupled charge and spin doping [1-5]. Among them, the Curie temperature T_C of 122-type bulk form $(Ba,K)(Mn,Zn)_2As_2$ DMS has reached to 230 K [2]. More recently, through the doping of Co onto Zn sites in $BaZn_2As_2$, we obtained a n-type DMS with T_C as high as 45 K [6]. μSR measurements have confirmed that ferromagnetism in these bulk form DMSs is homogenous and intrinsic. We will show the results from some representative materials and discuss the possibility to search for new DMS materials with higher T_C

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Two-dimensional ferromagnetic semiconductors with room Curie temperatures

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To obtain room-temperature ferromagnetic semiconductors and to realize the room-temperature quantum anomalous Hall effect (QAHE) have been big challenges for a long time. Recent advances in magnetism in two-dimensional (2D) van der Waals materials have provided a new platform for the study of magnetic semiconductors.

By density-functional-theory (DFT) calculations, we predict several stable 2D ferromagnetic semiconductors with high Curie temperature Tc above room temperature [1-3]. The Tc of $Cr_2Ge_2Se_6$ can be dramatically increased beyond room temperature by applying a few-percent strain. Based on superexchange interactions, the increased Tc by strain can be understood by the decreased energy difference between 3d orbitals of Cr and 4p orbitals of Se[1]. We propose 2D Ising-type ferromagnetic semiconductors $TcSiTe_3$, $TcGeSe_3$, and $TcGeTe_3$ with high Tc around 200-500 K. Owing to large spin-orbit couplings, the large magnetic anisotropy energy (MAE), large anomalous Hall conductivity, and large magneto-optical Kerr effect were discovered in these intriguing 2D materials [2]. In addition, we report that $PdBr_3$, $PtBr_3$, PdI_3, and PtI_3 monolayers are ferromagnetic semiconductors that could exhibit a high-temperature QAHE. It is shown that the large band gaps in these 2D materials are induced from multiorbital electron correlations [3].

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High mobility Ni-doped topological Dirac semimetal Cd_3As_2 films

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As a representative material of topological Dirac semimetal, Cd_3As_2 has been intensively studied both theoretically and experimentally in recent years [1-9]. Many novel physical properties have been identified in this material, among which the electronic Weyl orbits enable the observation of quantum Hall effect in bulk material, providing a new scheme for the exploration of three dimensional quantum Hall physics [7-9]. Nevertheless, the studies on Cd_3As_2 films with magnetic doping are rare. In this work, the magnetic and transport properties of Ni-doped topological Dirac semimetal Cd_3As_2 films have been investigated. A ferromagnetic transition temperature of ~45 K is observed in a 2% Ni-doped sample, while its electron mobility as high as ~1000 cm^2/Vs at 3 K is obtained and manifested by the Shubnikov-de Haas oscillation and the quantum Hall effect. A small band gap in the range of 50-150 meV is deduced by the semiconducting-like temperature dependence of the longitudinal resistance, which is ascribed to the strain exerted by the GaAs substrate.

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Material systhesis and μSR research on Diluted Magnetic Semiconductor

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New Diluted magnetic semiconductors (DMSs) with independent spin and charge doping, such as Li(Zn,Mn)As [1] & $(Ba,K)(Zn,Mn)_2As_2$ (BZA) [2, 3], attracted considerable attention due to its unique advantages in physical properties and heterojunction fabrication. Here we report the $(Ba,K)(Zn,Mn)_2As_2$ single crystal research for the first time, including material growth and spin polarization measurements via Andreev reflection junction [4, 5]. Then we summarize almost all the μSR data as far as possible to offer clues to reveal the long-ferromagnetic mechanism [6]. In the end, we summary this subject by discussing possible future directions in basic and applied studies [7].

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A New Diluted Magnetic Semiconductor $(Ca_{1-x}Na_x)(Zn_{2-x}Mn_x)Sb_2$

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Since ferromagnetism was observed in (Ga,Mn)As, diluted magnetic semiconductors (DMSs) have attracted a lot of attentions[1-5]. However, the substitution of Mn for Ga sites induces spin and charge doping, simultaneously, which makes it difficult to control the spin and carrier density separately. Furthermore, due to the mismatch valences of Mn^{2+} and Ga^{3+}, metastable (Ga,Mn)As only exists in thin film state by MBE method, which is hardly measured by some powerful probes such as nuclear magnetic resonance and neutron scattering that are based on bulk form samples.

