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Current-Induced Crystallisation in Heusler Alloy Films

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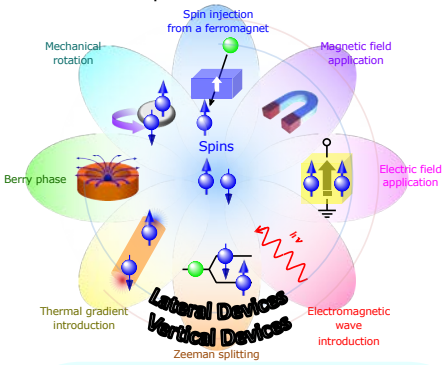
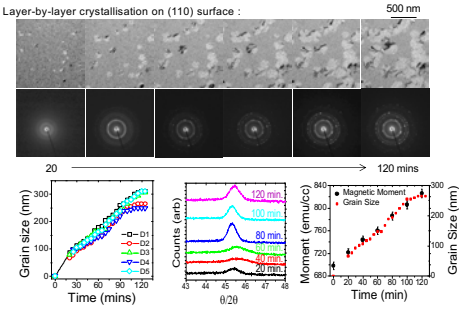
Spin Generation [1]



Roadmap on Heusler Alloys [2]

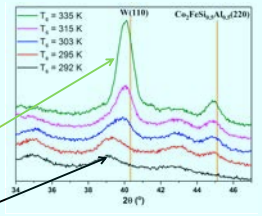
[1] A. Hirohata *et al.*, *J. Magn. Magn. Mater.* **509**, 166711 (2020).
[2] A. Hirohata *et al.*, *IEEE Trans. Magn.* **51**, 07160747 (2015).
[3] J. Sagar *et al.*, *Appl. Phys. Lett.* **105**, 032401 (2014).

Low-Temperature Crystallisation [3]



Low-Temperature Deposition

$Co_2FeAl_{0.5}Si_{0.5}$ (CFAS)/W/CFAS trilayers were sputtered at substrate temperatures T_S :

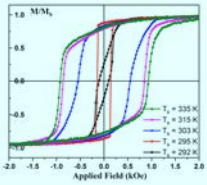


T_S (K)	2θ (°)	D (nm)
292	39.01	8.28
295	39.32	6.60
303	39.72	3.96
315	39.95	3.56
335	40.04	3.32

Magnetic Properties

CFAS/W/CFAS trilayers : *

- Low T_S film has strong intergranular exchange coupling.
- This gives a highly square, low H_C loop.
- Higher T_S → 50% of the reversal is via domain rotation.
- The remainder is via nucleation and domain wall pinning.

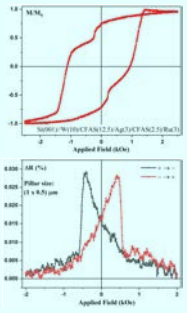


→ The is similar to CoFe and would be suitable for a GMR device.

Device Characterisation

CFAS/Ag/CFAS nanopillars fabricated :

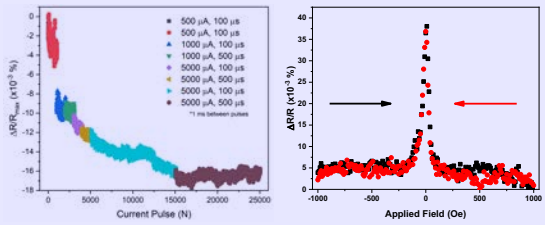
- Due to the lack of individual layer switching in multilayers using a W spacer, Ag was used.
- A 3 nm layer of Ag provided a loop with two distinct switches dependent on layer thickness.
- A small GMR of 0.025% was observed perpendicular-to-plane for device of (1 x 0.5) μm².
- Switching occurs at the same field as in the *M-H* loop, confirming layer thickness dependent switching.



[4] A. Hirohata *et al.*, *Materials*, **11**, 105 (2018).

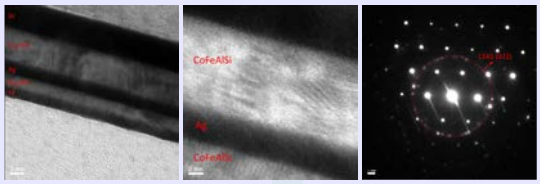
Current-Induced Crystallisation

CFAS/Ag/CFAS nanopillars :



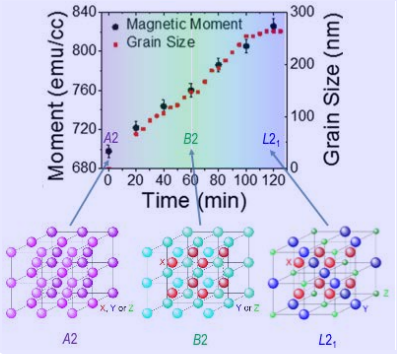
- Resistance change after a series of pulse current applications of 500 μA up to 5 mA for 100 μs up to 500 μs in a GMR device consisting of CFAS/Ag/CFAS.
- The initial GMR effect is extremely small at only 0.04% and is very unstable, with no stable anti-parallel configuration.
- Using Ohm's law, the application of a 100 μA current for 10 s introduces 6.24×10^{-14} J to a Heusler alloy nanopillar (10 nm thick and 100 nm diameter).
  - By assuming the resistivity is similar to that of Co (6.24 nW·m).
- For an ideal case, this increases the temperature of the Heusler layer by 51.5K.
  - Since the heat capacity of Co is 24.81 J/mol·K and the density of Co is 8.90 g/cm³.

High-resolution transmission electron micrographs :



- Cross-sectional TEM images of the GMR device with 300k and 800k magnification.
- Diffraction pattern confirms CFAS (220) crystallisation.
- Lattice constant is estimated to be 0.57 nm, which is 96.6% of that estimated by the corresponding XRD.

$Co_2Fe(Al,Si)$ / Ag / $Co_2Fe(Al,Si)$ trilayers : *



- The current-induced crystallisation leads to the reduction in the corresponding resistivity.
- This acts as memory potentiation for an artificial GMR synapse.
- This offers more realistic neuromorphic computation with higher efficiency.

Summary

- The concept of the current-induced crystallisation has been successfully demonstrated in a Heusler-alloy GMR junction.
- Due to the nature of a simple electrical current introduction, a nanoelectronics device does not require annealing processes but stores the operation cycle permanently.
- The current-induced crystallisation minimises any atomic diffusion and interfacial mixing to degrade their performance.
- The current-induced crystallisation is expected to be used in a variety of nanoelectronics devices, including a neuromorphic node network.

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