Ultrafast Spin-Charge Conversion in Rashba states probed by Terahertz time-domain emission spectroscopy

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***Abstract*— Terahertz (THz) emission spectroscopy in spin systems has become a very powerful method to generate THz radiation and to investigate the properties of Rashba or Topological Insulator surface states. Broadband THz emission can be generated in heavy metallic or in more general Rashba systems. In 3d/5d transient metal bilayers THz emission is via the Inverse Spin Hall effect. Beyond heavy metal structures, Rashba states are strong candidates for THz-spintronics owing to their high spin to charge conversion properties. Here we present a 2D Electron Gas with strong Rashba spin-orbit coupling, NiFe/LaAlO$_3$/SrTiO$_3$, and demonstrate THz emission is via the Inverse Edelstein Effect.**

INTRODUCTION

Terahertz (THz) emission spectroscopy has become a very important method to investigate the character and properties of Rashba or topological insulator (TI) surface states. In particular, using this technique, one can probe the efficiency of spin-to-charge conversion (SCC) at ferromagnetic junctions in the time domain within the sub-picosecond time scale. The interest is firstly from an application point of view for the realization of powerful, ultra-broadband THz emission (up to 30 THz) [1] whose linear polarization of the electric field can be controlled by magnetization, and secondly in terms of fundamental physics of SCC. THz emission is typically observed in heavy metallic [1-3] or in more general Rashba systems [4] that this work investigates.

In 3d/5d transient metal bilayers such as Fe/Pt, Co/Pt, NiFe/Pt, the magnetization of the ferromagnetic material (Fe, Co, NiFe) is excited by a femtosecond (100 fs) laser pulse in the optical domain. Consequently, an out-of-equilibrium spin current at sub-picosecond timescales is generated, which relaxes in a heavy material (Pt) by creating charge dipoles via the Inverse Spin Hall Effect (ISHE) giving rise to THz electromagnetic emission. The electric field of the THz emission from the transition metal bilayers is comparable to that provided by nonlinear crystals such as ZnTe (figure 1). Beyond heavy metal structures, Rashba states and Topological insulators are strong candidates for future spintronic-terahertz domains as a result of their high SCC properties. In this scheme, we are interested in the 2D electron gas samples with strong Rashba spin-orbit coupling such as NiFe/LaAlO$_3$/SrTiO$_3$ and NiFe/AlO$_3$/SrTiO$_3$. Our THz emission spectroscopy results show that THz dipole radiation can be generated but in contrast to 3d/5d layers, this is via the dynamic inverse Edelstein effect (IEE) for SCC (Fig. 2). This is shown through the unexpected large reduction in THz field despite the expected large SCC. This is supported by in-depth theoretical developments of the dynamics of these junctions. In this context, this work shows methods to optimize the THz emission in different types of spintronic-THz samples and understand the fundamental physics. In particular, we will highlight the role of physical parameters (e.g. interface transmissions, spin Hall angle, spin diffusion length) in the system via Finite-Difference Time domain (FDTD) analysis of THz spectra in various spintronics heterostructures. The latter uses a spin-polarized time-dependent diffusion model.in multi-layered systems with adequate boundary conditions..

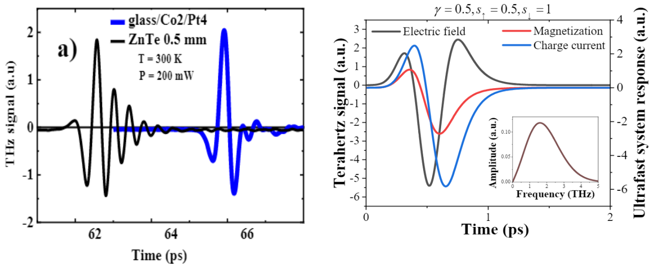

Fig 1. Left: a) THz emission from Co(2 nm)/Pt(4 nm) system under a 100 fs laser pulse compared with ZnTe nonlinear crystal. Right: FDTD simulations of time evolution of the emitted terahertz signal (grey), the ultrafast surface charge current jc (blue) and the out-of-equilibrium spin accumulation at the bilayer interface (red).

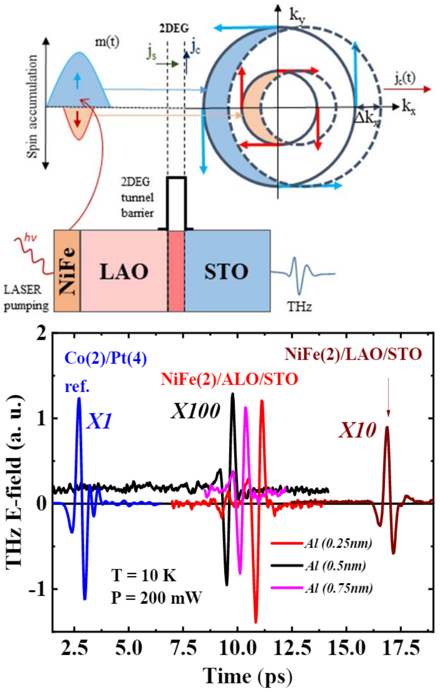

Fig 2. a) Laser induced inverse Edelstein effect. b) THz-TDS spectra acquired at low temperature (10 K) on NiFe(2 nm)/LAO(4 u.c.)/STO 2DEG under a 100 fs laser pulse at a power of P=200 mW.

References

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