Thermal Spin Current from a Ferromagnet to Silicon by Seebeck Spin Tunneling

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Kang, Byeongki

Ref.: J.C. Le Breton, S. Sharma, H. Saito, S. Yuasa, R. Jansen, Nature **475**, 82 (2011)

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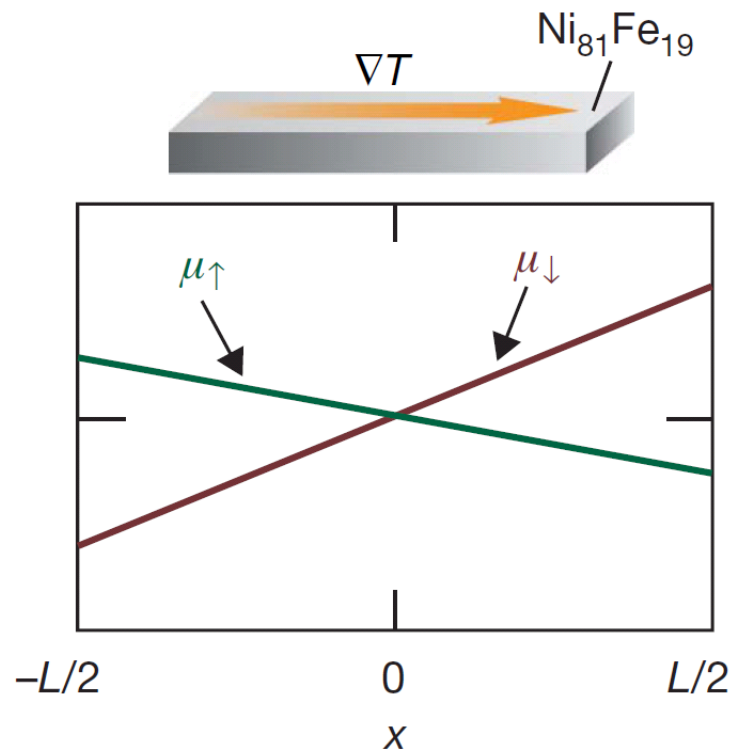- Discussion of Physical origin
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Seebeck Effect

- Temperature gradient makes electrical voltage difference : S = $\Delta V / \Delta T$
- Electric thermometer

Thermocouple
Metal A
Metal B
E
E
V
T_1
T_2
∇T
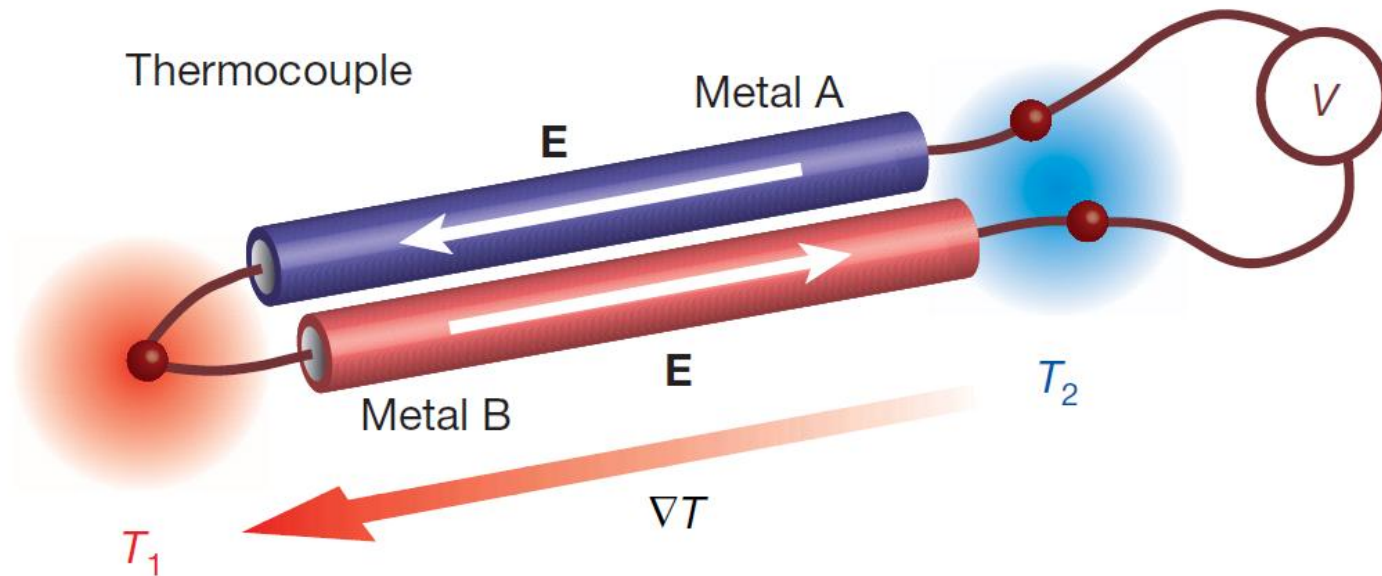
Spin Seebeck Effect

