Empowered by Innovation

NEC

東北大学

# Development of Technology for Increasing Reliability of Logic Circuit Components

## Broadening applications of spintronics logic integrated circuits

June 12: Session 7-4

Spintronics Primitive Gate with High Error Correction Efficiency $6(P_{error})^2$ for Logic-in Memory Architecture

**June 11, 2012**
**NEC Corporation**
**Tohoku University**

# Concern About Existing Electronics Equipment

- Growing power consumption of electronic equipment after growth of cloud computing and smartphones
- Tight power supply after the Great East Japan Earthquake
- Equipment should be powered off while not in use, but …

→ The startup process is time-consuming

→ Equipment is kept powered on during standby in order to maintain data

**Concern about increase in standby power consumption in line with increase in equipment**

**Hope is placed on non-volatile logic integrated circuits based on spintronics technologies**

# Examples of Standby Power Consumption of Electronic Equipment

## Desktop computer

Approx. 2.4 W in sleep mode

Approx. 37 W in e-mail editing process

## Television

Approx. 0.1 W in standby mode

Approx. 18 W at maximum if quick start is enabled

In the office and at home,
many different appliances consume power on standby.

# Spintronics Logic Integrated Circuits with Non-Volatile Features

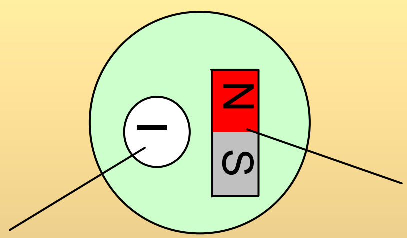
- Non-volatile: Data retained without power supply
- Spintronics (spin + electronics):

  Technology capitalizing on the spin of electrons (a characteristic of magnets) and negative electric charge

  → Applied to logic integrated circuits as data storage devices

  ( = Non-volatile spintronics logic integrated circuits)
- Achieving massive cuts in power consumption and performance improvement without limits on rewrite cycles

Characteristic of electrons




Spin of fine magnet

Negative electric charge

Conventional electronics used the electric charge alone

# Concept of Future Application in Electronic Equipment



- In many electronic appliances, integrated circuits remain powered on even in standby mode.
  - ➔ Unplugging is necessary to save power.
  - ➔ Power-saving electronic equipment with no need to unplug can be created.
- Integrated circuits currently remain powered on when they are idle for as long as the device is in operation.
  - ➔ A technology of powering off integrated circuits in operation while they are not being used
  - ➔ Optimal power-saving electronic equipment can be created.
- Ultra-low power consumption computers that immediately start up and are ready to use
- LCD televisions without standby power consumption despite their quick startup

**Toward creating information equipment without standby power consumption and that can immediately be used**

# Problems with Conventional Spintronics Logic Integrated Circuits



## Problem of reliability unique to non-volatile circuits:

Low-probability occurrence of errors in failing to correctly store computation result data

(Causes: cosmic rays, high- or low-temperature heat, voltage or current fluctuations in the writing process, etc.)

## Application of conventional reliability improvement method

Past designs cannot be reused → Higher design costs

Resulting chip will be larger in size → Higher manufacturing costs

**Barriers to enlarging applications**

*The chip size may be 25% larger if it has a cyclic circuit or 200% larger with a non-cyclic circuit.

