

Magnetyzm epitaksjalnych warstw Fe/FeO

A. Kozioł-Rachwał, W. Janus, M. Szpytma, P. Drózdź, M. Ślęzak, K. Matlak, T. Ślęzak, N. Spiridis, K. Freindl,
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Wydział Fizyki i Informatyki Stosowanej AGH

seminarium WFIS AGH

14.12.2018

Plan seminarium

- motywacja
- epitaksjalne warstwy MgO/FeO/MgO oraz Fe/FeO/MgO
- „exchange bias” w układzie Fe/FeO/MgO
- jak zwiększyć oddziaływanie warstw Fe/FeO

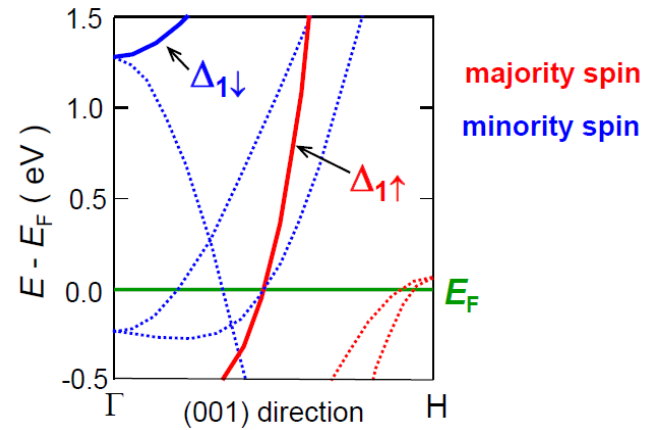
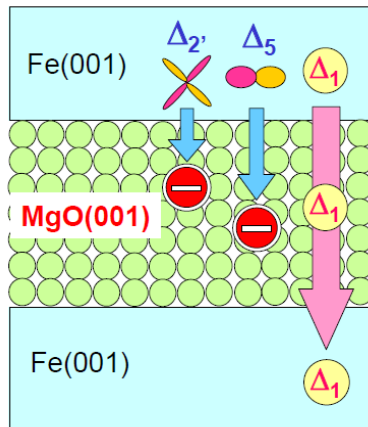
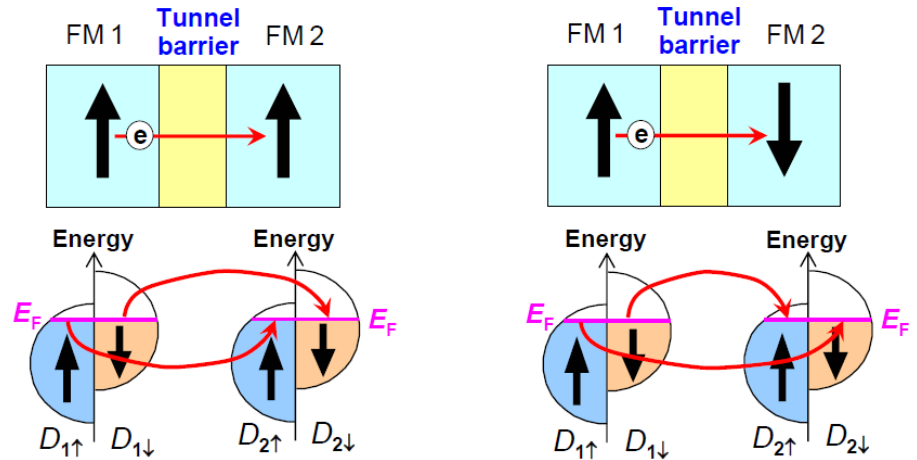
dlaczego Fe/FeO?



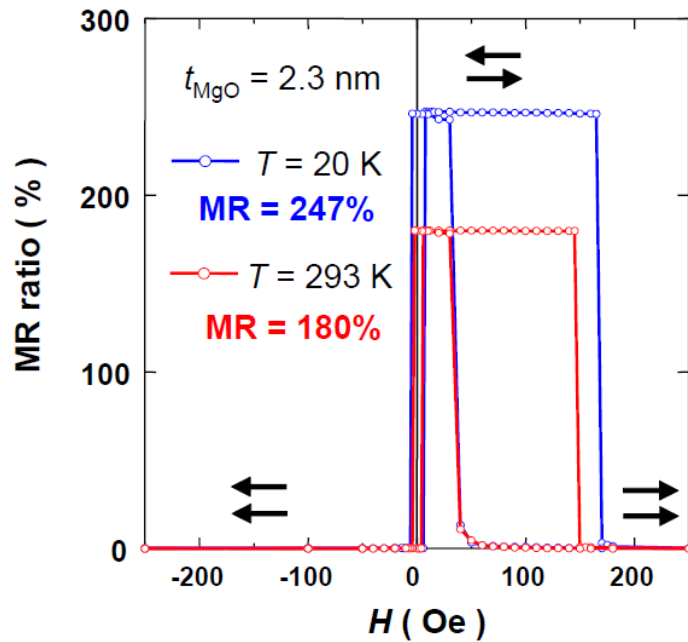
$$MR = (R_{AP} - R_P) / R_P \sim 1000\%$$

Butler *et al.* Phys. Rev. B, 63 056614 (2001).

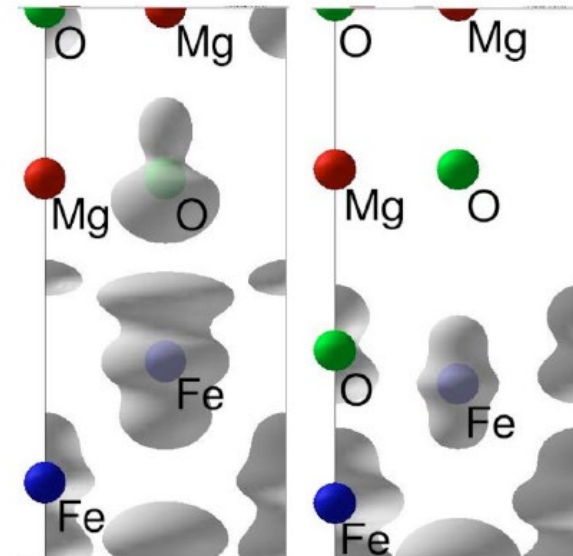
Mathon & Umerski, Phys. Rev. B 220403 (2001).



Fe/(FeO)/MgO/Fe - TMR



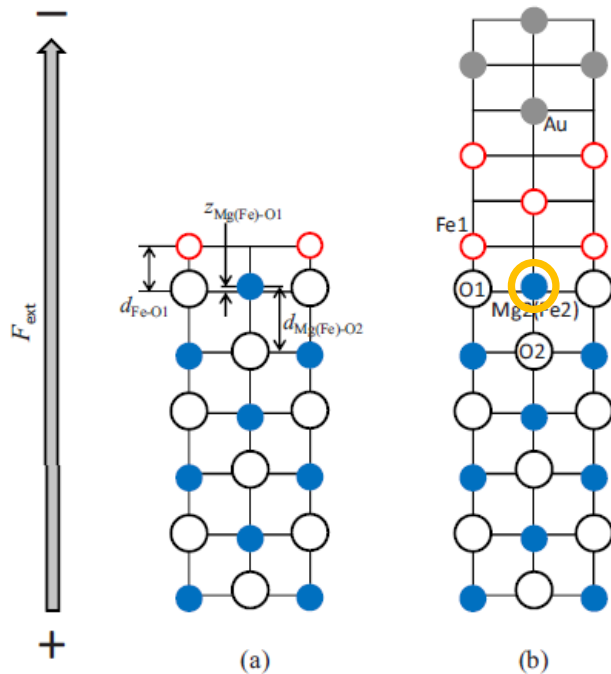
S. Yuasa et al., Nature Mat. 3, 686 (2004)



X.-G. Zhang, Phys. Rev. B 68, 092402 (2003)

Fe(FeO)/MgO efekt VCMA

modyfikacja anizotropii magnetycznej (MCA) warstwy Fe polem elektrycznym (VCMA)

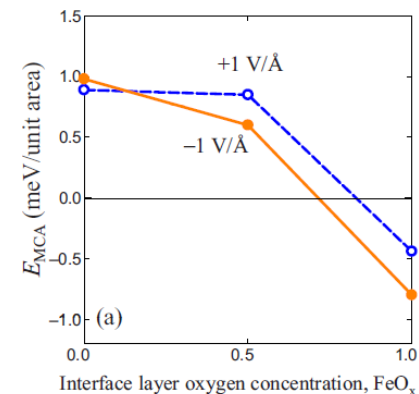


	$d_{\text{Fe-O1}}$	$d_{\text{Mg(Fe)-O2}}$	$z_{\text{Mg(Fe)-O1}}$	E_{MCA}
Fe/MgO	2.09	2.16	0.08	1.28
Au ₃ /Fe ₃ /MgO	2.08	2.14	0.05	0.94
Fe/FeO/MgO	1.91	2.35	0.32	-0.18
Au ₃ /Fe ₃ /FeO/MgO	1.91	2.30	0.27	-0.56

