Temperature Dependence of Coercivity and Magnetic Reversal in $SmCo_x$ Thin Films

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Purpose of Work

1) Look at thickness dependence of permanent properties of $SmCo_5$

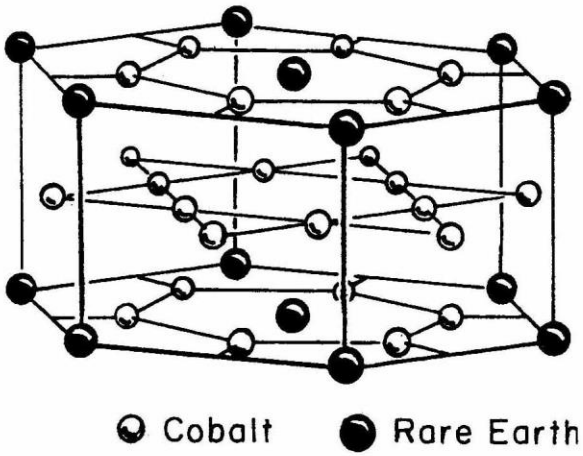
2) Determine the best preparation/treatment route to obtain strongly exchange coupled $SmCo_5$ – Co two-phase films

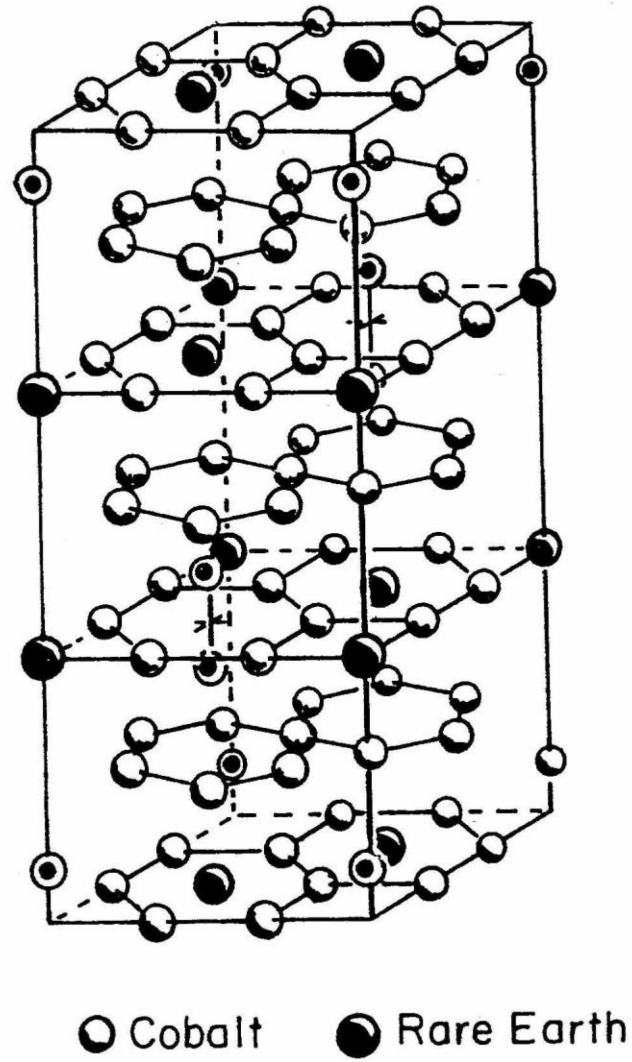
Previous work by us on this material:
Andreescu, O'Shea, Jour. Appl. Phys. 91, 8183 (2002)
Andreescu, O'Shea, International Jour. Mod. Phys. B 15, 3243 (2001).

