# Voltage control of permanent magnets $SmCo_5$ thin film by hydrogen intercalation for energy-efficient information recording technology


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Field of research: PhD candidate of Material science, focusing on

- Investigation of new magnetic materials and apply them in magnetoelectric coupling effect
- Apply voltage tuning methods on industrial mature magents for energy-efficient information storage technology and magnetic sensor.

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## Introduction

Permanent magnet $SmCo_5$ is widely used in magnetic data storage technology due to its high coercivity and thermal stability. However, these two properties meanwhile make $SmCo_5$ magnetization switching with a large magnetic field. The application of large field consumes higher energy compared with other magnetic data storage technology such as spintronics, which uses the polarised current. Therefore, novel architectures and advanced Control techniques are expected to reduce the amount of energy required to write, read, and manipulate data. Regard to this, voltage control of magnetism or magnetoelectric coupling is promising because electric field generally consume less energy than traditional magnetic fields, leading to reduced energy requirements for data writing and reading operations.

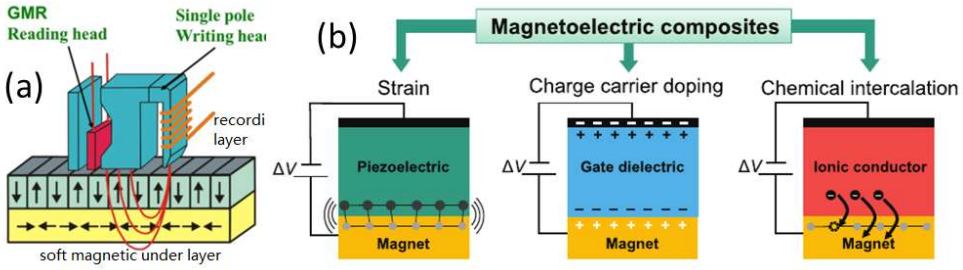



*Fig. 1. (a) schematic of $SmCo_5$ magnetic data storage setup. (b) magnetoelectric coupling mechanisms*

In my doctoral research, we focus on the magnetism modification for permanent magnet $SmCo_5$ thin film via magnetoelectric method. The voltage gated hydrogen insertion into $SmCo_5$ thin film changes its coercivity from pristine 3.2 T to 0.01 T at room temperature. Voltage-assisted magnetization reversal can be realized by a weak field of 0.2 T instead of normal 7 T. The non-volatile and reversable control of $SmCo_5$ coercivity make it a promising candidate for energy-efficient magnetic data storage technology.

## Results

The motivation of the research project comes from that the electrochemistry can provide the chemical redox for material with low applied voltage. Therefore, it is promising to tune magnetic properties for oxides by this energy-efficient way.

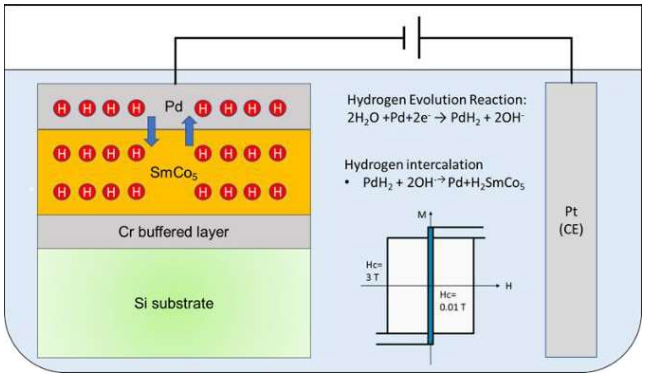



*Fig. 2. Schematic view of the electrochemical tuning $SmCo_5$ coercivity by voltage gated hydrogen insertion.*

We use magnetron sputtering to synthesis $SmCo_5$ thin film on Si substrate. The high-resolution X ray diffraction (HRXRD) and atomic force microscopy (AFM) are used for sample structure and surface morphology characterization, which demonstrate the high quality of $SmCo_5$ thin film sample with excellent high coercivity.

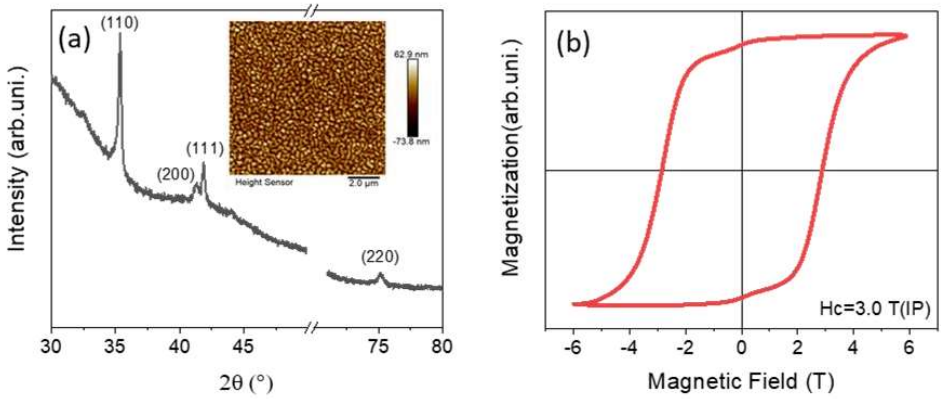



*Fig. 3: HRXRD and AFM (inset) for SmCo5 thin film(a) and in-plane M-H curve at 300 K (b).*