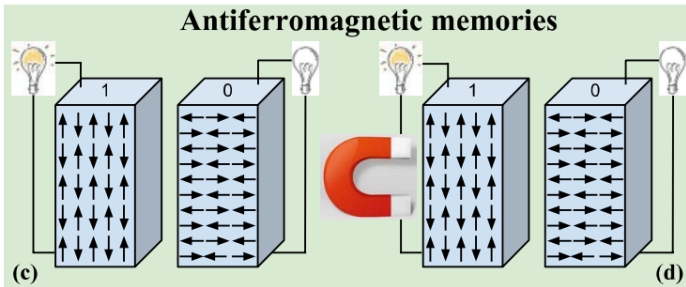
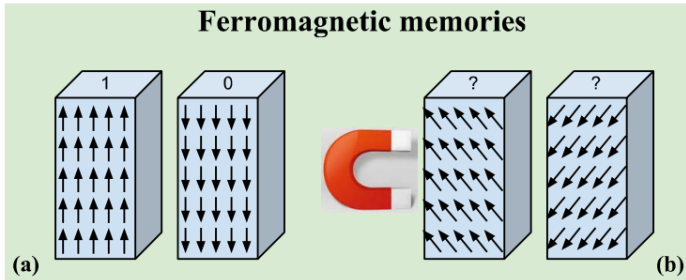
	-1 V/\AA				1 V/\AA			
	$d_{\text{Fe-O1}}$	$d_{\text{Mg(Fe)-O2}}$	$z_{\text{Mg(Fe)-O1}}$	E_{MCA}	$d_{\text{Fe-O1}}$	$d_{\text{Mg(Fe)-O2}}$	$z_{\text{Mg(Fe)-O1}}$	E_{MCA}
Fe/MgO	2.07	2.12	0.03	1.43	2.10	2.17	0.10	1.18
Au ₃ /Fe ₃ /MgO	2.07	2.10	0.06	0.89	2.10	2.17	0.08	0.98
Fe/FeO/MgO	1.89	2.29	0.28	-0.07	1.93	2.43	0.36	-0.34
Au ₃ /Fe ₃ /FeO/MgO	1.90	2.25	0.23	-0.44	1.93	2.37	0.31	-0.80
Au ₃ /Fe ₃ /FeO _{0.5} /MgO	1.85	2.26	0.29	0.85	1.87	2.39	0.35	0.60

Nakamura *et al.* Phys. Rev. B 81, 220409(R) (2010).

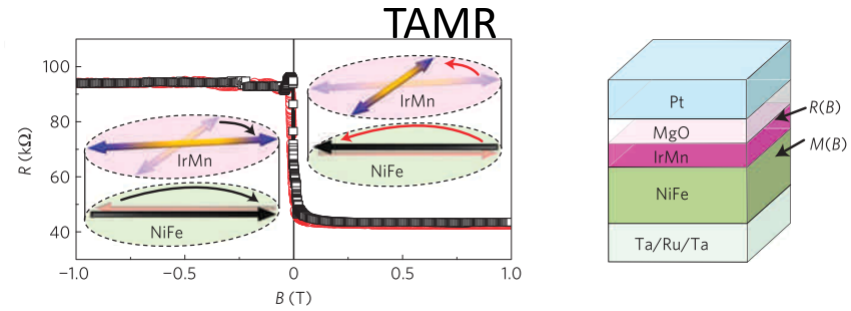
Kluczowa rola FeO dla efektu VCMA



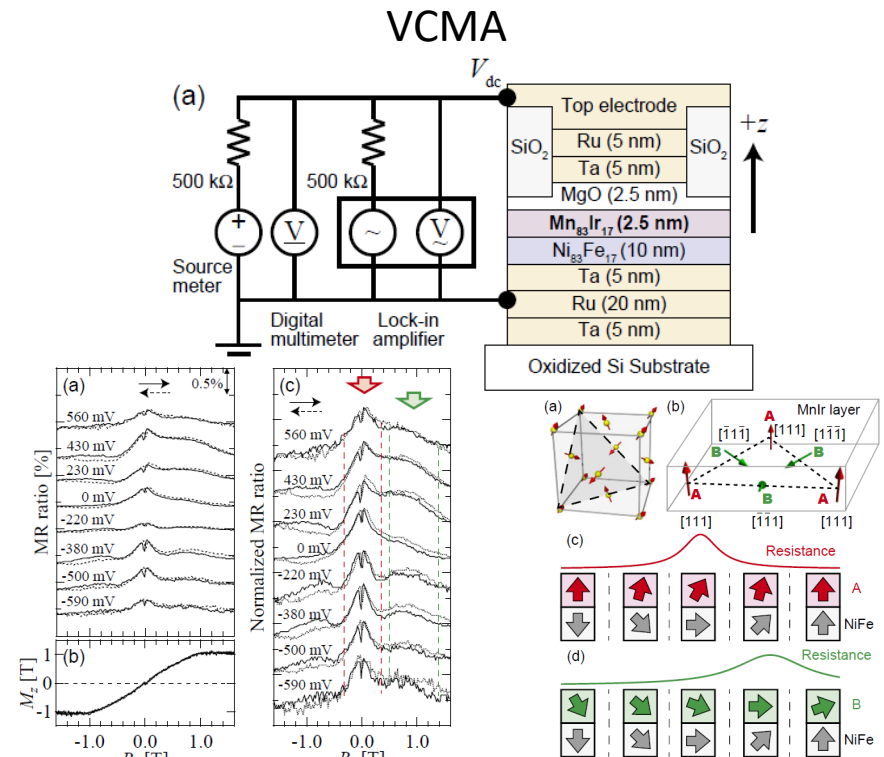
AFM – przyszłość spintroniki?