- Different Seebeck Coefficients for spin up and down electrons

Spin Seebeck Tunneling
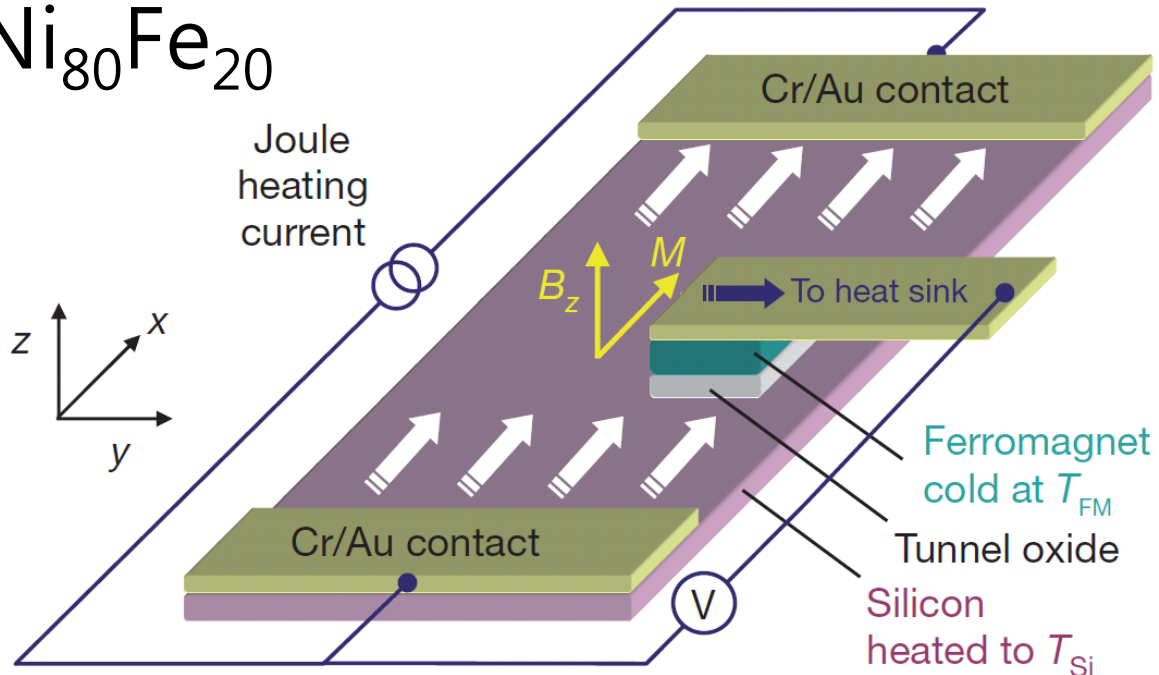
- Temperature difference makes spin tunneling

