Cr酸化物系垂直交換バイアス薄膜の界面磁性と機能性

大阪大学大学院工学研究科　白土 優

共同研究者

大阪大学　中谷亮一

高輝度光科学研究センター(SPring-8)　中村哲也，木下豊彦，鈴木基寛

東北大学　鳴海康雄，野尻浩之

物質・材料研究機構　三俣千春

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「スピントロニクス材料におけるX線磁気観察の新展開」

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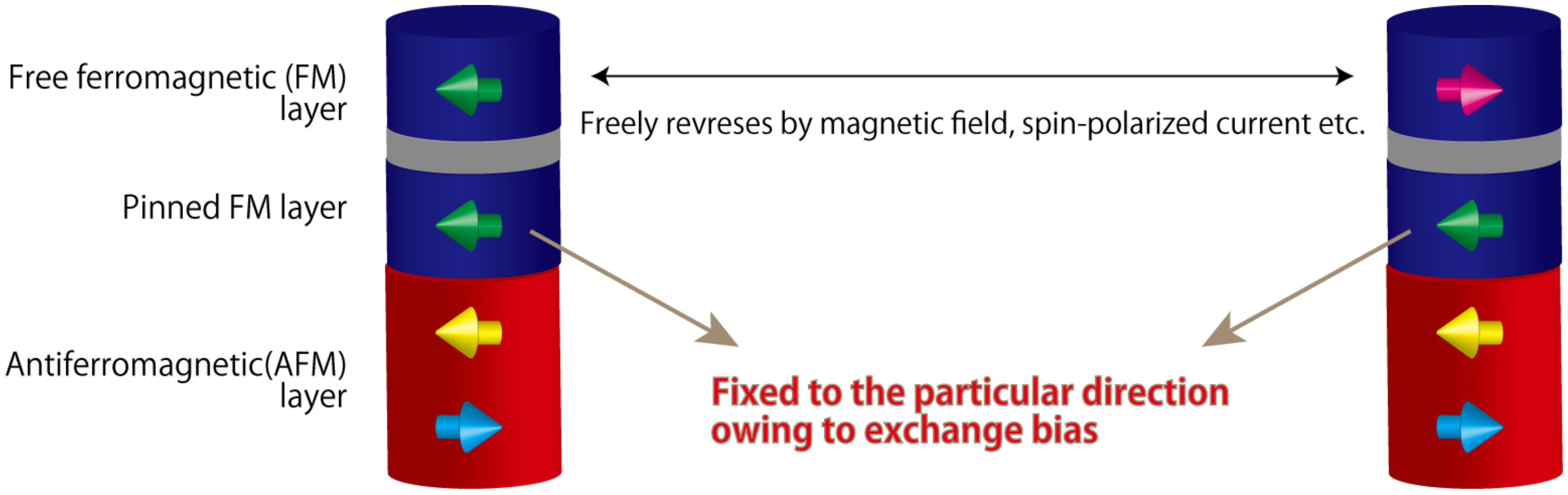
Contents

- 研究背景，目的
  - 磁気デバイスとスピンバルブ薄膜
  - 交換バイアスと反強磁性材料
  - 交換バイアスの新しい機能性と新規デバイス
- α-Cr_2O_3(0001)薄膜による垂直交換バイアスとその等温反転
  Y. Shiratsuchi et al., Physical Review Letters, vol.109, pp.077202(4pp) (2012).
  Y. Shiratsuchi et al., Applied Physics Letters, vol. 100, pp.262413(4pp) (2012).
- まとめ，今後の展望

Exchange bias and antiferromagnet

Exchange bias

- Unidirectional magnetic anisotropy at FM/AFM interface
- Exchange-biased magnetization of FM is fixed to the particular direction.

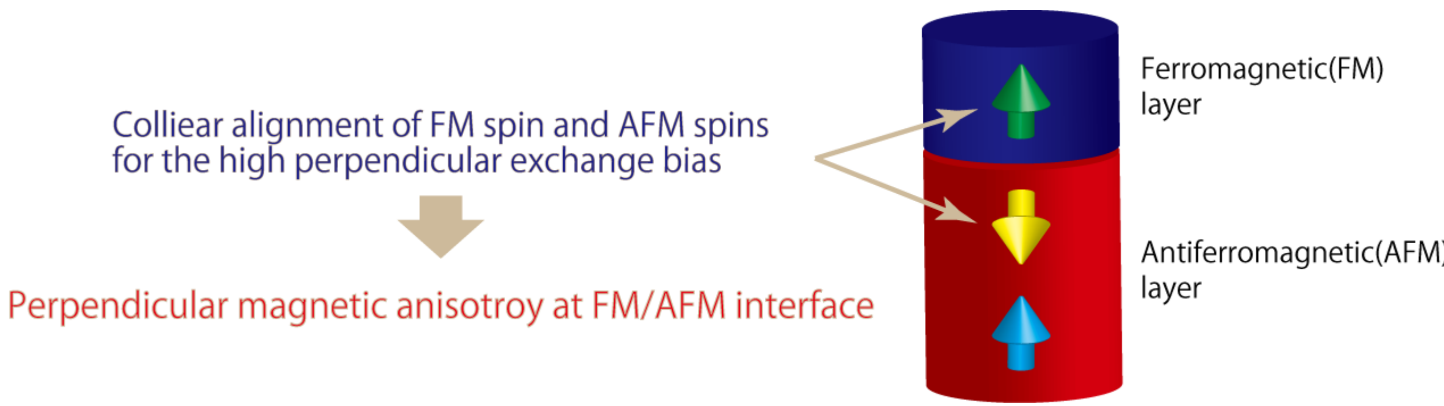


- Conventional exchange bias by Mn_3Ir alloy
  - High J_K, high T_B, low critical thickness, high oxidative resistance …
  - Rare-metal (both Mn and Ir)
  - In-plane directed effect
  - Static effect

Exchange bias for future spin-electronics

- Exchange bias for the future spin-electronics devices
  - **Rare metal free**
  - **Out-of-plane (perpendicularly) directed effect**

    Especially for the perpendicularly magnetized devices, both interfacial FM spins and interfacial AFM spins have to be perpendicular to film.



  - **Isothermal switching; Make the exchange bias a dynamic effect.**

Exchange coupling energy

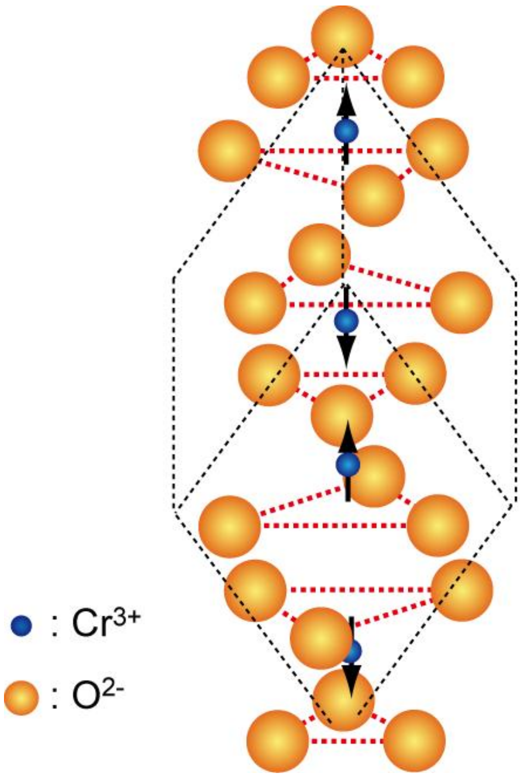
$$J_{\text{int}} \propto J \cdot \frac{\boldsymbol{S}_{FM} \cdot \boldsymbol{S}_{AFM}}{a^2}$$

Exchange bias can be reversed
by reversing the antiferromagnetic spin direction.