After achieving good performance with a $SmCo_5$ thin film, a layer of hydrogen storage material Pd is deposited onto the $SmCo_5$ thin film. Electrochemical gating is then conducted to determine the appropriate potential for introducing hydrogen into the $SmCo_5$ thin film. In Figure 3 (a), the red spot indicates the potential for hydrogen evolution reduction, while the blue spot corresponds to the potential for hydrogen extraction oxidation.

A gating process at -1.2 V is performed on the $SmCo_5$ thin film in a 1 M KOH electrolyte for a duration of 10 minutes. Following this, ex-situ magnetization-hysteresis (M-H) measurements are conducted. Substantial changes in coercivity and saturated magnetization are observed after hydrogen charging, as shown in Figure 3 (b). The coercivity is adjusted from its initial value of 3.2 T to 0.8 T, while the saturated magnetization is enhanced to 250% compared to the as-prepared $SmCo_5$ thin film.

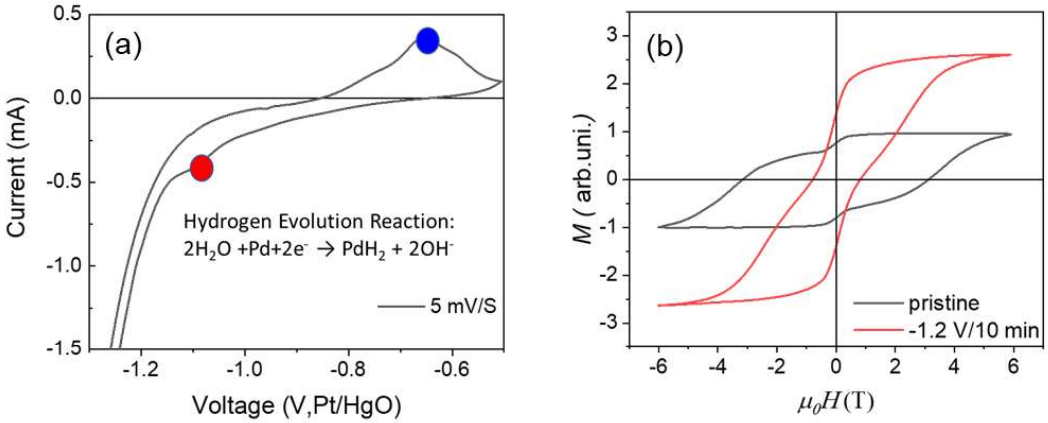



*Fig. 2. (a) cyclic voltammetry of $SmCo_5$ in electrochemical cell. (b) room-temperature M-H: ex-situ control of coercivity by voltage gated hydrogen insertion in $SmCo_5$.*

Real-time in-situ SQUID measurements were conducted as shown in the figure 4(a). The initial M-H loop of pristine Pd/$SmCo_5$ exhibited high coercivity (3.2 T). Following the first hydrogen charging at -1.6 V, the coercivity reduced to 100 Oe. The red loop depicts the discharge M-H of the Pd/ $SmCo_5$ system, with recovered coercivity reaching 1.7 T (partial recovery) and sustained enhanced saturated magnetization. These findings demonstrate reversible coercivity control in $SmCo_5$ thin film through

voltage-induced hydrogen charging, facilitating energy-efficient applications. The hydrogen-charged $SmCo_5$ exhibits soft magnet behaviour, enabling effective magnetization reversal with a weak field.

Figure 4 (b) illustrates the process: Pd/$SmCo_5$ initially saturates at 7 T, followed by a field reversal to -0.2 T after 25 minutes, resulting in magnetization reduction. Another 25-minute wait is followed by an applied voltage of -1.6 V, causing a rapid 180° magnetization rotation within 10 seconds. This electric-field-assisted reversal occurs in a remarkably weak magnetic field, indicating its potential technological significance.