Recently, a series of new bulk form DMSs have been reported[6-8]. In these new DMSs, spins are introduced by the substitution of Mn^{2+} for Zn^{2+}, and carriers are introduced at a different site.

In this paper, a new bulk form ferromagnetic materials, $(Ca_{1-x}Na_x)(Zn_{2-x}Mn_x)Sb_2$ (x = 0.08, 0.10, 0.12, 0.16, 0.20) with $T_C \sim 10$ K have been successfully synthesized. $(Ca_{1-x}Na_x)(Zn_{2-x}Mn_x)Sb_2$ has the same crystal structure as that of "122" type iron-based superconductor $CaFe_2As_2$[9]. Na substitution for Ca introduces carriers, and Mn substitution for Zn introduces spins respectively. Doping Mn alone does not introduce magnetic ordering. Iso-thermal magnetization shows that the coercive field is up to 240 Oe at 2 K.

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A New Fluoride-antimonide Diluted Magnetic Semiconductor: $SrF(Zn_{1-2x}Mn_xCu_x)Sb$ with Decoupled Spin and Carrier Doping

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Diluted ferromagnetic semiconductors (DMSs) that combine the properties of semiconductors with ferromagnetism have potential applications in spin-sensitive electronics (spintronics) devices[1,2]. The highest Curie temperature T_C of (Ga,Mn)As films has reached ~200K[3]. Recently, a series of of bulk form DMSs that are derivatives of iron-based superconductors have been successfully synthesised and reported, including 111-type Li(Zn,Mn)As[4], 122-type $(Ba,K)(Zn,Mn)_2As_2$[5] and 1111-type (La,Ba)(Zn,Mn)AsO[6]. Here we report the synthesis and characterization of a new fluoride-antimonide DMS, $SrF(Zn_{1-2x}Mn_xCu_x)Sb$, with a ferromagnetic transition below Curie temperature $T_C \sim 40$ K[7]. Our results show that the new DMS material has a coercive field ~ 8000 Oe, and a negative magneto-resistance up to 27% under 9 Tesla at 2 K.

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Spin-orbit torque induced magnetization switching in $L1_0$-MnGa mediated by a noncollinear antiferromagnet

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The spin generation and transport in magnetic ordered system have drawn much interest for their fundamental role in various spintronic phenomena. Recently, it has been demonstrated that the spin coherence length can be very long in antiferromagnets because of the staggered spins on an atomic scale [1,2]. Here, we report on the spin-orbit torque induced magnetization switching in perpendicularly magnetized $L1_0$-MnGa mediated by a noncollinear antiferromagnet FeMn. The high-quality samples with the stacking structure of $L1_0$-MnGa/FeMn/Pt are grown on GaAs(001) substrates by molecular-beam epitaxy system. The out-of-plane hysteresis loops and anomalous Hall effect measurements suggest the large perpendicular magnetic anisotropy and spontaneous perpendicular exchange bias in the samples. The proportion of flipped magnetic domains was estimated by comparing change of the R_H in the current-induced switching experiment with that obtained by the field switching experiments. After the insertion of thin FeMn layer, the proportion of flipped magnetic domains shows a dramatic drop at first and then increase to a peak value of 25%. It is found that the spin current generated by heavy metal Pt can even transmit through 6-nm-thick FeMn and exert on the magnetization of $L1_0$-MnGa thin film, which indicates that metallic antiferromagnetic FeMn can be a prominent materials for realizing long spin diffusion length. All these results have enriched the understanding of spin transport behaviors in antiferromagnetic materials.

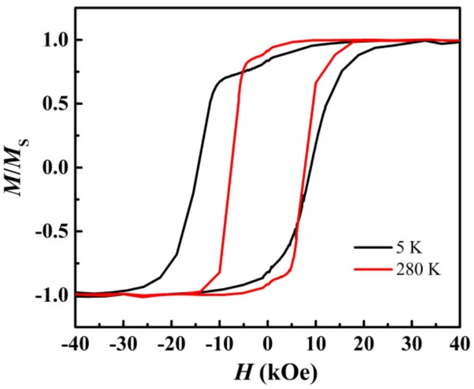

FIG. 1. Out-of-plane hysteresis loops of the sample.

