Perpendicular magnetic anisotropy and Dzyaloshinskii-Moriya interaction in ultrathin Pd/Co/Ta films

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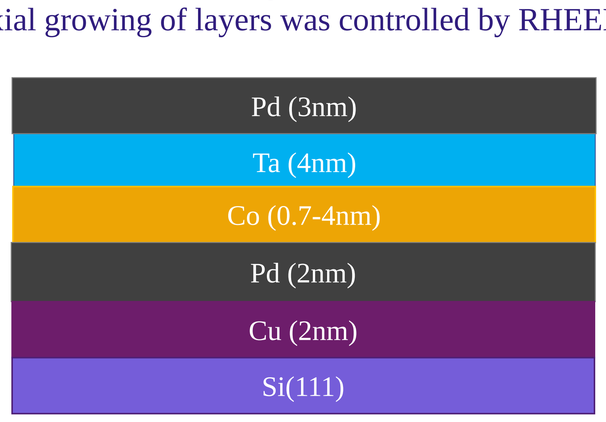
Introduction

In this research, we investigated an ultrathin epitaxial heavy metal1(HM1)/ferromagnetic (FM)/heavy metal2(HM2) films. The main magnetic parameters such as thickness of transition from perpendicular magnetic anisotropy (PMA) to in-plane magnetic anisotropy (IMA), value of dead magnetic layer on the Co/Ta interface and thicknesses dependence of coercivity were studied. Existence of Dzyaloshinskii-Moriya interaction and chiral dumping effect were showed.
Development of Spintronics demand a search of new nanostructure materials with opportunity to use one in controllable magnetic processes for creation skyrmionium racetrack memory, logic devices etc. Interfaces TM/FM are perspective for creation of spintronics devices because contain series of interface effects: enhancement of perpendicular magnetic anisotropy (PMA), interfacial DMI (iDMI), spin-Hall effect etc. [1]. These effects are used for formation, stabilization and controlling spin textures.

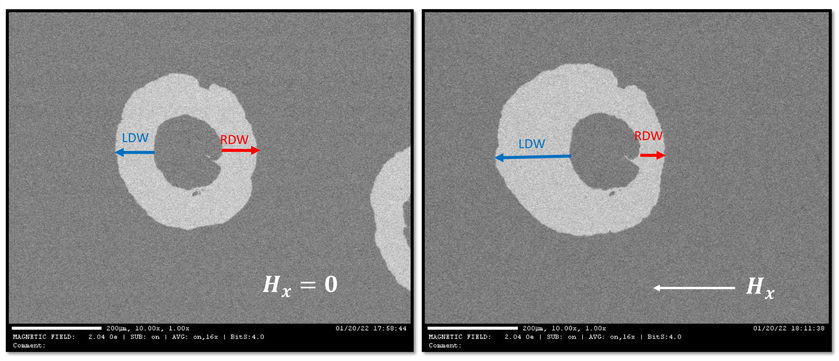
Experiment

In our work we prepared a series of thin Pd(111)/Co/Ta films with different value of Co thickness using ultrahigh vacuum system (Omicron Nanotechnology) which consisted of a molecular beam epitaxy chamber and an analysis chamber interconnected with each other. We used monocrystalline Si(111) as a substrate with Cu (2nm) buffer layer to prevent a silicide formation and avoid of mismatch Si and Pd crystallography structure. Tantalum was used as a heavy metal with strong spin-orbit interaction. Bottom Pd layer induced PMA in Co layer. Epitaxial growing of layers was controlled by RHEED.



Valid structure of Pd(111)/Co/Ta film

Hysteresis loops M(H) were measured in two external field directions (in-plane and out-of-plane) with vibrating sample magnetometer (7410 VSM, LakeShore) and processed for getting plots of magnetic parameters in dependence of Co thickness.
Domain structure visualization was carried out with Kerr microscopy (Evico Magnetics). To investigation of iDMI, we measured asymmetrical moving of right and left domain walls after applying continuous magnetic field H_x in plane of simples and impulse of field H_z in perpendicular direction.



