Ultrafast Optical Control and Characterization of Carrier and Spin Dynamics in Novel Magnetic Topological Insulator System

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William & Mary, Department of Applied Science, 2021
Field: Lasers and Optics Degree: Ph.D.

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Abstract

Magnetic topological insulators (MTIs) are of considerable interest in developing novel spintronics and quantum computing applications. Under the topological protection by time-reversal Z2 invariant number, magnetic topological insulators are provided with robust electronic and magnetic properties against local perturbations. The quantum anomalous Hall effect (QAHE), which harbors dissipationless chiral edge states in MTIs, provides a competitive platform for future low-power consumption and high-speed spintronic devices. Although the present studies on both bulk and surface magnetic properties in MTIs has made significant progress, the in-depth understanding of the exchange couplings and the interaction between the two magnetization sources is far from completion. In addition, the optical control of the non-trivial properties in MTIs is important in achieving novel applications for ultrafast optoelectronics and optical spintronics. The goal of this dissertation is to understand and manipulate the dynamical spin coupling as well as the carrier relaxation dynamics in MTIs, using static magneto- optical Kerr effect (MOKE) and time-resolved magneto optical Kerr effect (TRMOKE) techniques.First, a pronounced spin-valve-like structure of dynamical magnetization is observed in Cr-(Bi,Sb)2Te3/CrSb bilayer heterostructure through the pump- modulated MOKE characterization. The characters of the soft and resilient ferromagnetic phases are distinguished in terms of the spin coupling between the dynamical surface and bulk ferromagnetism. The dynamical bulk ferromagnetic ordering is softened by laser-induced heat effect on the lattice, while the dynamical surface magnetization is enhanced via the strengthening Dirac-hole- mediated exchange coupling. In addition, the pump-fluence-dependent measurement of exchange-bias effect provides further evidence for the enhancement of MTI surface magnetization at the MTI/AFM interface. Lastly, we propose a theoretical model that includes the long-range p-d exchange coupling and Dirac-hole-mediated exchange interaction and estimate the exchange coupling energies in the MTI/AFM bilayer structure.Second, ultralong carrier lifetimes (3~20 ns) of the optically pumped surface states are observed in Cr-(Bi,Sb)2Te3 MTI which corresponds to the slow radiative recombination within the gapped Dirac cone. The photoinjection dependency of radiative lifetimes suggests a strong Coulomb screening effect of electron-hole plasma on surface excitons. The experimental results are consistent with the theoretical simulation. On the other hand, the nonradiative nature of bulk electron relaxation is identified with a lifetime of ~1000 ps by photoinjection- and temperature- dependent reflectivity measurements. The finding of long-lived excited carriers in MTI improves the understanding of the general carrier dynamics in topological insulators-based materials.