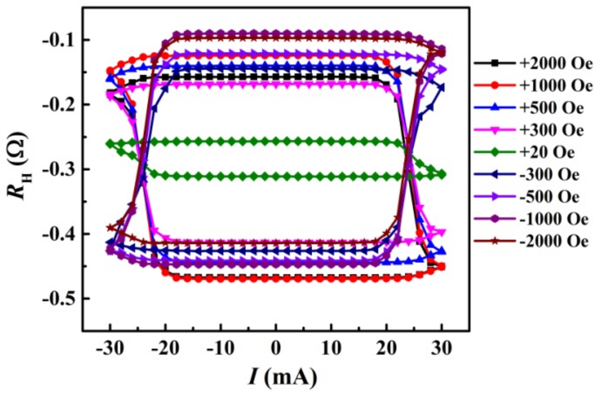

FIG. 2. R_H-I curves of Hall device.

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Observation of tunneling magnetoresistance effect in $L1_0$-MnAl/MgO/Co_2MnSi/MnAl perpendicular magnetic tunnel junctions

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Magnetic tunnel junctions (MTJs) with perpendicularly magnetized ferromagnetic electrodes are of great interests because they can be used for the core memory cells in spin-transfer-torque magnetoresistance random access memory (STT-MRAM). Among all the candidate materials with perpendicular magnetic anisotropy (PMA), $L1_0$-ordered MnAl (also known as τ-phase MnAl) displays unique superiority. It has been demonstrated that $L1_0$-MnAl shows a huge PMA constant $K_u \sim 10^7$ erg/cc and high Curie temperature up to 655 K, which can satisfy the demand of thermal stability for MRAM at sub - 10 nm technology nodes. Moreover, its relatively low saturated magnetization (M_s ~ 490 emu/cc) is also appropriate for low power current-induced magnetization switching. However, because of the difficulties of material preparation, experimental researches on MnAl-based MTJs are very rare up to now.

In this work, we report on the tunneling magnetoresistance (TMR) effect in fully perpendicular magnetic tunnel junctions (p-MTJs) with the core structure of $L1_0$-MnAl/MgO/Co_2MnSi/MnAl. The multilayer is epitaxially grown on GaAs (001) substrate by molecular-beam epitaxy (MBE), and both the top and bottom MnAl layers show well PMA. Meanwhile, an inverse TMR effect with the MR ratio of 10% is observed at 5 K, which is attributed to the intrinsic negative spin polarization of MnAl in contrast to the positive one in Co_2MnSi. This work proposes a MnAl-based fully p-MTJ for future STT-MRAM applications.

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Unsaturated Linear Magnetoresistance Effect in High-Quality Free-Standing InSb Single-Crystal Nanosheets

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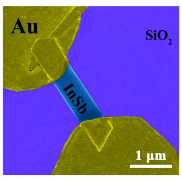
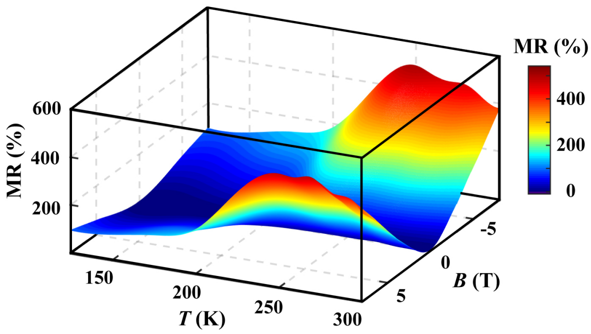
Narrow band gap semiconductor InSb has attracted tremendous attentions due to the high electron mobility, small electron effective mass, and large Landé g-factor, which makes InSb gain potential exploitation in novel electronic and spintronic devices. In addition, with lowering dimension and downscaling size, various quantum phenomena might emerge in low-dimensional InSb structures. In this work, the magneto-transport characteristics of high-quality free-standing InSb single-crystal nanosheets are systematically explored. A large and unsaturated linear magnetoresistance is observed at temperature ranging from 125 K to 300 K. And this linear magnetoresistance exhibits non-monotonic temperature dependence, which is different with previous studies. Further analysis indicates that this phenomenon could be understood by the quantum magnetoresistance model. Thus, the study on the linear magnetoresistance of InSb is helpful to develop the physical model in InSb nanostructure and might extend to low-dimensional semiconductors. Additionally, it could lay a foundation for the future application in magnetic sensors.





