# Fabrication of nanoscale magnetoresistance devices using chiral molecules

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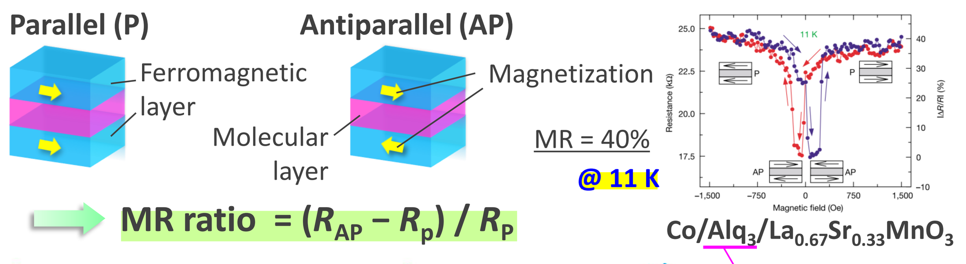
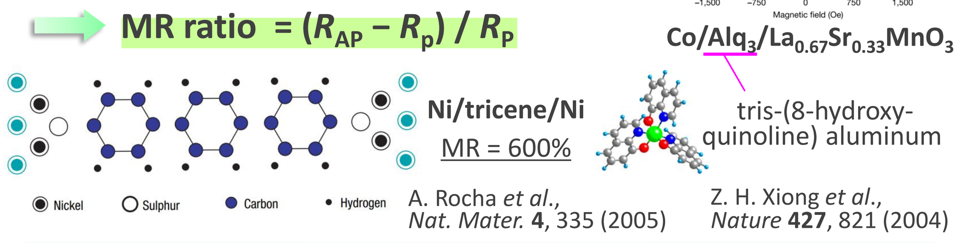
## Introduction

### Molecular spintronics

Magnetoresistance (MR) effect



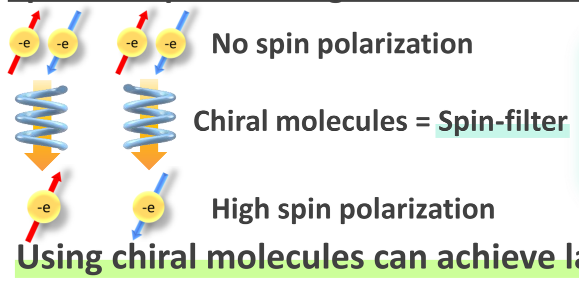

MR ratio $= (R_{AP} - R_P) / R_P$




Molecular spintronics has attracted considerable interest due to the unique possibilities. In particular, nanosized organic spintronic devices are expected to provide the high spin polarization. Moreover, chiral molecules are attractive for MR devices because they show chirality induced spin selectivity (CISS) effect, meaning that chiral molecules can act as spin filters.

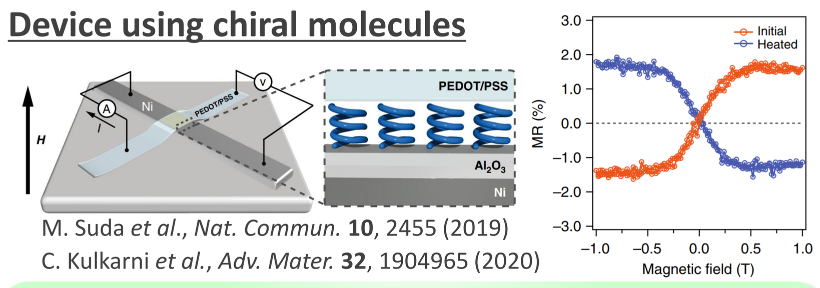
### Chiral molecules

Spin transport through chiral molecules



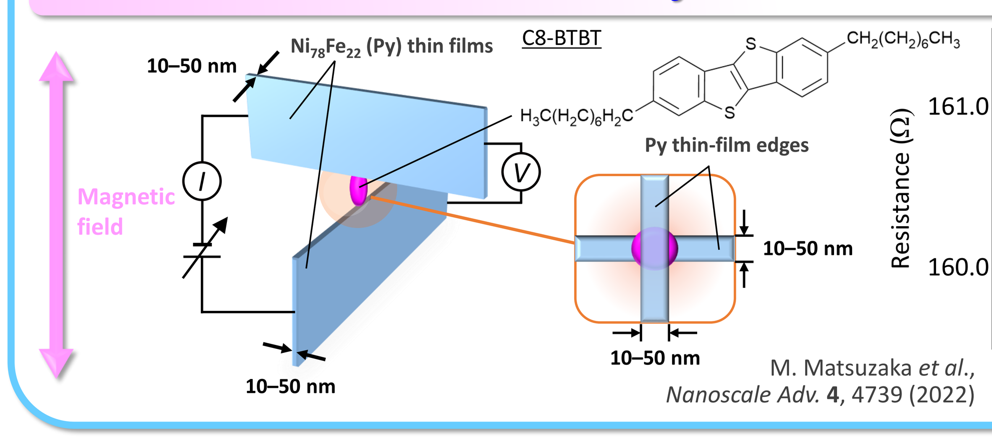

Using chiral molecules can achieve large MR effect.