α-Cr_2O_3 as an antiferromagnet

- Crystal structure : corundum (a = 4.961 Å, c = 13.599 Å)
- Néel temperature : ~307 K
- Cr spin direction : parallel to *c* axis
  ferromagnetic alignment in *c* plane

⇨ **Magnetoelectric effect**
$P = \alpha H,\ \ M = \alpha' E$



Crystal structure and spin configuration of α-Cr_2O_3

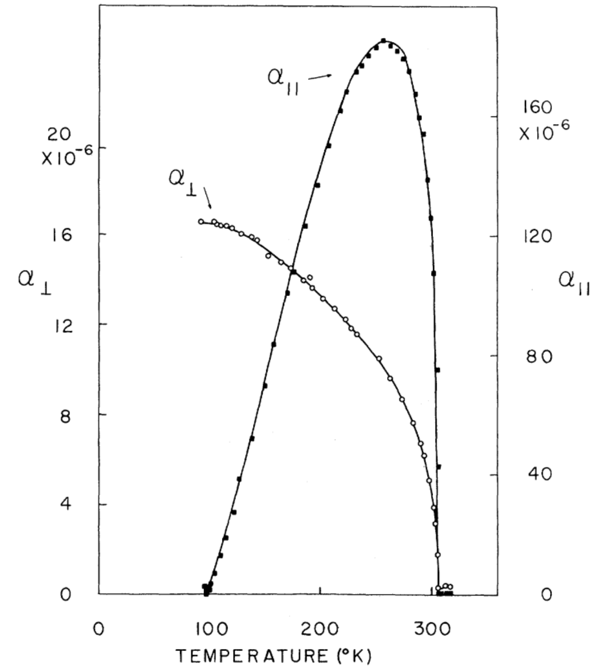
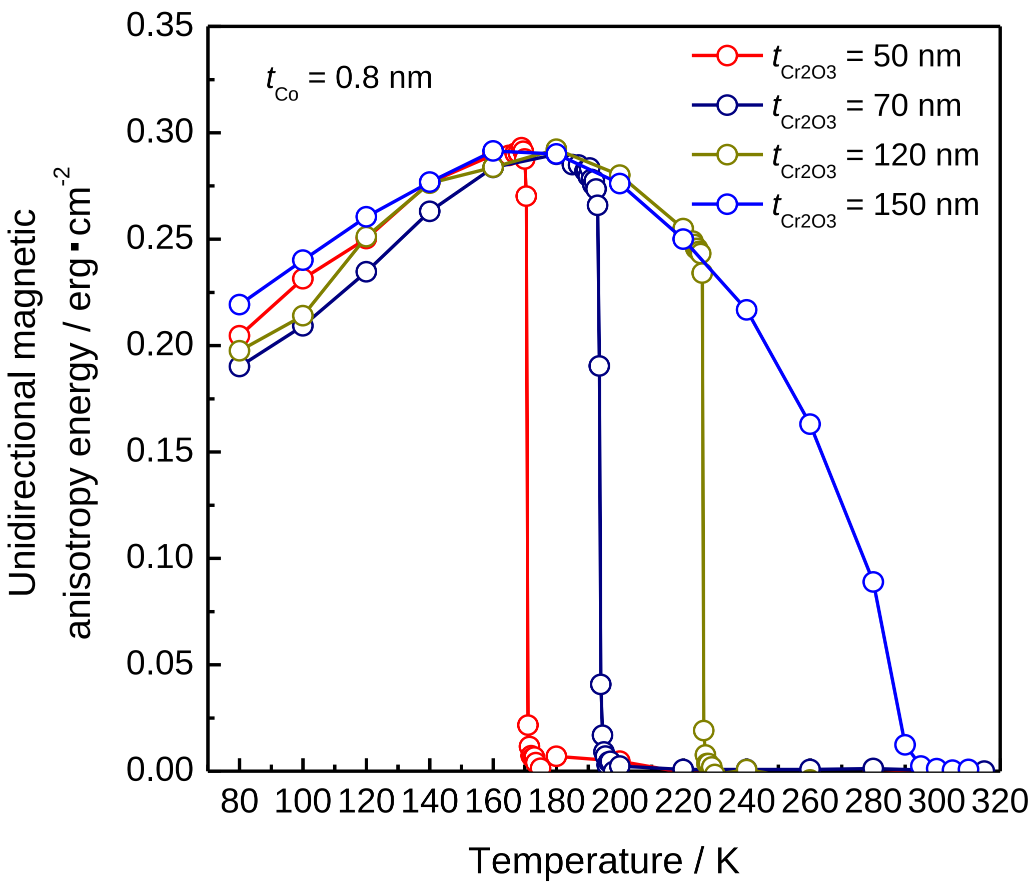
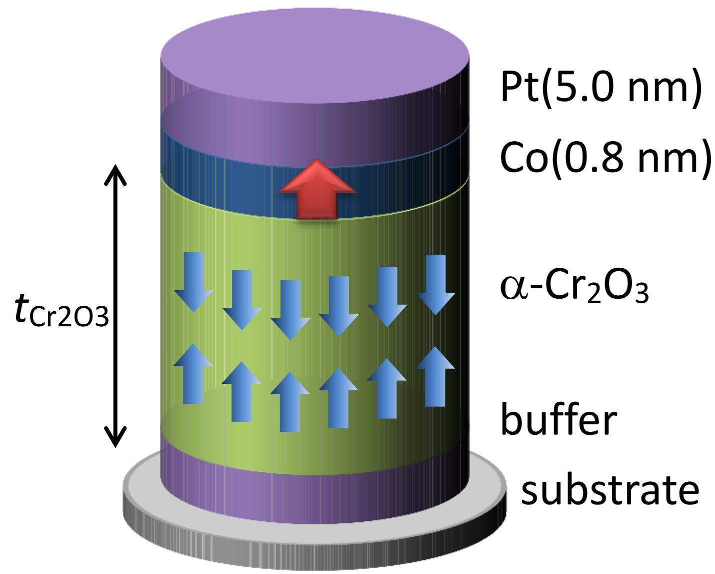


FIG. 1. Temperature dependence of the magnetoelectric parameters $\alpha_{\perp}$ and $\alpha_{\parallel}$. The α's are dimensionless in the Gaussian units used.

V. J. Folen et al., Phys. Rev. Lett. 6, 607 (1961).

Perpendicular exchange bias using α-Cr_2O_3 layer



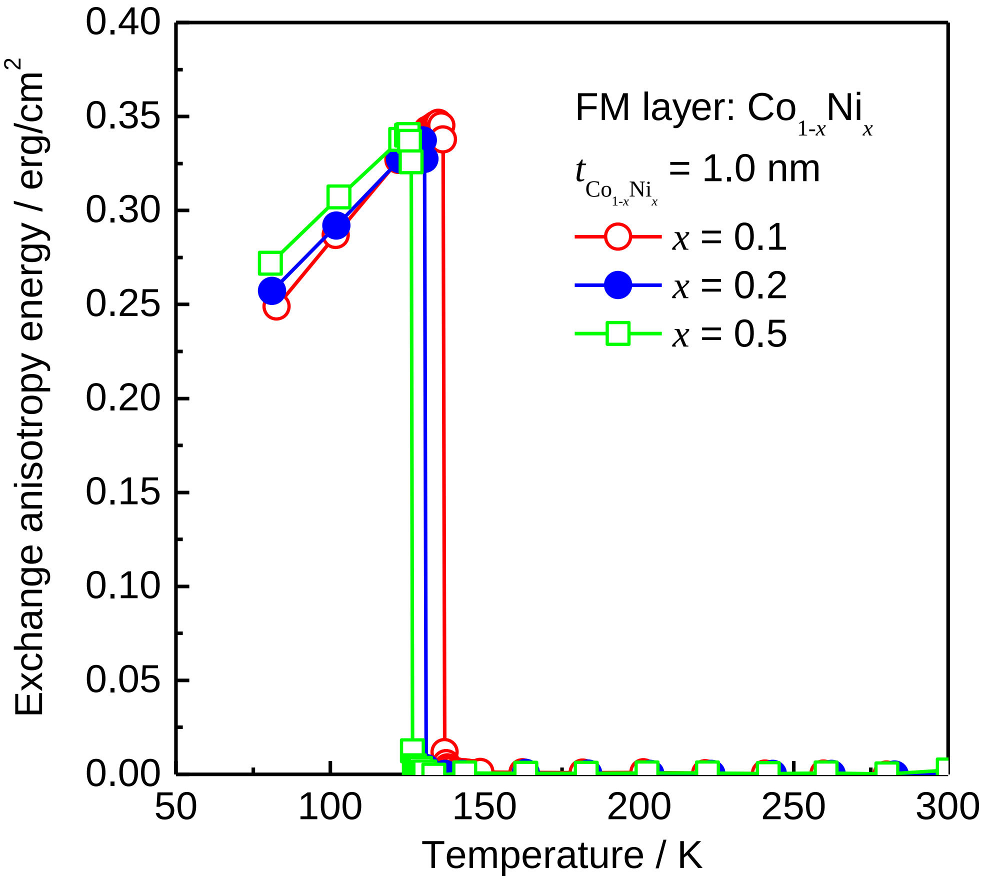


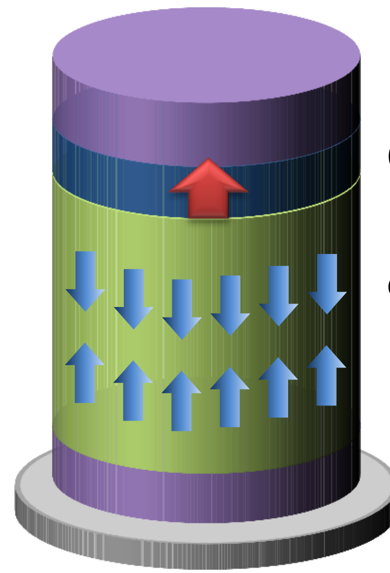
Y. Shiratsuchi et al., APEX, 3 113001 (2010).

