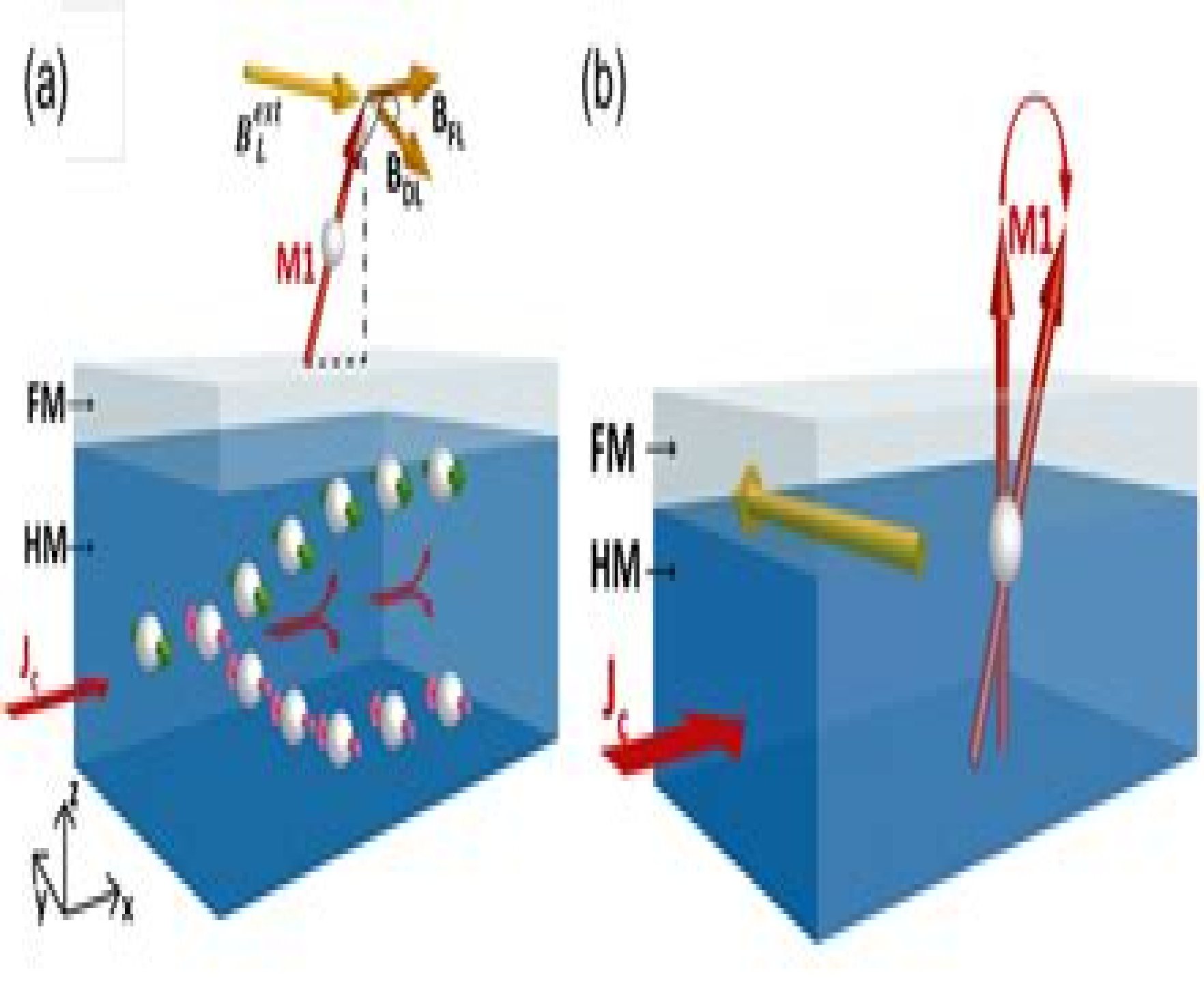
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Spin Hall Effect And Spin Orbit Torques

JA Banks

Spin Hall Effect And Spin Orbit Torques:

Current-driven Spin-orbit Torques in Ferromagnetic Heterostructures Jun Wu,2017 The spin Hall effect SHE is the generation of spin separation by a charge current in a heavy metal HM with strong spin orbit interaction The generated pure spin current orthogonal to the charge current can exert a torque on the magnetization of an adjacent ferromagnetic layer FM in FM HM bilayer Due to the inversion symmetry breaking in such FM HM bilayer there exists a Rashba effect at the interface that can cause spin accumulation at the interface The accumulated spin can also exert a torque on the magnetization of the ferromagnetic layer The torque arising from the current driven SHE or Rashba effect is referred to as spin orbit torque SOT There are two types of SOT field like FL and damping like DL SOT both can cause FM layer magnetization reorientation or switching SOT has attracted intensive interest recently due to its potential application in low energy memory and logic devices DL SOT has been observed and widely investigated by researchers However FL SOT was rarely observed and neglected in most cases since it only can be measured in very thin FM layer because of the short spin dephasing length usually on the order of several atomic layers In this work we first demonstrate the existence and observation of the effective field of FL SOT in a CoFeB Ta bilayer by the spin transfer torque ferromagnetic resonance method Then we quantitatively determine the FL SOT in NiFe Pt system using the second order planar Hall effect PHE It is found that FL SOT persists even with an insertion of Cu spacer layer between NiFe and Pt which indicates that the SHE is the dominant mechanism for SOT In order to investigate the interfacial and bulk effects of SOT in FM HM bilayer both the DL and FL SOTs are measured in the CoFeB Pt system by the polar magneto optical Kerr effect MOKE and second order PHE respectively We found that the SHE is also the dominant mechanism in CoFeB Pt system However there is also a distinct interfacial contribution which is attributed to the Rashba effect There are two mechanisms contributing to the SHE intrinsic and extrinsic effect We show that the SHE in Au Cu alloy can be enhanced by the extrinsic scattering compared to pure Au or Cu It is also found that the DL SOT and FL SOT depend on temperature very differently in NiFe AuCu system A nearly linear dependence between the spin Hall angle and longitudinal resistivity suggests that skew scattering one of the extrinsic effect for SHE may be the dominant mechanism in Au Cu alloy **Nanomagnetic and Spintronic Devices for Energy-Efficient Memory and Computing** Jayasimha Atulasimha,Supriyo Bandyopadhyay,2016-01-27 Nanomagnetic and spintronic computing devices are strong contenders for future replacements of CMOS This is an important and rapidly evolving area with the semiconductor industry investing significantly in the study of nanomagnetic phenomena and in developing strategies to pinpoint and regulate nanomagnetic reliably with a high degree of energy efficiency This timely book explores the recent and on going research into nanomagnetic based technology Key features Detailed background material and comprehensive descriptions of the current state of the art research on each topic Focuses on direct applications to devices that have potential to replace CMOS devices for computing applications such as memory logic and higher order information processing

Discusses spin based devices where the spin degree of freedom of charge carriers are exploited for device operation and ultimately information processing Describes magnet switching methodologies to minimize energy dissipation Comprehensive bibliographies included for each chapter enabling readers to conduct further research in this field Written by internationally recognized experts this book provides an overview of a rapidly burgeoning field for electronic device engineers field based applied physicists material scientists and nanotechnologists Furthermore its clear and concise form equips readers with the basic understanding required to comprehend the present stage of development and to be able to contribute to future development Nanomagnetic and Spintronic Devices for Energy Efficient Memory and Computing is also an indispensable resource for students and researchers interested in computer hardware device physics and circuits design Solid State Physics ,2017-11-18 Solid State Physics Volume 68 provides the latest information on a branch of physics that is primarily devoted to the study of matter in its solid phase especially at the atomic level Chapters in this updated volume include new research in the use of phonon polaritons in polar materials to do plasmonic like studies but without the plasmons along with a section on Polar oxide interfaces This prestigious serial presents timely and state of the art reviews pertaining to all aspects of solid state physics Contains contributions from leading authorities in the study of solid state physics especially at the atomic level Informs and updates on all the latest developments in the field Presents timely and state of the art reviews pertaining to all aspects of solid state physics *Handbook of Magnetic Materials* Ekkes H. Brück,2020-11-29 Handbook of Magnetic Materials Volume 29 highlights new advances in the field with this new volume presenting interesting chapters written by an international board of authors on topics such as spin orbit torque Provides the authority and expertise of leading contributors from an international board of authors Presents the latest release in the Handbook of Magnetic Materials series **Advances in Non-volatile Memory and Storage Technology** Yoshio Nishi,Blanka Magyari-Kope,2019-06-15 Advances in Nonvolatile Memory and Storage Technology Second Edition addresses recent developments in the non volatile memory spectrum from fundamental understanding to technological aspects The book provides up to date information on the current memory technologies as related by leading experts in both academia and industry To reflect the rapidly changing field many new chapters have been included to feature the latest in RRAM technology STT RAM memristors and more The new edition describes the emerging technologies including oxide based ferroelectric memories MRAM technologies and 3D memory Finally to further widen the discussion on the applications space neuromorphic computing aspects have been included This book is a key resource for postgraduate students and academic researchers in physics materials science and electrical engineering In addition it will be a valuable tool for research and development managers concerned with electronics semiconductors nanotechnology solid state memories magnetic materials organic materials and portable electronic devices Discusses emerging devices and research trends such as neuromorphic computing and oxide based ferroelectric memories Provides an overview on developing nonvolatile memory and storage

