Deliverable Report
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TRANSPIRE

Deliverable	**Deliverable name (Short name)**	**WP No.**	**Lead participant**	**Type**	**Diss. Level**	**Date**
D2.1	First GMR/TMR measurement	2	HZDR	Report	Public	M6

Progress beyond state-of-the-art:
First measurement of TMR with a zero-moment ferrimagnet

Partner	**Contribution**
TCD	Film optimisation and growth; Structural characterisation; Low temperature electrical measurements (post patterning @ HZDR)
HZDR	Device patterning; Room temperature electrical measurements; Magnetisation measurements

The deliverable was met with the publication of a paper from the consortium with authors only from the TCD and HZDR research groups.
Title: "Tunnelling magnetoresistance of the half-metallic compensated ferrimagnet Mn2RuxGa"
Authors: K Borisov[1], D Betto[1], YC Lau[1], C Fowley[2], A Titova[2], N Thiyagarajah[1], G Atcheson[1], J Lindner[2], AM Deac[2], JMD Coey[1], P Stamenov[1], and K Rode[1],
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Journal Data: Applied Physics Letters, 108, 192407 (2016) (green-model)

The Trinity College Dublin group began the deliverable by depositing several samples in their Shamrock sputter deposition tool. In order to optimize the growth of a high quality magnesium oxide (MgO) tunnel barrier on a half metallic ferrimagnetic electrode of manganese ruthenium gallium (MRG), characterisation techniques such as scanning electron microscopy, atomic force microscopy and X-ray reflectivity were utilised. In the end, a continuous MgO barrier of thickness 1.7 nm was grown successfully on top of several MRG electrodes. A top electrode consisting of perpendicularly magnetised CoFeB was also optimised in order to have a complete magnetic tunnel junction possessing perpendicular magnetic anisotropy.

To prevent oxidation of the half metallic electrode, insertion barriers of aluminium, tantalum and titanium nitride were deposited. Of each insertion barrier several thicknesses were grown. The extended multilayer samples were then sent to Helmholtz-Zentrum Dresden-Rossendorf for subsequent patterning. There the Nanofabrication Facilities Rossendorf at the Ion Beam Centre were used. An ultraviolet lithography process was developed so that a high yield of the finished devices was obtained (100%).

The extended films were patterned into junctions measuring 20 µm by 20 µm and 6 µm by 6 µm using a three-step lithography / ion-milling / oxide passivation / lift-off process (see Figure 1). The final devices were characterised electrically for device-to-device variation and calculation of the process yield. Each initial 1 cm x 1 cm chip sent from Dublin produced sixty-six individual magnetic tunnel junctions, thirty-three 20 µm x 20 µm and thirty-three 6 µm x 6 µm.

Sample chips were then cut into several pieces in order for post-annealing at HZDR. The purpose of annealing is two-fold, to improve the crystal quality of the MgO barrier and CoFeB counter electrode and to ensure that the devices are stable up to relevant industrial process temperatures (i.e. solder reflow steps, where samples are exposed to 250°C for approximately 5 minutes). The raw data was captured and stored on the HZDR central servers (as per HZDRs data policy). Data analysis

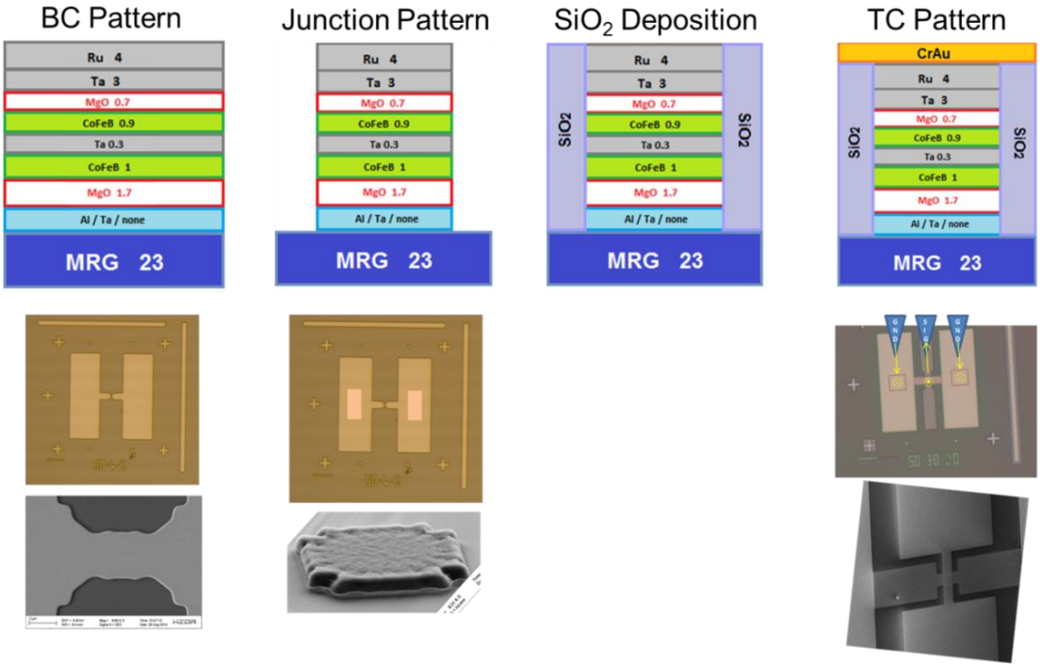

Figure 2: Typical device structure (above) as well as outline of the UV lithography process gong from left to right. BC pattern, bottom contact patterning, where individual mesas are separated from each other by ion milling. Junction pattern, where a small area containing only the magnetic tunnel junction is defined by ion milling. SiO2 deposition is when the top and bottom areas of the stack are separated by an oxide layer to ensure that electrons may only pass through the junction itself. TC pattern, where a bi layer of chrome and gold is deposited to finish the device and allow us to measure tunnel magnetoresistance.

was carried out individually by the PhD student and presented in the weekly group meetings and discussed initially in the meetings of Alina Deac and in the subsequent face-to-face and monthly Skype meetings.