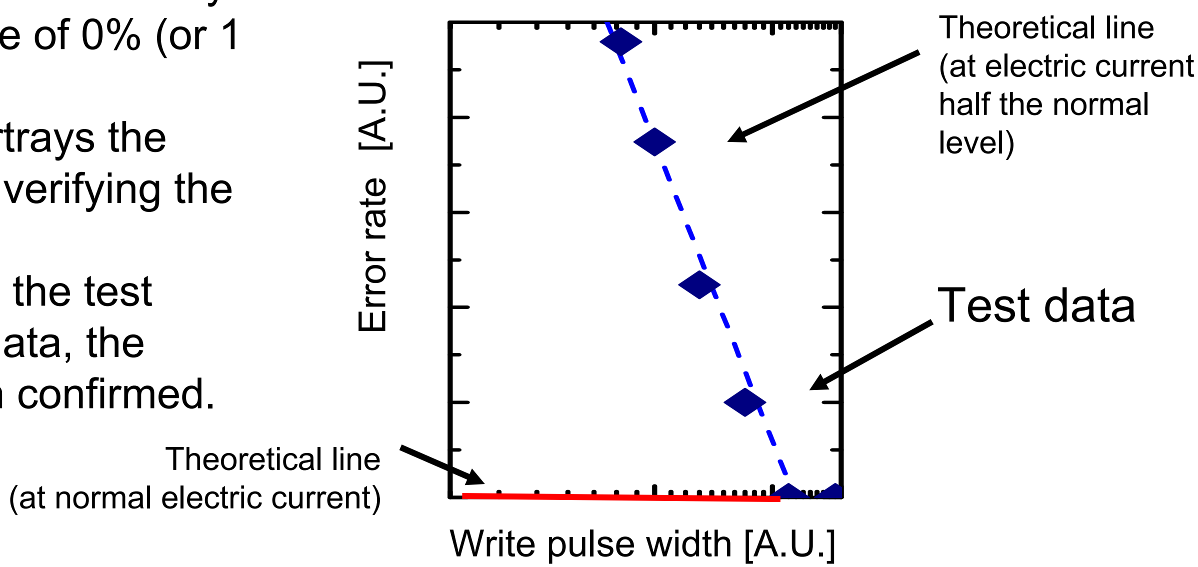
Empowered by Innovation NEC

# Achievements of the Study

1. A number of spin devices that temporarily store computation results are mounted on a circuit component of a spintronics logic integrated circuit for multiplexing purposes.
   → Multiplexed spin devices serve to correct errors to achieve high reliability in the circuit.
2. The circuit component embedded with spin devices supports automatic placement and routing technology for programmed design of transistors.
   → This paves the way for designing non-volatile circuits by conventional methods without knowledge about the spin.

**World's first chip is prototyped and its operation is verified**

1. The technology developed in this study in principle has an error rate of 0% (or 1 ppm or less).
2. The diagram on the left portrays the results of the test aimed at verifying the theory.
3. Since the data gained from the test agree with the theoretical data, the theory stated in 1 has been confirmed.

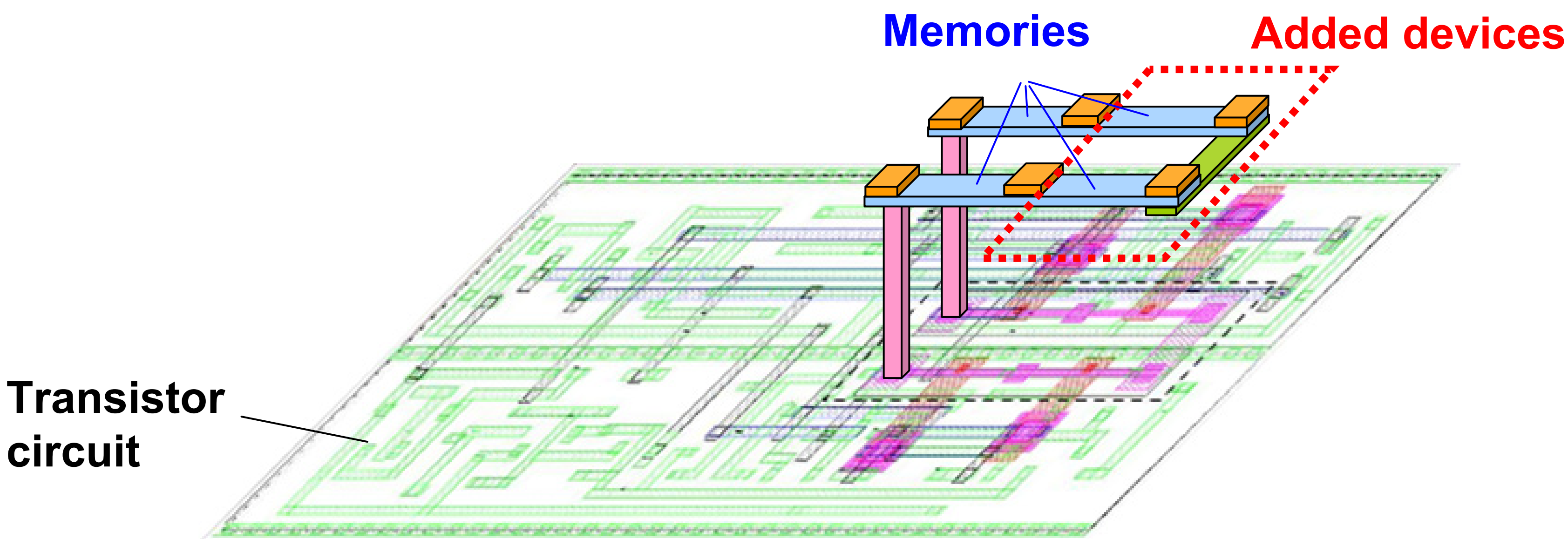


# Feature 1: High-reliability Non-Volatile Logic Integrated Circuit

- Spin devices (domain wall devices) are serially connected for multiplexing.
  → Two spin devices are added (multiplexed) to two other spin devices to correct errors and improve reliability.
- Spin devices are stacked over transistor devices.
- Multiplexed devices are serially connected.

