Spintronics lecture

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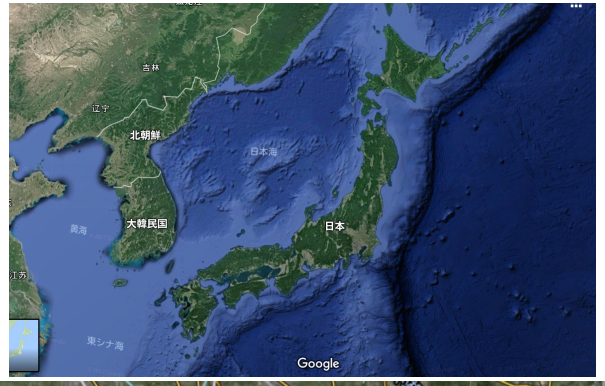
2022/2/22-3/3 Online

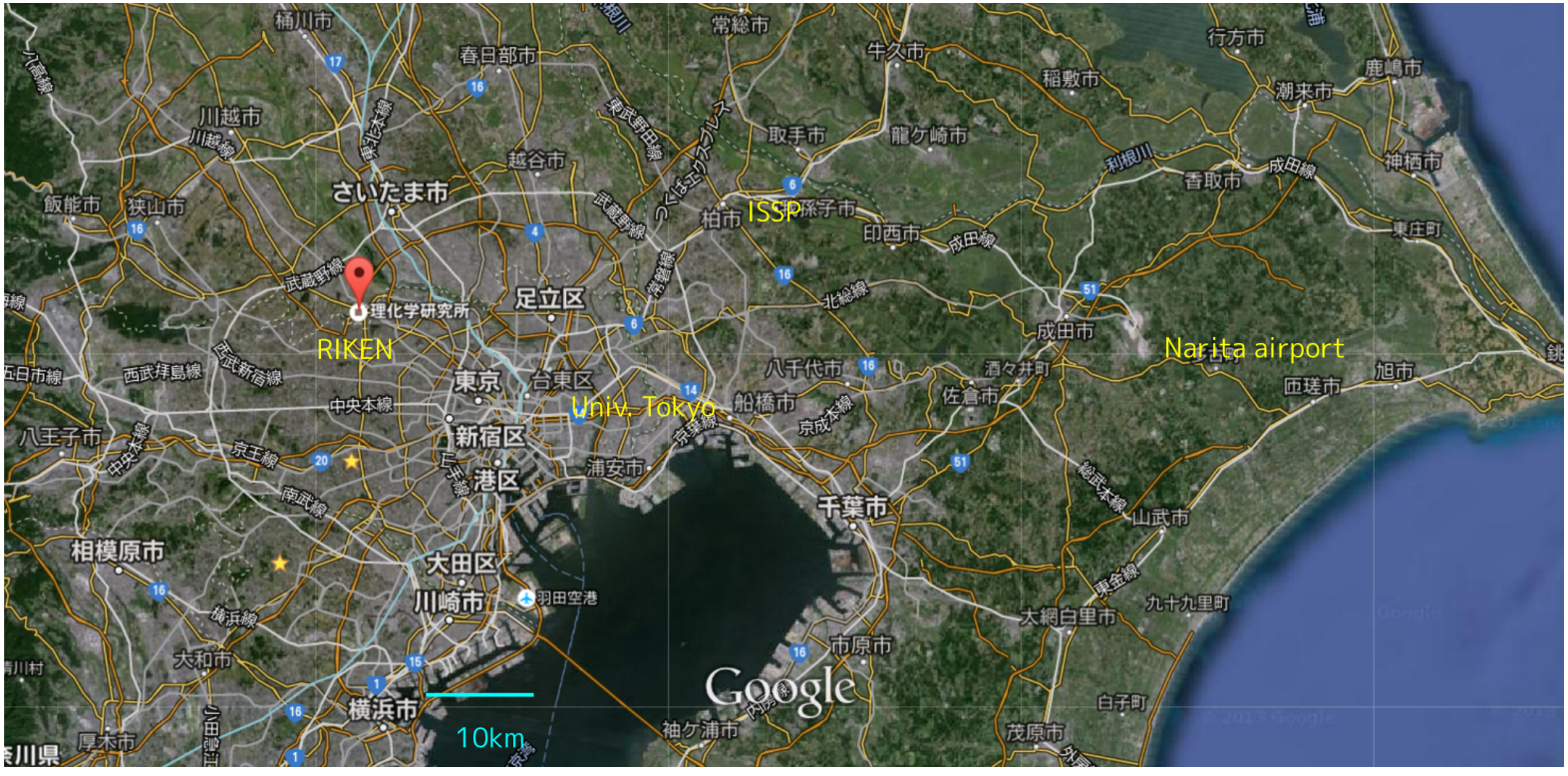
- Introduction to spintronics
- Effective gauge field, Spin Berry phase
- Applications to spintronics

References

- GT, Physica E: Low-Dim.**106**, 208 (2019).
- GT, "Physics of spintronics" (Textbook in Japanese).