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Spin-orbit Torque Switching of Co_2MnSi/MnGa Synthetic Antiferromagnet

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Spintronic devices with high frequency and high speed have important potential applications in high density magnetic recording, millimeter wave communication and magnetic random access memory. Several strict demands on the magnetic material are needed to be satisfied simultaneously, such as high magneto-crystalline anisotropy, high spin polarization, low saturation magnetization and low magnetic damping factor. Synthetic antiferromagnet (SAFM) composed of Mn-based ordered alloys with perpendicular magnetic anisotropy and low magnetic damping factors and Co-based half metals, like Co_2MnSi/MnGa bilayers, not only behaves magnetically like an antiferromagnet, but also has a high spin polarization and low magnetic damping factor, which make it an ideal candidate for this kind of spintronic devices[1-3]. A novel SAFM based on a thin Co_2MnSi/MnGa bilayer with Pt capping was proposed in this work. Large coercive force and small saturation magnetic moment have been investigated in this structure. And the magnetic compensation point has been observed at 190 K. Moreover, spin-orbit torque switching was investigated at different temperatures. Comparing with conventional antiferromagnets, SAFM could be used to overcome the detection difficulty in antiferromagnets and reveal new mechanisms of spin-orbit torque effect in SAFM.

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Spin Polarization Compensation in CoTb Revealed by the Spin Hall Magnetoresistance

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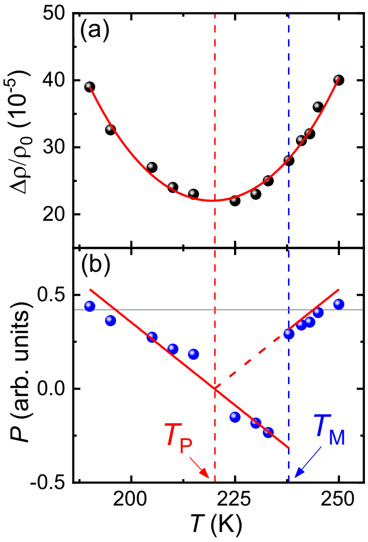
Ferrimagnets are considered as new candidate materials in the development of energy-efficient and high-speed spin memory devices [1], which is critical to the application of spintronics. Among the abundant and fascinating characteristics near the magnetic compensation of the RE-TM ferrimagnets, we unraveled the changing behavior of their spin polarization and proposed a method to identify it by the SMR. This work shows the reliability of the ferrimagnetic spin devices functioning near the compensation and the potential of ferrimagnets being used as the tunable spin current source. Our results pave the way towards the development of the ferrimagnetic spintronics.



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Strain-Induced Room-Temperature Ferromagnetic Semiconductors with Large Anomalous Hall Conductivity in Two-Dimensional $Cr_2Ge_2Se_6$

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By density-functional-theory calculations, we predict a stable two-dimensional (2D) ferromagnetic semiconductor, $Cr_2Ge_2Se_6$, where the Curie temperature TC can be dramatically increased beyond room temperature by applying a few-percent strain. In addition, the anomalous Hall conductivity in 2D $Cr_2Ge_2Se_6$ and $Cr_2Ge_2Te_6$ is predicted to be comparable to that in the ferromagnetic metals Fe and Ni, and is an order of magnitude larger than that in the diluted magnetic semiconductor Ga(Mn,As). Based on superexchange interactions, the increased TC in 2D $Cr_2Ge_2Se_6$ caused by strain can be understood by the decreased energy difference between 3d orbitals of Cr and 4p orbitals of Se. Our findings highlight the microscopic mechanism to obtain room-temperature ferromagnetic semiconductors by strain.