Temperature dependence of unidirectional magnetic anisotropy energy for the films with different α-Cr_2O_3 layer thickness

- High perpendicular exchange bias about 0.3 erg/cm^2
- The abrupt onset of exchange bias.

Perpendicular exchange bias using α-Cr_2O_3 layer



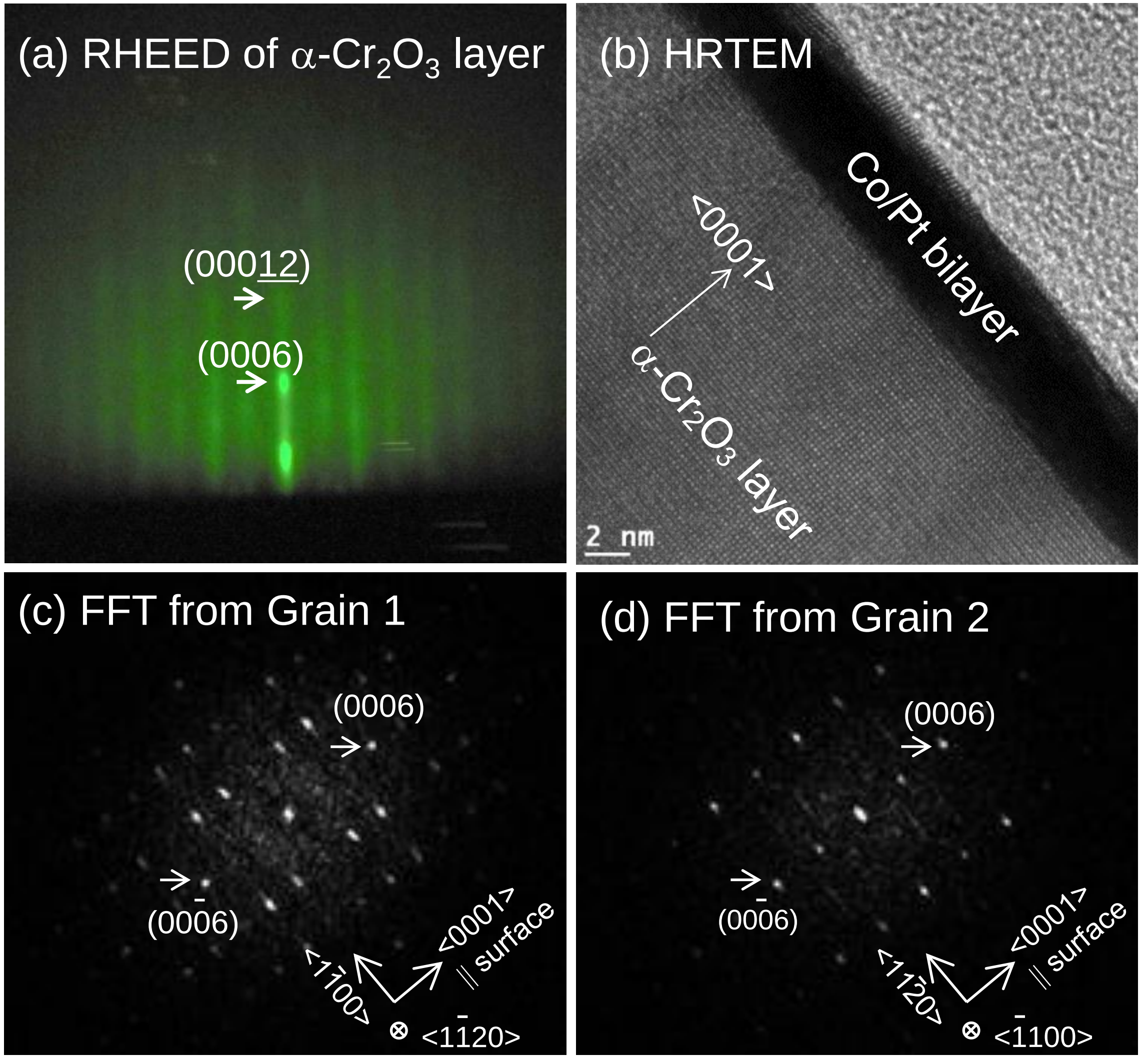


Y. Shiratsuchi et al., IEEE Trans. Magn., 48, 2885 (2012).

Temperature dependence of exchange magnetic anisotropy energy for the Pt/$Co_{1-x}Ni_x$/α-Cr_2O_3/Pt thin films with different Ni composition.

- Exchange anisotropy energy hardly changes by the Ni composition when the Ni composition $x < 0.5$.