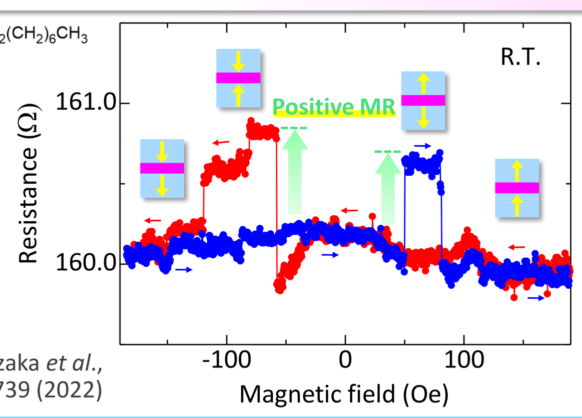
Device using chiral molecules




- In micro-device, MR ratio is low (0.03%–2%) because of the electrons passed through pinholes in the chiral molecular layer.
- To observe MR effect owing to CISS effect, a high magnetic field (~5 kOe) is needed.

### Molecular nanojunctions utilizing metal thin-film edges

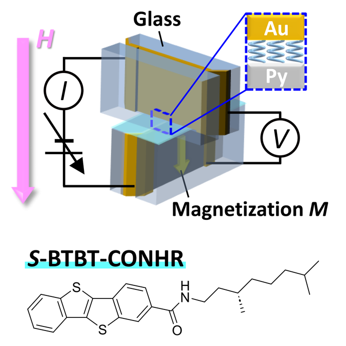



Room-temperature MR for the first time

Next, we focused on chiral molecules showing CISS effect.

## Objective




In this study, towards the observation of MR effect owing to CISS effect under low magnetic field, we fabricate Au/*N*-(3*S*)-3,7-dimethyloctyl[1]benzothieno[3,2-*b*]benzothiophene-2-carboxyamide (*S*-BTBT-CONHR)/Py nanoscale devices, and investigate their structural, electrical and magnetic properties.

## Methods

### Film deposition

$Ni_{78}Fe_{22}$, Au films: DC magnetron sputtering

Substrates: Low-softening-point (LSP) glasses (Glass deformation temperature: 503°C; 10 × 10 × 2 mm³)

*S*-BTBT-CONHR films: Spin-coating

Solvent: Dichloromethane
Concentration: 6 mg/ml

### Thermal pressing

Temperature: 513°C, Pressure: 0.75 and 1.0 MPa, Time: 5 min, Atmosphere: $N_2$

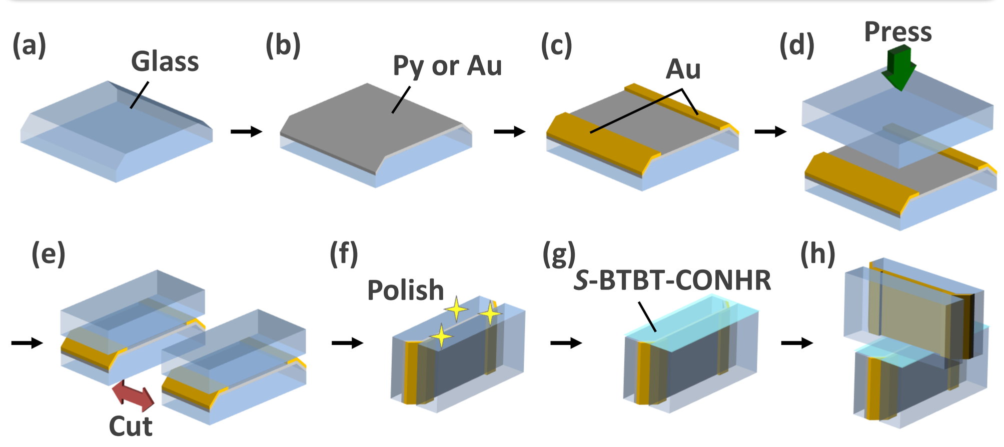
### Structural analyses

Atomic force microscopy (AFM)

