SPIN-DEPENDENT TUNNELING CHARACTERISTICS OF Co_2MnGe-BASED MAGNETIC TUNNEL JUNCTIONS

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Manipulation of the spin degree of freedom of the conduction electron in an electron device, or spintronics, has been extensively studied recently. Half-metallic ferromagnets (HMFs) feature an energy gap for one spin direction (mostly the minority-spin band) at the Fermi level (E_F), which provides complete spin polarization at E_F making HMFs one of the key materials for ferromagnetic electrodes in spintronic devices. Co-based Heusler alloys (Co_2YZ) are amongst the most extensively studied potentially half-metallic electrode materials due to the half metallicity theoretically predicted for several of these alloys and because of their high Curie temperatures, which are well above room temperature. Our purpose in this study was to investigate the spin–dependent tunneling characteristics of Co_2MnGe/MgO/Co_2MnGe magnetic tunnel junctions (MTJs) fabricated as a function of Mn compositions α for $Co_2Mn_\alpha Ge$ and to understand the origin of the observed dependence in terms of the effect of defects possibly associated with non-stoichiometry in prepared Co_2MnGe electrodes. We fabricated Co_2MnGe/MgO/Co_2MnGe by co-sputtering from a Co_2MnGe target and a Mn target for both the lower and upper Co_2MnGe electrodes. Through the use of co-sputtering, we were able to precisely control the Mn composition α in the $Co_2Mn_\alpha Ge$ electrodes. The tunnel magnetoresistance (TMR) ratios at both 4.2 K and room temperature increased systematically with increasing α in the $Co_2Mn_\alpha Ge$ electrodes, which indicates the TMR ratio is explicitly dependent on the Mn composition. The observed lower TMR ratio for MTJs with Mn-deficient Co_2MnGe electrodes is explained by the existence of Co_{Mn} antisites, where a Mn site is replaced by a Co atom. Co_{Mn} antisites result in the appearance of minority-spin gap states around E_F and thereby leads to the increased tunnel conductance for the antiparallel (AP) state. On the other hand, the observed higher TMR ratio for MTJs with Mn-rich Co_2MnGe electrodes is explained by the suppressed Co_{Mn} antisites, which results in the decreased density of minority-spin gap states around E_F and thereby leads to the decreased tunnel conductance for AP. Our experimental findings suggest that the density of minority-spin gap states can be reduced by appropriately controlling the defects in Co_2MnGe electrodes.

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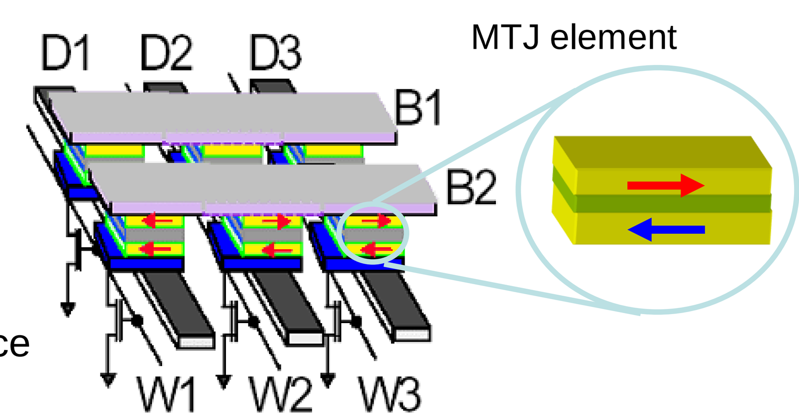
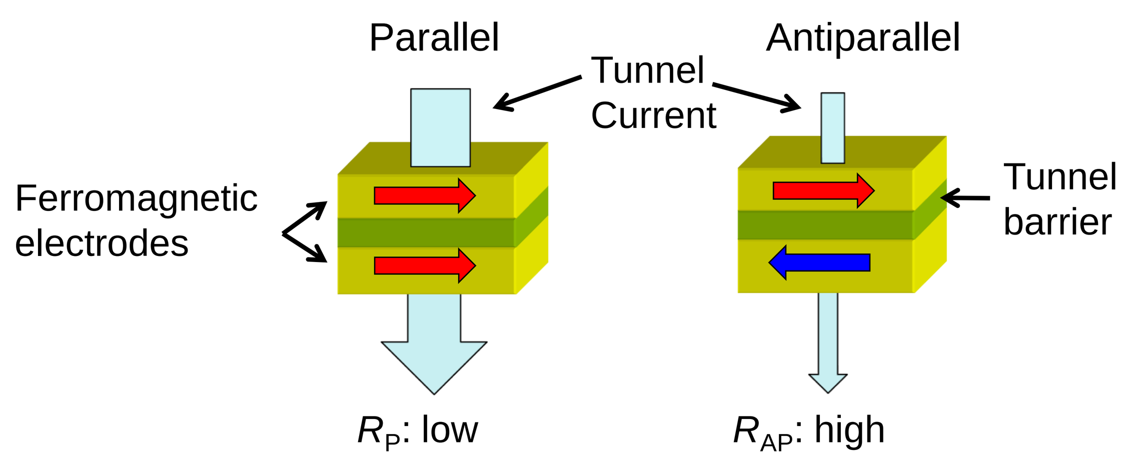
Introduction