$T_{FM} > T_{Si}$

$T_{Si} > T_{FM}$

Ferromagnet — Hot

Tunnel oxide

Cold

Silicon

Ferromagnet — Cold

Tunnel oxide

Hot

Silicon

Spin polarization induced by Seebeck spin tunnelling
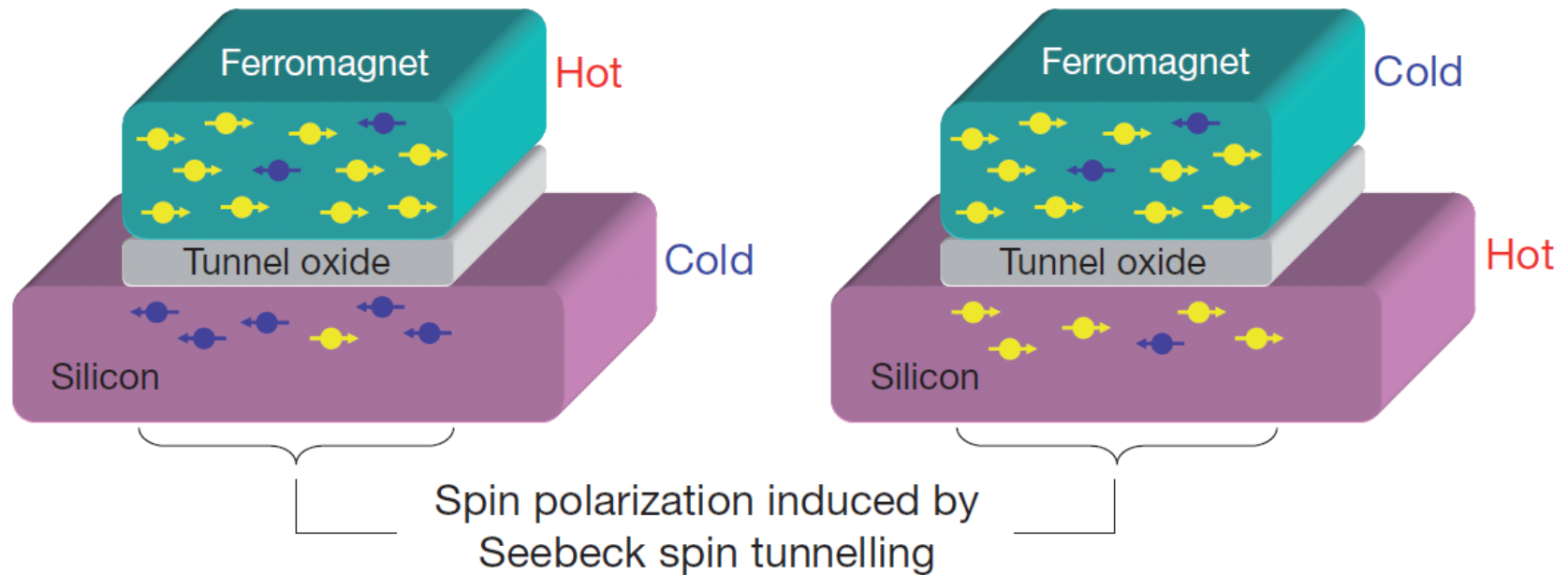
Experiment