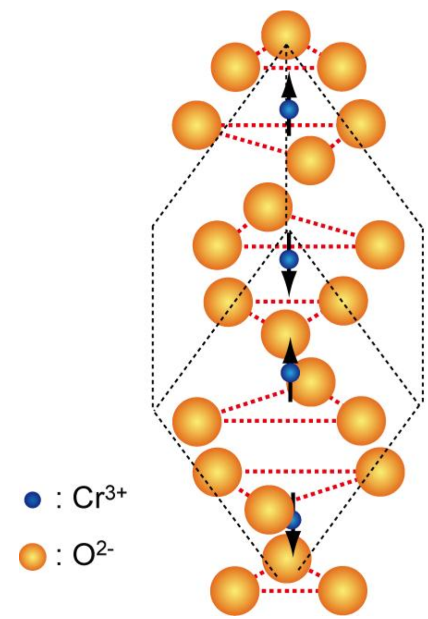
Structural characterizations



- Well-ordered α-Cr_2O_3 layer
- Sharp interface
- Oriented growth

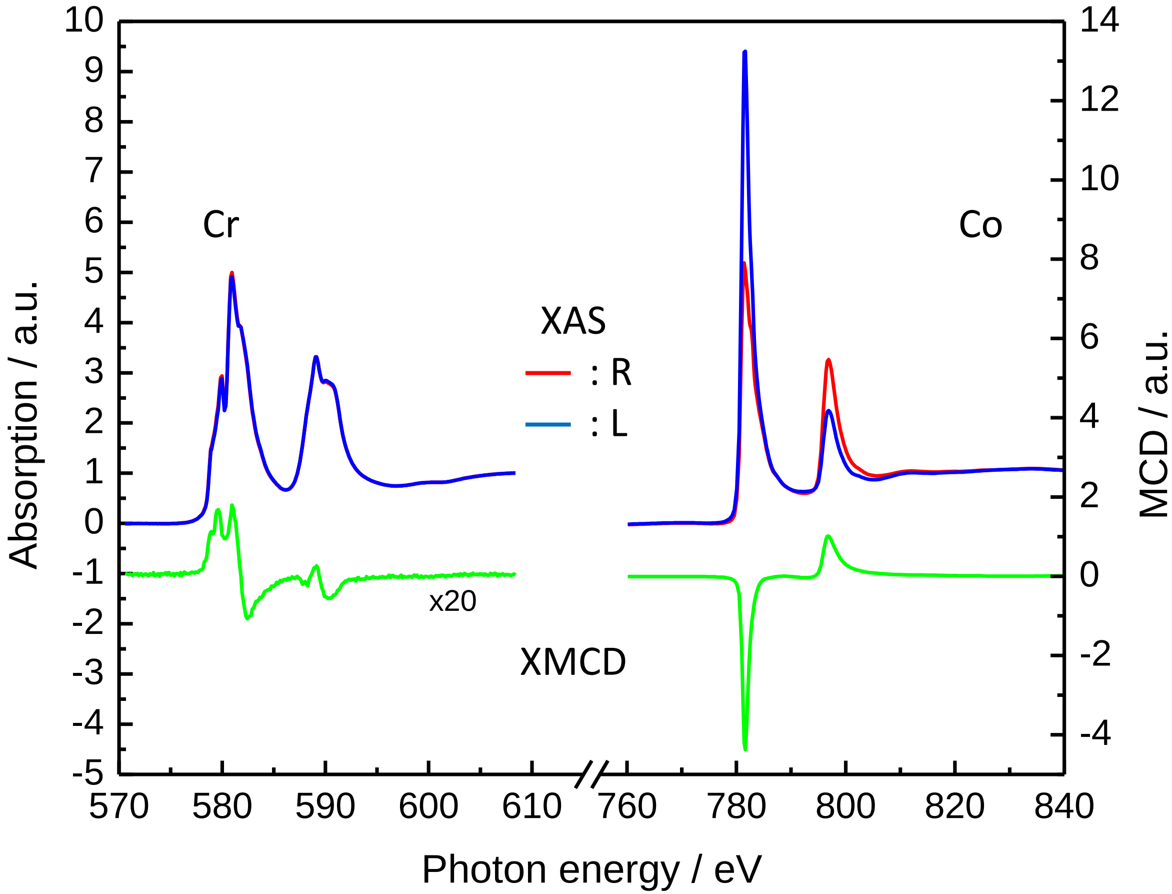
Pt(111) ∥ Co(111)
∥ α-Cr_2O_3(0001) ∥ Pt(111)

Interfacial Cr spins ⊥ film



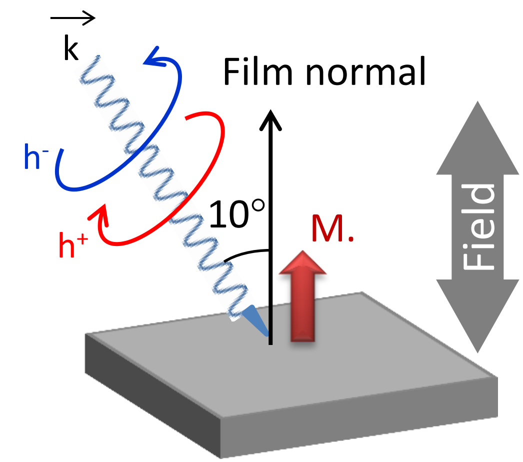
Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Spin orientation after field cooling



XAS and XMCD spectra at Co $L_{2,3}$ edges and Cr $L_{2,3}$ edges.

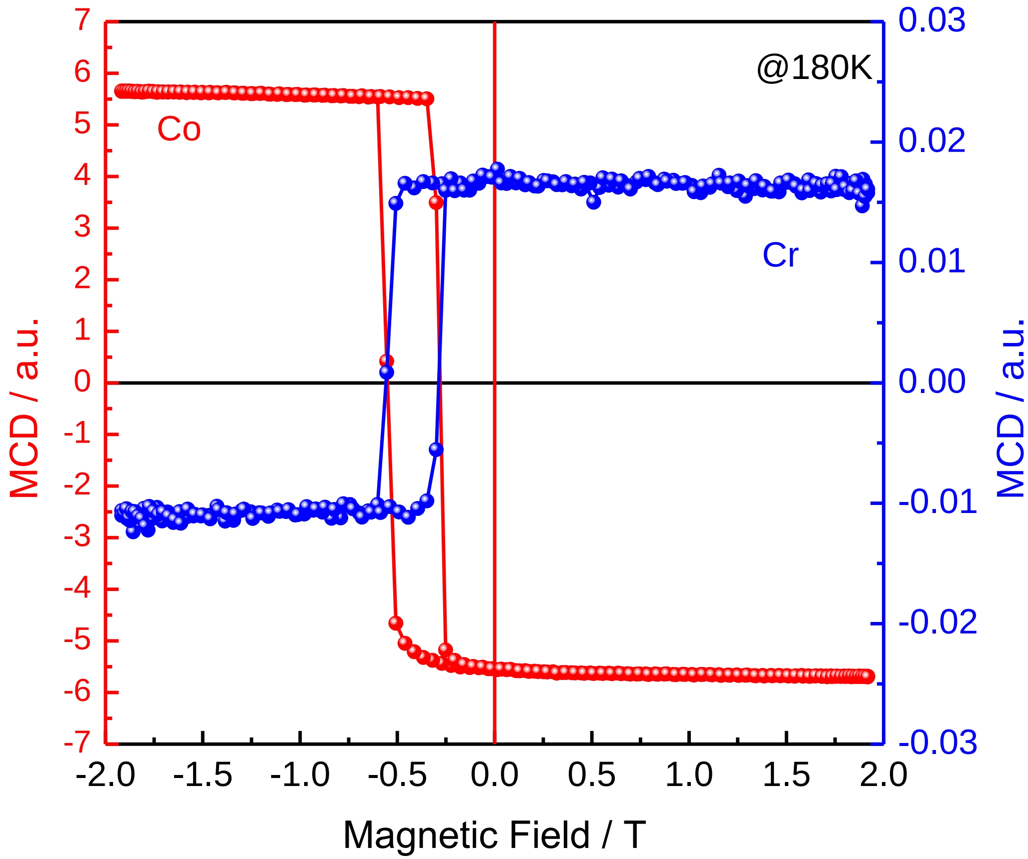
- TEY mode
- Temperature: 180 K
- Magnetic field, 1.9 T ⊥ Film



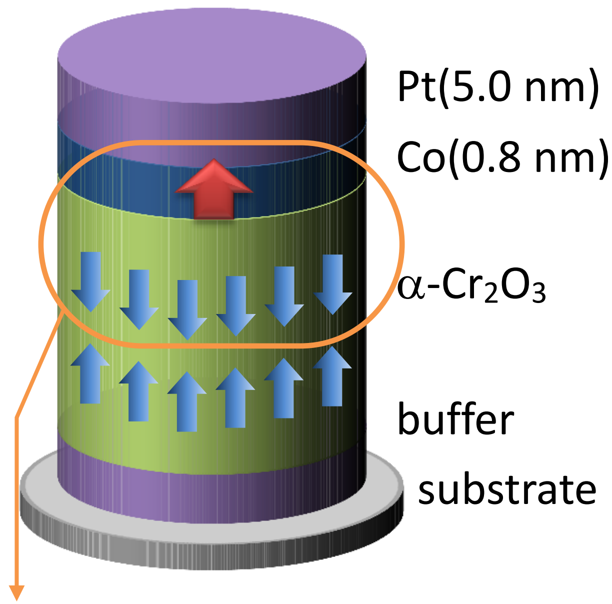
- Clear MCD signal of Co and Cr
- XAS of at Cr $L_{2,3}$ edges are similar to that of bulk α-Cr_2O_3.

Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Element-specific magnetization curve



XMCD hysteresis loops of Co and Cr.