After the first devices were successfully fabricated and measured and the UV process was proven other samples with different insertion layers were also patterned and measured. In total, four different MRG compositions (with varying compensation temperature), three different insertion layers with three different thicknesses as well as one sample set without any insertion layer were prepared. The total number of measureable devices was over 2500. In the end a better insertion barrier was not found (see Table 1). However, given the uniqueness of the aluminium insertion layer (which was featured in the published paper) being the best, it has spurred additional research associated with the project which is the investigation of other tunnel barriers and the investigation of whether aluminium is mixing with MgO to for MgAlO.

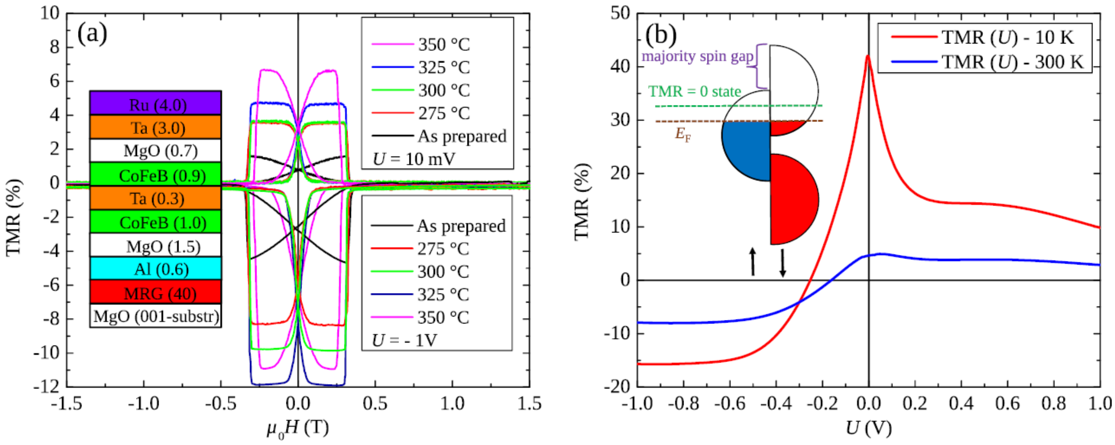

Figure 1: (a) Room temperature (300K) TMR data of the Mn_2Ru_1Ga sample annealed at different temperatures. Positive TMR is observed at applied bias U = 10mV, and negative at U = 1V. (b) TMR (U) scans at 300K and 10K for a chip annealed at 350 °C. The top left inset represents the spin split density of states of MRG for this composition.

Risks Managed/Mitigated

Due to some irregularities during the fabrication of the new samples, designed to be identical to the original samples, the entire UV process was recalibrated and rechecked for consistency with standard magnetic tunnel junctions produced in Dublin. Those control samples showed the correct level of TMR. The lack of performance was then attributed solely to the different growth conditions. Further attempts to reproduce the original results were in the end successful.

Outlook / Future work

Currently the aim is to improve the TMR ratio, and the group at HZDR are conducting TEM investigation to determine the exact chemical composition of the MgO barrier and if the aluminium is playing an important role.

In order to have sample diversity, giant magnetoresistance samples based on MRG were also grown at TCD and are currently under investigation at HZDR. Device designs for nanopillars and nano-contacts have been also designed and are currently being implemented to feed into deliverables D2.4 and D2.5 as well as D3.4 and D3.5.

In summary, the deliverable was met with the publication of a paper in accordance with the “Green” model. The results have spurred new investigations which will provide better devices as well as providing a solid grounding for subsequent deliverables.

Insertion layer	Thickness [nm]	Ru concentration	RA product [Ohm.µm^{2}]	Max TMR [%]	Min TMR [%]
None		**0.65**	5.9x10^{3}	0.32	-0.68
		0.75	9.4x10^{3}	0.35	-0.61
		0.9	2.1x10^{4}	0.22	-0.44
		1.1	1.1x10^{4}	0.6	-0.24
Ta	0.3	**0.65**	1.2x10^{3}	-0.02	-0.35
		0.75	9.6x10^{2}	-0.02	-0.37
		0.9	1.6x10^{3}	AMR	
		1.1	9.2x10^{2}	0.22	-0.01
	0.6	**0.65**	1.2x10^{3}	AMR	
	0.9	**0.65**	7.6x10^{2}	AMR	
Al	0.3	**0.65**	2.1x10^{4}	AMR	
	0.6	**0.65**	8.0x10^{4}	2.09	-0.09
		0.75	6.2x10^{4}	1.57	0.42
		0.9	2.6x10^{5}	0.63	0.17
		1.1	2.0x10^{5}	-0.36	-0.36
	0.9	**0.65**	4.4x10^{6}	AMR	

Table 1: Resistance area product and max and min TMR for different insertion layers and thicknesses in the as-deposited state.