- Hanle Geometry
- Si: 4mm X 0.8 mm X 3μm
- Oxide: SiO_2/Al_2O_3 (1.5nm thick)
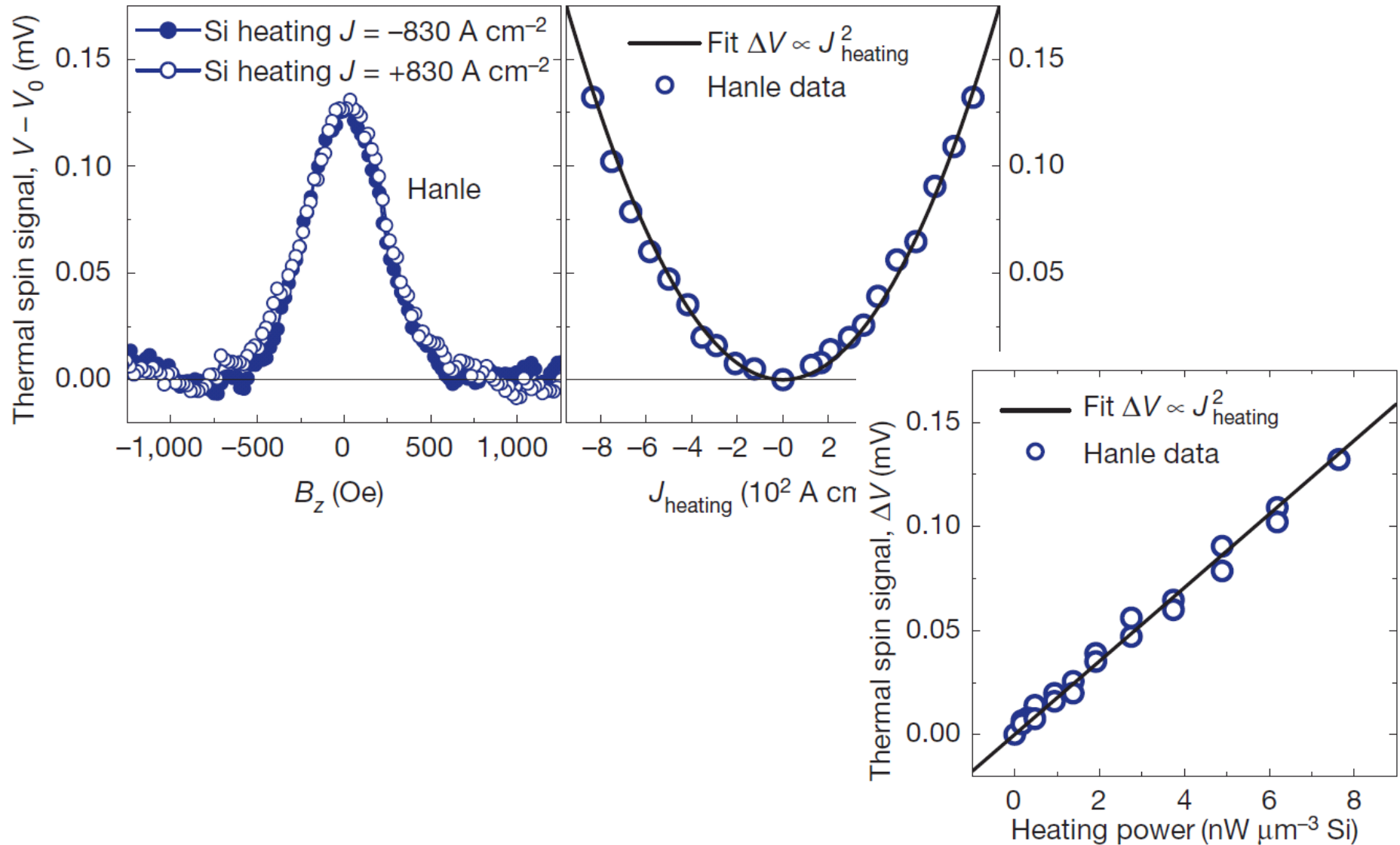- Ferromagnet: $Ni_{80}Fe_{20}$