technologies and explores their strengths and weaknesses Examines improvements to flash technology charge trapping and resistive random access memory Spin-Orbit Torques in Topological Insulators Qiming Shao,2015 Spin torque can toggle magnetization state of nanomagnets in magnetic tunnel junctions In heavy metals giant Spin Hall Effect gives rise to a large spin orbit torque SOT enabling magnetization switching of adjacent ferromagnets Spin torque ratio is the key parameter in determining energy efficiency Recently a giant SOT was demonstrated in topological insulators TIs which are a class of materials owing insulating bulk and metallic surface states Although several theoretical studies show that spin momentum locking of surface states generates this giant SOT experimental clarification is still lacking In this thesis we use the second harmonic anomalous Hall resistance to access the current induced spin orbit fields and thus SOTs Heavy metal ferromagnet hetoerstructure Ta CoFeB MgO is used to verify the validation of this method Then we quantitatively estimate the SOT in different TI chromium doped TI heterostructures with different magnetic dopant positions which shows the evidence of surface states originated SOTs At last we show that the magnitude of SOTs can be controlled by the gate voltage due to its semiconducting nature All these studies may contribute to the future low power spintronics **Frontiers in Materials: Rising Stars 2020** Anastasiia O. Krushynska,Amy Sarah Gandy,Miriam Navlani-García,David Salinas Torres,Chang-Mou Wu,Jong-Seok Oh,Federico Carosio,2021-07-08 The Frontiers in Materials Editorial Office team are delighted to present the second edition of the Rising Stars article collection Frontiers in Materials Rising Stars 2020 showcasing the high quality work of internationally recognized researchers in the early stages of their independent careers All Rising Star researchers featured within this collection were individually nominated by the Topic Editors in recognition of their potential to influence the future directions of their respective fields The work presented here highlights the diversity of research performed across the entire breadth of the materials science and engineering field and presents advances in theory experimentation and methodology with applications for solving compelling problems This Editorial features the corresponding author s of each paper published within this important collection ordered by section alphabetically highlighting them as the great researchers of the future The Frontiers in Materials Editorial Office team would like to thank each researcher who contributed their work to this collection We would also like to personally thank the Topic Editors for their exemplary leadership of this article collection their strong support and passion for this important community driven collection has ensured its success and global impact Emily Young Journal Development Manager *Nanowire Spin Torque Oscillator Driven by Spin Orbit Torques* Andrew Smith,2016 The field of spintronics deals with the use of the spin degree of freedom of the electron and the spin current that arises from it There are many static and dynamic applications for spin current whether it is supplied by spin polarized electric current from a magnetic layer or from spin orbit torques This dissertation will focus on the later cases where the spin Hall effect present in platinum supplies a spin torque on an adjacent permalloy layer creating a spin torque oscillator STO Previous studies have demonstrated the existence of STOs in the 0 dimensional case and its absence in the 2D