- RIKEN　Japanese word meaning research center for science



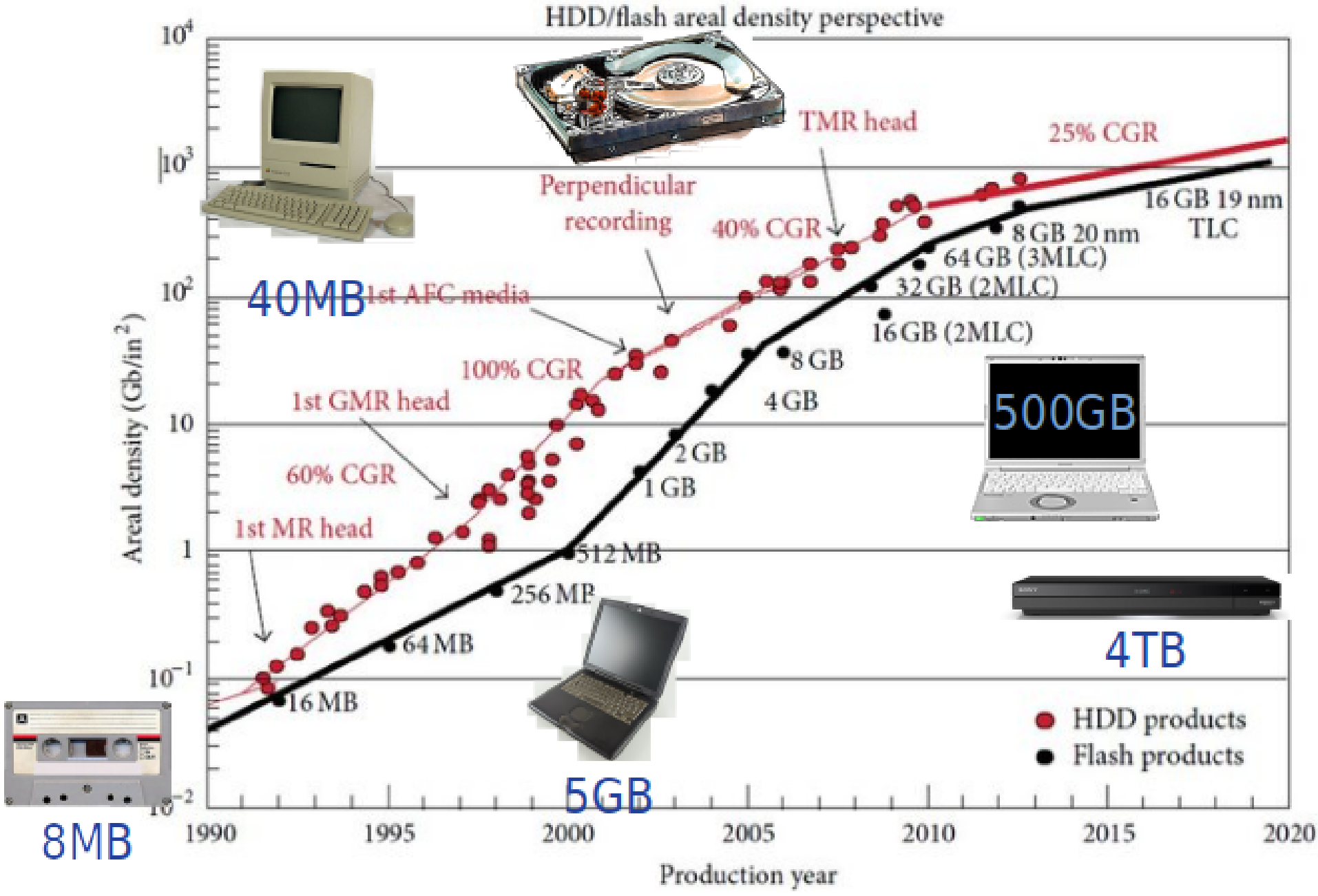


Spintronics

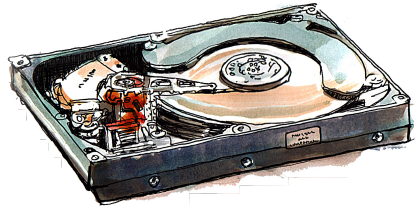
- Nanomagnetism controlled by Electronics
- Electronics controlled by Nanomagnetism

Novel magneto - electric coupling effects

Information technology to date

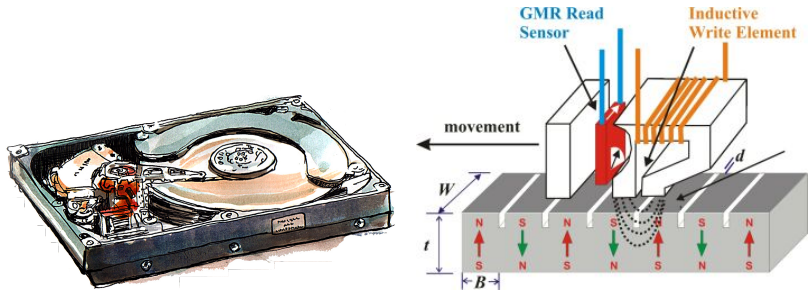


Magnetic recording

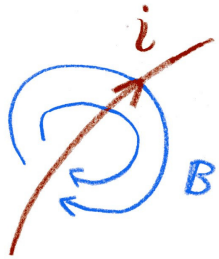


- Large capacity
- High density
- Stable
- Low cost
- Needs ‘electric-magnetic converter

Classical vs spintronics magnetic recording

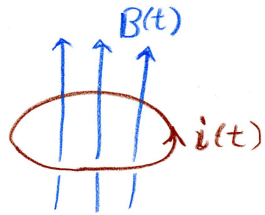


- Classical (Electromagnetic) Write
  Ampère

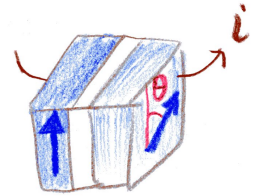


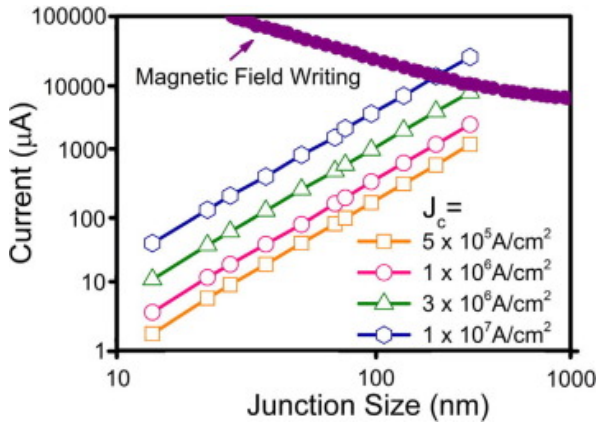
Weak at nano scale

Read
Faraday



⇒ Magnetoresistance
TMR, GMR



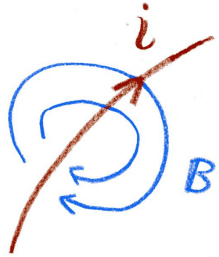


- Weak at nano scale

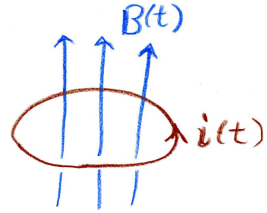
Classical vs spintronics magnetic recording