### Evaluation of electrical properties

Conductive atomic force microscopy (c-AFM)

### Device fabrication




### Measurement of magnetic properties

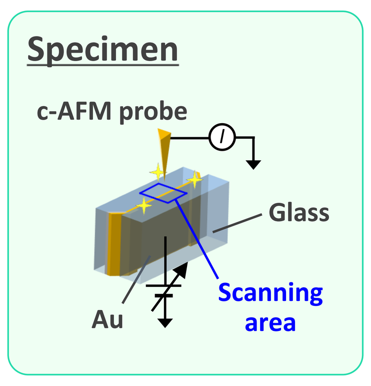
Focused magneto-optical Kerr effect (MOKE) spectroscopy

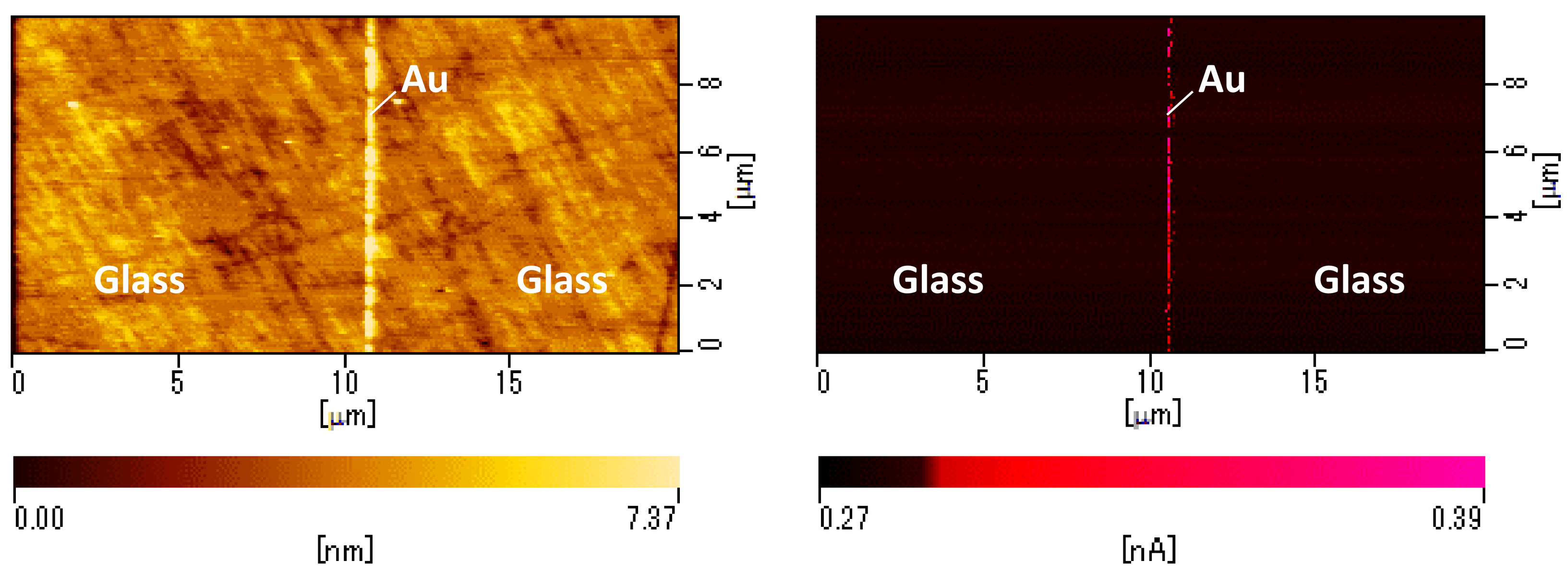
### Investigation of MR effect

DC four-probe method under magnetic field

## Results and Discussion

### Structural and electrical properties of glass/Au/glass samples



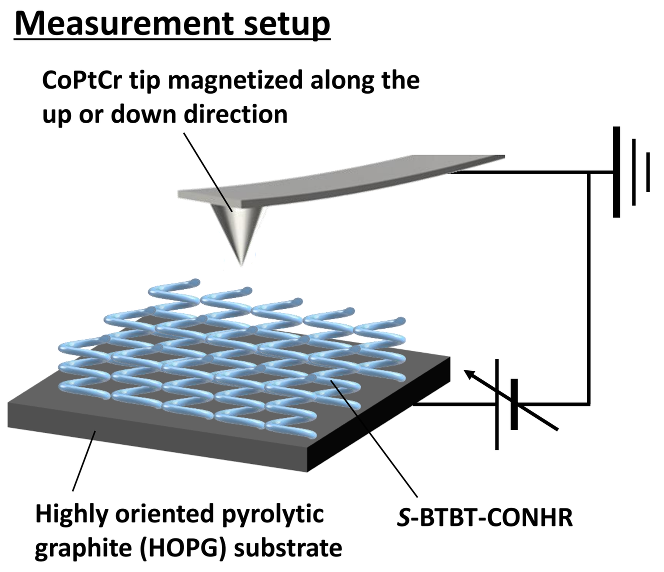



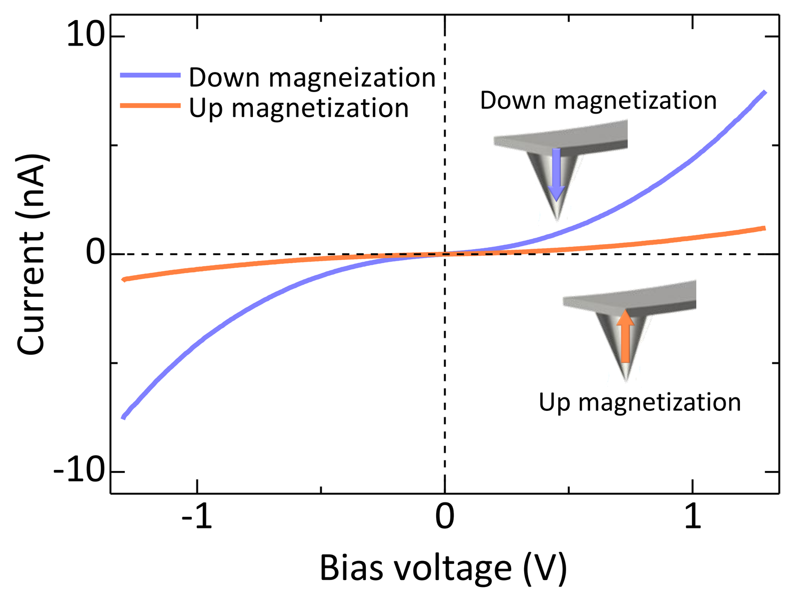

Surface roughness
$R_a$ = 0.58 nm