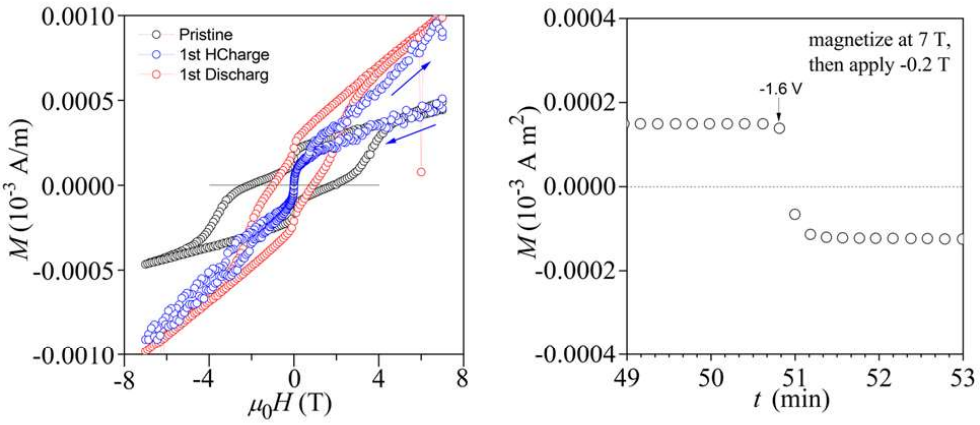



*Fig. 4. (a) cyclic voltammetry of $SmCo_5$ in electrochemical cell. (b) room-temperature M-H:ex-situ control of coercivity by voltage gated hydrogen insertion in $SmCo_5$.*

Karlsruhe Institute of Technology

MARIE CURIE ACTIONS

STIFTUNG ENERGIE & KLIMASCHUTZ
Energiezukunft im Dialog

# Voltage control of nano permanent magnets $SmCo_5$ thin film by hydrogen intercalation for energy-efficient information recording technology

PhD candidate: Zhibo Zhao
Supervisor: Prof. Horst Hahn

Institute of Nanotechnology

Karlsruhe Institut für Technologie

# Background

Computers

Cell Phones

Hi-Fi Systems

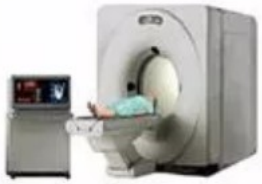
Automobile

Motors

Electric Tools

Wind Generations

MRI



Medical equipment

We use magnets:

- Every day
- Every corner
- From nano to bulk
- From earth to space

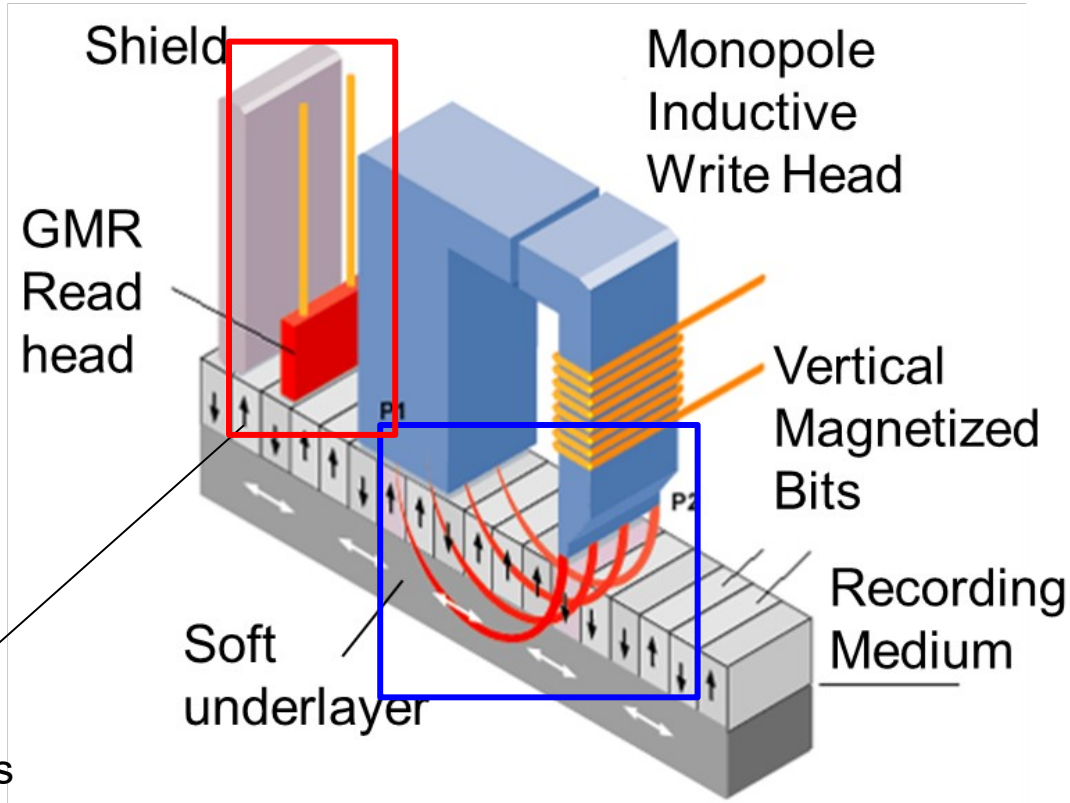
What we want:

- Higher speed
- Higher efficiency
- Smaller size
- Lower energy consuming
- Less power dissipation

