ESRF	**Experiment title:** Magnetic proximity effect of Pt in Pt/PtMnSb bilayers investigated by x-ray resonant magnetic reflectivity	**Experiment number**: HC-2861
Beamline: BM28	**Date of experiment**: from:16 November 2016 to:22 November 2016	**Date of report**: March 09, 2020
Shifts: 18	**Local contact(s)**: Laurence Bouchenoire	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Jan Krieft*, Panagiota Bougiatioti*, Timo Kuschel*

Center for Spinelectronic Materials and Devices, Department of Physics, Bielefeld University, 33615 Bielefeld, Germany

Johannes Mendil*

Department of Materials, ETH Zurich, 8093 Zurich, Switzerland

Report:

If non-magnetic material is close to the Stoner criterion as in the case of Pt, it can become magnetic in the proximity to ferromagnetic material [1]. This magnetic proximity effect (MPE) is a key phenomenon for spintronic and spin caloritronic effects, such as for the spin Hall magnetoresistance [2] or the spin Seebeck effect [3]. We have investigated the MPE in the half-Heusler material PtMnSb [4] which lacks crystal inversion symmetry and is therefore important for spin-orbit torque applications [5].

We studied sputter-deposited PtMnSb thin films with either Pt or oxide capping layer by x-ray resonant magnetic reflectivity (XRMR) [6-12] at BM28 at the Pt L_3 absorption edge (11.567keV). Thus, we obtain the spin depth profile of the whole layer stack and study a volume MPE within the PtMnSb as well as an interface MPE due to the capping material Pt. XRMR is a powerful technique which is highly sensitive to interface magnetism due to the interference of reflected x-rays at the interfaces. This has already been shown by our group in prior XRMR experiments at BM28 for Fe/Pt and $NiFe_2O_4$/Pt [9] as well as for oxygen-reduced $NiFe_2O_x$/Pt [3].

Figure 1 presents the data set of a 20.5nm PtMnSb film with a 3.4nm AlO_x/MgO capping. The x-ray reflectivity (XRR) curve I in Fig. 1(a) has distinct interference oscillations (Kiessig fringes) which can be simulated by the recursive Parratt algorithm [13] obtaining thicknesses and roughnesses of the layer stack by, e.g., the element mode of the analysis program ReMagX [6]. Furthermore, the depth profiles of the diffusion δ and absorption β coefficient defining the refractive index n=1-$\delta+i\beta$ can be obtained as shown in Fig. 1(b). The asymmetry ratio $\Delta I=(I_+-I_-)/(I_++I_-)$ in Fig. 1(c) calculated from XRR curves with opposite x-ray helicities ($I_\pm$) can be modelled using the depth profile of the magnetic change in absorption $\Delta\beta$. The density depth profiles of the individual layers and the best-fit depth profile of $\Delta\beta$ are summarized in Fig. 1(d).