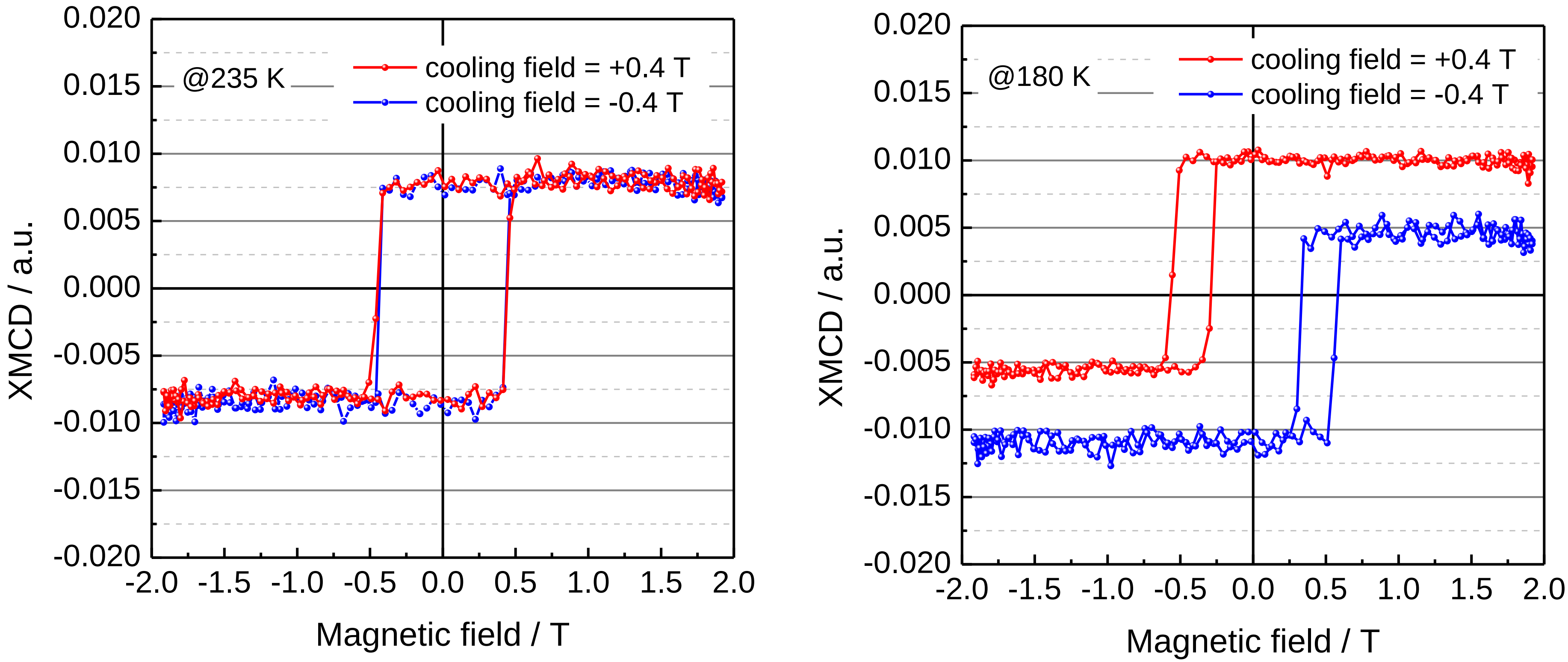


Antiferromagnetic interfacial coupling
Between Co and Cr.

- Cr spin reverses together with Co spins.
- Vertical shift seems to be visible in XMCD loop of Cr. However, verification is needed.

Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Element-specific magnetization curves

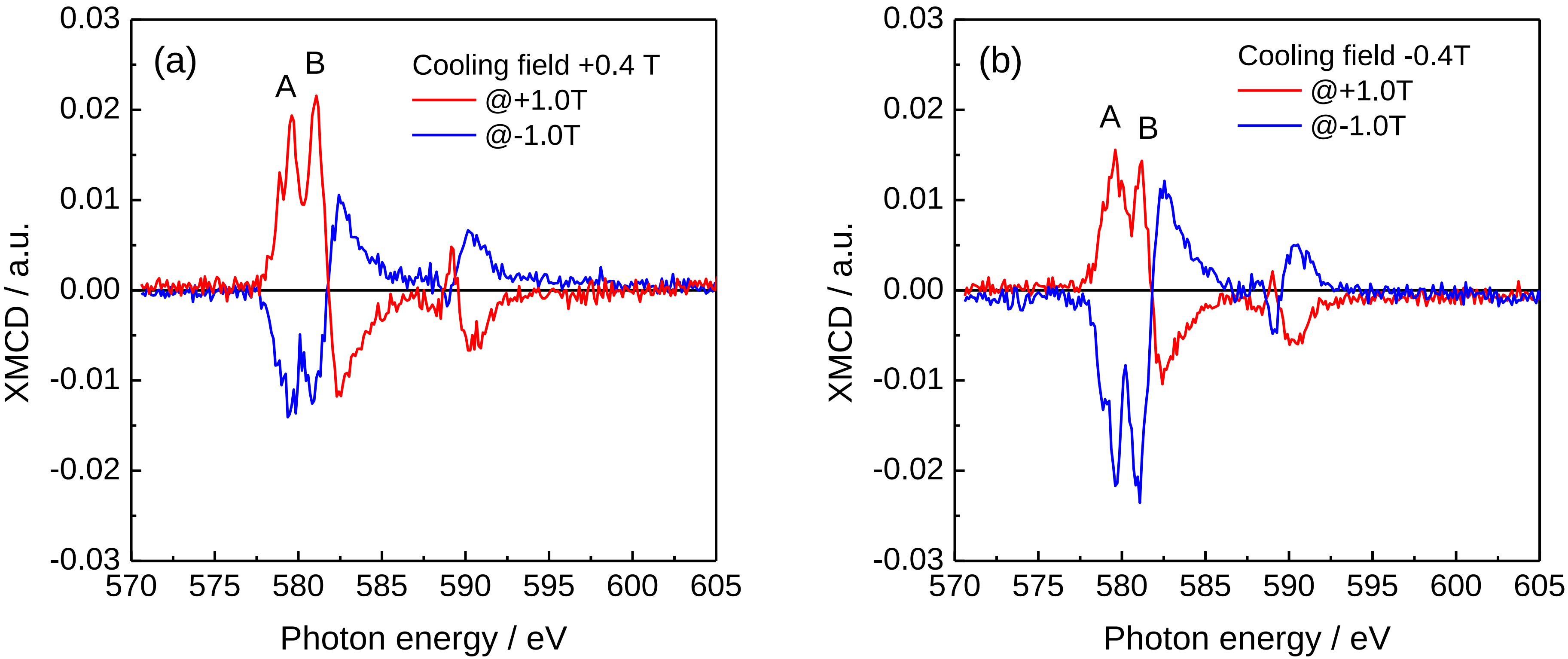


Element-specific magnetization cures at (a) 235 K and (b) 180 K after field-cooling of +0.4 T (red) or -0.4 T(blue).

- The vertical shift of the Cr M-H curve is accompanied with the exchange bias.
- Both vertical shift and exchange bias field are reversed by the cooling-field direction.

Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Shape of XMCD spectrum

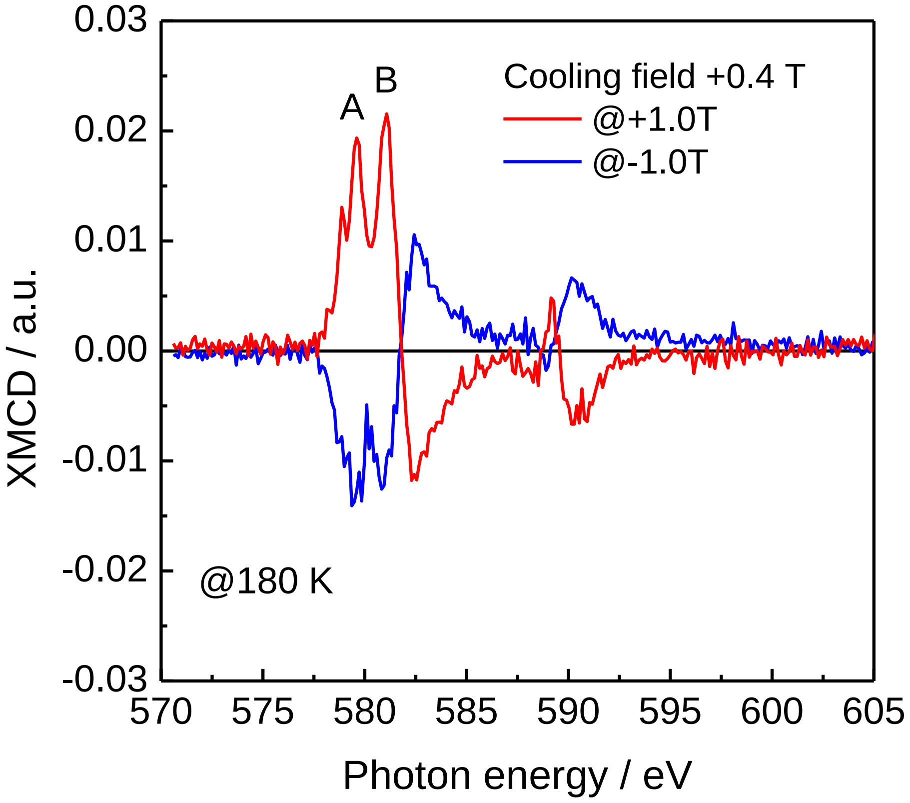


XMCD spectrum at Cr $L_{2,3}$ edges at 180 K after field-cooling of +0.4 T (red) or -0.4 T(blue).