What we can do

- New material design
- New way for properties control

# Traditional $SmCo_5$ magnetic storage

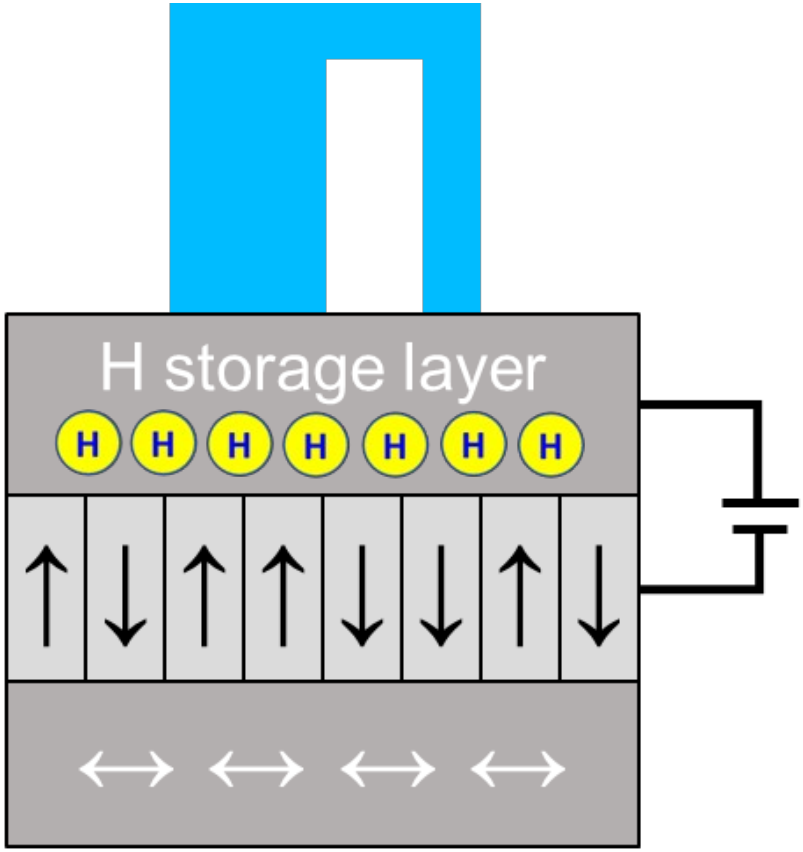



- $SmCo_5$ domains as a single storage bit

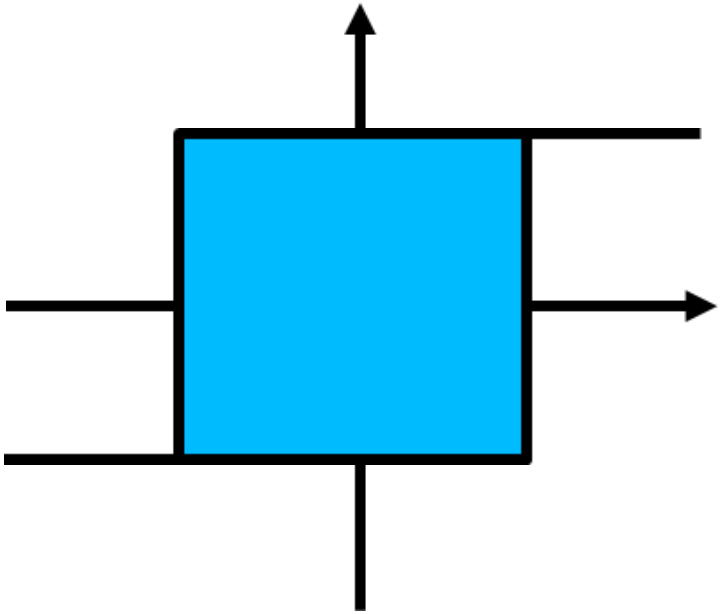
  - Writing: write head induced magentic field aligning bit in the desired direction(↑↑ as 1, ↓↑ as 0)

  - Reading: read head detects domains and receive the induced signal, interpreting as the stored data (either "1" or "0").