Magnetoresistive Random Access Memory (MRAM)

MRAM characteristics:
- Non-volatile
- High speed read/write
- High density
- Unlimited read/write endurance



Magnetic Tunnel Junctions (MTJs)

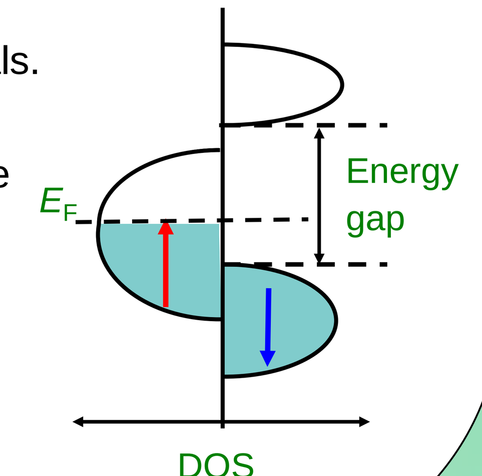


$$\text{TMR ratio} = \frac{R_{AP} - R_P}{R_P} = \frac{\Delta R}{R_P}$$

- High TMR ratios in MTJs are necessary in order for constructing high-speed MRAMs with large-scale-integration.

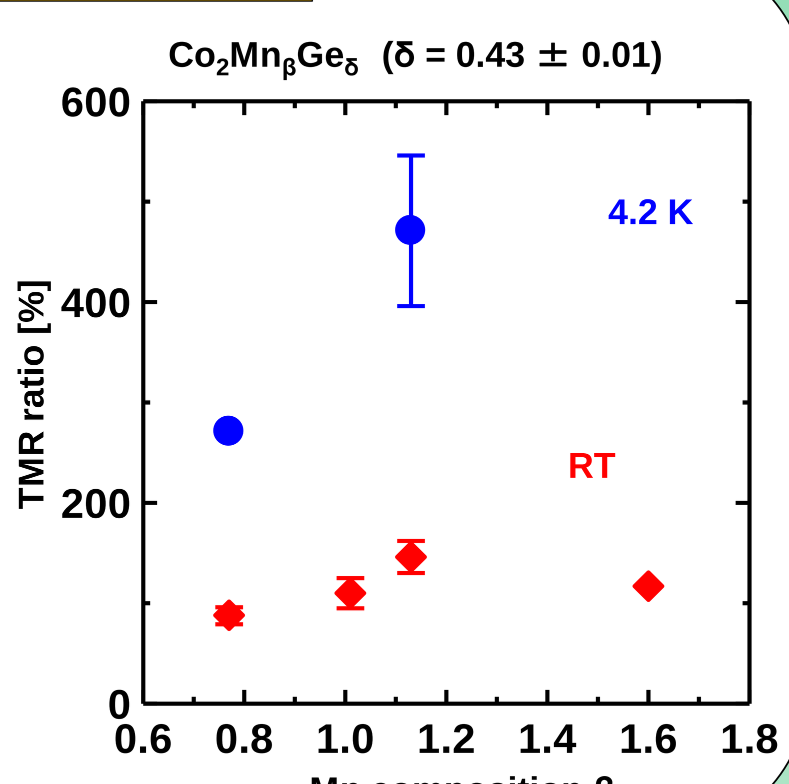
Heusler Alloys

- Heusler alloys are theoretically predicted to be half-metals.
- They have high Curie temperatures which are well above room temperature.
- Co_2MnGe was chosen for the MTJ electrodes due to its small lattice mismatch of -3.6% with MgO for a 45° in-plane rotation with the (001) plane.