- Classical (Electromagnetic)

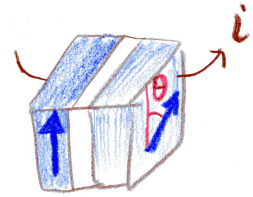
Ampère



Faraday



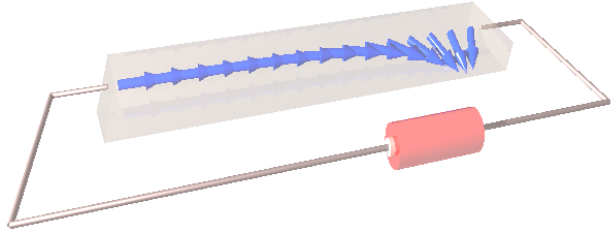
TMR, GMR

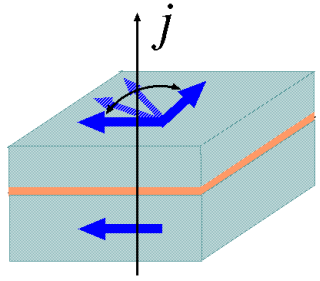


- Spintronics

Spin transfer

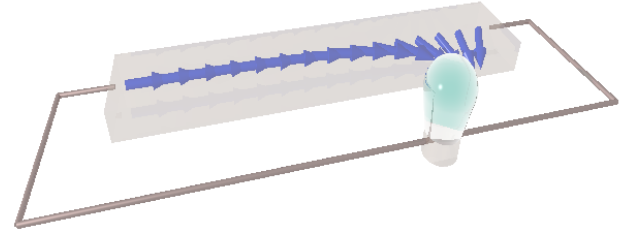
Spin current injection





Spin motive force

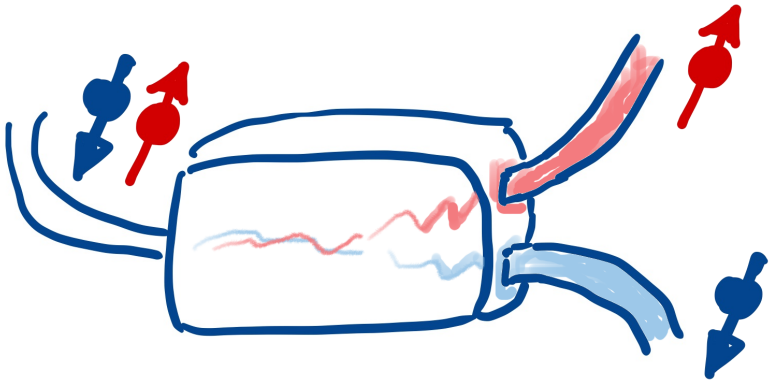
Spin Berry phase



Effective gauge field for spin

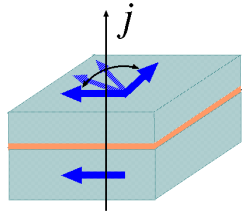
Spin current

Central concept of spintronics



by use of

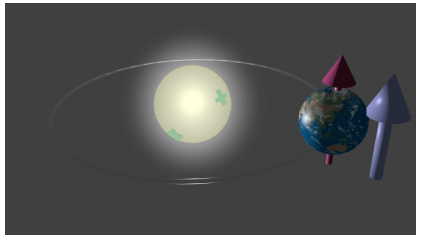
- 2 layers of ferromagnet
- Spin-orbit interaction Quantum relativistic

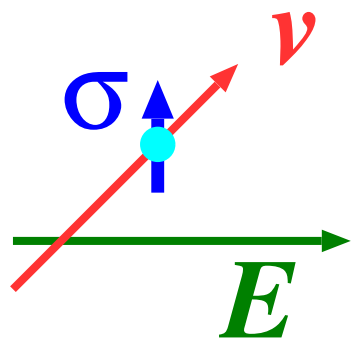


Spin-charge conversion

Spin-orbit interaction　Quantum relativistic interaction

- Electrons around atom
  $v/c \sim \frac{Z}{137}$　Z: Atominc number
  Electrons are relativistic in heavy elements
- Magnetic field B from electric field E of atoms
  $\boldsymbol{B} = -\frac{\boldsymbol{v}}{c} \times \boldsymbol{E}$　Special relativity
  ⇨ Electric field in solids couples to spin $\boldsymbol{\sigma}$
  $H_{so} = \lambda \boldsymbol{E} \cdot (\boldsymbol{v} \times \boldsymbol{\sigma})$
  Electron spin couples to orbital motion
- Strong in heavy elements　Pt, Bi, Rare earth