case therefore the 1D case a ferromagnetic nanowire is tackled here This will cover the first instance of a micrometer scale STO and will show the excited modes are the edge and bulk spin wave eigenmodes of the nanowire Anomalous Hall Effect and Spin-orbit Torques in Noncollinear Antiferromagnetic Mn3Ni0.35Cu0.65N Thin Films Adithya Rajan,2025 The continued scaling of conventional charge based electronics faces significant challenges creating an urgent need for alternative paradigms capable of delivering lowpower high speed and scalable computing technologies Spintronics by exploiting the spin and orbital degrees of freedom of electrons has emerged as a promising pathway particularly through the development of spin orbit torque SOT based memory devices In this context noncollinear antiferromagnets NCAFM offer a unique materials platform combining vanishing net magnetization with exotic spin textures that can give rise to robust electronic transport phenomena such as the anomalous Hall effect AHE and unconventional spin orbit torques This thesis investigates the anomalous Hall effect and spin orbit torques in the cubic antiperovskite Mn3Ni0 35Cu0 65N Mn3NiCuN A detailed experimental framework was established to disentangle higher order contributions to the AHE by performing angular dependent Hall measurements under both in plane and out of plane magnetic field geometries A nontrivial in plane AHE was observed confirming the presence of higher order multipolar contributions specifically an octupolar moment rather than conventional dipolar magnetization The angular dependence of the AHE exhibited a 120 symmetry consistent with the symmetry of the octupolar spin texture and was further supported by phenomenological modeling that incorporated scalar spin chirality SSC contributions to the transport signal In parallel spin orbit torques were investigated via second harmonic Hall measurements and spin torque ferromagnetic resonance ST FMR A significant enhancement of the damping like torque was observed near the N el temperature This enhancement could be attributed to two alternative mechanisms i increased spin and orbital current generation from critical fluctuations of the noncollinear antiferromagnetic order and ii spin currents arising from fluctuation induced scalar spin chirality Notably this work presents the first experimental indication of orbital Hall effect contributions in a NCAFM offering a new perspective on angular momentum generation in complex magnetic systems The findings of this thesis provide direct insight into the role of higher order magnetic multipoles critical spin fluctuations and orbital transport in NCAFM Beyond advancing fundamental understanding these results highlight the potential of NCAFMs for developing energy efficient field free spintronic devices marking a significant step toward exploiting complex magnetic textures for future information technologies *Journal of the Physical Society of Japan* ,2018 **Spin Current** Sadamichi Maekawa,Sergio O. Valenzuela,Eiji Saitoh,2012-07-26 In a new branch of physics and technology called spin electronics or spintronics the flow of electrical charge usual current as well as the flow of electron spin the so called spin current are manipulated and controlled together This book is intended to provide an introduction and guide to the new physics and application of spin current Spintronics Tomasz Blachowicz,Andrea Ehrmann,2019 Starting from quantum mechanical and condensed matter foundations this book introduces into the necessary theory behind spin electronics

Spintronics Equations of spin diffusion evolution and tunelling are provided before an overview is given of simulation of spin transport at the atomic scale Furthermore applications are discussed with a focus on elementary spintronics devices such as spin valves memory cells and hard disk heads *Crystallographic Dependence of Spin Orbit Torques in Epitaxial Thin Films* Bharat Grover,2024* Spintronics is an emerging field in nanoelectronics utilizing the spin of electrons for data storage and manipulation In this thesis the characterization of spin orbit torques SOTs generated by spin currents from the spin Hall effect SHE in heavy metals is presented with a focus on Pt and the non collinear antiferromagnet Mn3Pt In Pt three crystallographic orientations 111 110 and 001 were studied using optically detected ferromagnetic resonance OFMR and spin torque ferromagnetic resonance ST FMR with comparisons made to DC bias technique In Mn3Pt the role of exchange bias was examined along 111 and 001 by inserting Cu between Mn3Pt and Permalloy Py Damping like and field like torques were observed due to different spin polarization in Mn3Pt Finally field dependent switching of ferromagnets with perpendicular anisotropy through Mn3Pt SOT was demonstrated *Handbook of Magnetism and Advanced Magnetic Materials: Spintronics and magnetoelectronics* Helmut Kronmüller,Stuart S. P. Parkin,2007 *Interplay of Rashba Effect and Spin Hall Effect in Perpendicular Pt/Co/MgO Magnetic Multilayers *Project Supported by the National Basic Research Program of China (Grant No. 2015CB921401), the National Natural Science Foundation of China (Grant Nos. 51331002, 51371027, 51431009, 51471183, and 11274371), the National Instrumentation Program of China (Grant No. 2012YQ120048), and the Instrument Development Program of Chinese Academy of Sciences (Grant No. YZ201345).* ,2016 Abstract The interplay of the Rashba effect and the spin Hall effect originating from current induced spin orbit coupling was investigated in the as deposited and annealed Pt Co MgO stacks with perpendicular magnetic anisotropy The above two effects were analyzed based on Hall measurements under external magnetic fields longitudinal and vertical to dc current respectively The coercive field as a function of dc current in vertical mode with only the Rashba effect involved decreases due to thermal annealing Meanwhile spin orbit torques calculated from Hall resistance with only the spin Hall effect involved in the longitudinal mode decrease in the annealed sample The experimental results prove that the bottom Pt Co interface rather than the Co MgO top one plays a more critical role in both Rashba effect and spin Hall effect *Spin-orbit Torque Measurements in Heavy Metal/ferromagnet Heterostructures Using the Magneto-optic Kerr Effect* Halise Celik,2018 Spin orbit coupling in heavy metal ferromagnet HM FM bilayer heterostructures has attracted considerable attention because it provides an efficient way to manipulate the magnetization with strong current driven spin orbit torques SOTs which may lead to new technologies for nonvolatile magnetic memory and logic devices An electric current flowing through a heavy metal generates a field like spin orbit torque FT and a damping like spin orbit torque DT on the magnetization of a neighboring ferromagnet Two mechanisms have been proposed to explain the generation of SOTs the Rashba Edelstein effect due to interfacial spin orbit coupling and the spin Hall effect in the bulk of materials with strong spin orbit coupling SOC Much

