Electric polarization controlled TMR in FE-MTJs

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Introduction

Magnetic tunnel junctions

- **Structure:** FM1/Insulator/FM2
- **Tunneling current** through the I layer
- **R changes** for P and AP of FMs

Tunneling MR

- **Jullière equation:**[4]

$$TMR = \frac{2P_1P_2}{1-P_1P_2}$$

- **Spin polarization (P_1, P_2)**

Electric P controlled TMR

- **FE-tunneling barrier**
- **Electric field → Polarization of FE → TMR**
  - ✓ Value of TMR[5] (Fig. 3)
  - ✓ Sign of TMR [3] (Fig. 1, MFTJ)
- **Mechanisms:** (under debate)
  - ✓ Interfacial magnetoelectric coupling[5]
  - ✓ Co-Ti interactions [3] (reversible MR)
  - ✓ Spin dependent surface screening, etc.

❖ **Relationship of P and TMR,** this work!

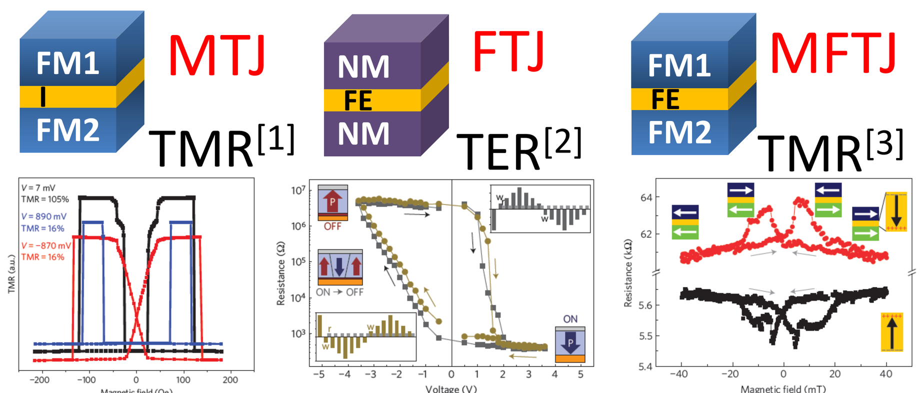

Fig. 1 MTJ, FTJ, MFTJ and their field controllable resistances

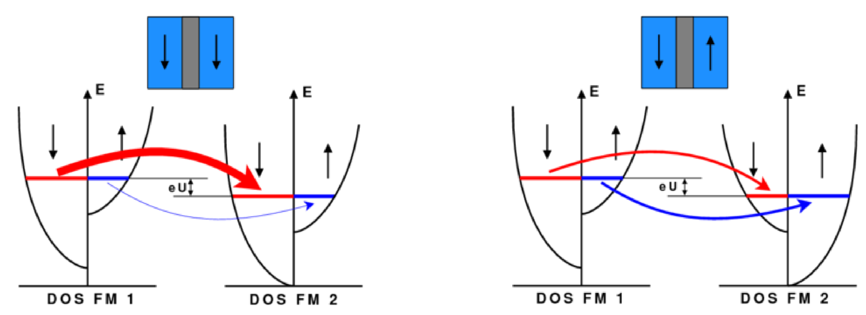

Fig. 2 Tunneling current in MTJ

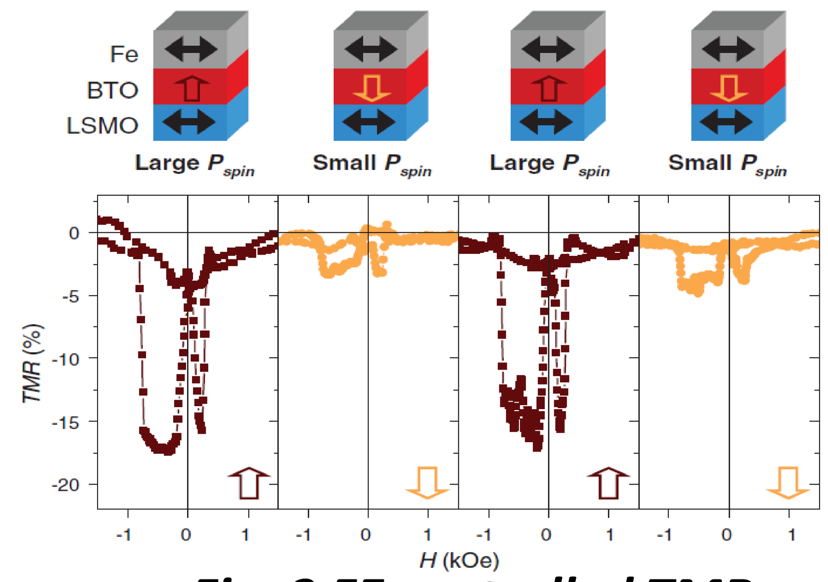

Fig. 3 FE controlled TMR

Methods

- **Laser MBE:**
  - ✓ $La_{0.67}Sr_{0.33}MnO_3$ (LSMO, 30 nm, FM2)
  - ✓ $PbZr_{0.2}Ti_{0.8}O_3$ (PZT, 5 nm, FE)
- **Thermal MBE:**
  - ✓ Co (~10 nm, FM1)
  - ✓ Au (~10 nm, capping layer)
- **Measurements:**
  - ✓ PFM: FE of PZT
  - ✓ PPMS: MR measurements
- **Programmed V for FE polarization**
  - ✓ V_{MAX}: for polarization of PZT
  - ✓ V_{MR}: for MR measurement