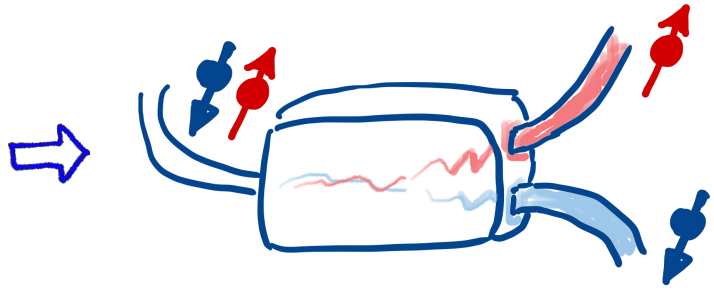




Spin Hall effect

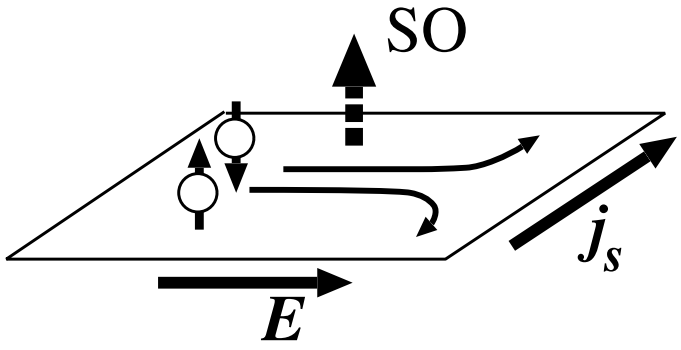
Spin-charge conversion

Spin-orbit interaction ⇨ Spin-dependent scattering of electron



Spin-charge converter

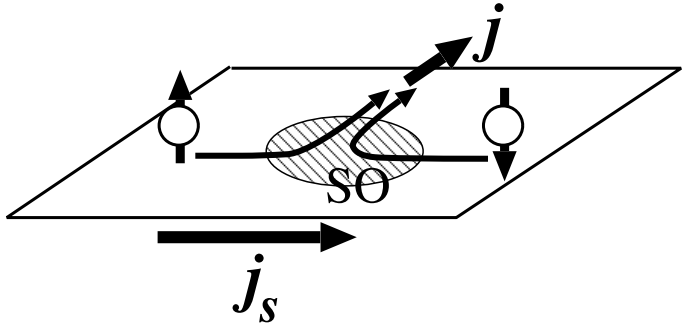
- Spin Hall effect



$j_s = \lambda_{sh} j$

Generate spin current j_s
from electric current j (or field E)

- Inverse spin Hall effect



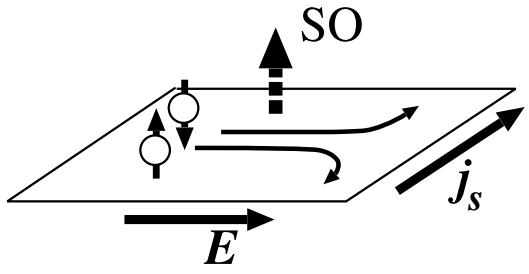
$j = \lambda_{ish} j_s$

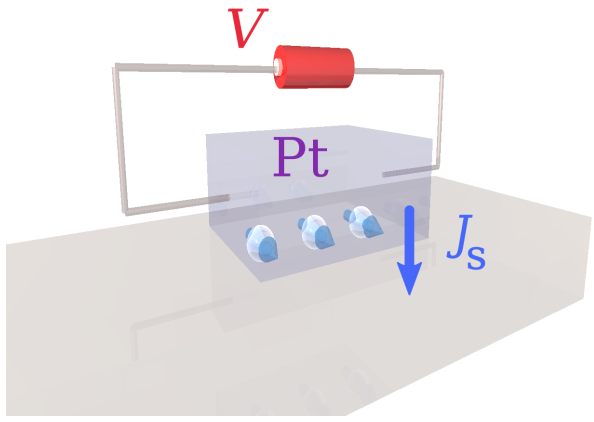
Spin-charge conversion

Simple to realize : Just a heavy metal contact Pt

- Spin Hall effect

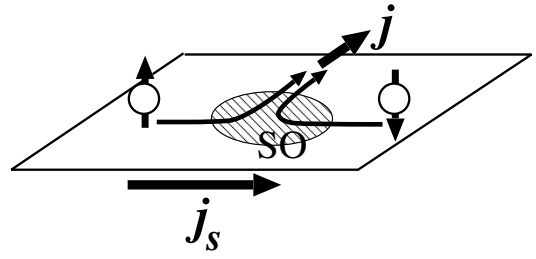
$$j_s = \lambda_{sH} j$$

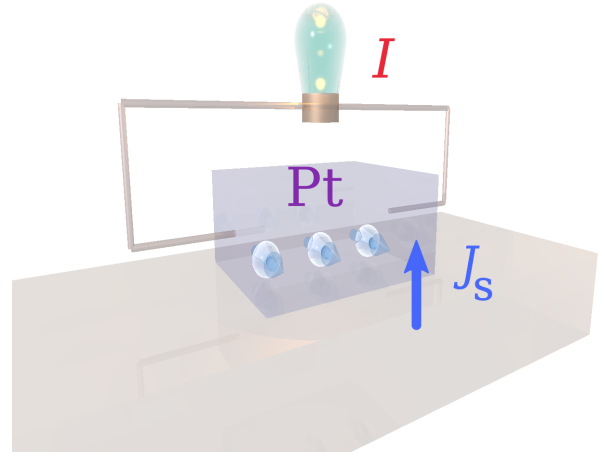




- Inverse spin Hall effect

$$j = \lambda_{isH} j_s$$





Spin-charge conversion

Simple to realize : Just a heavy metal contact Pt

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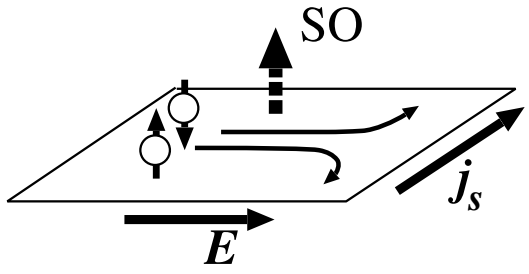