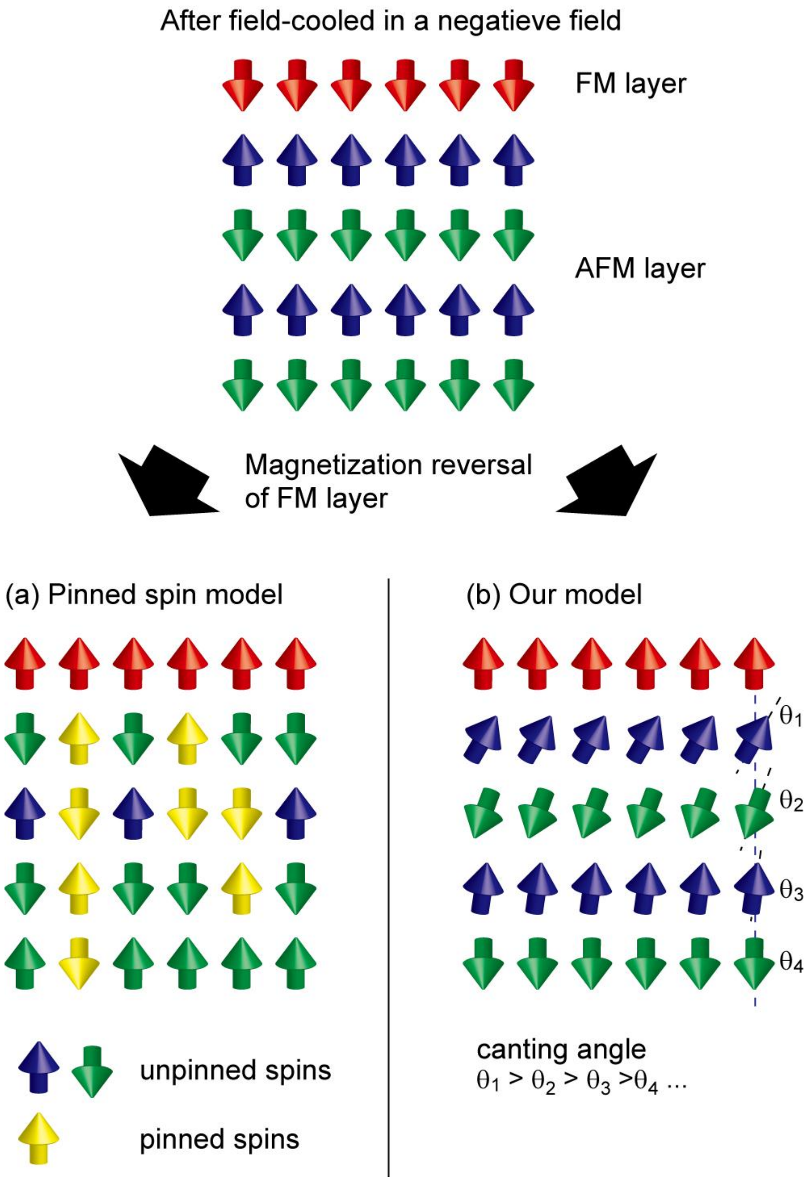
- The relative peak intensity of A & B is changed by the applied field direction.
- The shape of the XMCD spectrum is reversed by the cooling-field direction.

Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Is the pinned spin model available in our case?

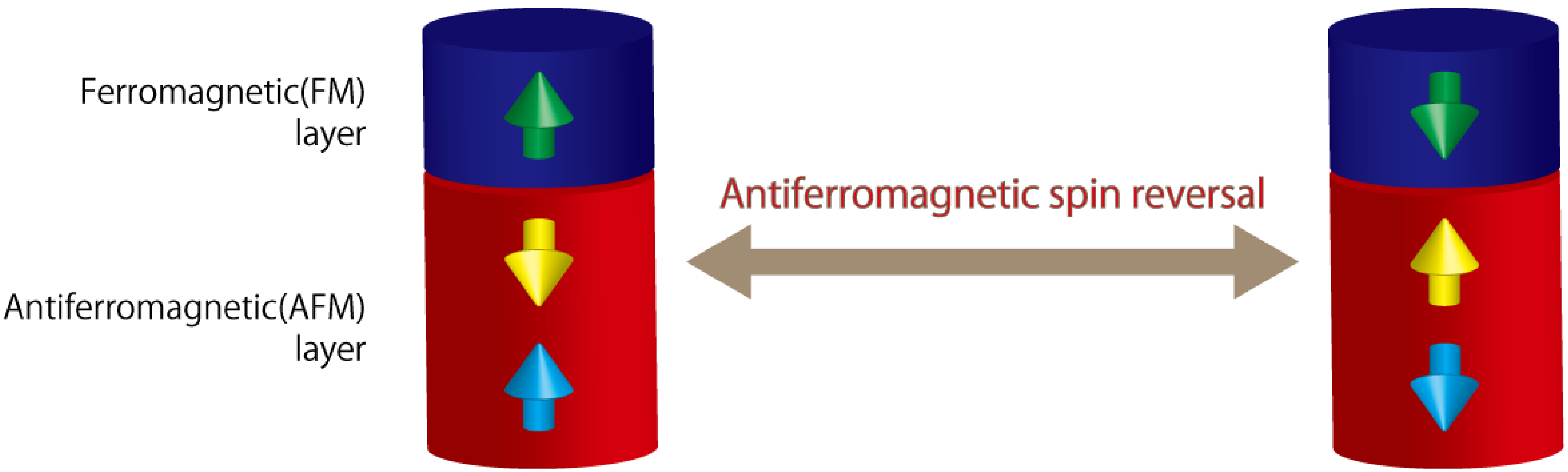


XMCD spectrum for Cr $L_{2,3}$ edges at 180 K after field-cooling under +0.4 T.



Y. Shiratsuchi et al., PRL 109, 077202 (2012).

Isothermal switching of exchange bias



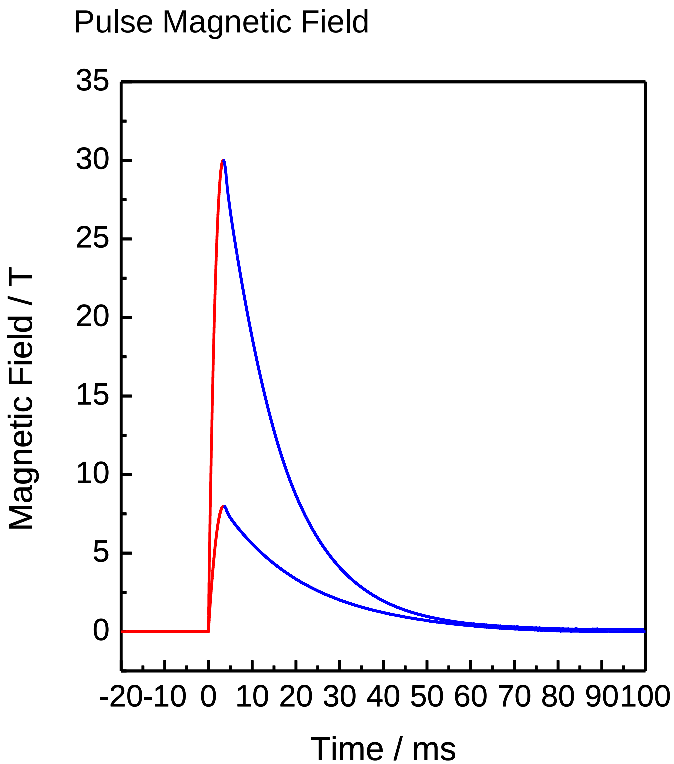
Exchange coupling between FM and APM spins