Experiment

- $V = V_{Si} - V_{FM} = V_0 + \Delta V$
  - V_0: Ohmic voltage drop, ordinary thermovolatge
  - ΔV: Seebeck spin tunneling voltage $\propto \Delta\mu$
  - J: Joule heating current
- B_z: spin precession, reduction of $\Delta\mu$
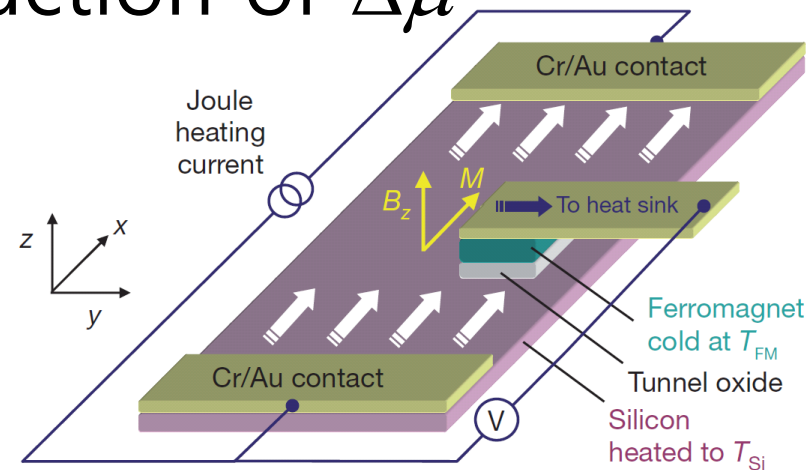
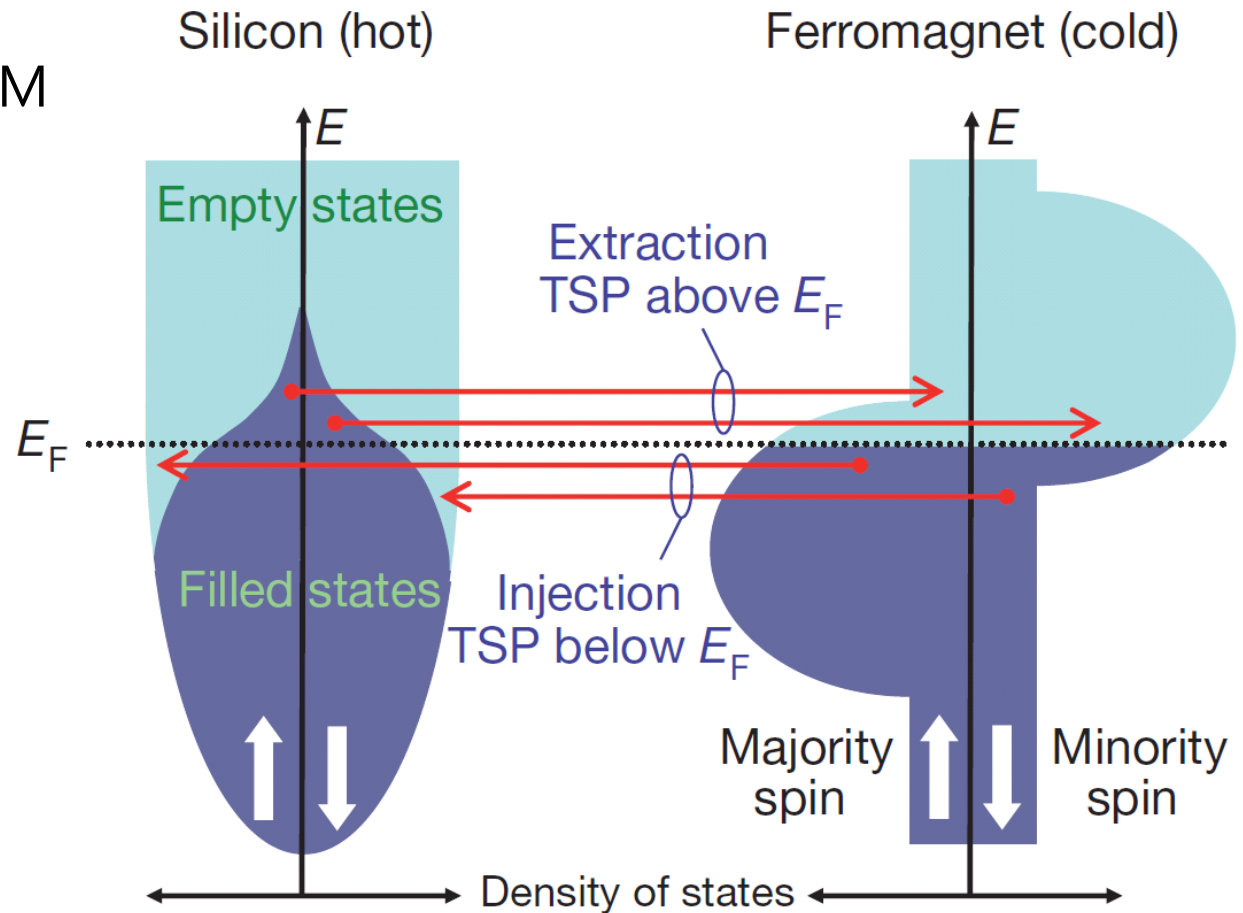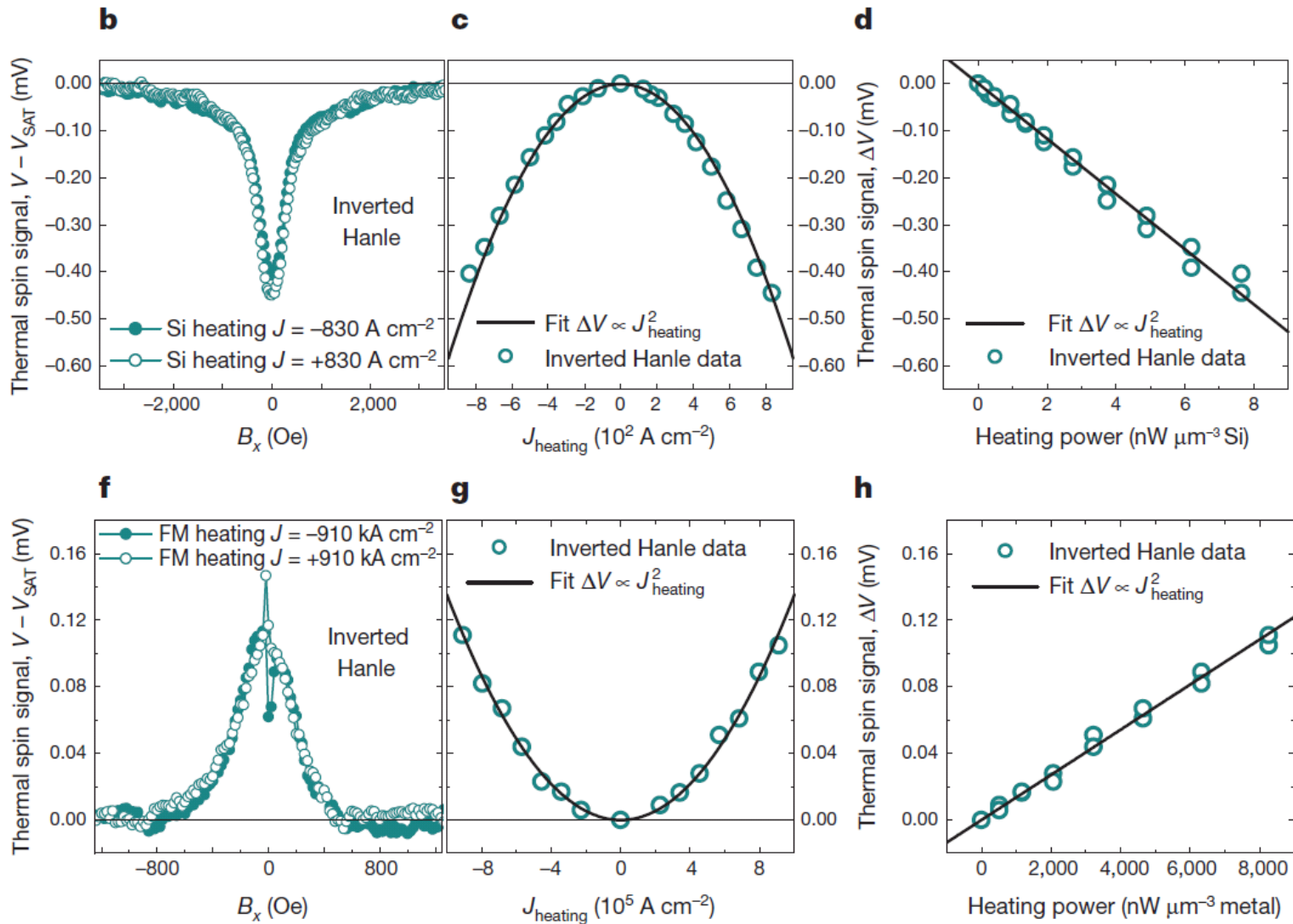# Experimental results

Origin of spin Seebeck tunneling

- No tunnel charge current
- For $T_{Si} > T_{FM}$

Silicon (hot)   Ferromagnet (cold)

Empty states

Extraction TSP above E_F

Injection TSP below E_F

E_F

Filled states

Majority spin   Minority spin

Density of states

Result (invert Hanle effect)

Summary

- Seebeck spin tunneling
  at ferromagnet-oxide-silicon

- Thermal spin current with voltage
  difference but no net charge current