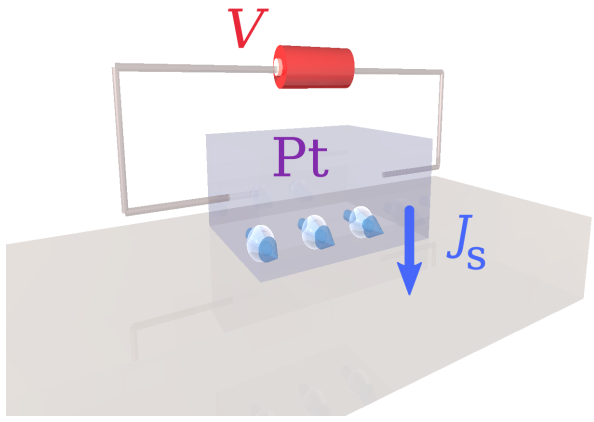

- Inverse spin Hall effect

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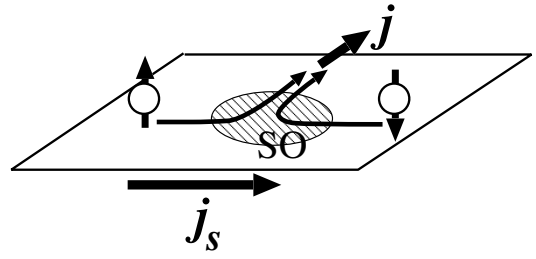
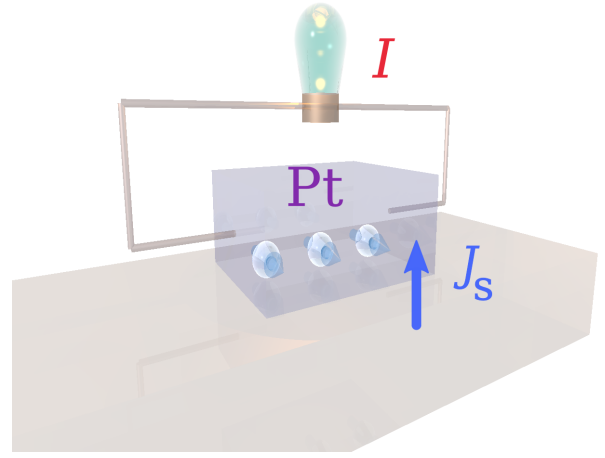
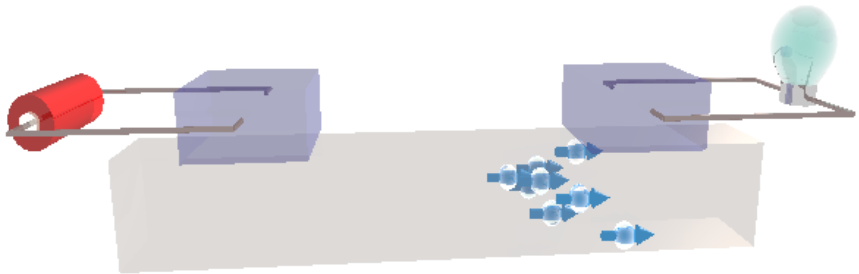