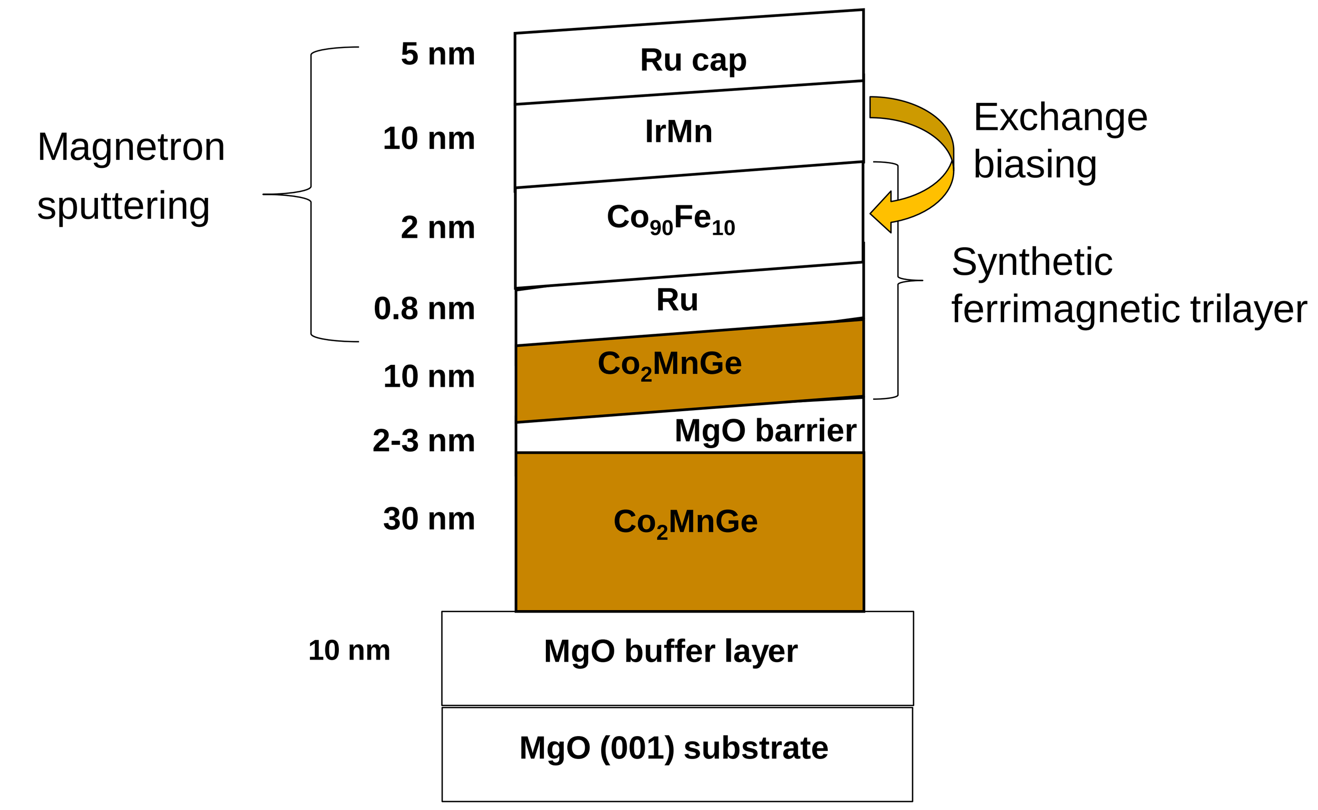


Purpose

- There is an increasing TMR ratio for increasing Mn composition β from 0.77 to 1.13 at RT.
- Investigate the spin–dependent tunneling characteristics of $Co_2MnGe/MgO/Co_2MnGe$ MTJs fabricated as a function of Mn compositions β for $Co_2Mn_\beta Ge_\delta$ at 4.2 K.
- Understand the origin of the observed dependence associated with non-stoichiometry in prepared Co_2MnGe electrodes.