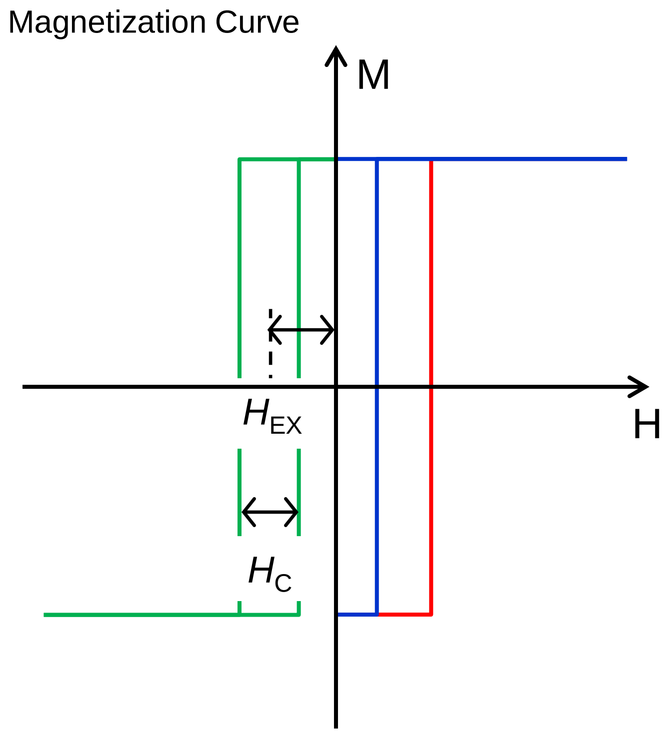
$$J_{\mathrm{int}} \propto J \cdot \frac{\boldsymbol{S}_{FM} \cdot \boldsymbol{S}_{AFM}}{a^2}$$

AFM spin revsersal results in
the switching of the exchange bias.

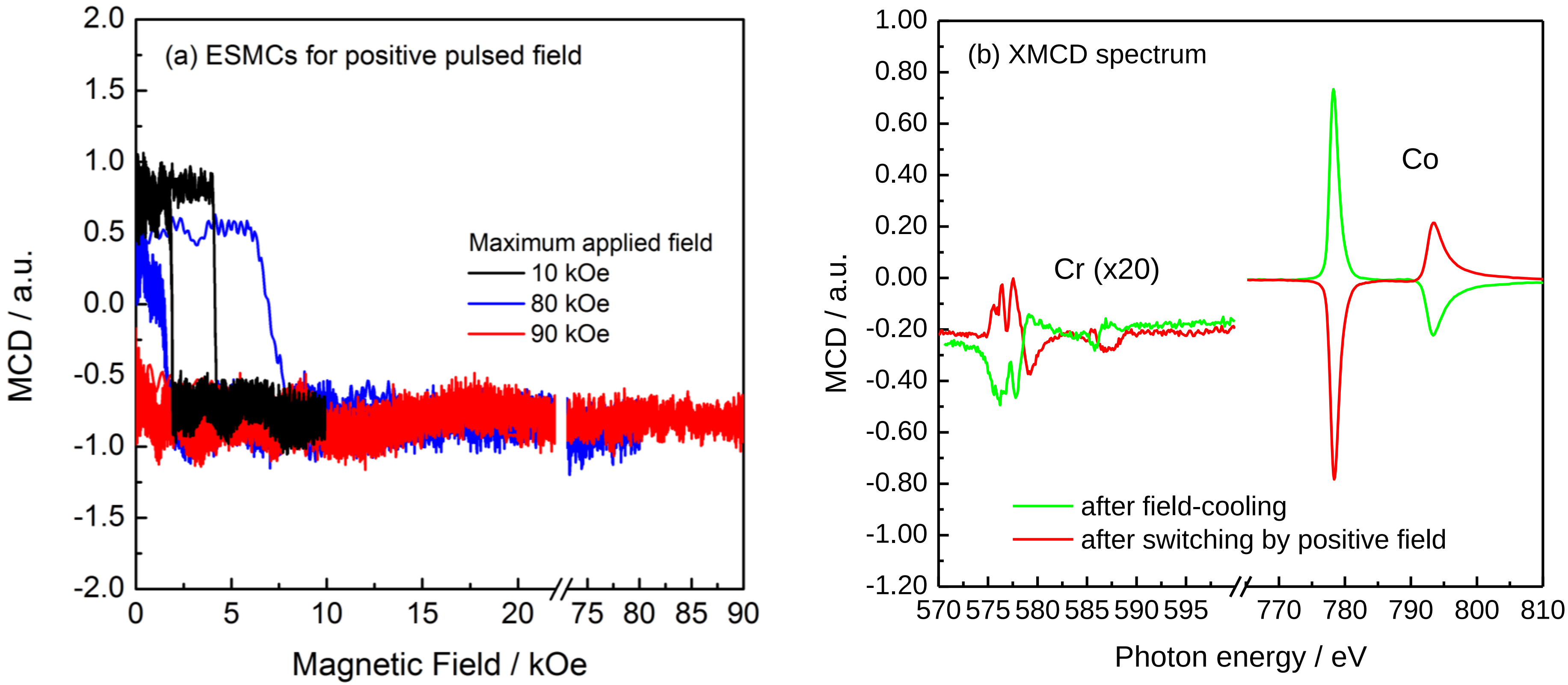
Detection of switching of exchange bias

- Sample: Pt(1.0 nm)/Co(0.5 nm)/α-Cr_2O_3(50 nm)/Pt(20 nm)/subs.
- Switching of exchange bias, experiment@BL25SU, SPring-8
  - Temperature: 77 K after field-cooling at -5 kOe from 320 K
  - Detection method: XMCD measurements under pulsed magnetic field
  - XMCD spectrum at remament state





Switching of exchange bias 1: positive magnetic field

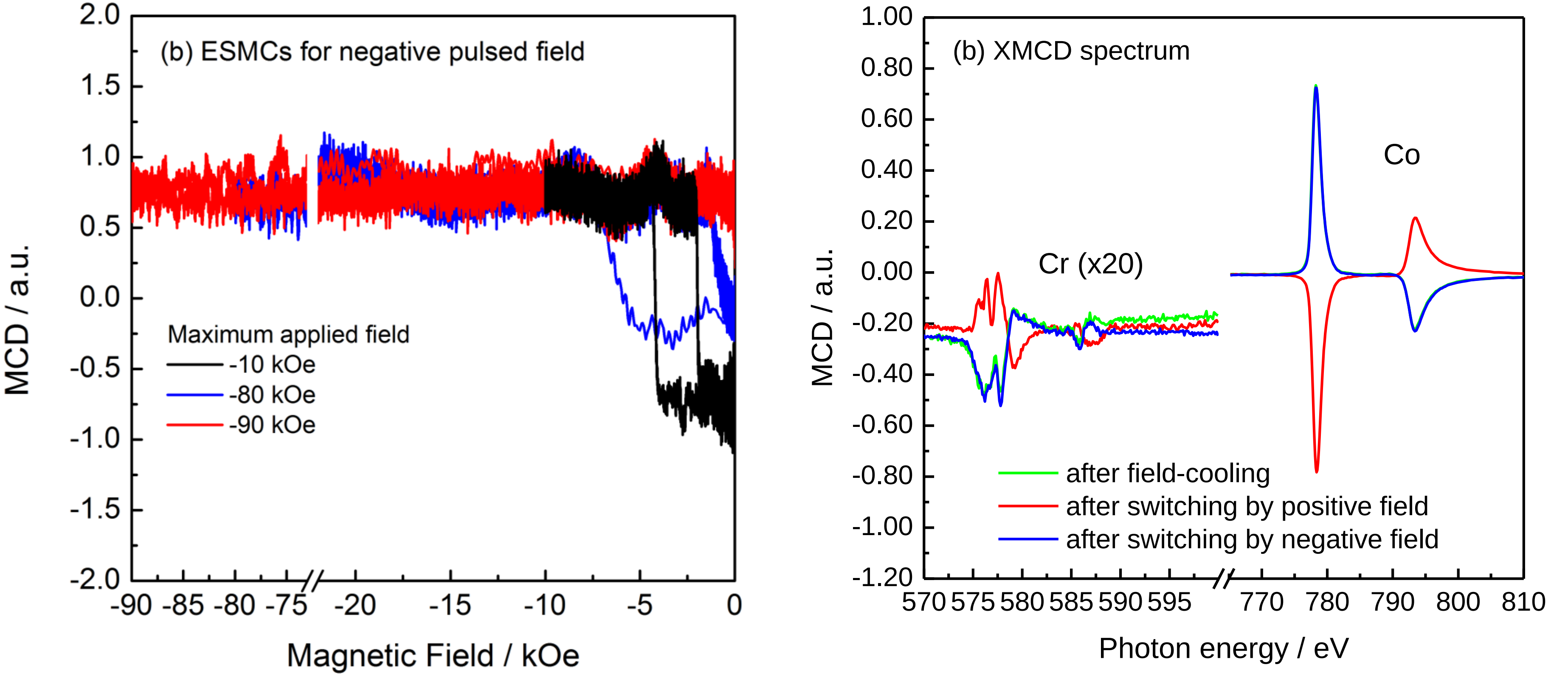


(a) ESMCs of Co and (b) XMCD spectrum
before and after the switching of exchange bias by positive magnetic field.