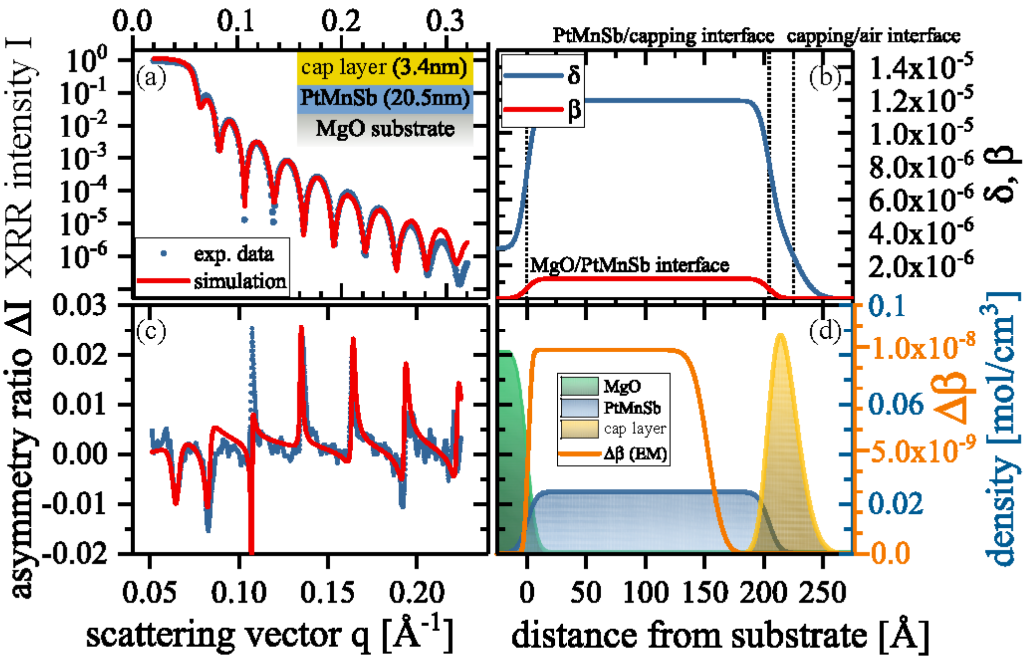

Figure 1: (a) XRR intensity I of 20.5nm of PtMnSb with AlO_x/MgO capping layer (Pt L_3 edge at 11.567keV). (b) Magnetooptic depth profile of δ and β used for the best-fit simulation in (a). (c) Asymmetry ratio ΔI and the corresponding simulation generated with the element mode of ReMagX. (d) XRR density depth profile together with the magnetooptic depth profile $\Delta\beta$ used in the asymmetry ratio simulation in (c).

A clear volume MPE can be identified, since a finite asymmetry ratio is present (Fig. 1(c)). In addition, one can clearly identify a magnetic dead layer at the PtMnSb-capping interface, because the density depth profile of PtMnSb (blue area in Fig. 1(d)) has a larger extend than the magnetic $\Delta\beta$ depth profile (orange curve in Fig. 1(d)). This result could be probably achieved by partially oxidized PtMnSn at the interface due to the oxide capping layer.

The second investigated sample system PtMnSb/Pt showed similar results. However, the magnetic Pt depth profile reached the interface and no magentic dead layer was observable, neither an interface MPE could be detected. These XRMR results have been written up in a manuscript and discussed in terms of modelling strategies and differences of capping materials on PtMnSb [14].

The next step will be to study the magnetic depth profile of Mn in these samples and compare it to the magnetic Pt depth profile in order to identify any Pt magnetic dead layer with different magnetic extend between Pt and Mn. Therfore, we have already performed XRMR at soft x-ray energies at BL 4.0.2, ALS, and are currently in progress of processing and fitting the data. The outcome will be part of another manuscript, currently in preparation [15].

References and own publications:

[1] E. C. Stoner et al., *Proc. Royal Soc. A* **169**, 339 (1939)
[2] M. Althammer, T. Kuschel et al., *Phys. Rev. B* **87**, 224401 (2013)
[3] P. Bougiatioti, T. Kuschel et al., *Phys. Rev. Lett.* **119**, 227205 (2017)
[4] J. Krieft, J. Mendil, T. Kuschel et al., *Phys. Status Solidi (Rapid Res. Lett.)* **11**, 1600439 (2017)
[5] C. Ciccarelli et al., *Nat. Phys.* **12**, 855 (2016)
[6] S. Macke et al., *J. Phys.: Condens. Matter* **26**, 363201 (2014)
[7] T. Kuschel et al., *Phys. Rev. Lett.* **115**, 097401 (2015)
[8] C. Klewe, T. Kuschel et al., *Phys. Rev. B* **93**, 214440 (2016)
[9] T. Kuschel, P. Bougiatioti et al., *IEEE Trans. Magn.* **52**, 4500104 (2016)
[10] P. Bougiatioti, T. Kuschel et al., arXiv:1807.09032
[11] A. Mukhopadhyay, T. Kuschel et al., arXiv:1911.12187
[12] A. Moskaltsova, J. Krieft, T. Kuschel et al., *AIP Advances* **10**, 015154 (2020)
[13] L. G. Parratt, *Phys. Rev.* **95**, 359 (1954)
[14] J. Krieft, T. Kuschel et al., *under review*
[15] J. Krieft, T. Kuschel et al., *in preparation*