# Energy-effiecent application




- **Pristine: for the fabrication with hydrogen storage layer.**



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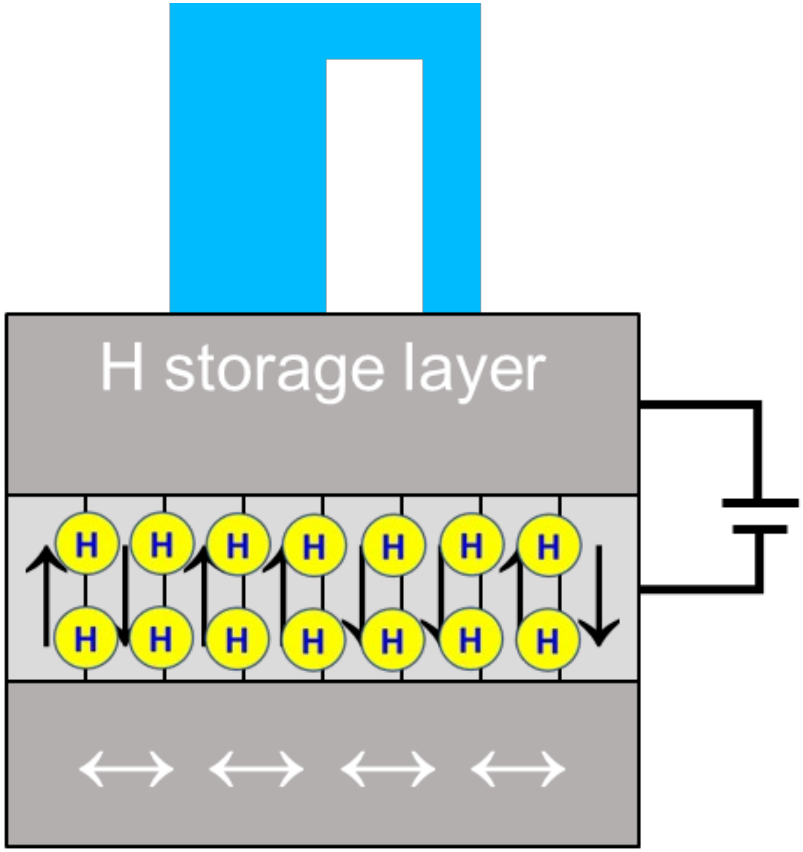
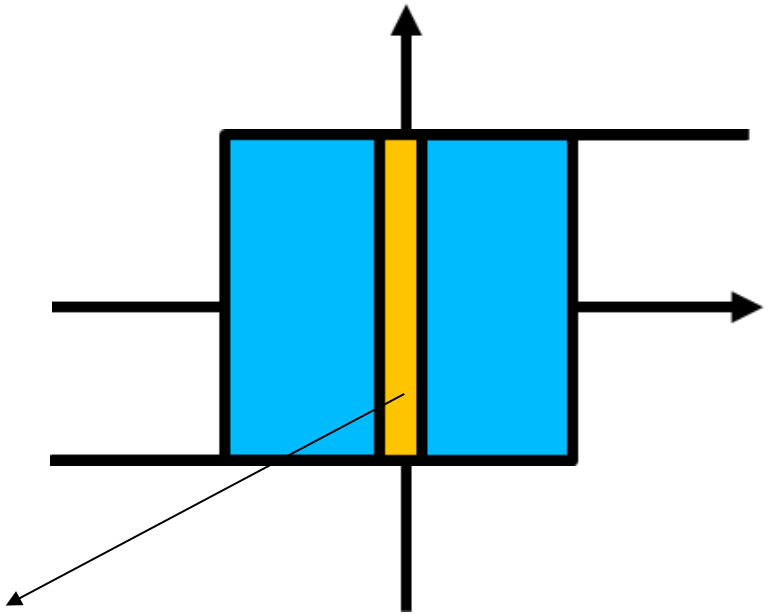
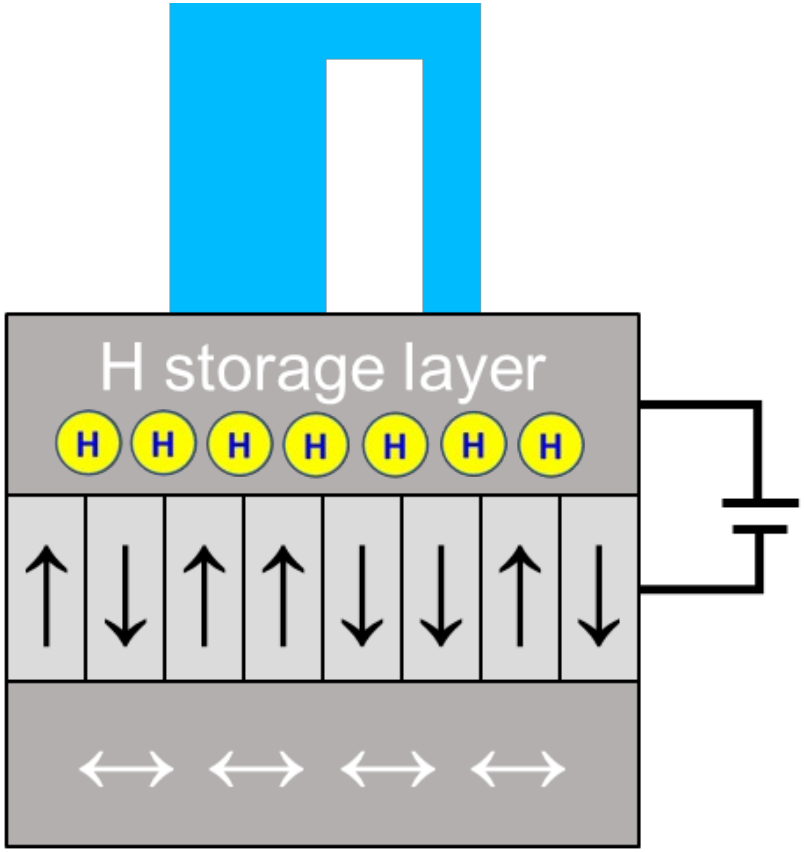