X. Martí *et al.* IEEE Trans. Magn., 51, 4(2015).

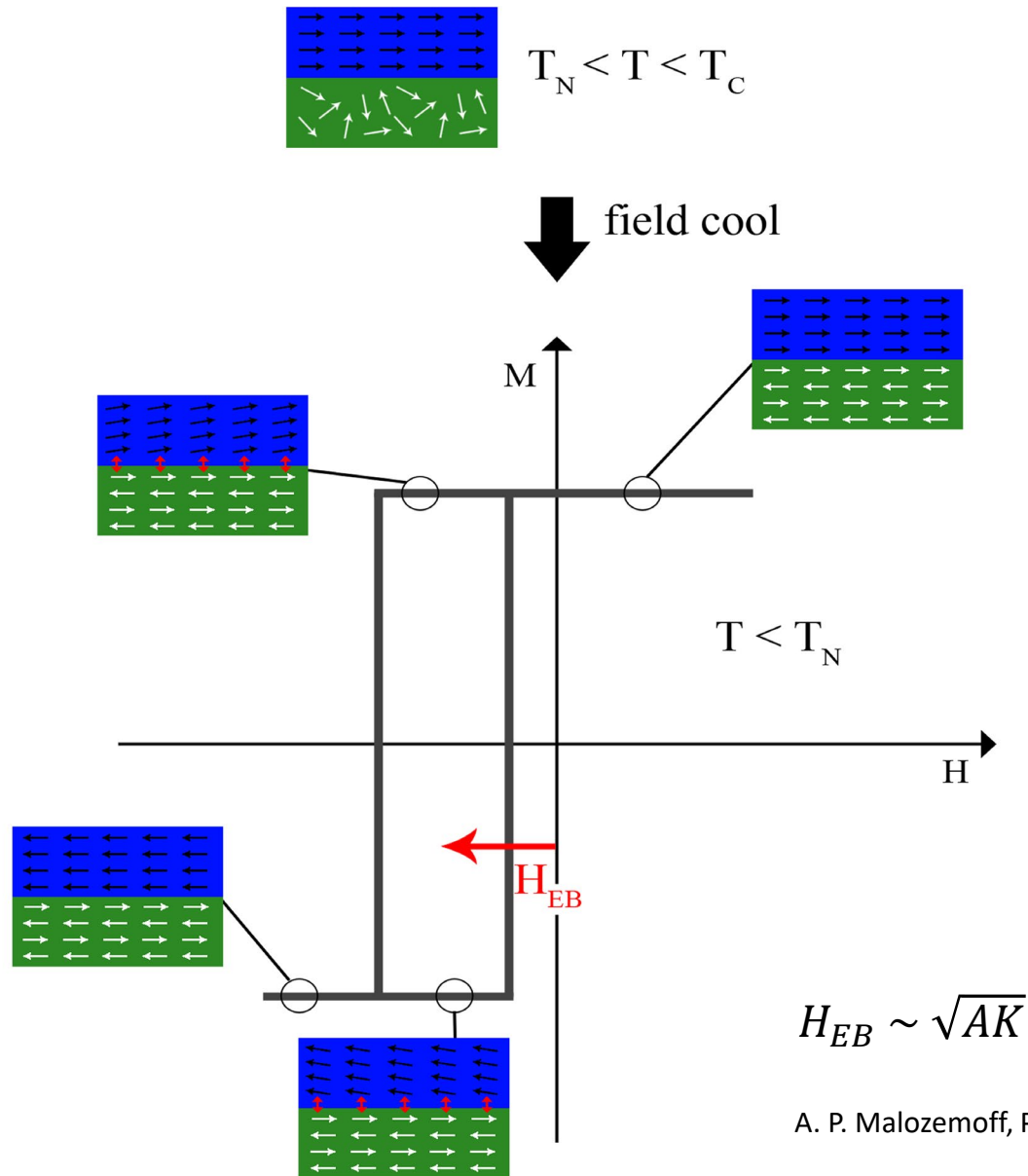


B. G. Park *et al.* Nature 10, 347 (2011).

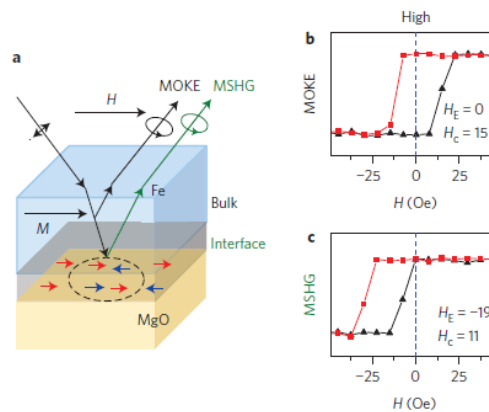
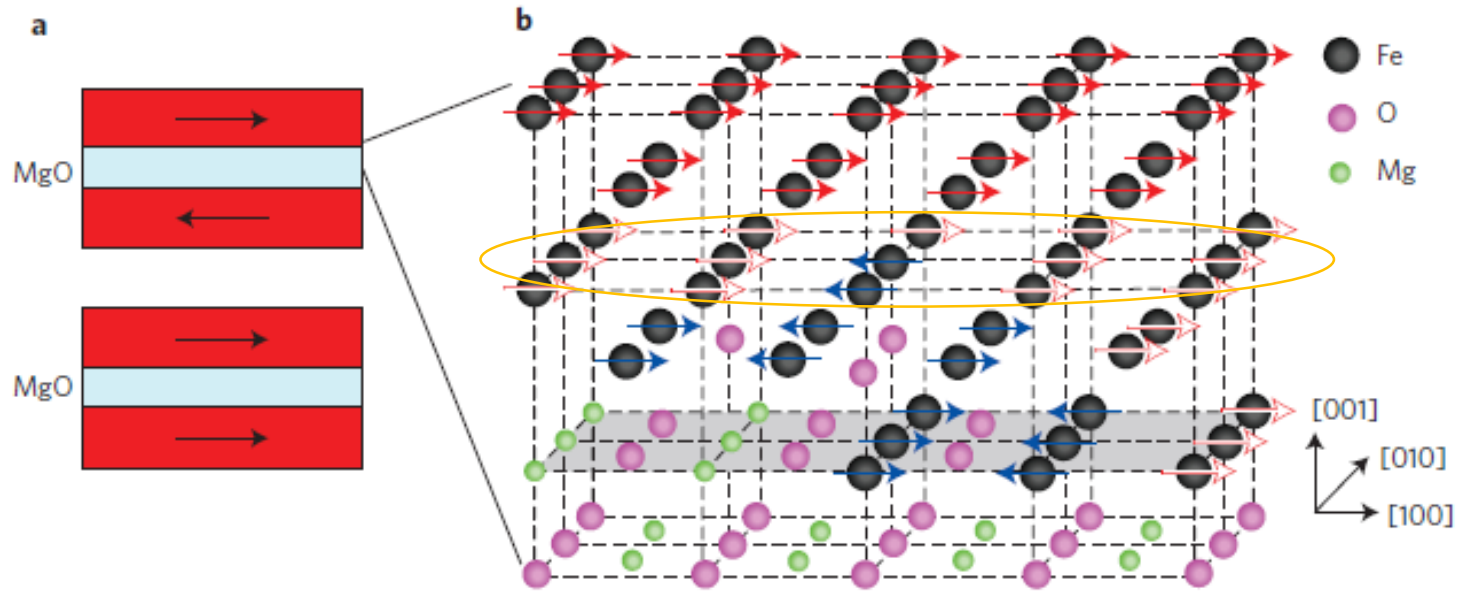