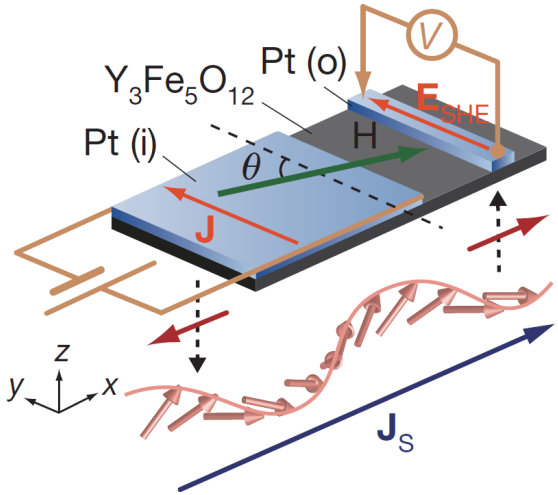


Spin-charge conversion : Applications

- Nonlocal transmission of electric signal
  Spin Hall + Inverse SH

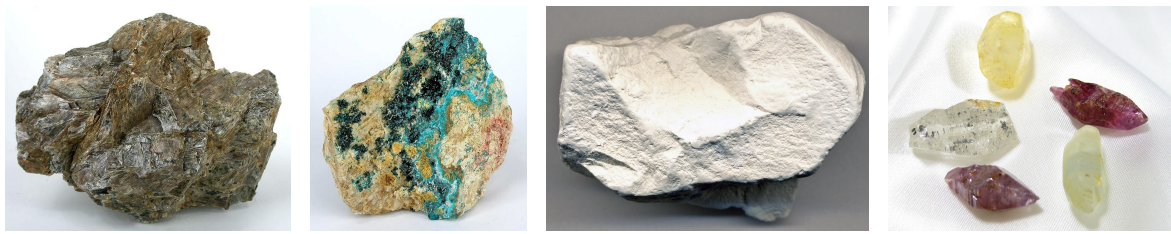


- *Kajiwara, Saitoh et al. Nature 464, 262 (2010).*



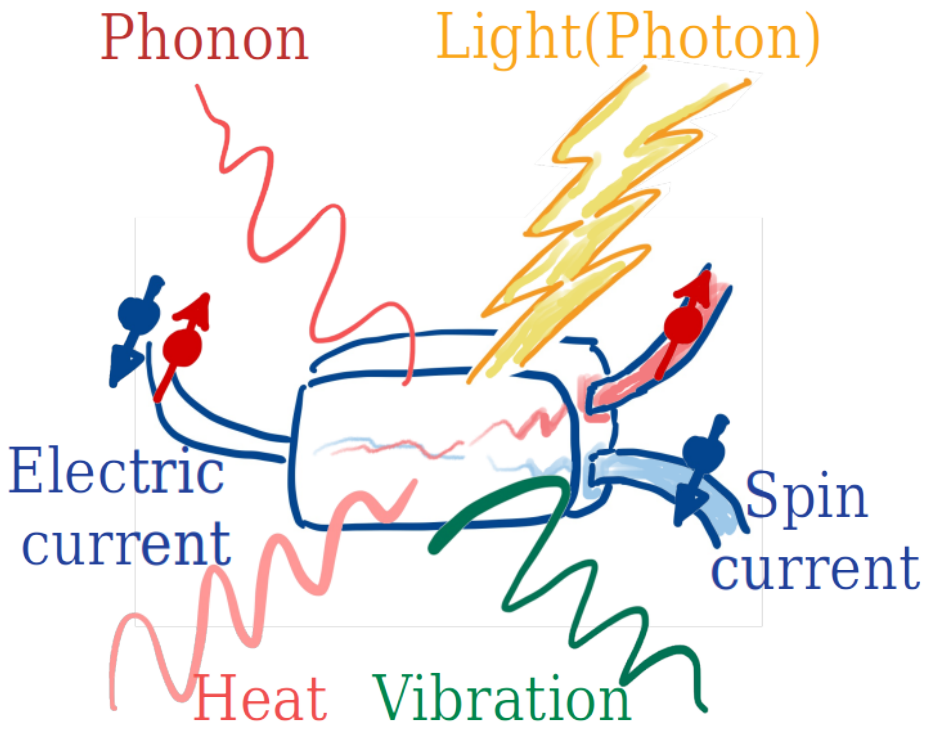
Signal through insulator

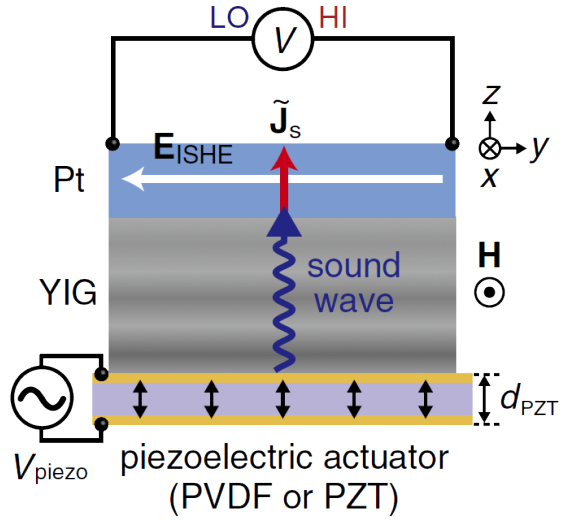
- Many spin current conductors
  Metal, Insulator, Antiferromagnet · · ·



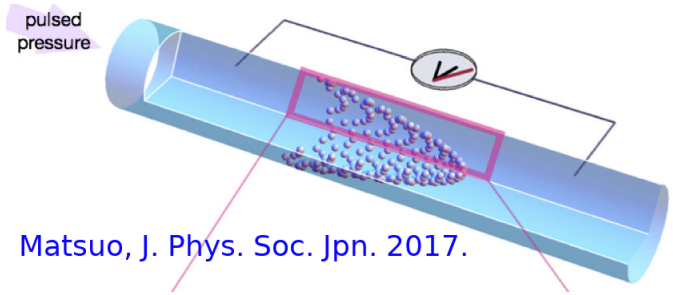
Can be used for signal transmission

More conversions

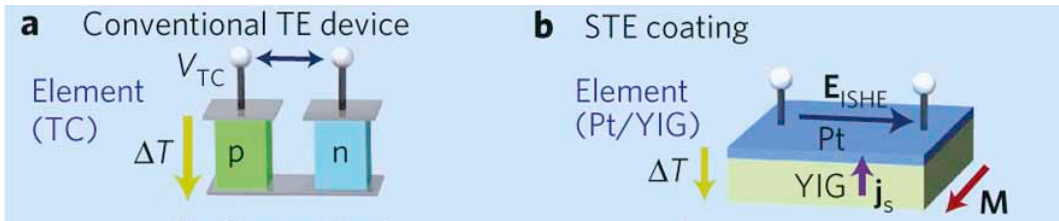




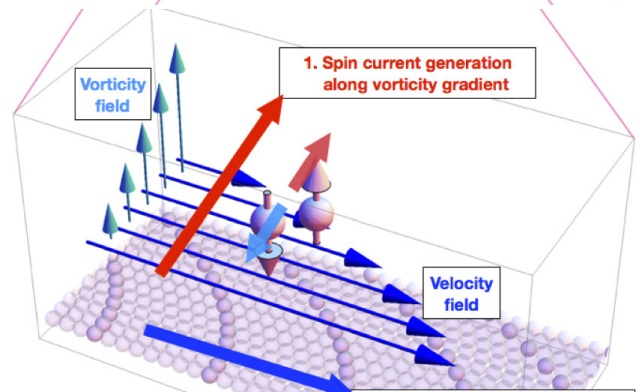
Uchida, Nature Mater. 10, 737 (2011)



Matsuo, J. Phys. Soc. Jpn. 2017.