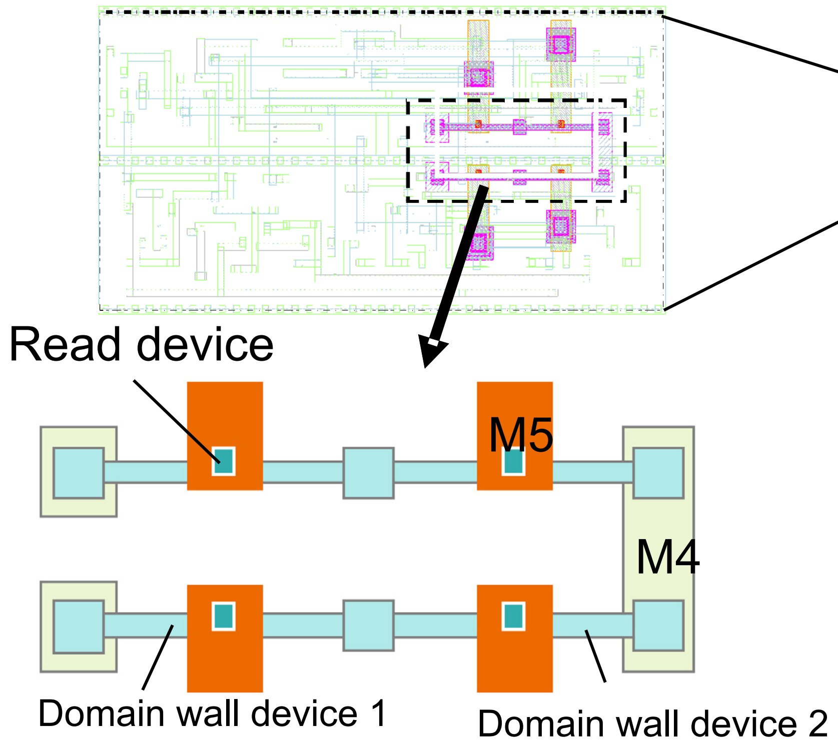
→ No increase in area

- The serial connection results in no increase in writing current or time.




**Reliability is increased by multiplexing of devices with no area increase.**

# Feature 2: Circuit can be designed without knowledge about spin




Logic circuit component developed by improving reliability of the D-type flip flop circuit that was made non-volatile