M. Goto *et al.* Jpn. J. Appl. Phys. 55, 080304 (2016).

Exchange bias

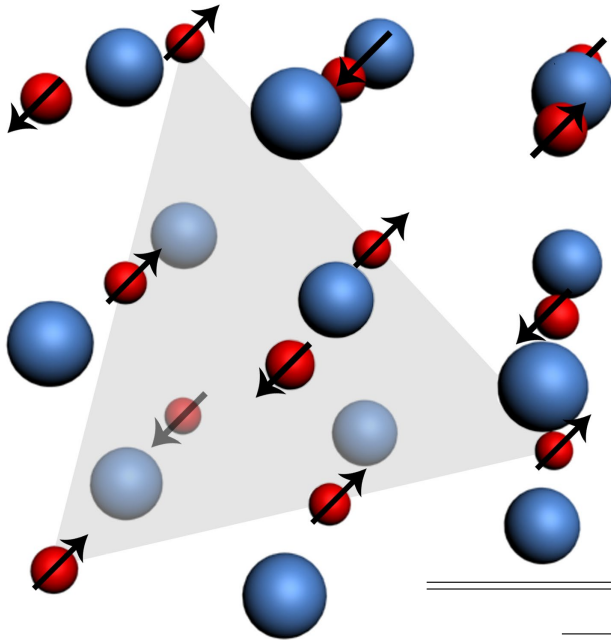


EB w układzie Fe/MgO/Fe

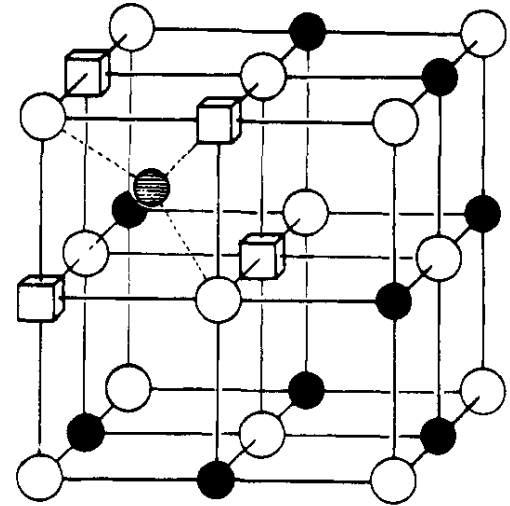


EB interfejsowych spinów Fe

FeO



- $T_N = 198\text{K}$
- $a_0 = 4.375\text{\AA}$

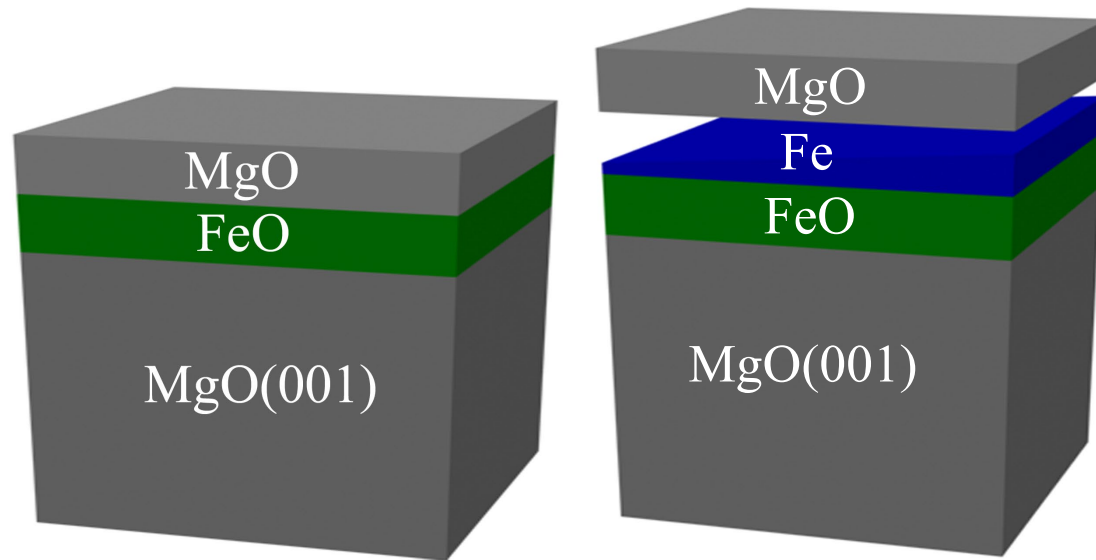


C. Wilkinson *et al.*, *Inorg. Chem.* 23, 3136 (1984).

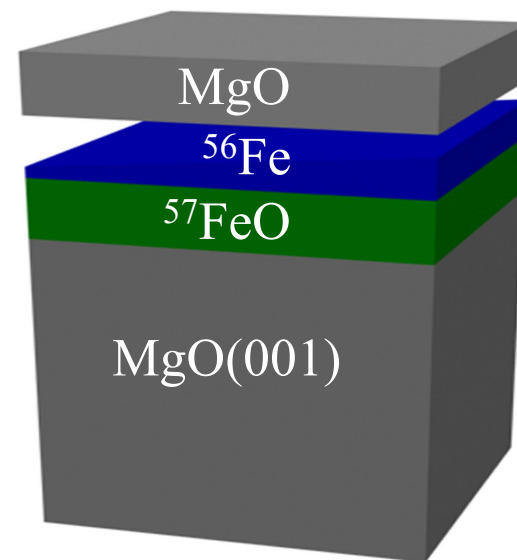
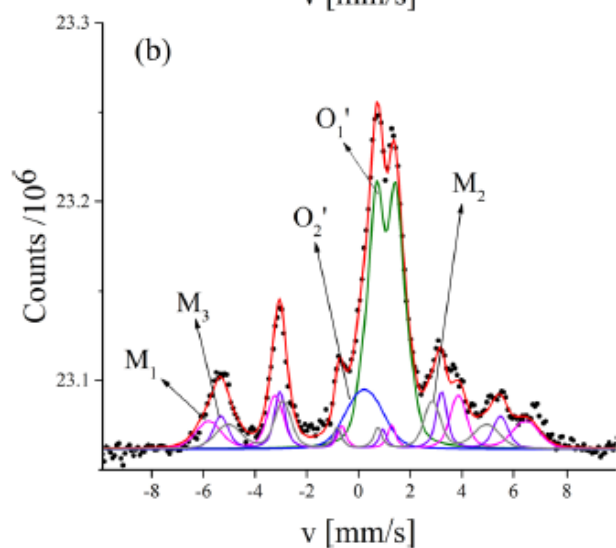
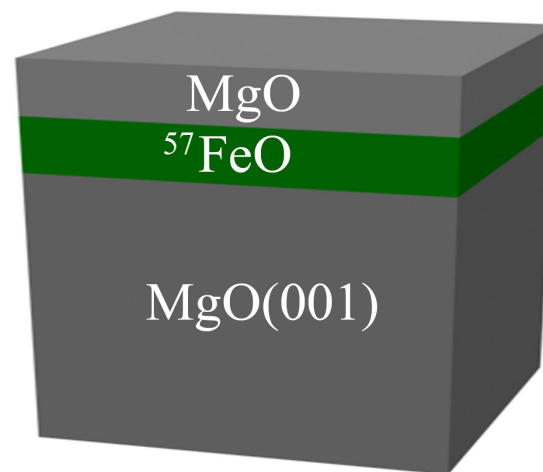
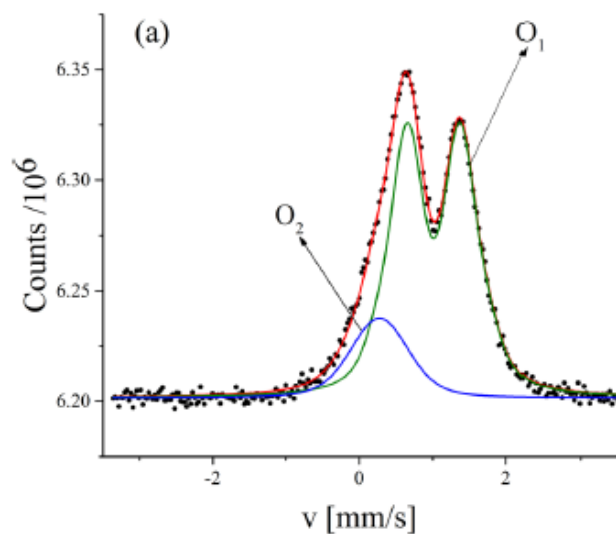
	MnO		FeO		CoO		NiO	
	GGA+ <i>U</i>	Expt.	GGA+ <i>U</i>	Expt.	GGA+ <i>U</i>	Expt.	GGA+ <i>U</i>	Expt.
S_0	(111)	(111) ^a	$\approx[110]$	$\approx[1.0, 1.8, 1.4]^b$	$\approx[-1, -1, 7.2]$	$\approx[-1, -1, 7.1]^a$ $\approx[-1, -1, 3.9]/\approx[110]^d, e$ $\approx[-1, -1, 2.8]^g$	$[\bar{1}10]$	(111) ^{a, c} $[\bar{1}10]^f$ $[\bar{1}\bar{1}2]^h$
γ (deg)	-	-	-90.3	-56.5 ^{b, i}	11.1	11.3 ^a $\approx 20/\approx -90^d, e$ 27 ^g	90.0	-
μ_s (μ_B)	4.60	-	3.69	-	2.68	-	1.62	-
μ_l (μ_B)	0.00	-	0.12	-	0.25	-	0.17	-
μ (μ_B)	4.60	4.58 ^j	3.81	4.0 ^b	2.93	3.8 ^{a, g} , 3.98 ^d	1.79	1.9 ^j
K (meV)	0.000	-	1.518	-	1.243	-	-0.013	-
K' (meV)	0.000	-	-0.342	-	-0.818	-	0.003	-
K_d (meV)	-0.278	-	-0.202	-	-0.126	-	-0.050	-

Schörn *et al.* *Phys. Rev. B* 8, 115134 (2012).

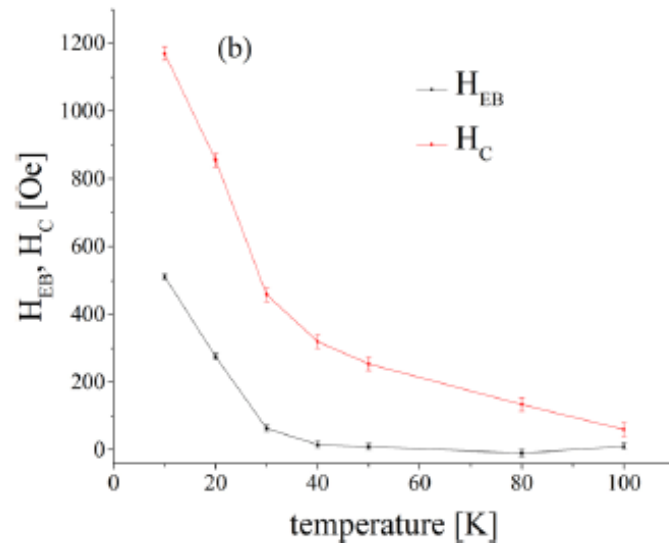
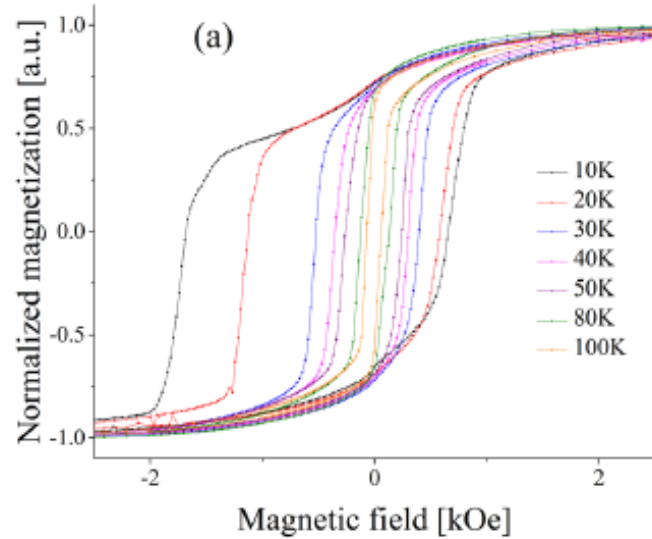
MgO/FeO/MgO