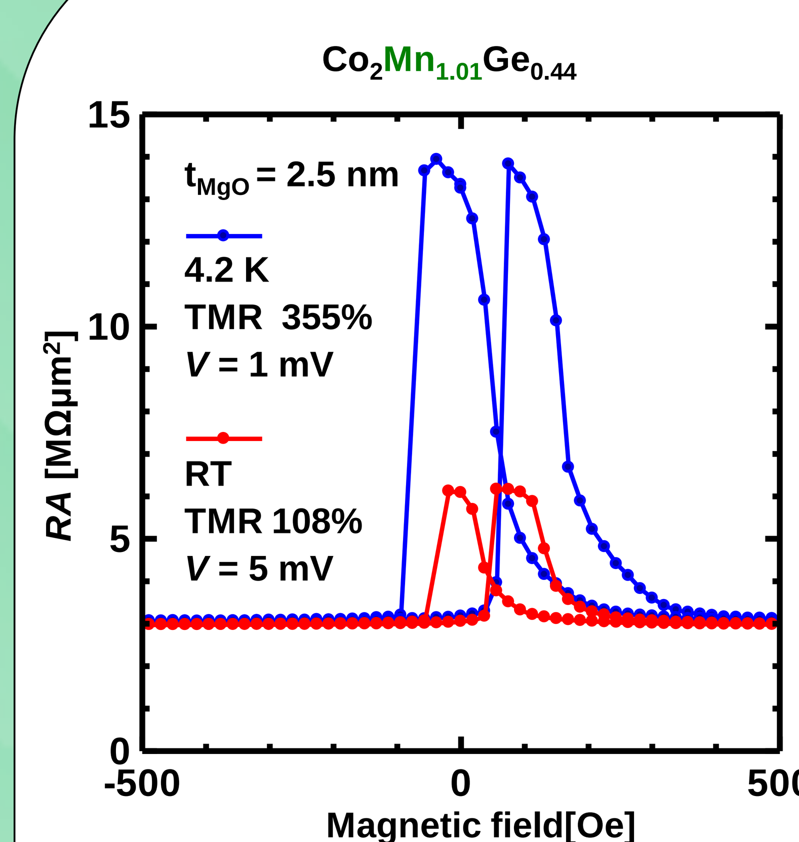


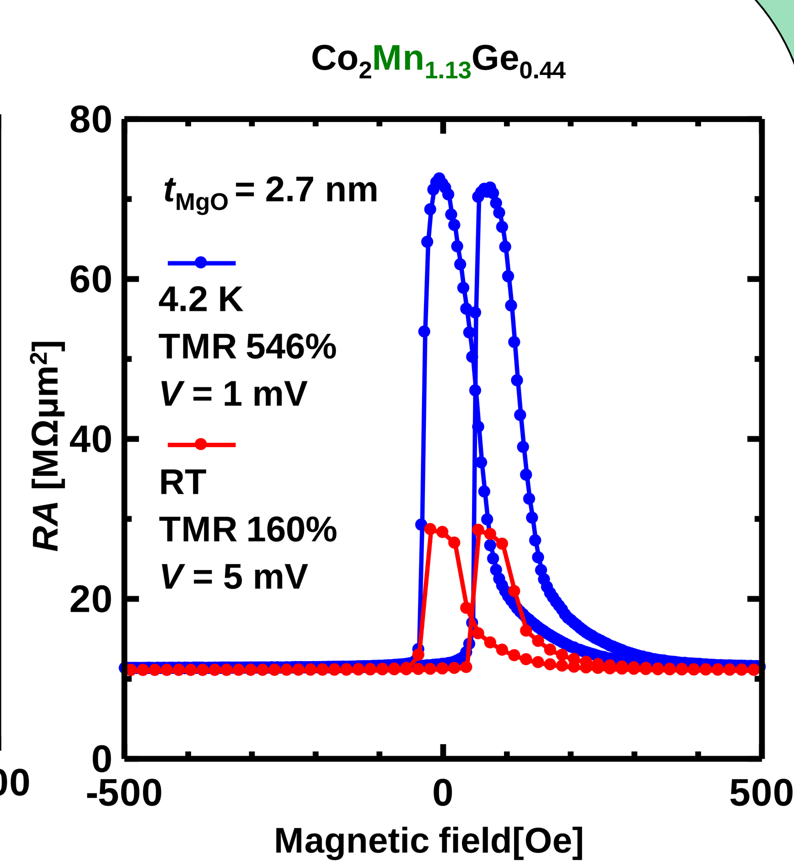
Layer Structure



- All of the layers were deposited in an ultrahigh vacuum chamber (~8 x10^{-8} Pa).
- The CMG layers were deposited by co-sputtering from a Co_2MnGe target and a Mn target in order to precisely control the Mn composition β in the $Co_2Mn_\beta Ge$ electrodes.
- Immediately after being deposited, both the upper and lower CMG electrodes were annealed *in situ* at 500° C for 15 minuets.