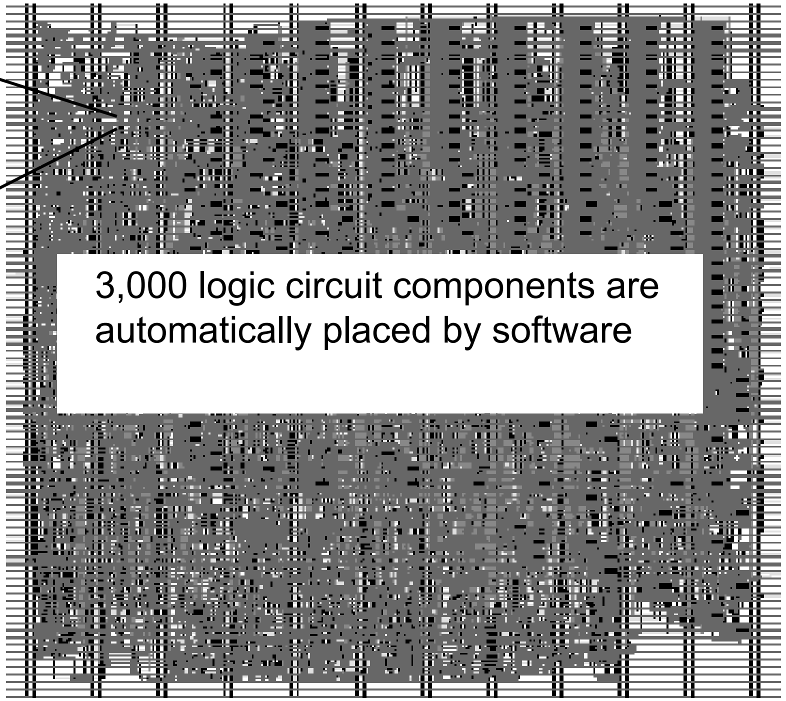



Diagram of design layout of a processor core

**Non-volatile logic circuits can be designed by the conventional design method.**

Empowered by Innovation NEC

# Summary and Future Outlook

東北大学

- World's first verified technology to increase reliability of non-volatile logic circuits that allows reuse of design assets
- Spin devices (domain wall devices) are multiplexed to improve reliability without increase in area
- Technology supports existing circuit design tools, including automatic placement and routing
- Chosen in FY2009 as a subject under the Funding Program for World-Leading Innovative R&D on Science and Technology (FIRST Program) operated by the Cabinet Office. NEC participated in this program.
- Research and development efforts target early commercialization of spintronics logic integrated circuits.

Part of the achievements from research activities on energy-saving spintronics logic integrated circuits under the Cabinet Office's FIRST Program

Empowered by Innovation

NEC

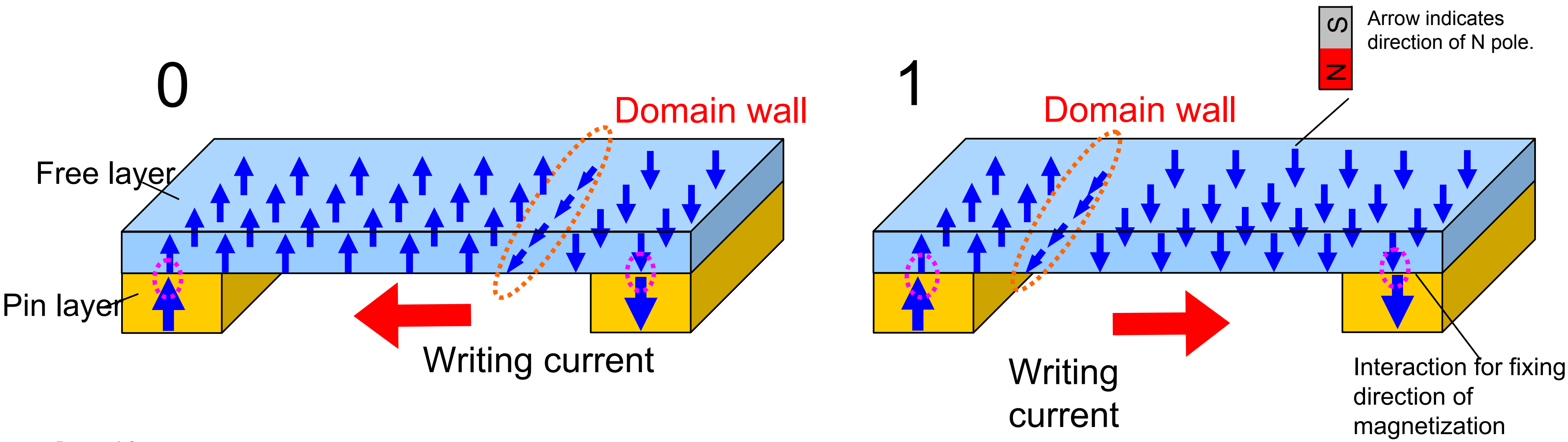
# Reference: Vertical Domain Wall Devices