- **Pristine: for the fabrication with hydrogen storage layer.**
- **H charged: low coercivity for efficient and fast read-write operations.**

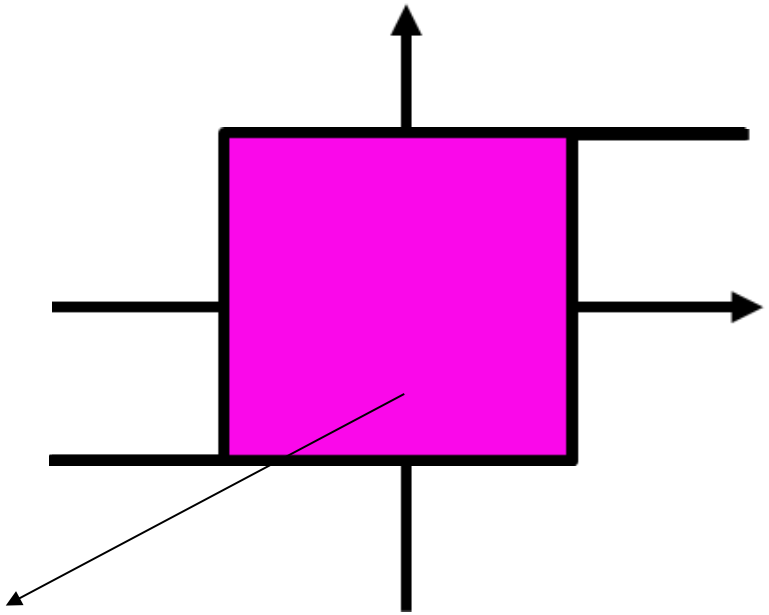


**Data writing: Small magnetic field needed for small coercivity**

# Energy-effiecent application

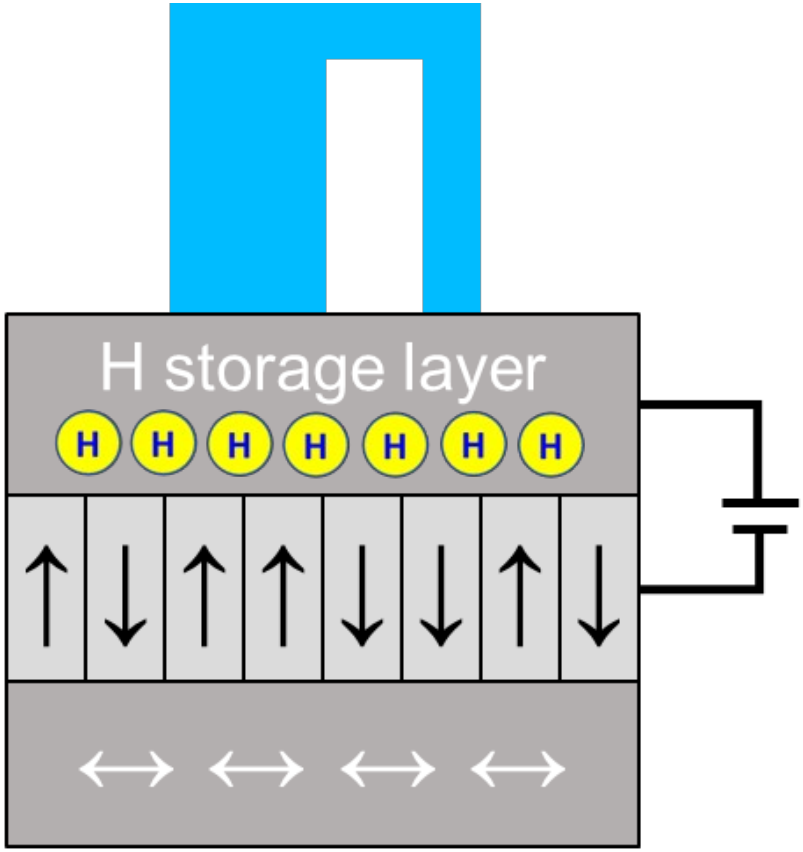



- Pristine: for the fabrication with hydrogen storage layer.
- H charged: low coercivity for efficient and fast read-write operations.
- H discharged : back to high Hc for application.