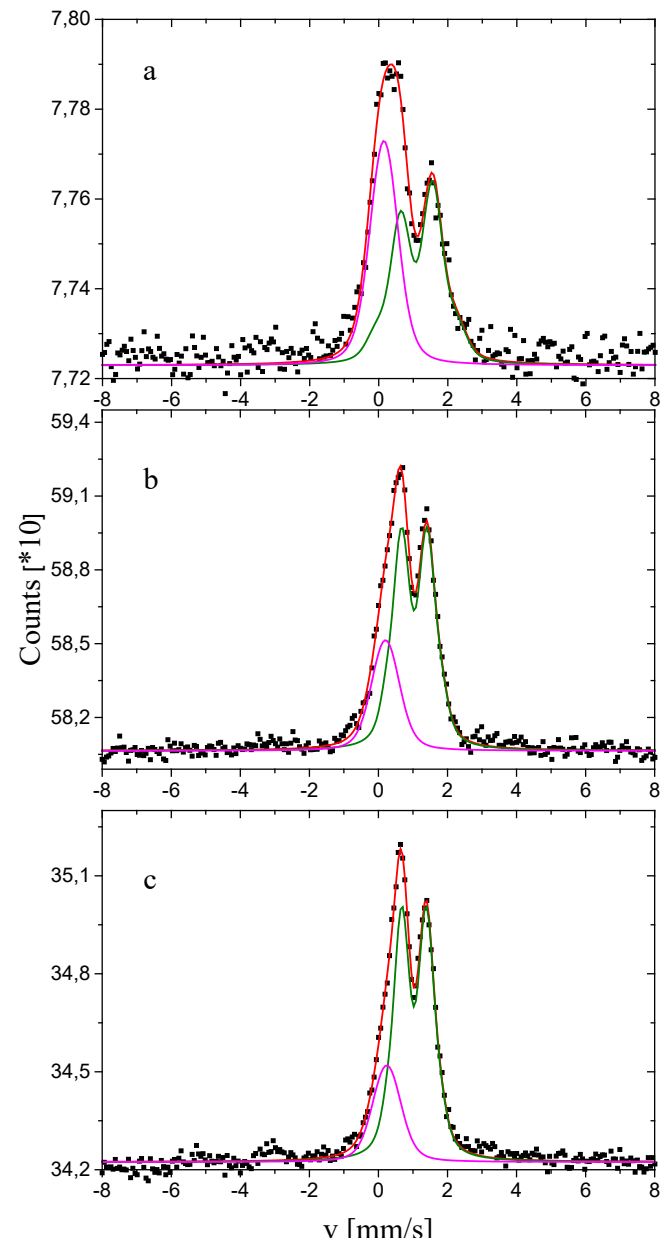
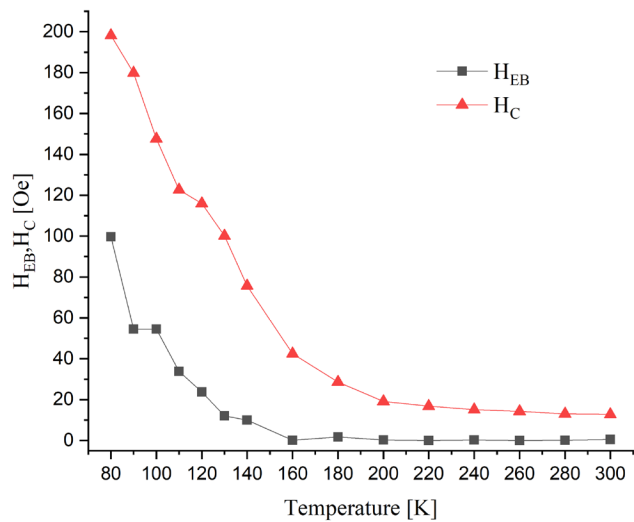
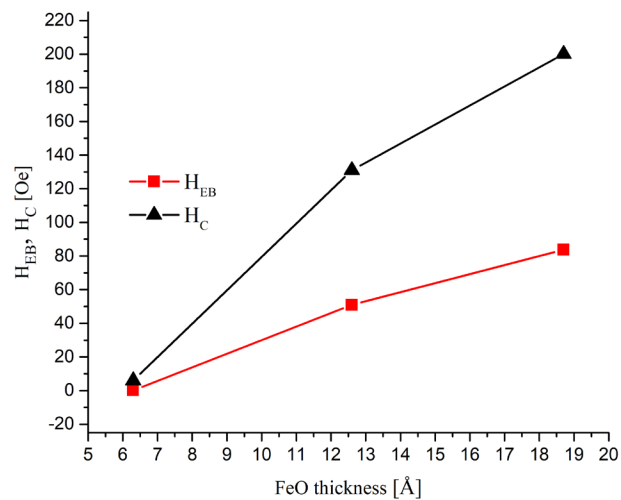
MgO/⁵⁷Fe/(⁵⁶Fe)/MgO – MS



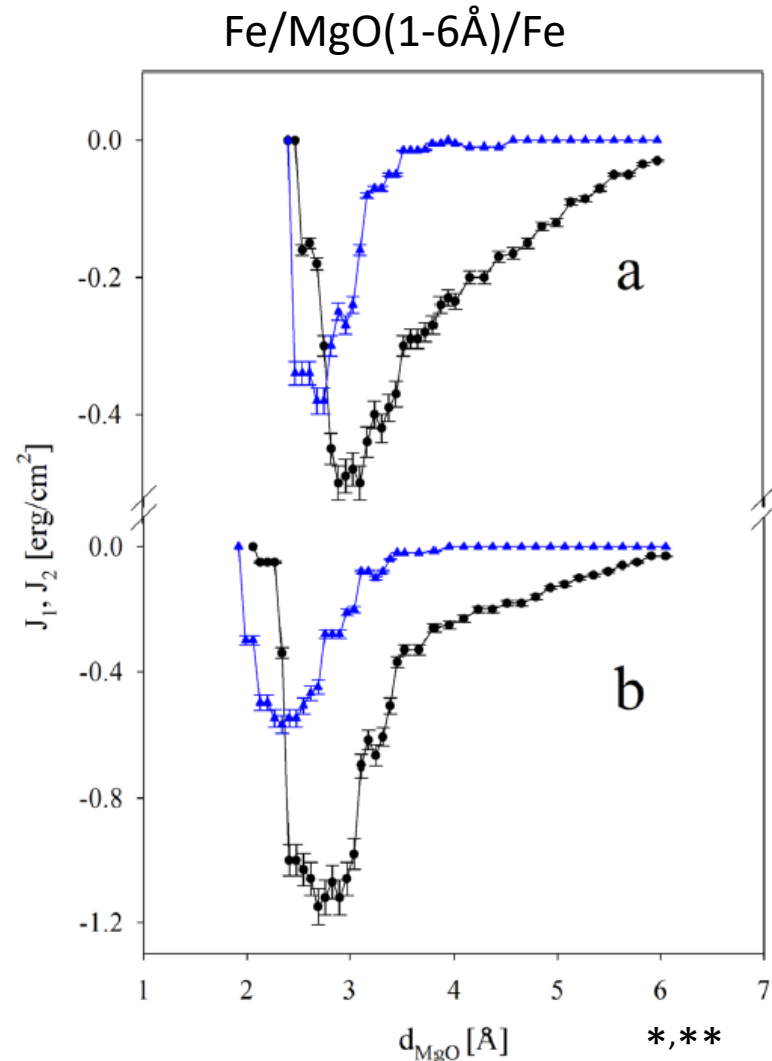
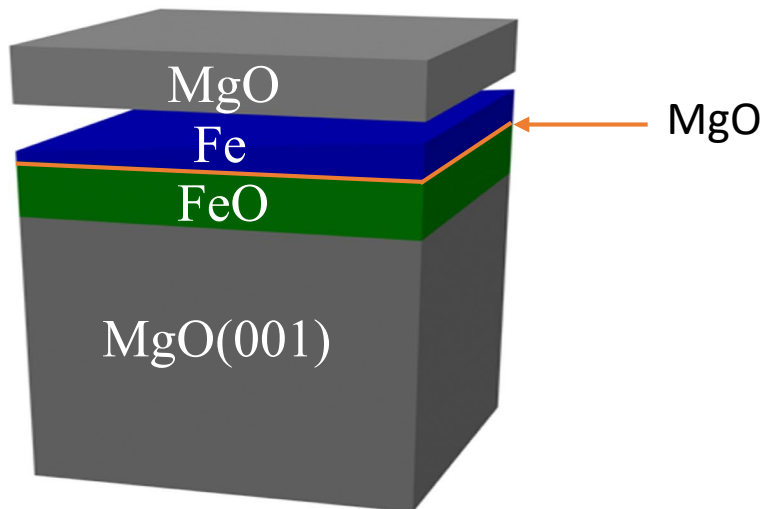
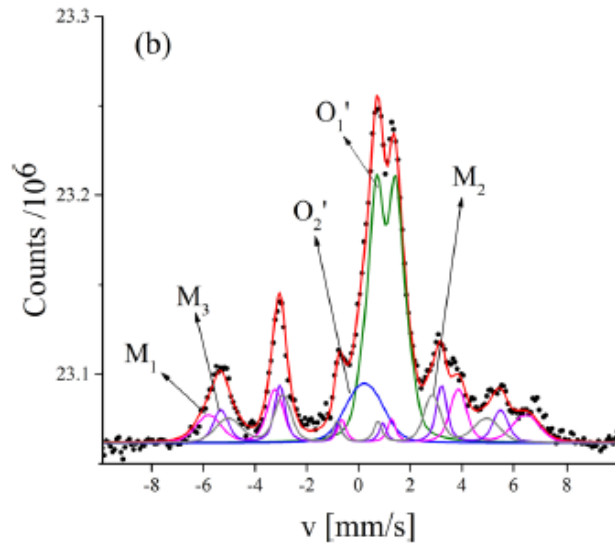
Fe/FeO - EB