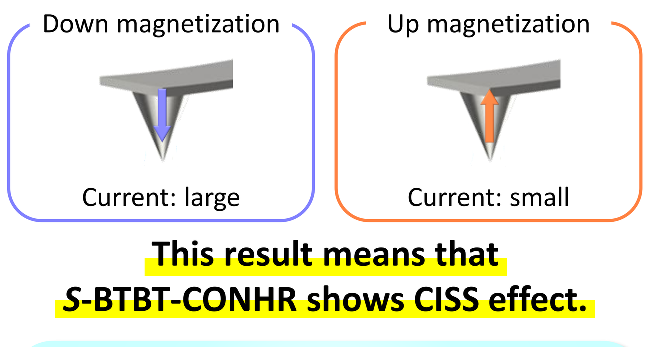
The polished cross-sectional surfaces of both glass/Py/glass and glass/Au/glass samples show a low roughness (< 1 nm). The c-AFM images of the same samples indicate uniform electrical conduction along the metal edges.

The results of AFM and c-AFM studies reveal that both glass/Py/glass and glass/Au/glass can be used as electrodes in the nanojunctions using chiral molecules.

### Magnetic c-AFM studies of *S*-BTBT-CONHR



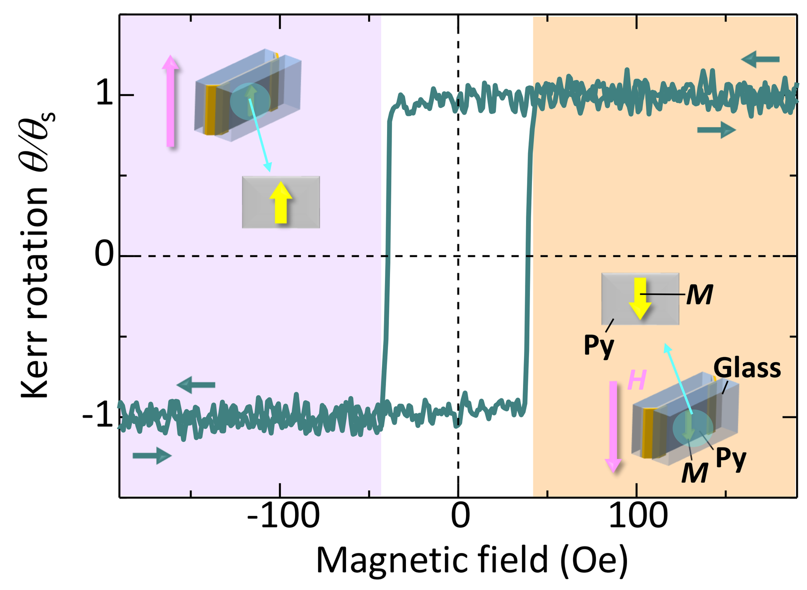




This result means that *S*-BTBT-CONHR shows CISS effect.