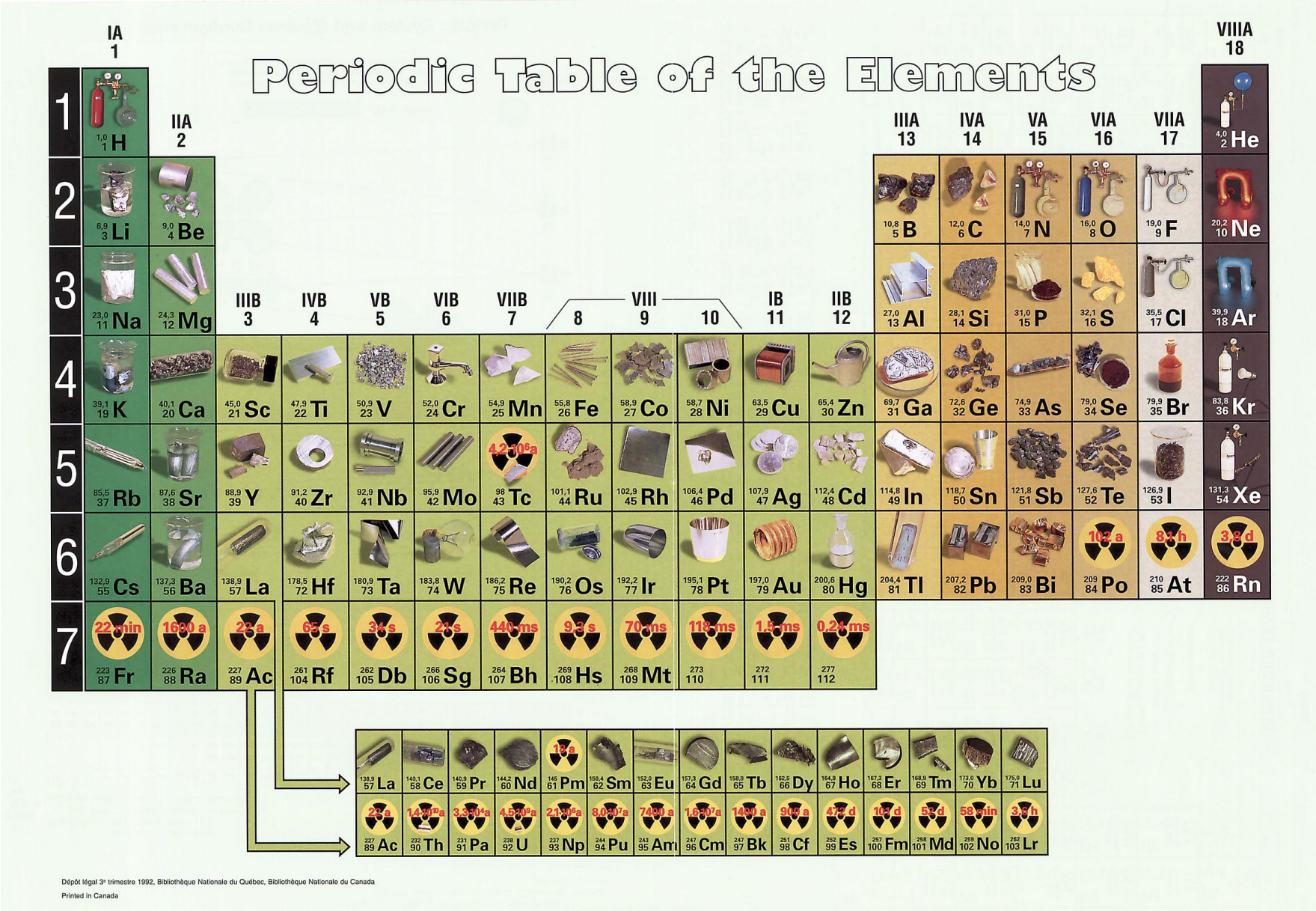


Kirihara, Saitoh, Nature Mater. 11, 686 (2012)



For high efficiency

- Strong spin-orbit interaction Heavy elements Pt, Au, Bi
- Rare metals may be useful Nd magnet NdFeB with Dy

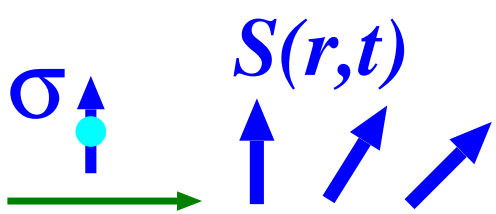


Dépôt légal 3e trimestre 1992, Bibliothèque Nationale du Québec, Bibliothèque Nationale du Canada
Printed in Canada

Gauge field in spintronics

Spin + Electronics

- Main player : conduction electron spin
  Electron spin σ interacting with localized spin $\boldsymbol{S}(r,t)$ (magnetization)

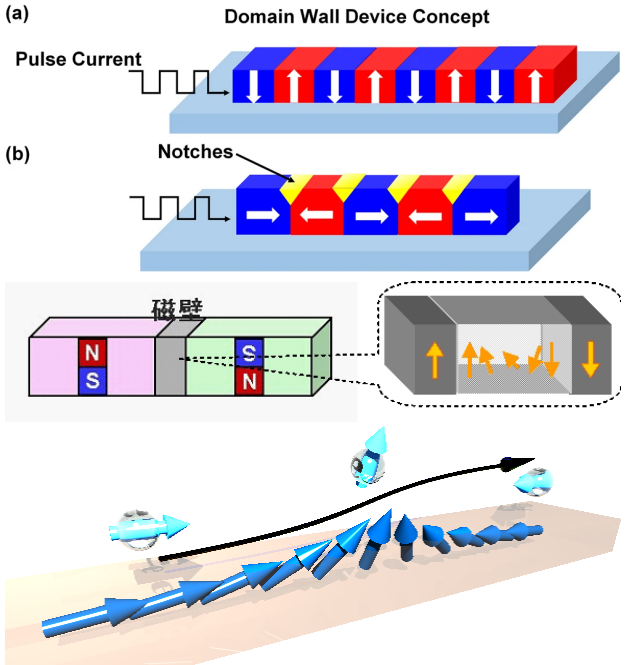


⇨ Unitary transformation

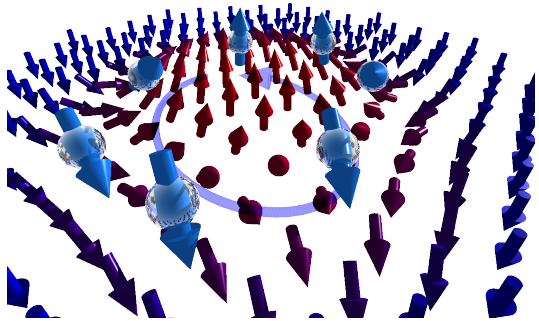
Electron spin with effective gauge field