Fe/FeO



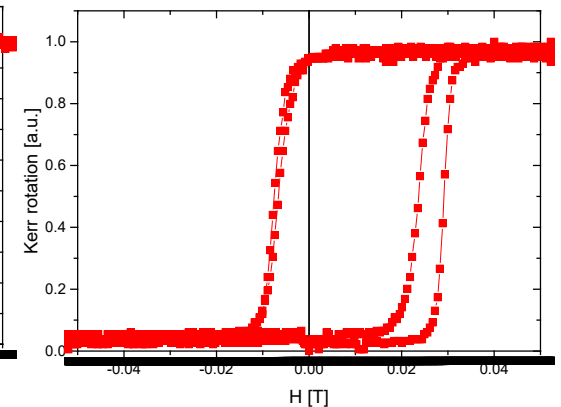
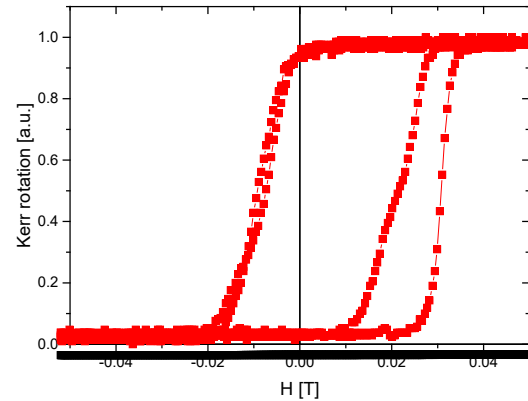
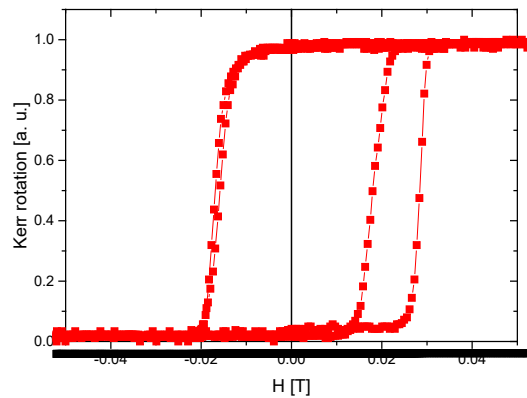
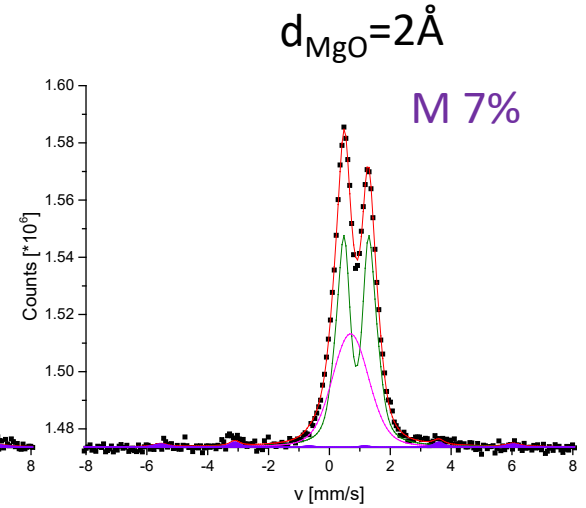
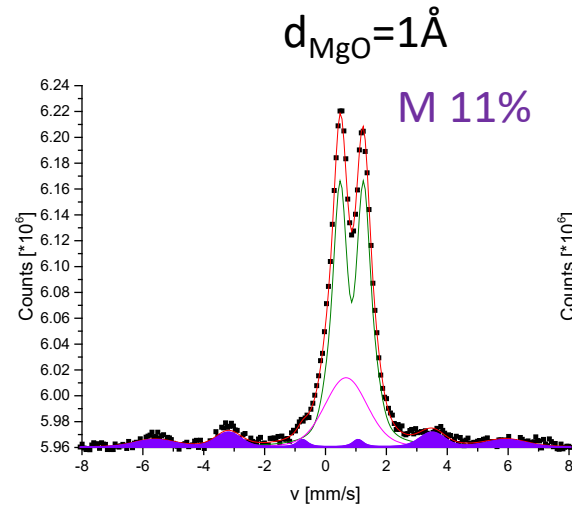
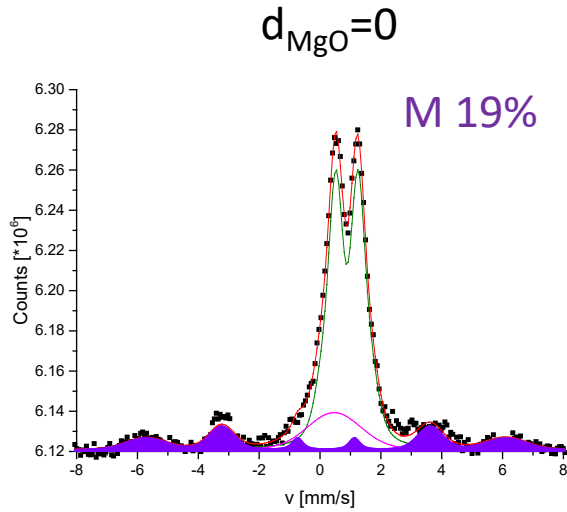
Jak zwiększyć EB w układzie Fe/FeO?



* AKR, T. Ślęzak, M. Ślęzak, K. Matlak, E. Młyńczak, N. Spiridis, and J. Korecki, et JAP, 115, 104301 (2014).

** AKR, W. Skowroński, M. Frankowski, J. Chęciński, S. Ziętek, P. Rzeszut, M. Ślęzak, K. Matlak, T. Ślęzak, T. Stobiecki, J. Korecki, JMMM, 424, 189 (2017).