Data reading:back to high coercivity for information reading

# Energy-effiecent application

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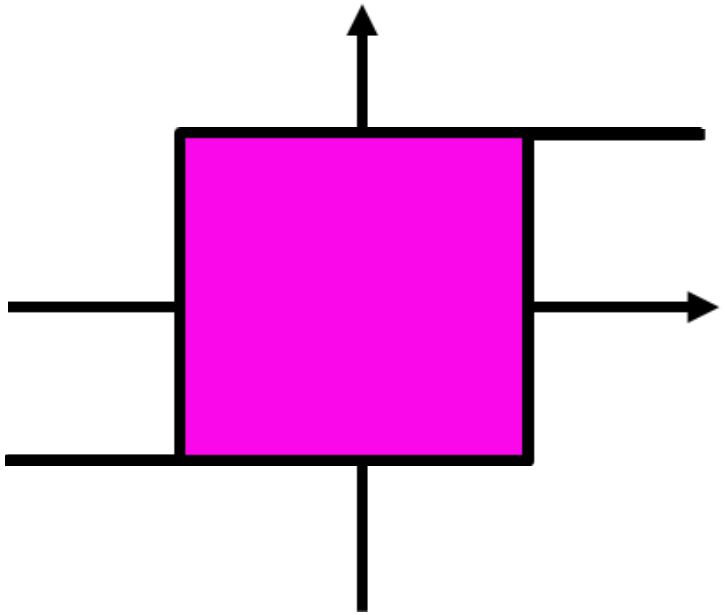
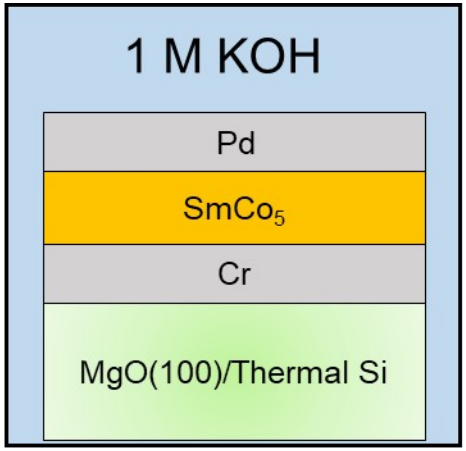
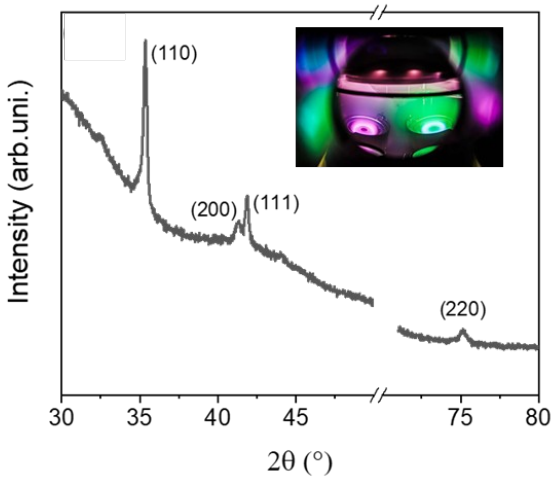
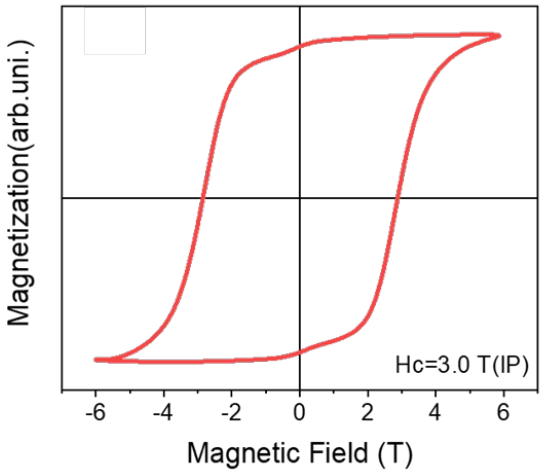


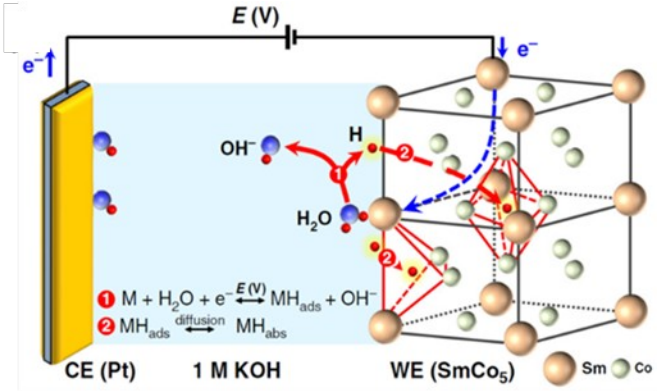
- Energy-efficient
- High speed write/read performance
- High storage density and compatibility