The current–voltage (*I*–*V*) curves indicate that using *S*-BTBT-CONHR can lead to the observation of MR effect due to CISS effect in the nanoscale MR devices.

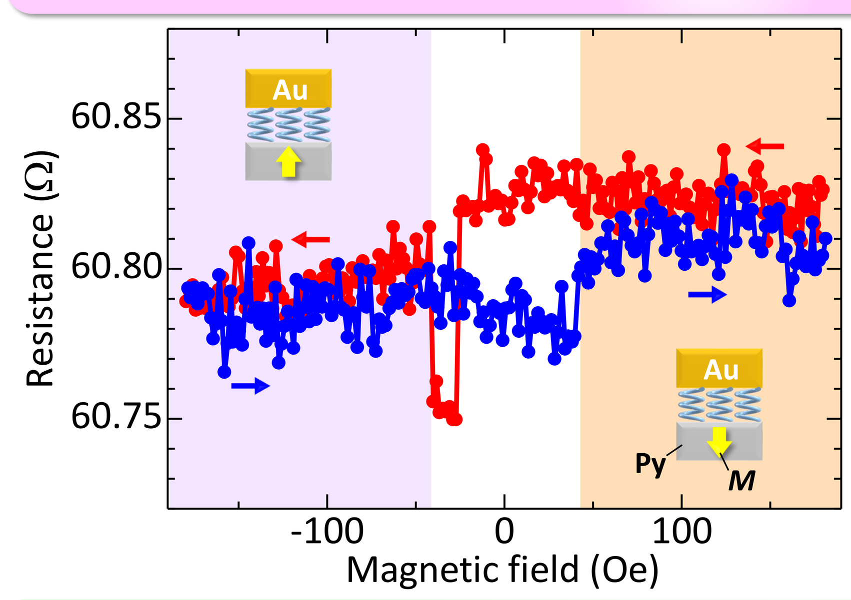
### Magnetic properties of Py electrodes




The coercivity of Py electrode is 39 Oe after thermal pressing. By using this electrode for the device, CISS effect can be observed under lower magnetic field than that of previous study.

### MR effect in Au/*S*-BTBT-CONHR/Py nanoscale devices

We fabricate Au/*S*-BTBT-CONHR/Py nanojunctions and investigate MR effect in the devices under low magnetic field at both positive and negative bias voltages.




The MR curves correspond to the magnetization states of Py electrodes. This means that MR effect based on CISS effect is observed in nanoscale devices using chiral molecules under low magnetic field. This study can lead to the realization of the nanoscale MR devices with high magnetic sensitivity.

The MR curves exhibit the same polarity at both positive and negative bias voltages. This fact indicates that the sign of spin selectivity is independent of the spin injection direction in the devices.

## Conclusion

1) Both glass/Py/glass and glass/Au/glass samples have been fabricated by using our methods. The polished surfaces of both samples provide a low surface roughness $R_a$ (< 1 nm) and uniform electrical conduction along the metal edges is observed. In addition, Py electrodes show a coercivity of 39 Oe. Therefore, these samples can be used as electrodes for nanojunctions using chiral molecules which show CISS effect under low magnetic field.

2) The current through a tip with down magnetization is larger than that with up magnetization in c-AFM studies using magnetized tips. The obtained *I*–*V* curves indicate that using *S*-BTBT-CONHR can lead to the observation of MR effect due to CISS effect in the nanoscale MR devices.

3) We fabricate Au/*S*-BTBT-CONHR/Py nanoscale devices and observe MR effect in the fabricated devices. MR curves correspond to the magnetization states of Py electrodes, in which the coercivity is ~39 Oe. This means that MR effect based on CISS effect is observed in nano-devices using chiral molecules under low magnetic field. This study can lead to the realization of the nanoscale MR devices with high magnetic sensitivity and provide a new insight into CISS effect for spintronic device application.

## Acknowledgements

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