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Two-dimensional Weyl half-semimetal and tunable quantum anomalous Hall effect

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Topological states of matter and two-dimensional (2D) magnetism are two fascinating topics attracting tremendous interest in current research. In this work, we explore their interplay in a single 2D material system by proposing a different topological quantum state of matter—the 2D Weyl half-semimetal (WHS), which features 2D Weyl points at the Fermi level belonging to a single spin channel, such that the low-energy electrons are described by fully spin polarized 2D Weyl fermions. We provide the condition to realize this state, which requires an in-plane magnetization and a preserved vertical mirror symmetry. Remarkably, we prove that the WHS state is a critical state sitting at the topological phase transition between two quantum anomalous Hall (QAH) insulator phases with opposite Chern numbers, such that a switching of the QAH states as well as the direction of chiral edge channels can be readily achieved by rotating the magnetization direction. Furthermore, we predict a concrete 2D material, monolayer $PtCl_3$, as a candidate for realizing the 2D WHS state and the above intriguing effects. Our findings open up a new direction of research at the confluent point of topology and magnetism in two dimensions, and the revealed route towards switchable QAH phases will enable new designs of topological nanoelectronic devices.

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Strain-controlled magnetic and electric polarized states in two-dimensional magnetic Janus semiconductor

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Two-dimensional (2D) Janus semiconductors with mirror asymmetry can introduce novel properties, such as large spin-orbit coupling (SOC) and piezoelectric polarization, which have attracted a great interest for their potential applications. Inspired by the recently fabricated 2D ferromagnetic (FM) semiconductor CrI_3, the 2D Janus materials $M_2Cl_3I_3$ (M=3d transition metals) are studied by the density functional theory (DFT) calculations. A stable 2D (in x-y plane) antiferromagnetic (AFM) Janus semiconductor $Fe_2Cl_3I_3$ with out-of-plane magnetization of sublattice is obtained. By applying tensile strain up to about 15%, the following four magnetic states sequentially occur: AFM with out-of-plane magnetization of sublattice, AFM with in-plane magnetization of sublattice, FM with in-plane magnetization, and FM with out-of-plane magnetization. Such novel magnetic phase diagram driven by strain can be well understood by a Heisenberg Hamiltonian with the single-ion anisotropy term, where the SOC of I atoms is found to play an essential role. In addition, the electric polarization of $Fe_2Cl_3I_3$ preserves with strain due to the broken inversion symmetry. Our results predict the Janus material $Fe_2Cl_3I_3$ as a rare example of 2D semiconductors with both spin and charge polarizations, and reveal the highly sensitive strain-controlled magnetic states and magnetization direction, which highlights the 2D magnetic Janus semiconductor as a new platform to design spintronic materials.

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Na and Mn co-doped $CaCd_2As_2$: A new diluted ferromagnetic semiconductor with spin and charge decoupled

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A new spin and charge decoupled diluted ferromagnetic semiconductor ,$(Ca,Na)(Cd,Mn)_2As_2$, was successful synthesized. It crystallize into hexagonal $CaAl_2Si_2$-type structure. [1] Carriers and spins were introduced by substitution of (Ca,Na) and (Cd,Mn) respectively. Magnetization measurements show that the maximum Curie temperature reached to 19 K, and coercive force is less than 100 Oe. Electrical transport measurement indicate resistivity of $CaCd_2As_2$ is 3 orders magnitude larger than all the Na-doped $(Ca,Na)(Cd,Mn)_2As_2$, indicating significantly increased carrier concentrations via Na doping. In contrast, it's gradual increases with increasing Mn concentrations. A negative magnetroresistance up to 15% was observed at H = 7T,T = 2K, larger than analogues $(Sr,Na)(Zn,Mn)_2As_2$ and $(Ca,Na)(Zn,Mn)_2As_2$ as well as $(Ba,K)(Zn,Mn)_2As_2$ which has a much higher Tc. [2,3,4] With lower coercive and larger magnetroresistance, $(Ca,Na)(Cd,Mn)_2As_2$ can be served as a promising candidate for spin manipulations. [5,6,7,8]

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