effort has been dedicated to identifying the dominant mechanism of the SOTs however the underlying mechanism for the SOC driven phenomena remained unsettled In this thesis we develop a sensitive SOT magnetometer based on the magneto optic Kerr effect MOKE that measures the SOTs for HM FM bilayers over a wide thickness range We observe that the DT inversely scales with the ferromagnet thickness and the FT has a threshold effect that appears only when the ferromagnetic layer is thinner than 1 nm Through a thickness dependence study with an additional copper insertion layer at the interface we conclude that both SHE and Rashba effect exist in HM FM heterostructures The relative strengths of their contributions depend on the material system We have also demonstrated that MOKE with normal incidence light can be used to obtain the DT and FT in HM FM bilayers by analyzing the polar Kerr effect as well as the quadratic Kerr effect The two effects can be distinguished by properly selecting the polarization of the incident light We study a series of Pt Py bilayers to verify the accuracy of this method The angular dependence of SOTs in Ta 2 nm CoFeB 1 nm MgO 3 nm trilayers with perpendicular magnetization is quantified based on polar MOKE with field calibration A strong angular dependence is observed that is different from the previous experimental observations Based on this strong angle dependence we conclude there is a strong Rashba effect in this system Simultaneous detection of current driven DT and FT in HM FM bilayers by measuring all three magnetization components and using a vector resolved MOKE technique based on quadrant detection has also been accomplished The technique can be easily extended to measure SOTs in systems with perpendicular magnetization as well as in systems with arbitrary magnetization direction Relativistic Electronic Transport Theory Stephan Lowitzer,2010 Spintronics is an emerging technology that exploits the intrinsic spin of the electron and its associated magnetic moment in addition to its fundamental electronic charge The central issue of this multidisciplinary field is the manipulation of the spin degree of freedom in solid state systems Discoveries in recent years have inspired a new route in spintronic research which needs no ferromagnetic components The research field spintronic without magnetism is based on the possibility to manipulate electric currents via spin orbit coupling only The spin Hall effect SHE is one of the most promising effects for the generation of spin polarized currents which is even present in non magnetic materials The SHE appears when an electric current flows through a medium with spin orbit coupling present leading to a spin current perpendicular to the charge current In this work the SHE as well as the anomalous Hall effect AHE are investigated on a first principles level using the spin polarized fully relativistic Korringa Kohn Rostoker Green s function method SPR KKR GF in conjunction with the linear response Kubo Streda formalism Intrinsic as well as extrinsic contributions to the SHE AHE are treated on equal footing This opened up for the first time the possibility to reliably decompose the SHE AHE into skew and side jump scattering as well as intrinsic contributions in a quantitative manner *Magnetization Dynamics in Pt/Ni80Fe20 Nanowires Induced by Spin Hall Effect* Liu Yang,2015 Spin current is the flow of electron spin angular momentum It can either be partially spin polarized current generated due to the exchange interactions of spins and local magnetization or pure spin current generated from

spin orbit interaction Both sources of spin current are under intensive study for their efficient interaction with nanoscale magnetic structures and potential application of magnetoresistive random access memory MRAM spin torque nano oscillators STNOs and other innovative devices In this dissertation spin Hall effect mediated magnetization dynamics in Platinum Permalloy nanowires are excited by different means and studied experimentally This includes stead state self oscillation of magnetization in a ferromagnetic nanowire serving as the active region of a spin torque oscillator driven by spin orbit torques Our work demonstrate that magnetization self oscillations can be excited in a one dimensional magnetic system and that dimensions of the active region of spin torque oscillators for the first time can be extended beyond the nanometer length scale We also demonstrate that via proper design of the nanowire shape which results in spatial non uniform spin current density we can significantly decrease the phase noise of spin orbit torque oscillators It also stabilizes the single mode generation regime and points out a path for partial control of multi mode excitation in nanostructures We also parametrically excite magnetization dynamics in the nanowires and it demonstrates that nonlinear dynamic magnetic effect can have a larger efficiency than the direct linear excitation in spin Hall structures and it provides additional information about excited spin wave mode systems owing to its threshold nature that is unavailable from direct excitation **Chemical Abstracts** ,2002 **Low Temperature Physics** Y. Takano,2006-11-22 This book represents recent cutting edge developments in low temperature physics reported at one of the largest international conferences in physics The subjects covered are superconductivity magnetism quantum gases quantum liquids and solids electronic properties of solids low temperature experimental techniques cryogenics and applications

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