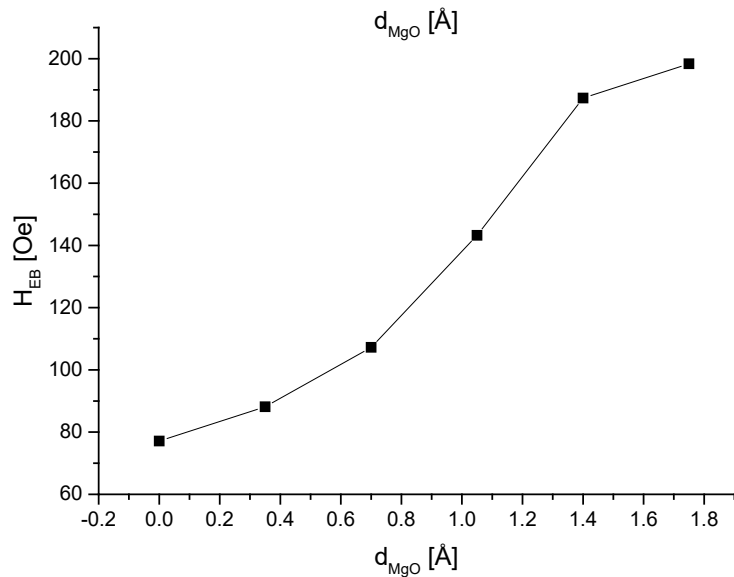
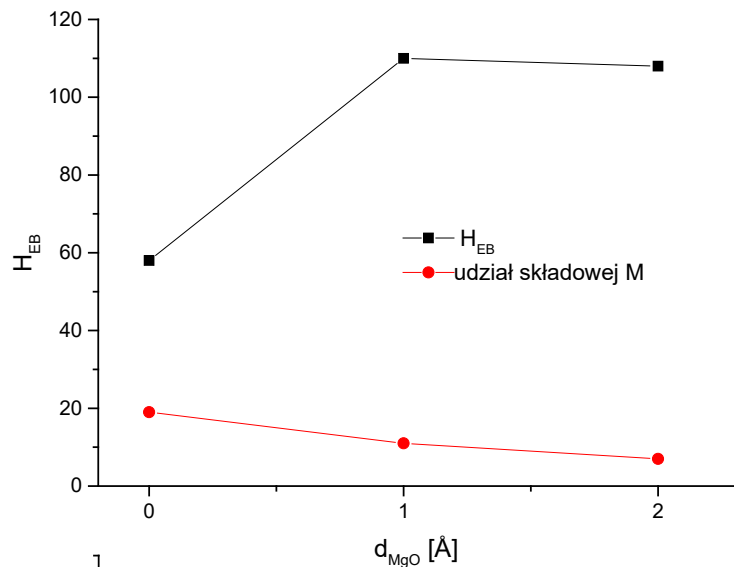
Jak zwiększyć EB w układzie Fe/FeO?



EB

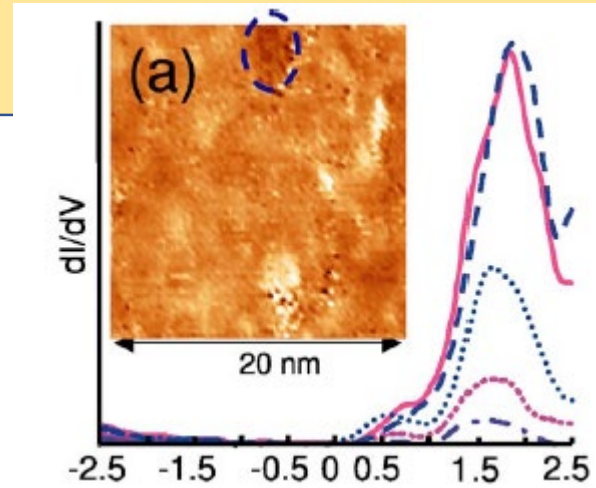
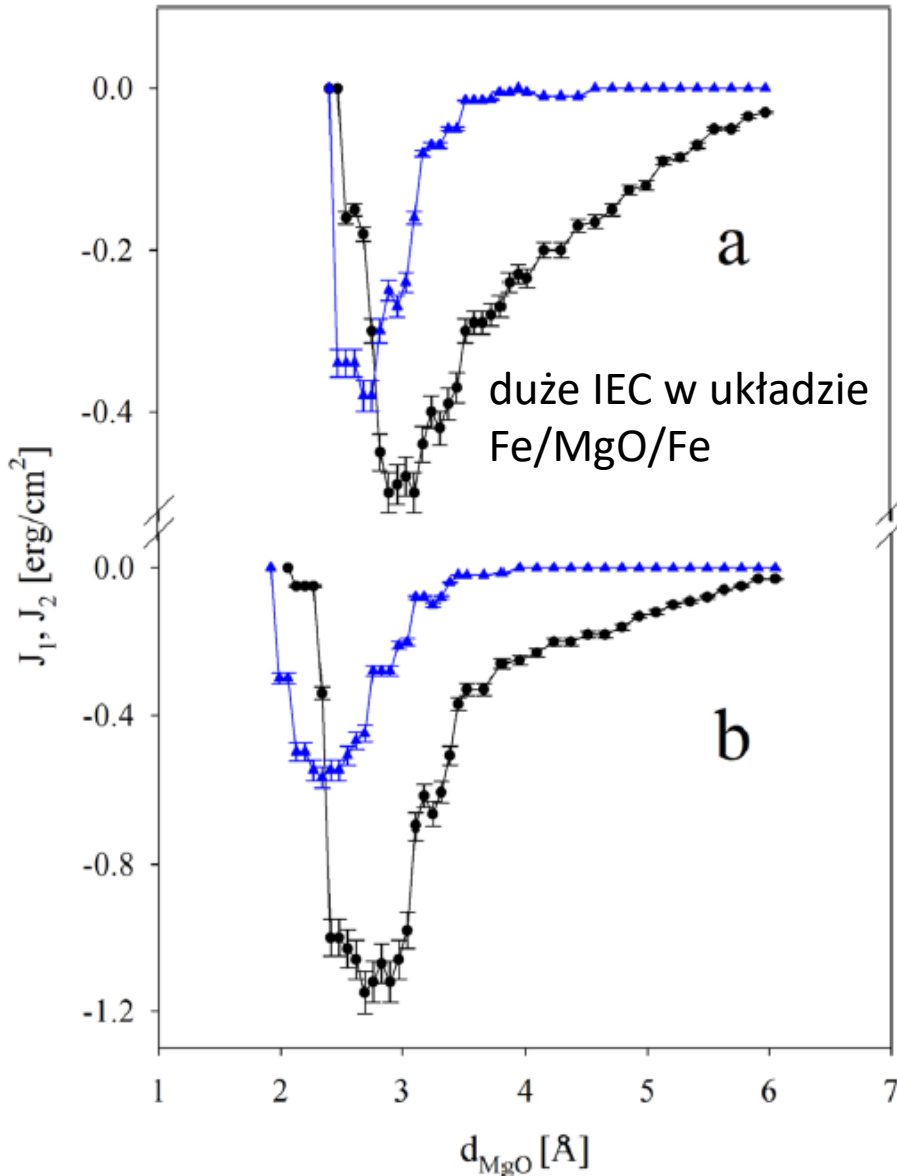


EB vs. d_{MgO}

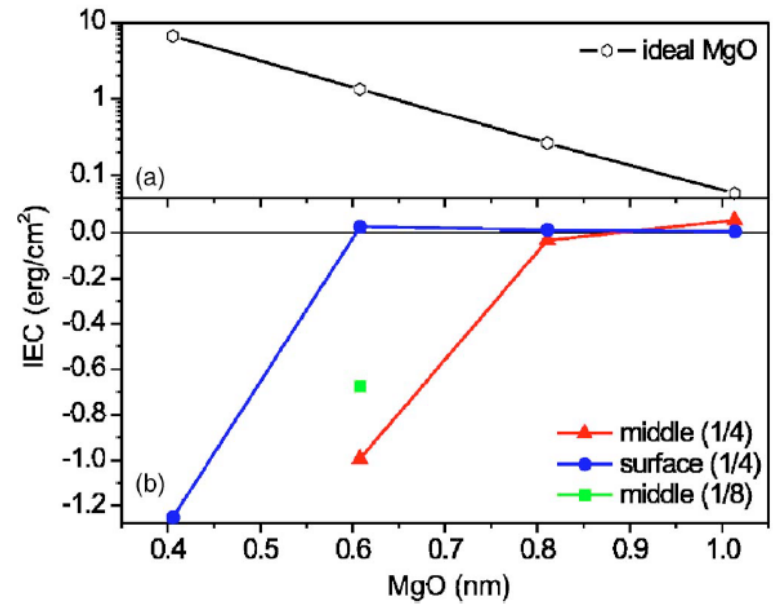


H_{EB} wzrosło 2.5 x!