- Epitaxial growth for all layers was confirmed from RHEED observations.
- The MTJs were fabricated using photolithography and argon ion milling.

Results

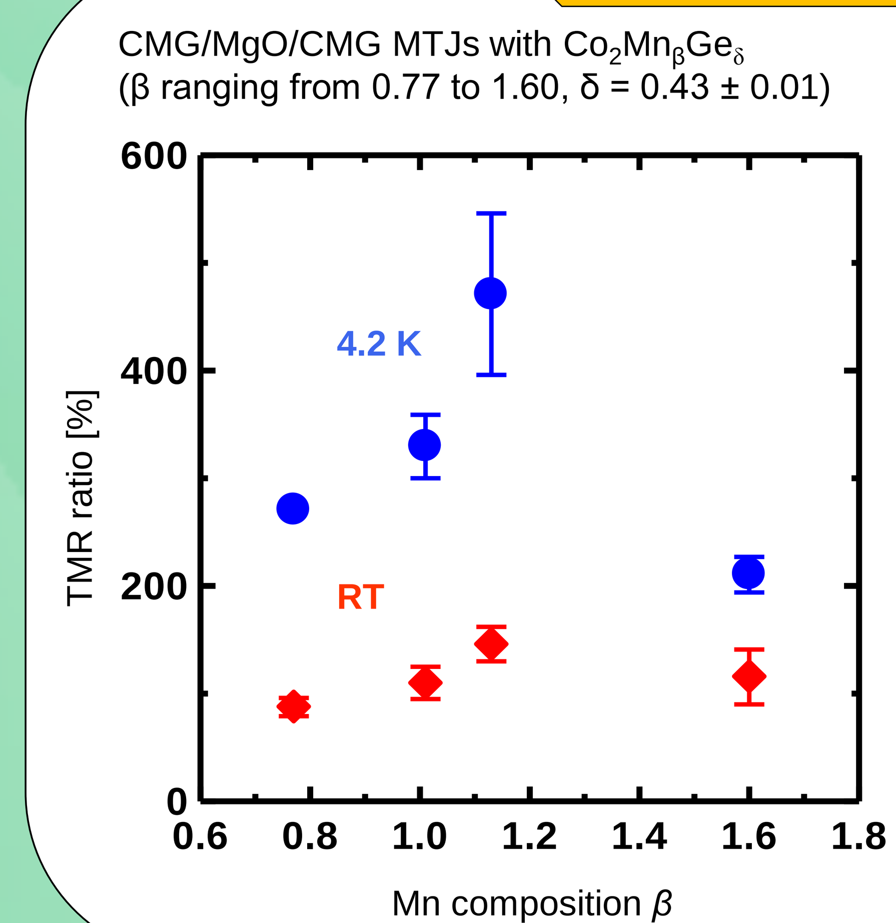




- For the almost stoichiometric $Co_2Mn_{1.01}Ge_{0.44}$ we measured TMR ratios of 108% at RT and 355% at 4.2 K.
- For the Mn-rich $Co_2Mn_{1.13}Ge_{0.44}$ we measured TMR ratios of 160% at RT and 546% at 4.2 K.

