Optical Characterization of Dynamic Exchange Coupling Interaction in Ferromagnetic Heterostructures

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Abstract

This thesis presents the optical characterization of interfacial exchange coupling interaction in ferromagnetic bilayer heterostructures. Both static and dynamic magnetic response is investigated in the exchange-coupled Co2FeAl/(Ga,Mn)As bilayer system using static magneto-optical Kerr effect (MOKE) and time-resolved magneto-optical Kerr effect (TRMOKE) techniques. The goal of this thesis is to understand the underlying physics of the interfacial exchange coupling effect on the ultrafast spin dynamics in a ferromagnetic metal/ferromagnetic semiconductor bilayer heterostructure. Our finding provides a viable pathway for designing advanced semiconductor spintronic devices for ultrafast low-power spin manipulation. First, a significant enhancement of the excitation efficiency of coherent magnetization precession is observed in the ferromagnetically exchange-coupled Co2FeAl/(Ga,Mn)As bilayer heterostructures at temperatures below the Curie temperature of (Ga,Mn)As, Tc = 50 K, under photoexcitation of low-fluence, near-infrared pump pulses. The coherent magnetization precession persists to room temperature, indicating that proximity-induced ferromagnetism plays an important role in the optical excitation mechanism. A subsequent simulation of the temperature-dependent precession amplitude and frequency behavior is performed based on the Landau-Lifshitz-Gilbert (LLG) equation, suggesting that the high-efficiency excitation mechanism can be attributed to the modulation of the exchange coupling field at the interfacial area, which is induced by the emergence of the dynamic exchange coupling effect between the precessing magnetizations in the two ferromagnets. Second, the Gilbert damping property of the magnetization precession in the Co2FeAl/(Ga,Mn)As bilayer system is studied. At temperatures below the Curie temperature of (Ga,Mn)As, Tc = 50 K, ultrafast pump excitation creates a counter-precessing, exchange-coupled mode in the ferromagnetic bilayer. The precessing magnetization in the Co2FeAl layer transfers a pure spin current directly into the (Ga,Mn)As layer at a certain intensity of external magnetic field where the Fe(Co) spins and the Mn spins precess at the same frequency. A photo-induced enhancement of the Gilbert damping constant α is observed, indicating that spin-angular momentum is transferred at the resonance magnetic fields. This can be attributed to the effect of the interfacial dynamic exchange coupling interaction between the precessing magnetizations in two ferromagnetic layers. A corresponding phase shift of the magnetization precession is also observed at the resonance field where the Gilbert damping peak appears.