Fe/MgO(0-6)Å/Fe



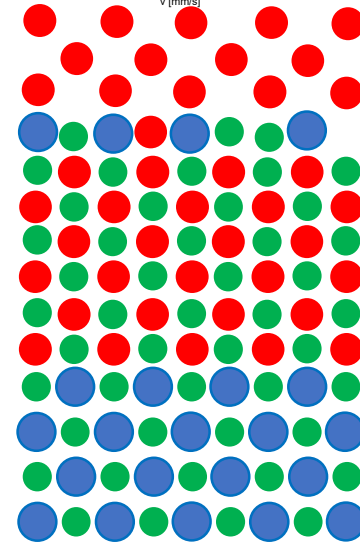
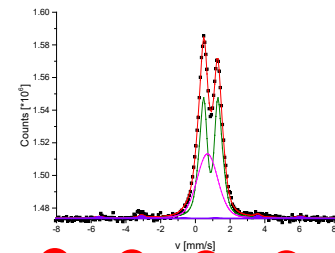
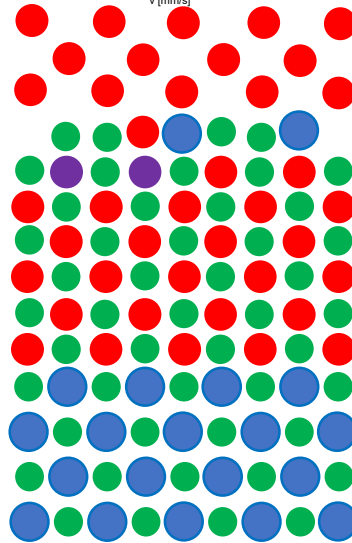
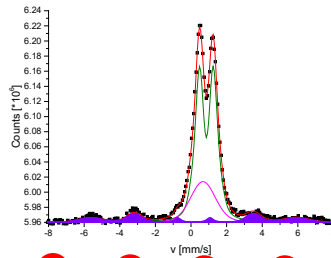
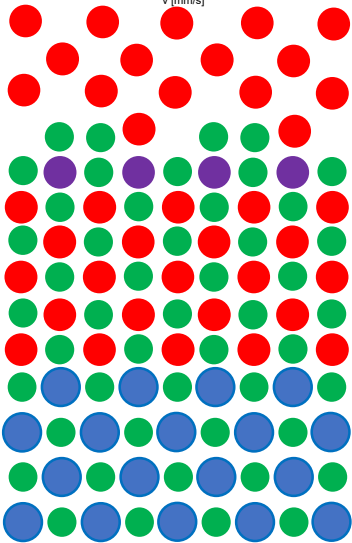
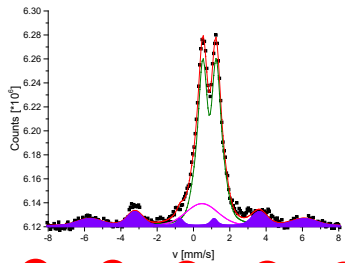
P. G. Mather *et al.* Phys. Rev. B 73, 205412(2006).



T. Katayama *et al.* Appl. Phys. Lett. 89, 112503 (2006).

Obecność wakancji tlenowych w barierze MgO ?

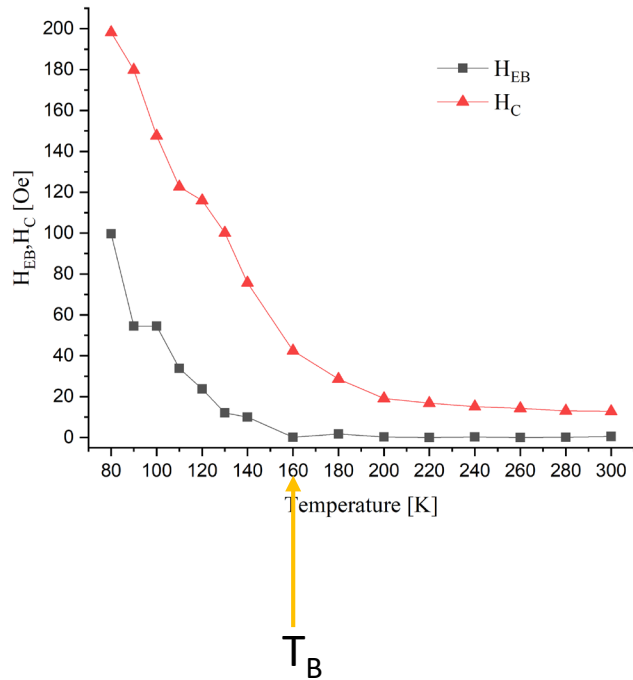
Fe/MgO_x/FeO/MgO



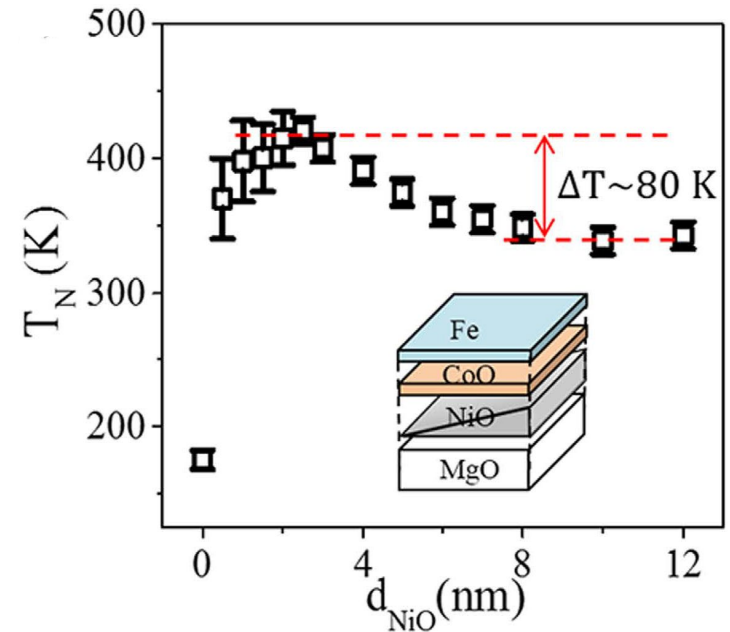
- Mg
- O
- Fe

Co dalej?

Czy możliwe jest podniesienie temperatury blokowania Fe/FeO($H_{EB} > 0$)?



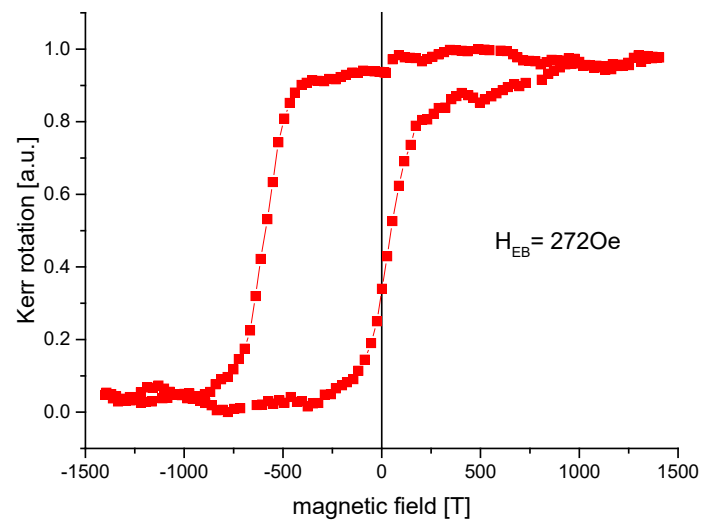
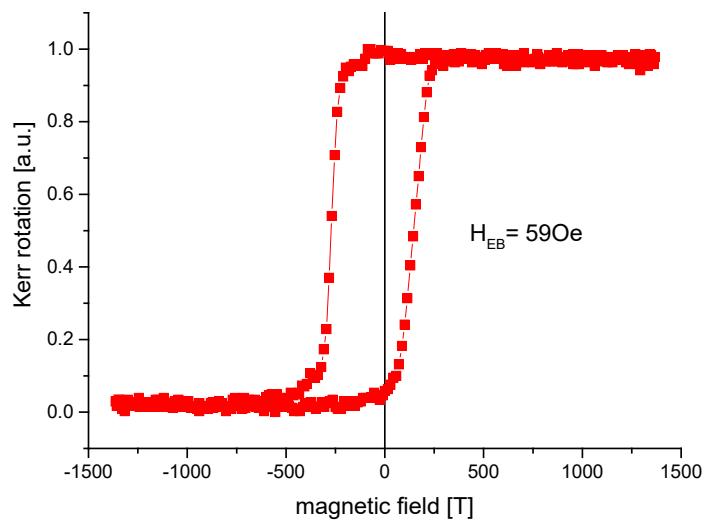
- efekt bliskości AFM



Q. Li *et al.* Scientific Reports 6, 22355 (2016).

Fe/FeO/NiO ?

Fe/FeO/NiO



Wzmocnienie HEB wskutek oddziaływania AFM/AFM!

Podsumowanie

- Kontrolowany wzrost epitaksjalnych warstw FeO/MgO(001)
- Oddziaływanie warstw FM/AFM w warstwowym układzie Fe/FeO
- Fe/MgO/FeO - zwiększenie EB
- Fe/FeO/NiO?

Dziękuję za uwagę