Magnetoelectric effects at Fe / BaTiO$_3$ (001) interface for new magnetic memory devices


LNESS center – Politecnico di Milano, Via Anzani 42, 22100 Como (Italy)
1. Introduction

2. Magnetoelectric effects on Fe films grown on
   - BTO single crystal substrates
   - epitaxial BTO/STO thin films

3. Electric control of the magnetization of CoFeB layers in MTJs grown on BTO

4. Conclusions
Introduction

Fe/BaTiO$_3$ interface

- Prototypical FM/FE interface
- 45° rotation. Mismatch: 1.6%
- RT operation
- Predicted ME effects

Applications: the case of MRAMs

Electric Control of Magnetism for novel spintronic devices for magnetic data storage with electrical writing and reading

- Lower power consumption
- Higher packing capability

simple is beautiful.

NO CURRENT LINES!
Barium titanate (BTO)

Displacive ferroelectric, piezoelectric:

RT tetragonal phase: \( a = 3.994 \, \text{Å} \)
\( c = 4.038 \, \text{Å} \)

BTO films on SrTiO$_3$ substrates

- Cube on cube growth
- Match with substrate: in-plane compression, out of plane expansion
ME mechanisms at Fe/BTO interface

Displacement in the Fe-Ti bonding

Duan et al, PRL 97, 047201 (2006)

Spin dependent screening


\[ \delta M(x) = \delta M_0 \exp(-x/\lambda_{FM}) \]

\[ \lambda_{FM} = 0.7 \text{Å} \]

Pure electrical ME effects

\( P \rightarrow \text{FE} \rightarrow M \)

Strain mediated ME effects

\( S \)

Strain

Experimental Result

Sahoo et al *PRB* 76, 092108 (2007)

\( \mu_0 H_c \) (mT)

Fe/BTO crystal

\( E \) (kV/cm)

-12 -8 -4 0 4 8 12
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ME effects @ RT (tetragonal phase)

- Sizable electro-optic effect on the "MOKE" amplitude (FE hysteresis loop)
- Non measurable variation of the XMCD signal on 5nm of Fe
- 40% variation of the coercive field

S. Brivio et al. APL 98, 092505 (2011)
Fe / BTO crystal

Magnetostriction is the physical mechanism

No practical use in real electronic devices where a single substrate cannot be easily integrated. High voltages would be required.

S. Brivio et al. APL 98, 092505 (2011)
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Fully epitaxial Fe/BTO

S. Brivio et al. This Solid Film 2011
ME experiments: Magneto Optical Kerr Effect

As expected no strain mediated effects (Hc doesn’t change).

BTO film blocked by the substrate.
Outlook

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CoFeB/MgO/CoFeB MTJs on BTO

**MTJ structure**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>20nm</td>
</tr>
<tr>
<td>IrMn</td>
<td>20nm</td>
</tr>
<tr>
<td>MgO</td>
<td>2.5nm</td>
</tr>
<tr>
<td>CoFeB</td>
<td>5nm (pinned)</td>
</tr>
<tr>
<td>CoFeB</td>
<td>5nm (free)</td>
</tr>
<tr>
<td>BTO</td>
<td>150nm</td>
</tr>
<tr>
<td>LSMO(50nm)/STO(001)</td>
<td></td>
</tr>
</tbody>
</table>

**Magnetron sputtering**

**PLD**
Nice behaviour of MTJs without MgO recrystallization

TMR about 40%

MgO thickness about 2.5 nm

High RA product

Pinned layer

Free layer

H(Oe)

Resistance (Ohm)

T=15 K
Effect of BTO polarization on magnetic anisotropies of the free layer at room temperature

Magnetic anisotropy of free CoFeB layer changes due to positive voltage application to BTO (before the MTJ annealing)
Conclusions

- The magnetization of Fe layers on BTO single crystals can be manipulated via magnetostriction.
- Epitaxial Fe grown on BTO films do not exhibit the same behavior.
- Preliminary results on MTJs grown on BTO show that it is possible to alter the magnetization of the bottom electrode via magnetoelectric coupling.
The people..


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