❖ The PZT was polarized by a V_{MAX} before each MR measurement

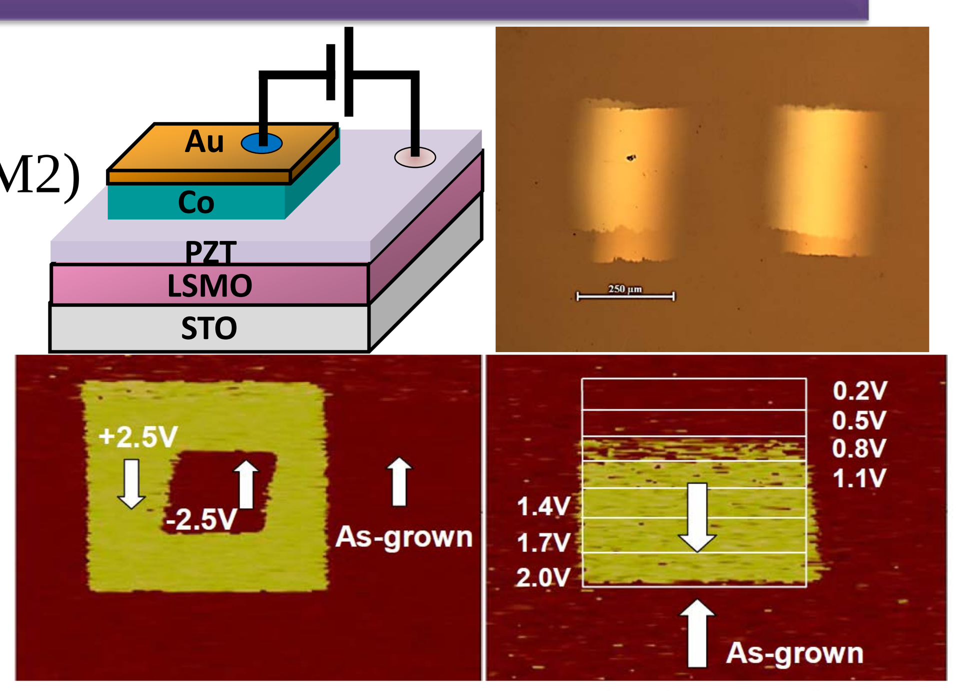

Fig. 4 Structure & morphology of our MFTJs, and FE response of the PZT film