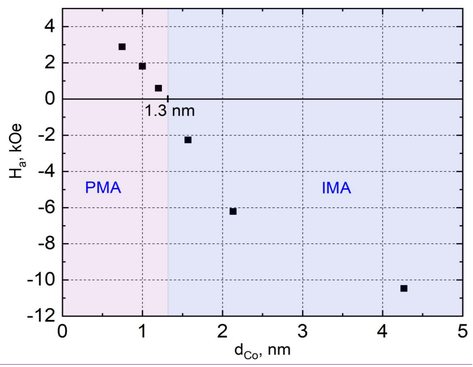
Asymmetrical moving of domain walls for different values of continuous magnetic field

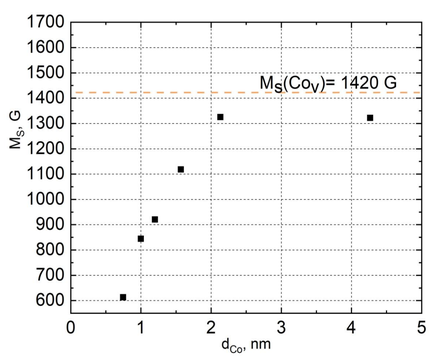
Results and discussion

As a result of processing hysteresis loops, which include subtraction of IP field from OOP field based on formula (1), dependence of anisotropy field was got. In this case we can determine the value of PMA to IMA transition (1.3 nm).

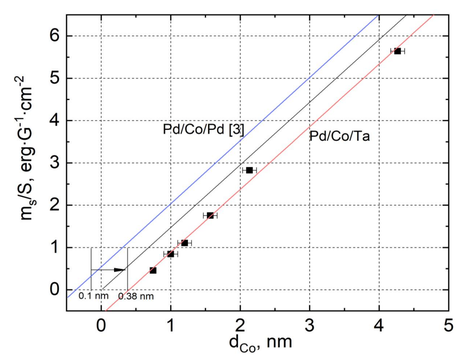
$$K_{eff} = \frac{1}{2}(H_{a\parallel} - H_{a\perp})M_s \quad (1)$$

Anisotropy field vs Co thickness →





Values of saturation magnetization at various Co thickness

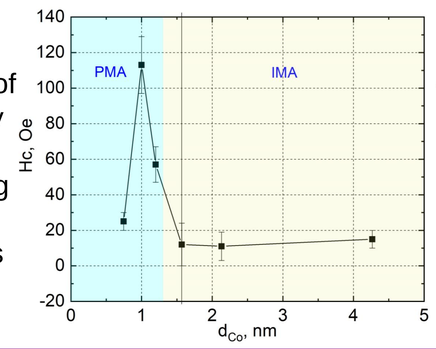


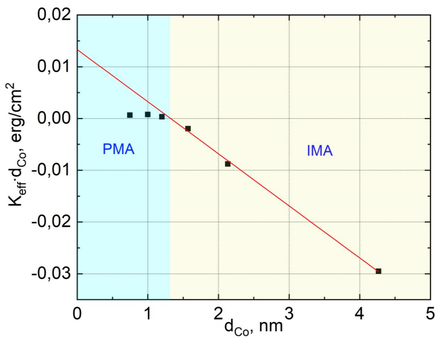
Saturation of parameter lower than saturation volume magnetization → existence of dead layer

Determination of dead layer in Co/Ta interface

$d_{DL} = 0.48\ nm$

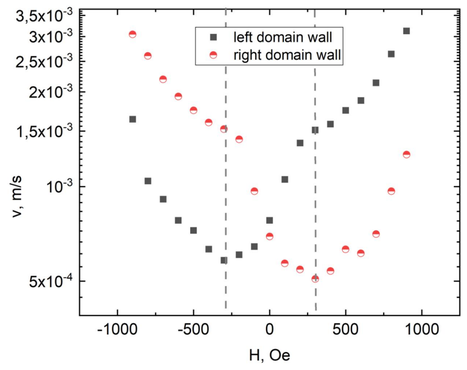
Behavior of coercivity with increasing Co thickness





Energy of magnetic anisotropy depending on Co thickness

$$K_{eff} = K_V + \frac{K_S}{d_{FM}} \quad (2)$$
$$K_S = 1{,}4 \cdot 10^{-2}\ erg/cm^2$$
$$K_V = 6{,}46 \cdot 10^4\ erg/cm^3$$



← Domain walls velocity curves

- Symmetrical view of right domain wall with respect to left one;
- Non-zero value of H_{min} (~ 300 Oe) indicates of DMI existence;
- Asymmetrical shape relative the minimum shows the chiral damping contribution. Consequently, $H_D \neq H_{min}$.

Conclusions

Eventually, we revealed realization of perpendicular magnetic anisotropy ($d_{Co} < 1.3\ nm$). It was found that trilayer Pd/Co/Ta films are characterized by existence of magnetic dead layer $d_{DL} = 0.48\ nm$. Therefore, system demonstrated interfacial Dzyloshinskii-Moriya interaction and chiral damping contribution

References

1. A.G. Kolesnikov, et. al – Appl. Surf. Sci. Vol.543, (2021), 148720A.
2. V. Davydenko, et. al Phys. Rev. B 103, 094435 (2021)
3. A. V. Davydenko, et. al Phys. Rev. B 95, 064430 (2017)