## Vertical Domain Wall Devices

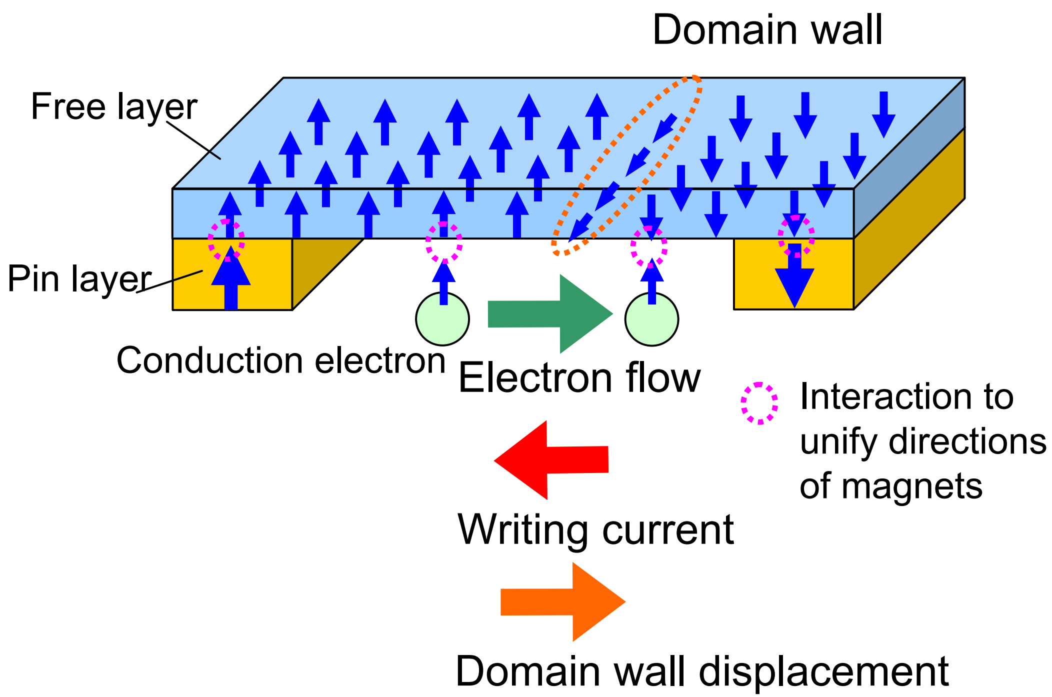
- The free layer fine magnets are a group that tends to face in the same direction.
- The free layer is fixed at both ends with pin layers (powerful magnets) in opposite directions.
  ➔ This forms a domain wall, or an area where the direction of fine magnets sharply changes.
- Spin torque, or interaction between electrons, moves domain walls. Depending on their positions, a data value of 0 or 1 is stored.
- CoNi, a material that turns the fine magnets in the vertical direction, is used.
  → The writing current can be reduced.

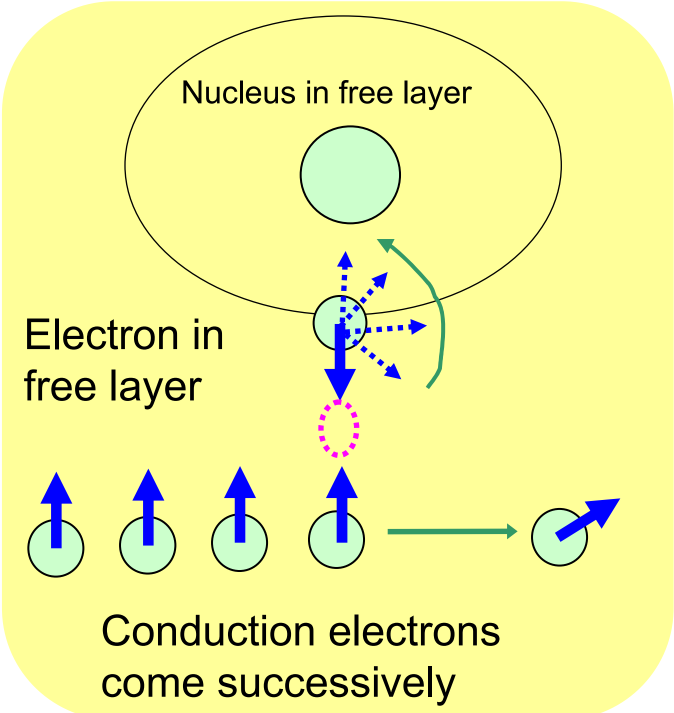
Features:

1) Low writing current of 0.2 mA or less
2) High writing speed at 5 ns or less



# Reference: Spin Torque – Action that moves domain walls



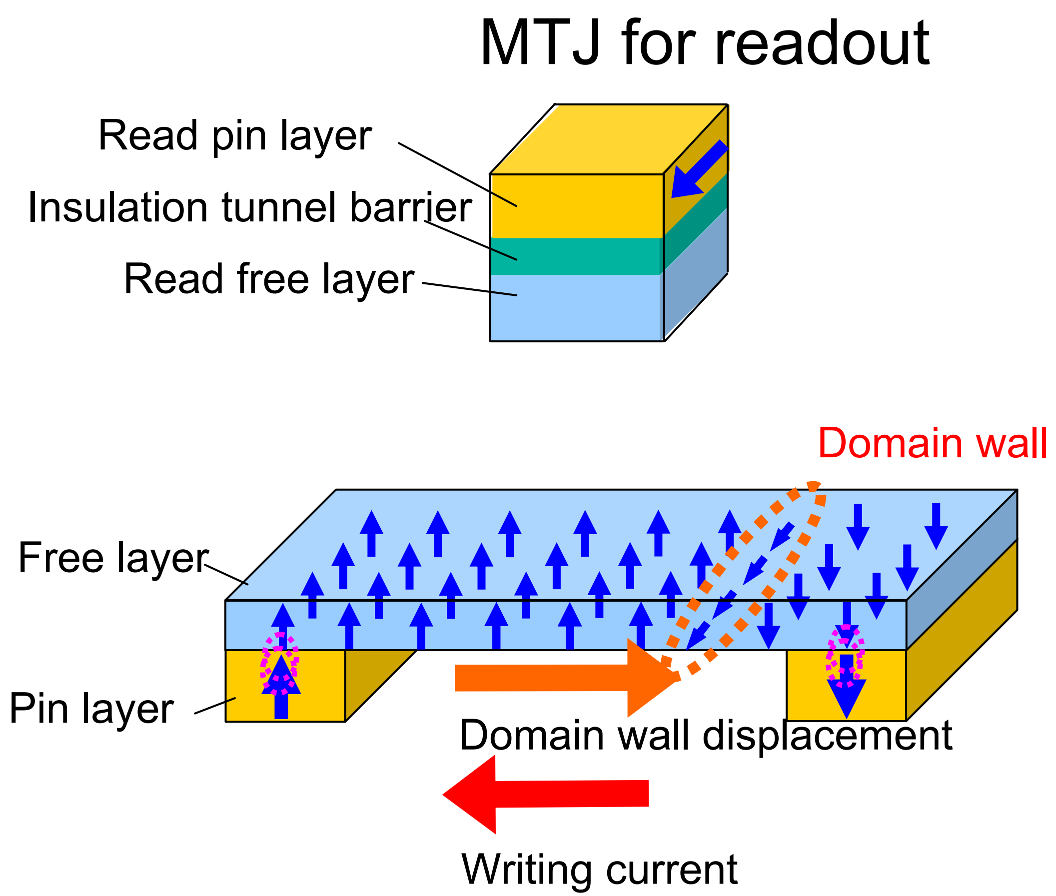

- Conduction electrons are also fine magnets. Their interaction with fine magnets in the free layer unifies the magnets' directions. This action is called spin torque.
  - ➔ Domain walls move in the same direction as the electron flow.
- Devices can be downsized using spin torque, as an action of individual electrons.

# Reference: Principle of Behaviors of Vertical Domain Wall Devices (1)



## Writing a data value of "0":

The writing current displaces the domain wall to change the magnetic field generated.