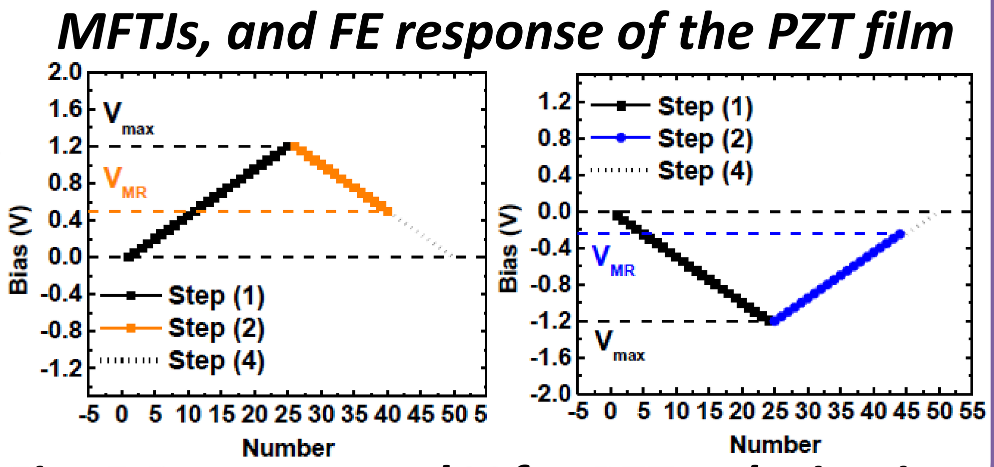

Fig. 5 Programmed V for PZT polarization

Results

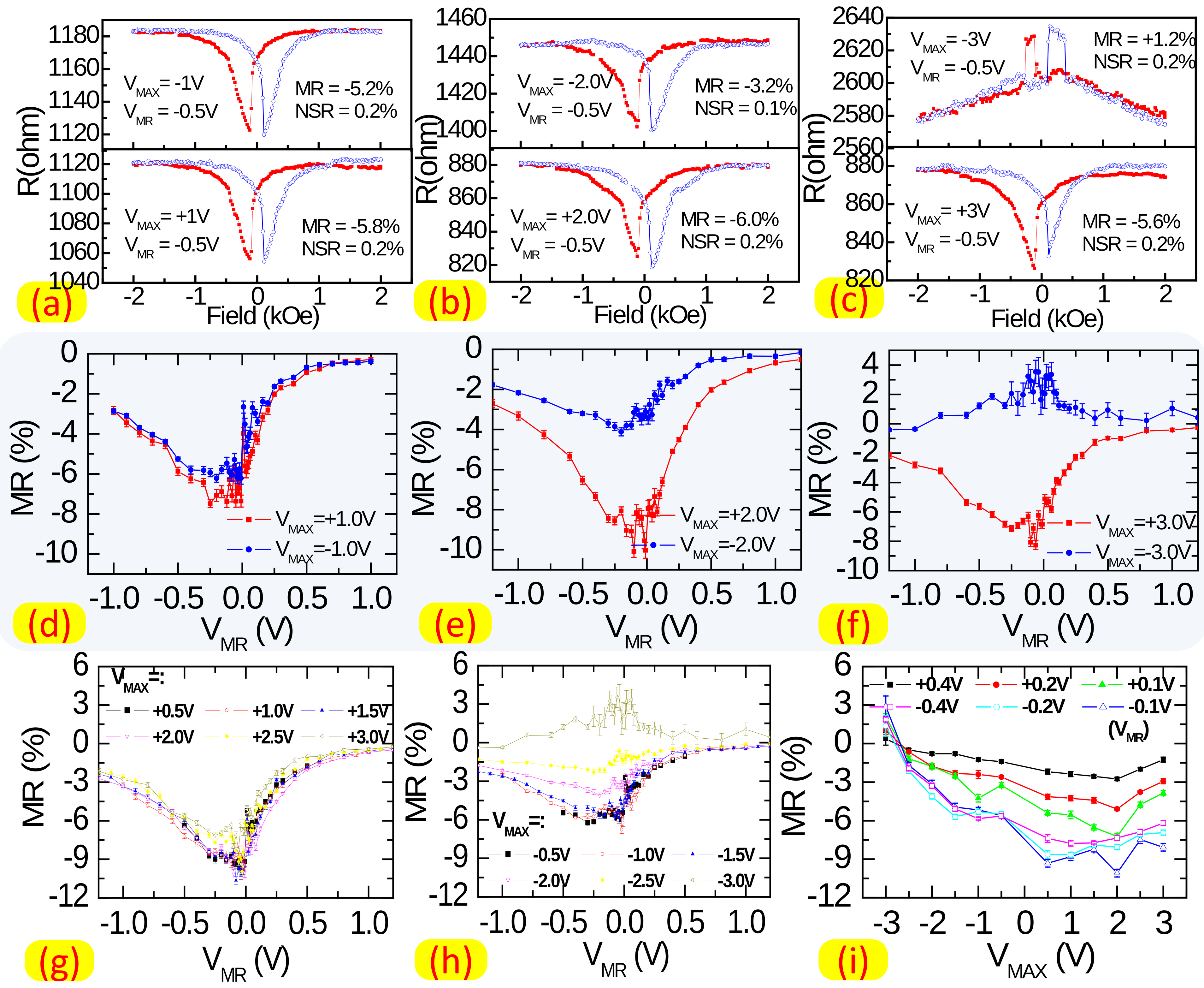

Fig. 6 (a-c) R vs. H loops; (d-h) MR vs. V_{MR} curves ; (i) MR vs. V_{MAX} curves.