- XMCD signal starts to decrease at 80 kOe and becomes constant above 90 kOe.
- XMCD spectrum reversed.

Y. Shiratsuchi et al., APL 100, 262413 (2012).

Switching of exchange bias 2: negative magnetic field

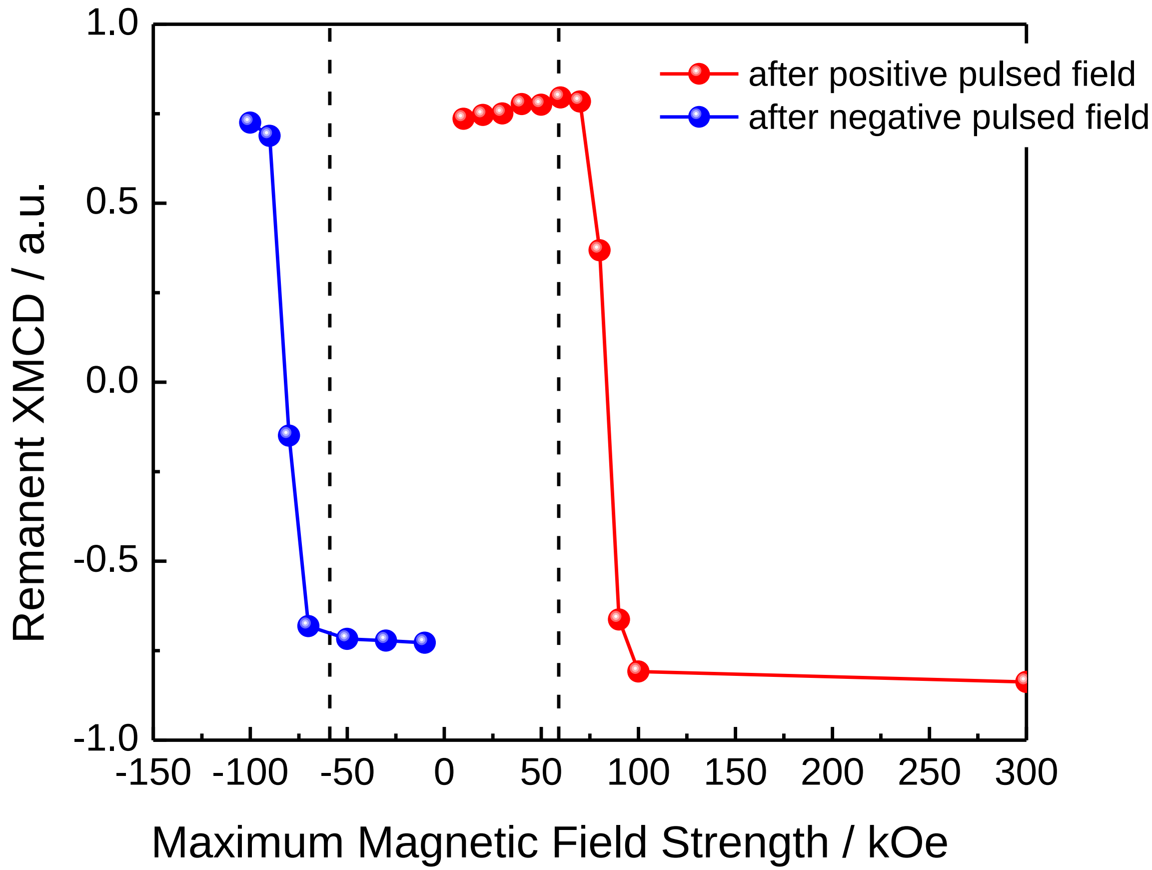


(a) ESMCs of Co and (b) XMCD spectrum
before and after the switching of exchange bias by negative magnetic field.

- Exchange bias in the negative direction
- Decrease of XMCD signal at -80 kOe, and constant above -90 kOe.
- XMCD spectrum was reversed.

Y. Shiratsuchi et al., APL 100, 262413 (2012).

Reversibility of switching of exchange bias



Dependence of remanent XMCD signal after applying the pulsed magnetic field.

- Switching of exchange bias is reversible.
- Switching field is same for the positive- and the negative-exchange bias.

Y. Shiratsuchi et al., APL 100, 262413 (2012).

Summary and future…

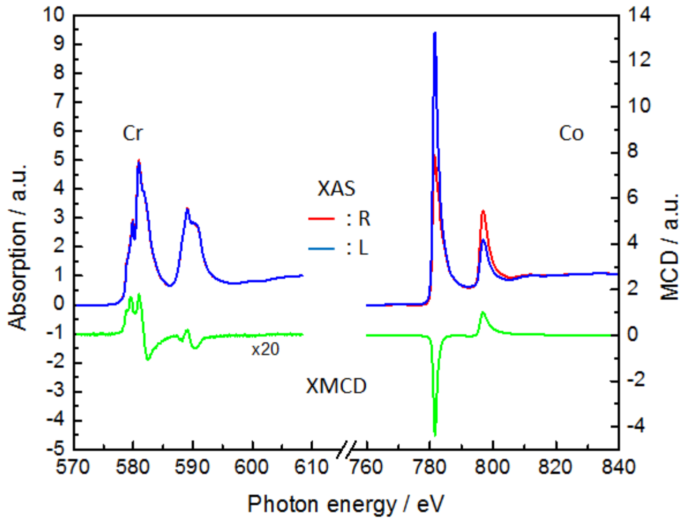
For the Co/α-Cr_2O_3 perpendicular exchange-biased system,

- Interfacial uncompensated (UC) Cr spins
- Un-reversed UC Cr spins

were detected, and

- Isothermal switching of PEB by pulsed high magnetic field

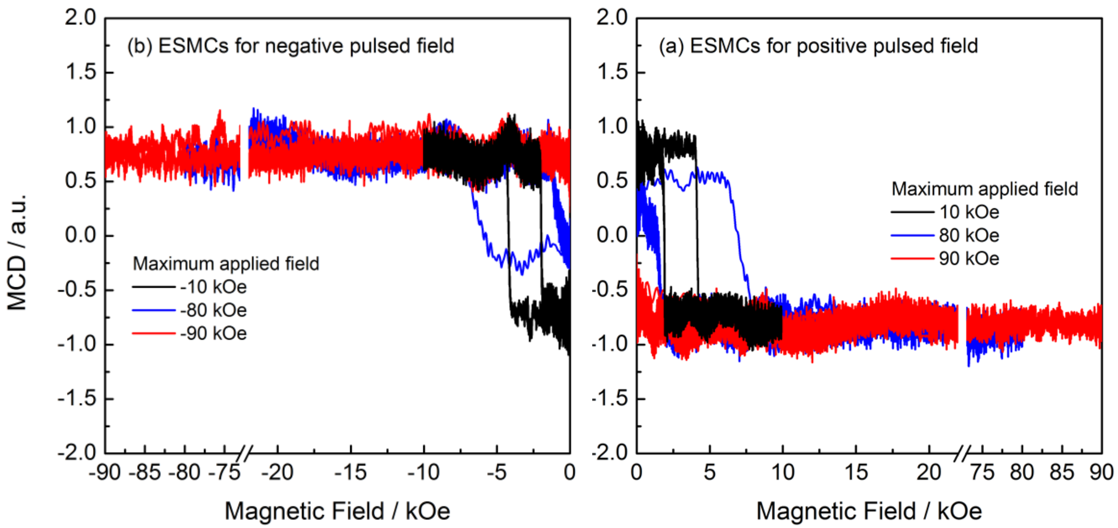
was demonstrated.



Problem and future

- Single device accessibility
- Low power consumption process
- High speed switching
- Working temperature etc

should be achieved.



➡ Innovative spin-electronics devices