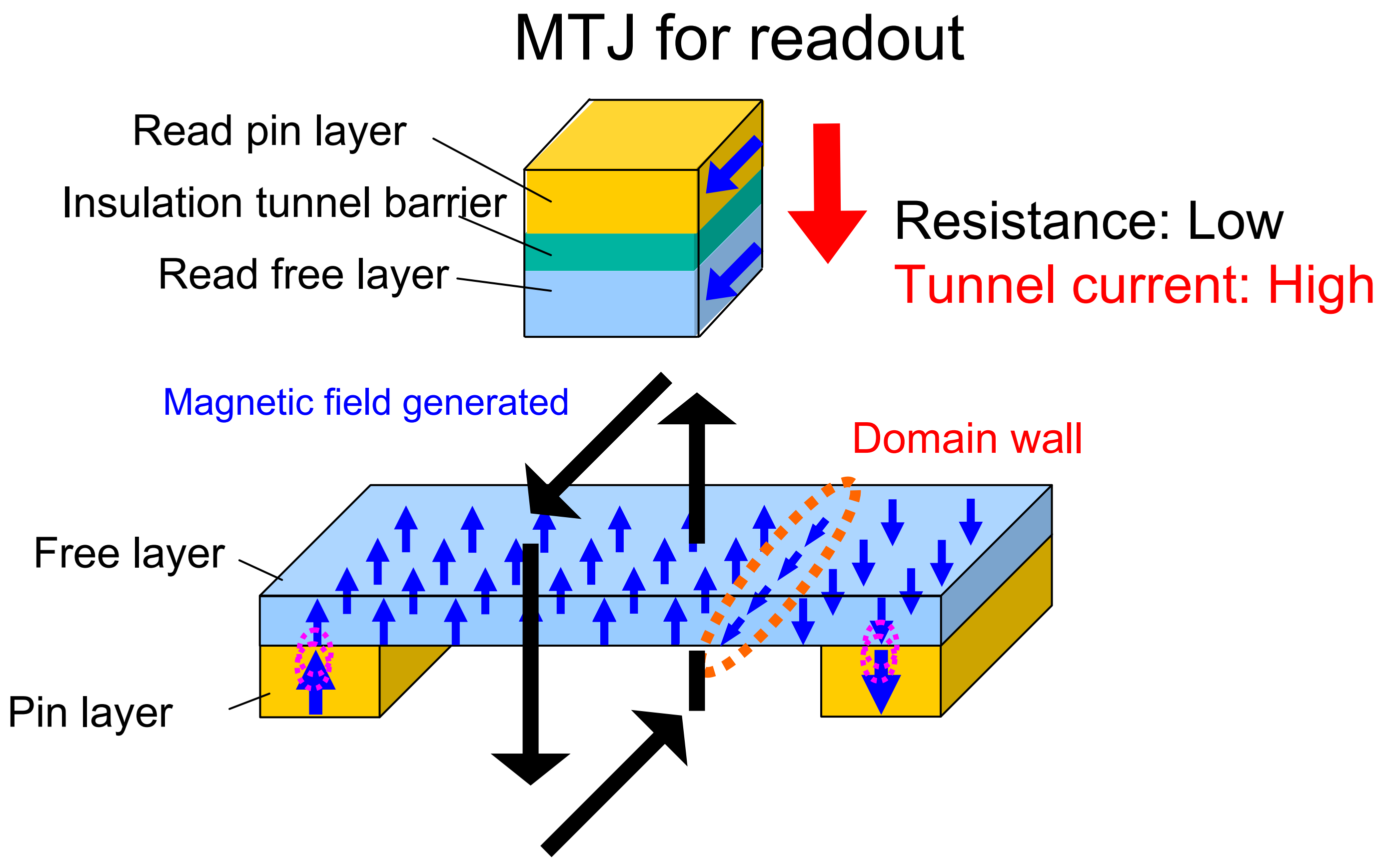

**MTJ** = Magnetic Tunnel Junction

# Reference: Principle of Behaviors of Vertical Domain Wall Devices (2)



## Reading a data value of “0”:

The resistance value of the MTJ that reacts to the magnetic field generated is read.




**MTJ** = Magnetic Tunnel Junction

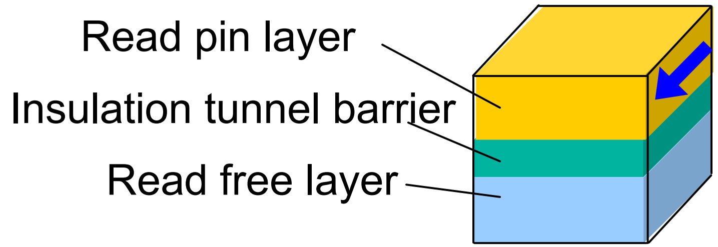
# Reference: Principle of Behaviors of Vertical Domain Wall Devices (3)

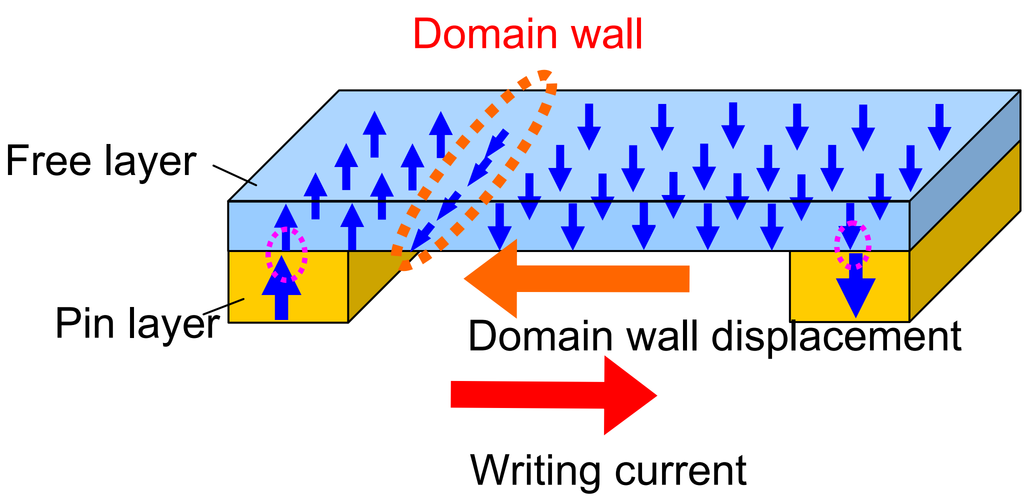


## Writing a data value of “1”:

The writing current displaces the domain wall to change the magnetic field generated.