- **MR depends on V_{MR}:** V_{MR} → E_F of FM electrodes → P_1 and P_2 → TMR
- **R depends on V_{MAX}:** V_{MAX} → P of PZT → TER ($R_\uparrow$, $R_\downarrow$)
- **MR depends on V_{MAX}:** V_{MAX} → P of PZT → P_1 and P_2 → TMR

TMR depends on the electric polarization of PZT!

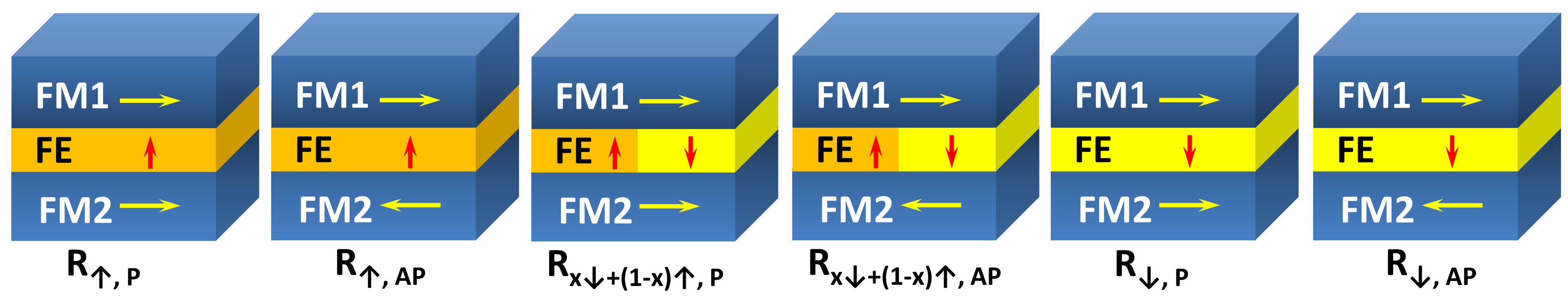

Fig.7 States of R corresponding to M alignments and E polarization in MFTJs.

➤ *R and MR:*

$$R = \rho\frac{L}{s} \qquad \rho = R\frac{S}{L} \qquad MR = \frac{R_{AP}-R_P}{R_P}$$

➤ *TER:*

$$\frac{1}{R_{x\downarrow}} = \sum\frac{1}{R_{i\downarrow}} = \sum\frac{s_i}{\rho_\downarrow L} = \frac{\sum s_i}{\rho_\downarrow L} = \frac{x\cdot s}{\rho_\downarrow L} = \frac{x}{R_\downarrow} \qquad \frac{1}{R_{(1-x)\uparrow}} = \frac{(1-x)}{R_\uparrow}$$

$$\frac{1}{R_{x\downarrow+(1-x)\uparrow}} = \frac{1}{R_{x\downarrow}} + \frac{1}{R_{(1-x)\uparrow}} = \frac{x}{R_\downarrow} + \frac{1-x}{R_\uparrow} \qquad R_{x\downarrow+(1-x)\uparrow} = \frac{R_\downarrow\cdot R_\uparrow}{x\cdot R_\uparrow + (1-x)R_\downarrow}$$

➤ *TMR :*

$$MR = \frac{R_{x\downarrow+(1-x)\uparrow,AP} - R_{x\downarrow+(1-x)\uparrow,A}}{R_{x\downarrow+(1-x)\uparrow,AP}} = 1 - \frac{R_{x\downarrow+(1-x)\uparrow,A}}{R_{x\downarrow+(1-x)\uparrow,AP}} = 1 - \frac{R_{\downarrow,AP}\cdot R_{\uparrow,AP}}{R_{\downarrow,P}\cdot R_{\uparrow,P}}\cdot\frac{x\cdot R_{\uparrow,P} + (1-x)R_{\downarrow,P}}{x\cdot R_{\uparrow,AP} + (1-x)R_{\downarrow,AP}}$$

Conclusions

1. **We fabricated magnetic ferroelectric tunnel junctions (MFTJ) successfully, and used voltage-program to reveal the effect of the polarization of PZT films on device TMR.**
2. **We found that both R and MR of the device changed with the electric polarization of PZT films. By switching its polarization from point up to point down, resistance of MFTJ increased while MR changed from negative to positive.**
3. **According to the two fully polarized states, R and MR for intermediate electric polarization states could be predicted.**

References

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[4] M. Jullière, Physics Letters A 54, 225 (1975).

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