Spin-Torque Effect in Asymmetric FeCoB/MgO/FeB Magnetic Tunnel Junctions

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Abstract:
Spin-torque effect in asymmetric FeCoB/MgO/FeB magnetic tunnel junctions exhibits asymmetric electronic transports, tunneling magnetoresistance (TMR) bias dependence and spin-torque effects. As-grown amorphous FeCoB and FeB alloy electrodes exhibit asymmetric transport and TMR bias dependence (TMR~20%), regardless of voltage bias polarities. Annealed FeCoB and FeB electrodes show high TMR (~90%) and reverse the asymmetry in the TMR bias dependence, conductance dI/dV and spin-torque ferromagnetic resonance measurements. These results suggest the spin-dependent electronic transports in the annealed asymmetric junctions dominate the transport behaviors and could possibly related to the strong peak in the minority density of state in bcc Fe electrodes.

Summary of Research:
Spin-torque effect enables electrical manipulation of a single nanomagnet. Because of its potential application to non-volatile random access memory, spin-torque effect has been studied extensively. Recent studies have found that there are two different spin torques. One is called in-plane torque acting like anti-damping effect. Another torque affects nanomagnets like magnetic fields and is called the field-like torque. Experiments [1, 2] have confirmed the existence of both types of spin torques.

Furthermore, several studies has found that the field-like torque could induce unreliable switching and could possibly affect switching reliabilities. Therefore, theses effects may significantly hinder the commercial application.

Oh, et al., [3] shows asymmetric electrode compositions in magnetic tunnel junction could lead to back-hopping switching. Here, we found that field-like torque is highly sensitive to chemical compositions of electrodes. The field-like torque can further be altered and manipulated by chemical compositions in the electrodes.

To understand how electrodes affecting the spin-torque effect, we studied the switching phase diagram (SPD) by measuring the P-to-AP and AP-to-P switching fields with various dc bias voltages. By the variation of switching fields, we could quickly and roughly estimate the field-like torque effect. Figure 1 shows the switching phase diagram of nanopillars with FeCoB/MgO/FeB and FeB/MgO/FeCoB electrode.
compositions. Figure 1 ([a], [b]) are the switching phase
diagram from as-grown nanopillar devices and ([c], [d]) are
from annealed nanopillar devices. As-grown devices are able
to perform bi-polar switching within certain field ranges in
both electrodes composition.

Figure 2 is the differentiate conductance dI/dV in asymmetric
MTJs. Figure 2 ([a], [b]) are as-grown nanopillar devices
exhibiting similar voltage bias dependence in dI/dV. Interestingly, annealed nanopillar devices show opposite
dI/dV while exchanging the electrode compositions. Other
than dI/dV reversal in the asymmetric MTJs, tunneling
magnetoresistance (TMR) also reversed. Regardless of
electrode chemical compositions, dI/dV with positive voltage
bias increases faster than negative voltage in all as-grown
devices. The high dI/dV with positive bias suggests there
are more accessible states or lower barriers in the electrode-
insulator interface from MgO RF sputtering. These as-grown
results indicate sputtering process dominates the electronic
transport properties in the asymmetric MTJs, not the electrode
compositions. On the contrary, annealed devices show
opposite dI/dV and TMR bias dependence while we exchange
electrode compositions. These annealed transport behaviors
point that the electronic structures in the asymmetric MTJs
manifest after annealing and dominates both the spin-
dependent and electronic transport in asymmetric MTJs.

We suspect that the strong peak in the
minor density of states in bcc Fe [4]
is responsible for the phenomenon.
The strong peak in the minority DOS
would induce the increasing in the dI/
dV in the positive bias and also lower
the spin-polarization with high bias
causing the asymmetric TMR bias
dependence. In addition, we utilize
spin-torque ferromagnetic resonance
(ST-FMR) to exam the spin-torque
effect in the asymmetric MTJs. ST-FMR
results exhibit opposite anti-symmetric
Lorentzian component while we reverse the electrode compositions in MTJs. Anti-symmetric
Lorentzian component in the FMR curve
is proportional to field-like torque
(derivative of torque with respect to
voltage). Opposite anti-symmetric
Lorentzian component points to sign
difference in the field-like torque. This
result further suggests highly asymmetric
field-like torque under high voltages.

In the conclusion, we have measured electronic transports, spin-
dependent transports and spin-torque effects in asymmetric
MTJs. We have found the asymmetry in the transport behavior is
directly related to electrode chemical composition, instead
of defects induced by sputtering processes in high TMR
devices. Through ST-FMR measurement and switching phase
diagrams, we found the field-like torque is highly sensitive
to electronic structures in the magnetic electrode materials.
Our results prove the concept that the field-like torque can
be altered and controlled by the electrode compositions and
possibly can be used to reduce the unreliable switching in the
in-plane MTJs.

References:
K. Tsunekawa, D. D. Djayaprawira, N. Watanabe, and S. Yuasa, Nature
J.-E. Lee, K.-T. Nam, Y. Jo, Y.-C. Kong, B. Dieny, and K.-J. Lee, Nature