### MTJ for readout



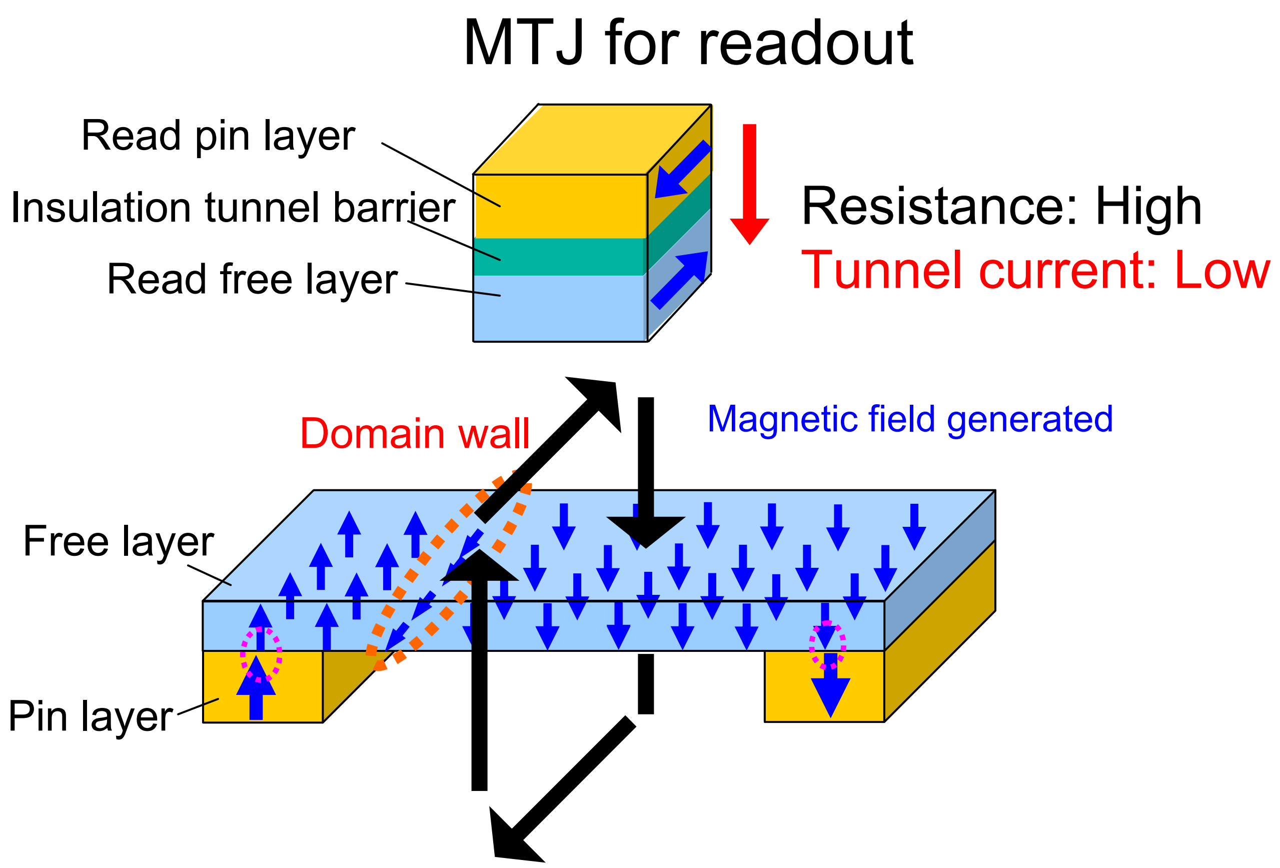

**MTJ** = Magnetic Tunnel Junction

# Reference: Principle of Behaviors of Vertical Domain Wall Devices (4)



## Reading a data value of “1”:

The resistance value of the MTJ that reacts to the magnetic field generated is read.




**MTJ** = Magnetic Tunnel Junction

# Reference: Vertical Domain Wall Device with Three Terminals

## Vertical domain wall device with three terminals:

- Current routes for reading and writing are different. This facilitates writing control. (Writing can be controlled with the current direction alone.)

→ Easier writing control leads to increased speed.

- The writing current route has no resistance, to pave the way for serial connection.

→ This helps reduce the device size.