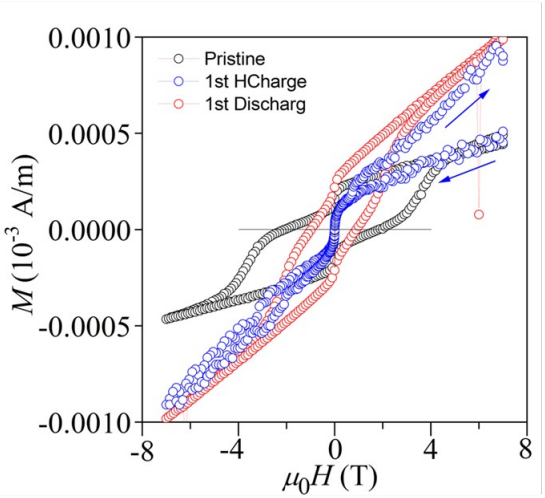
# System design: Pd(hydrogen)/$SmCo_5$(magnetism)

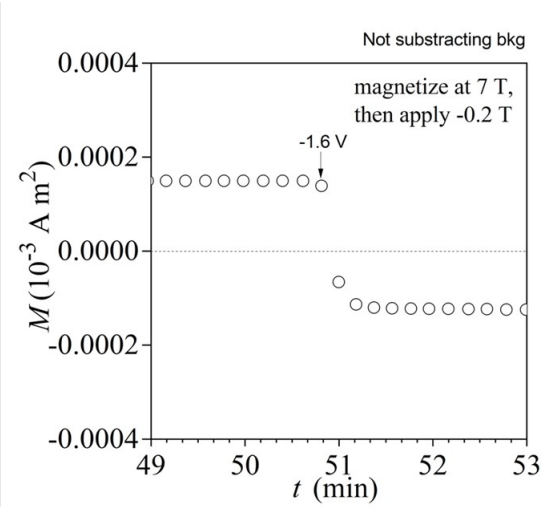


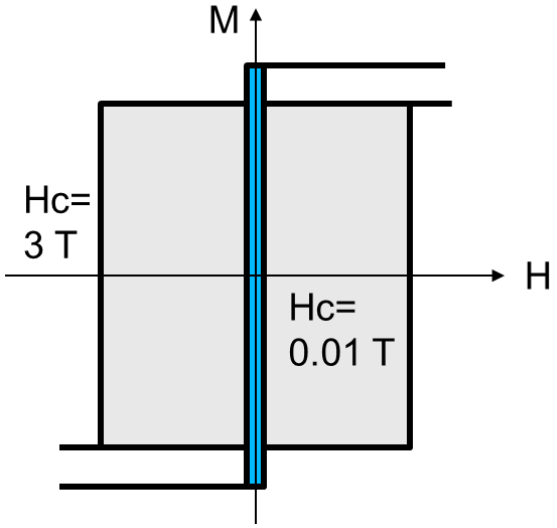



# Energy consumption comparision

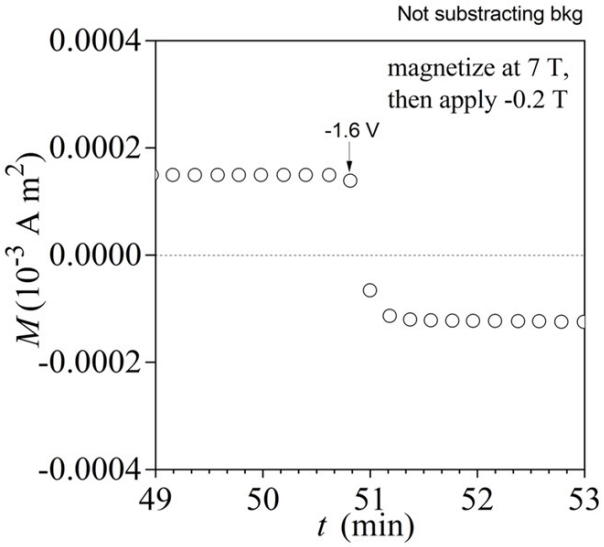



Energy for M reversal :

$E = (1/2) * Hc * V$

- Hc: coercivity
- V: magnets volume

If Hc from 3 T to 0.01 T reversibly,
the energy of M reversal can be saved for 99.6 %.




Energy for magnetic field generation:

$E = (1/2) * (B^2) * (V) * (\mu_0)$

- B =Magnetic field strength
- V = Volume of the magnetic field
- $\mu_0$ = Magnetic permeability of free space

If field from 7 T to 0.2 T, the energy for field generation can be saved by 99.9 %

Erneuerbare und saubere Energien nutzen

Energieeffizienz steigern: energieeffiziente Geräte verwenden

# Wasserstoff für Energiewende und Klimaschutz

# Acknowledgement

EnBW

STIFTUNG
ENERGIE & KLIMASCHUTZ
Energiezukunft im Dialog

Karlsruher Institut für Technologie

TECHNISCHE
UNIVERSITÄT
DARMSTADT