- Non-trivial effect emerges from magnetization spin structures

- Domain wall

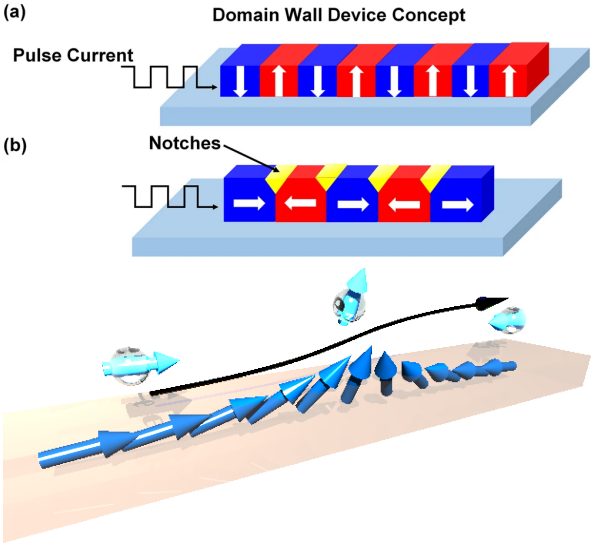


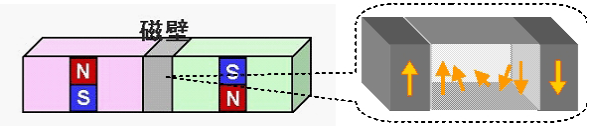
- Magnetic Skyrmion



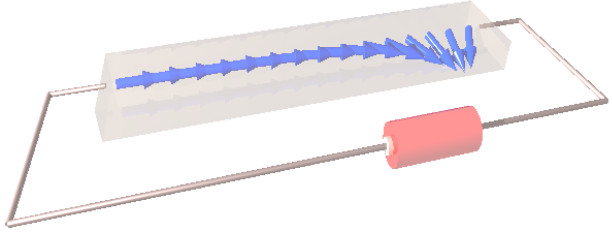
Gauge field in spintronics

- Non-trivial effect emerges from magnetization spin structures
  - Domain wall



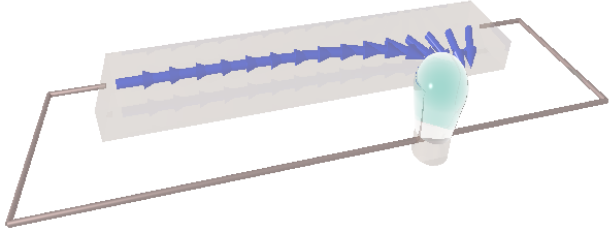


- DW 'pushed' by electron



Write information by current

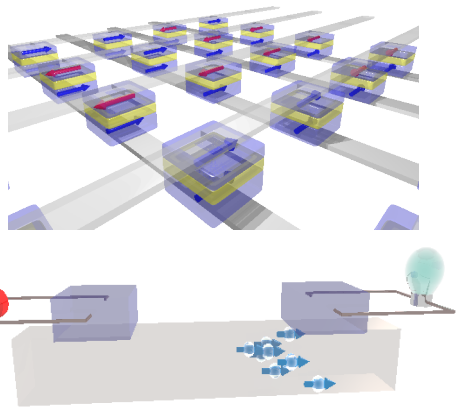
- Electron pushed by DW

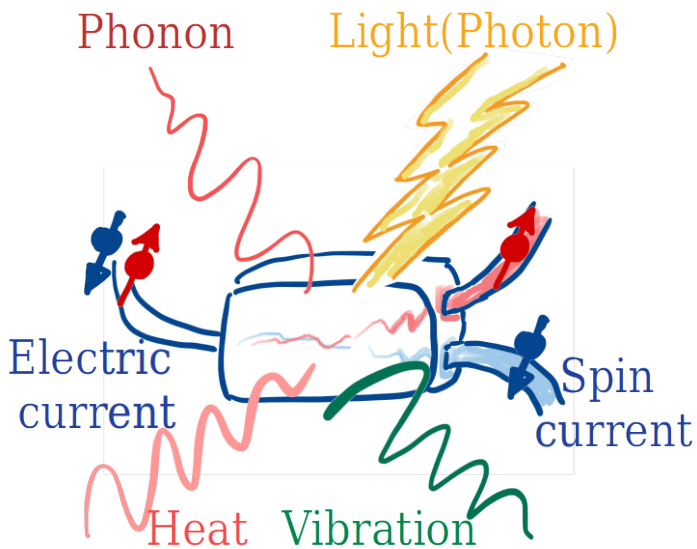


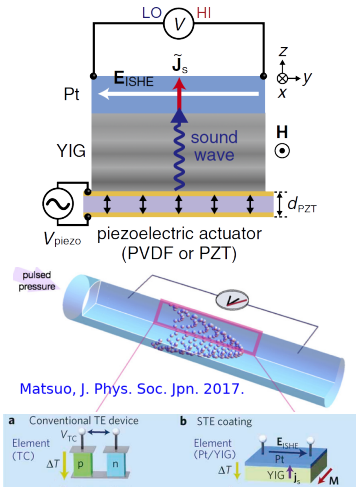
Read information, Spin battery

Summary

- Spintronics
  - Manipulation of spin
  - Conversion from/to electric current, light, heat, vibration $\cdots$
  - Novel devices To appear
- Heavy elements are essential Pt
  - Strong spin-orbit interaction Quantum relativistic effect







References

- GT, Physica E: Low-dim.**106**, 208 (2019). (Review, Gauge theory for spintronics)

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International programs of RIKEN

- International Program Associate (IPA)

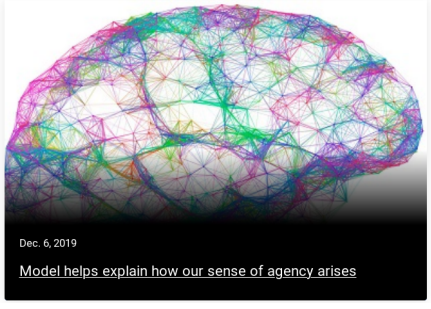
  https://www.riken.jp/en/careers/programs/ipa/

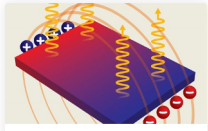
  - Ph.D students stay at RIKEN for research
  - 3 months to 3 years
  - RIKEN covers all and some salary
- Post doc and researcher positions
  - Special Postdoctoral Researchers Program (SPRP)

    https://www.riken.jp/en/careers/programs/spdr/
- My group

  Theoretical study of condensed matter, spintronics, plasmonics, etc.

  Please contact gen.tatara@riken.jp




Dec. 6, 2019

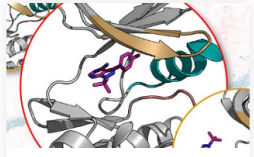
Exciplex emission observed over much longer distances than previously thought possible


Dec. 6, 2019

The genome and transcriptome of the parasitic plant *Striga* have been sequenced


Nov. 29, 2019

Extending associative memory through inhibitory circuits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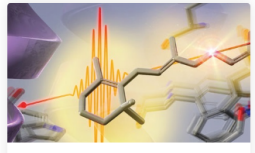
Faster modeling of interactions between ligands and proteins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Protein changes precede photoisomerization of retinal chromophore


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Stretchable, highly conductive film promising for wearable electronics