Spin-electricity conversion induced by spin pumping into topological insulators

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Spin injection into “bulk-insulating” topological insulators

Spin-Electricity Conversion Induced by Spin Injection into Topological Insulators

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TI is a promising material for spintronics application

Topological Insulator (TI)

Surface: metal
Interior: Insulator

1. spin current \( \neq 0 \)
   electric current = 0

2. spin-momentum locking

3. surface property determined by bulk property
Spin injection into surface states of topological insulators

Electric current induced by spin injection
Spin-electricity conversion induced by spin injection

- Same symmetry as ISHE
- Induced by spin-momentum locking (in principle, perfect conversion)

![Diagram showing spin-electricity conversion and inverse spin Hall effect](image)
Some trials for spintronics application of TI


Magnetization switching

Bulk insulating ⇒ tiny electric current in TI

- ST-FMR
- Hall angle > 1


Spin valve
Some trials for spintronics application of TI


Magnetization switching

Bulk-conductive TI ⇒ contaminated by bulk carriers
Bulk-insulating TI ⇒ not-efficient spin transfer (Res. mismatch)

How can we observe “pure” surface spin transport of TIs?

- spin pumping: free from impedance mismatch (K. Ando 2011)
- one more idea to minimize bulk-carrier contribution

Bulk insulating ⇒ tiny electric current in TI
Our experimental setup: Use of “Bulk form” topological insulators

**Bulk-carrier compensated TIs:**
- $\text{Bi}_{1.5}\text{Sb}_{0.5}\text{Te}_{1.7}\text{Se}_{1.3}$, $\text{BiSbTeSe}_2$
- Sn-doped $\text{Bi}_2\text{Te}_2\text{Se}$

**Bulk-metallic TIs:**
- $\text{Bi}_2\text{Se}_3$

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A. A. Taskin, et al. PRL 107, 016801 (2011)

From Yoichi Ando (Osaka Univ.)
Methods and samples

- ferromagnet: permalloy ($\text{Ni}_{81}\text{Fe}_{19}$) 20nm thick
- coplanar-type wave guide, network analyser (typically, 5 GHz is used)
- measurement down to 15K (probe station)
Methods and samples

- ferromagnet: permalloy (Ni$_{81}$Fe$_{19}$) 20nm thick
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Spin pumping

\[ H = v_F (\hat{z} \times \vec{\sigma}) \cdot \vec{p} + J_{sd} \vec{S} \cdot \vec{\sigma} = v_F (\hat{z} \times \vec{\sigma}) (\vec{p} + e\vec{a}) + J_{sd} S_z \sigma_z \]

\[ \vec{\alpha} = \text{voltage generation} \]

spin exchange interaction = torque

\[ \vec{T}_{\text{surface}} = \gamma \vec{M} \times J_{\text{eff}} \langle \vec{\sigma} \rangle \]

damping enhancement
Voltage signals at FMR of Py at various temperatures for a Bi$_{1.5}$Sb$_{0.5}$Te$_{1.7}$Se$_{1.3}$ (BSTS) sample

- High-T: symmetric signal (Seebeck effect)
- Asymmetric signal
- Sign inversion between +H and -H
- Correlation to surface conduction being dominant at low Ts

Depend on environment heating
Correlation between antisymmetric voltage signals and surface transport

\[ V^a = \frac{[V(H) - V(-H)]}{2} \]

\( V^a \) increases with decreasing \( T \)

\[ \times 10 !! \]

- **NOT shunting of AMR**

\[ \frac{R_{\text{BSTS}}}{R_{\text{Py}} + R_{\text{BSTS}}} V_{\text{AMR}} \times 2 \]

\( R_{\text{BSTS}} \approx R_{\text{Py}} (\approx 5\,\Omega) \) at 300 K

\( R_{\text{BSTS}} >> R_{\text{Py}} \) at low \( T_s \)

- **NOT Nernst effect**

\[ \propto T \text{ at low } T_s \]

(Mott relation)
NO antisymmetric signal in control samples:
bulk-metallic TIs (Bi$_2$Se$_3$); conventional semiconductors

- Reproducible for all BSTS samples
- not observed for BS1, n-Si, or n-InAs

Anti-symmetric signals arise on topological surface states
Mechanism of spin-electricity conversion effect

“spin-momentum locking” \implies \text{spin-electricity conversion}

\text{spin injection}

\begin{equation}
\Delta k = \left( \frac{e \tau}{\hbar} \right) E_x
\end{equation}

\text{shift of the Fermi circle}

\begin{equation}
\frac{\langle \sigma_y \rangle}{A} = \frac{1}{A} \sum_k f_k \langle \bar{k},+ | \hat{\sigma}_y | \bar{k},+ \rangle
\end{equation}

\text{same sign as the experiment}

\text{ISHE}

\text{spin injection}

\text{bulk}

if Hall angle $\theta$ defined, $\theta \approx 1\%$
Summary & perspective

- Observation of anti-symmetric signals on millimeter-thick bulk-insulating TIs
- Anti-symmetric signals arise on surface states
- Build a model: New spin-electricity conversion
  - The voltage sign is consistent in principle, high efficiency up to 100%, but only ~ 1% now.

- Improve the efficiency
  (Improve interface quality, reduce magnetic proximity effect, etc.)
- Experiments in BSTS|YIG systems

Perspective: BSTS on YIG

Growth of BSTS plates on Mica substrate $\Rightarrow$ transfer onto YIG

Catalyst-free vapor solid method


BSTS plate (\(\sim\) 1mm size)
$\Rightarrow$ transfer onto YIG

By Dr. Tanabe (Tohoku Univ.)

\[ \text{Au(20nm)} | \text{YIG} \]

\[ \text{Bi}_{1.5}\text{Sb}_{0.5}\text{Te}_{1.7}\text{Se}_{1.3} \text{ plate} \]
(50 nm thick)