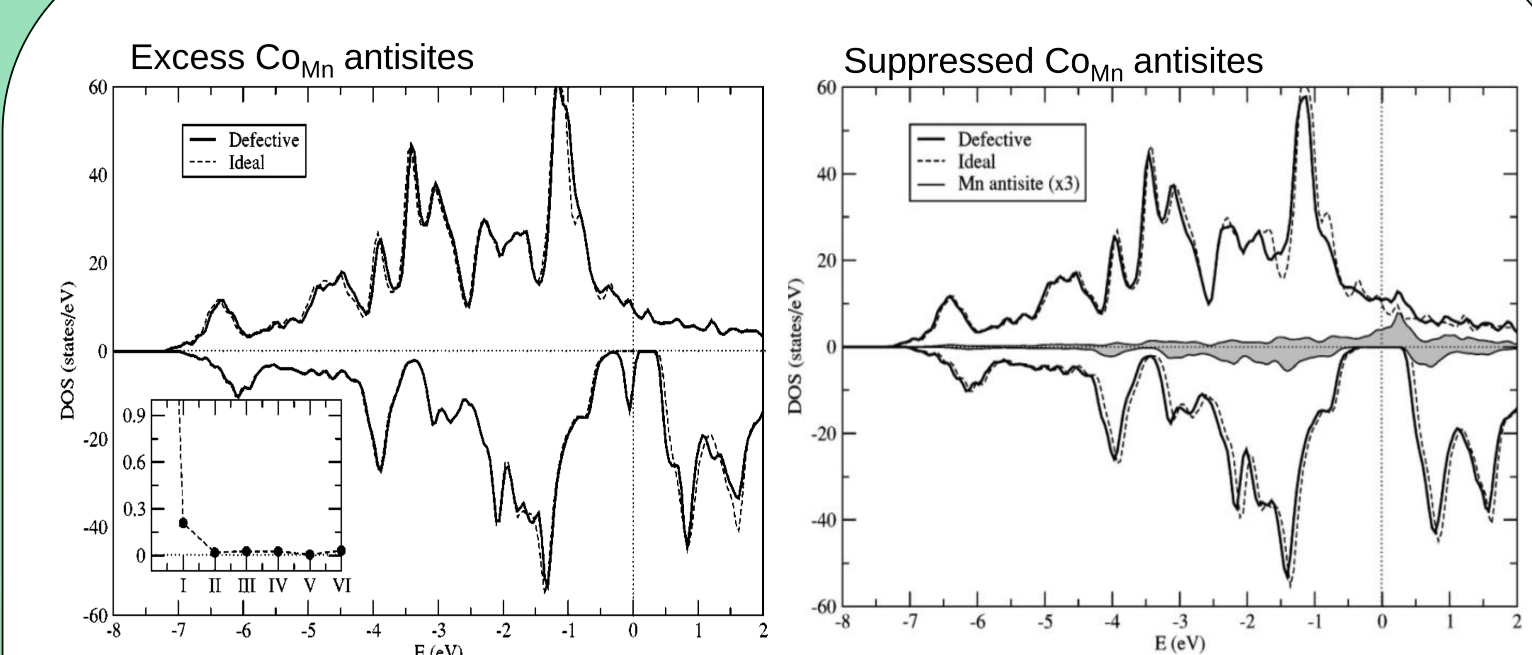
Results cont.

CMG/MgO/CMG MTJs with $Co_2Mn_\beta Ge_\delta$
(β ranging from 0.77 to 1.60, δ = 0.43 ± 0.01)



- The TMR ratio increased systematically with increasing β beyond β = 1 up to a certain composition.
- This indicates that the TMR ratio is explicitly dependent on the Mn composition.
- The highest TMR ratio can be obtained with Mn compositions above β = 1, not by using the stoichiometric composition of 2:1 which was previously thought to yield the highest TMR ratio.

Discussion



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- Co_{Mn} antisites, which induce minority spin gap states at the Fermi level, formed in Mn deficient Co_2MnGe films leading to lower TMR ratios.
- Conversely, in Mn rich Co_2MnGe films, there was a suppression of Co_{Mn} antisites which lead to an increase in the TMR ratios.

Conclusion

- Higher TMR ratios were obtained from MTJs with Mn-rich CMG electrodes.
- The density of minority-spin gap states can be reduced by appropriately controlling defects in Co_2MnGe electrodes.

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