Structure of Sm-Co

Sm_2Co_{17} (rhombohedral)

$SmCo_5$ (hexagonal)





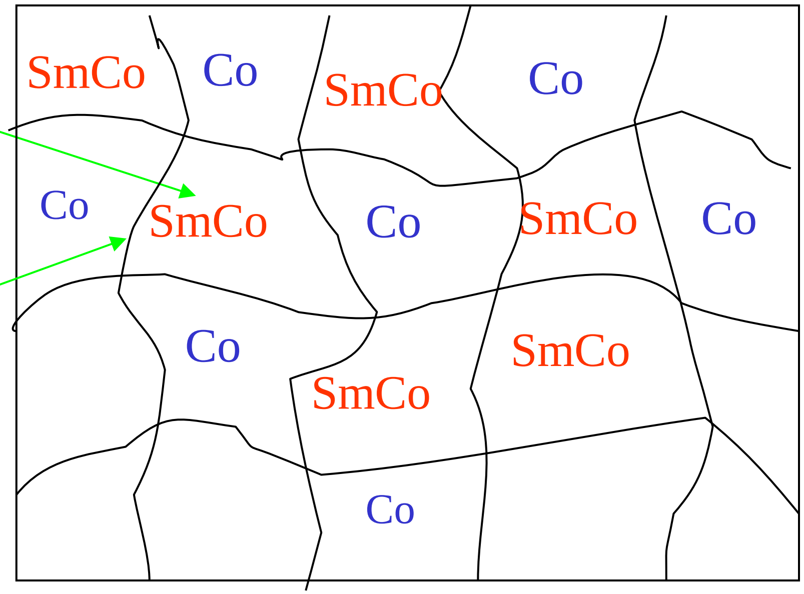
See O'Handley 'Modern Magnetic Materials', John Wiley and Sons (2000)
Barret et al 'Structure of Materials', Pergamon Press (1980)
Strnat, 'Ferromagnetic Materials', Vol 4, Wohlfarth ed., Elsevier Press (1988)

Exchange-Spring Magnet

Hard Phase + Soft Phase (nanostructured)

Small crystallite size →high coercivity

Large interface area → SmCo and Co coupled.



E. F. Kneller, and R. Hawig, IEEE Trans. Magn. 27, 3588 (1991).

R. Coehoorn, D.B. de Mooij and C. de Waard, J. Magn. Magn. Mater. 80, 101 (1989).

Properties of phases	K ergs/g	M emu/g	T_c °C
$SmCo_5$	$1x10^8$	105	685
Sm_2Co_{17}	$3x10^7$	126	810
Co	$3x10^7$	162	1115

Sm-Co studies

For $SmCo_5$: Vary thickness (d = 60 nm $\rightarrow$ 500 nm)

- homogeneous $SmCo_5$
- do permanent magnetic properties depend on thickness?

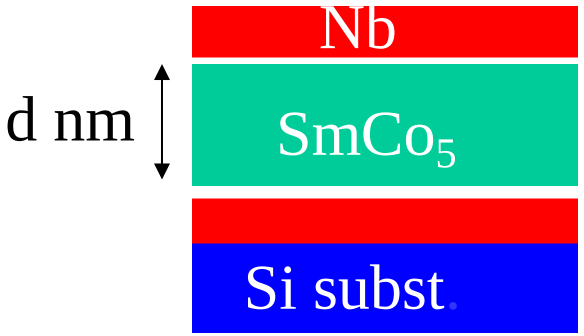
For $SmCo_x$, $x \geq 5$ (d ~500 nm) : Two starting geometries

- multilayers and homogeneous $SmCo_X$
- vary Co content to improve of energy product

Sample Preparation ($SmCo_5$)

for thickness dependence

Homogeneous



d = 6- 540 nm

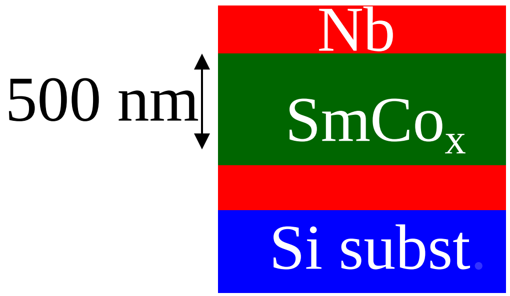
Anneal to crystallize Sm-Co

Vacuum anneal (20 minutes)
Or
Rapid thermal anneal (30 seconds)

Sample Preparation ($SmCo_x$)

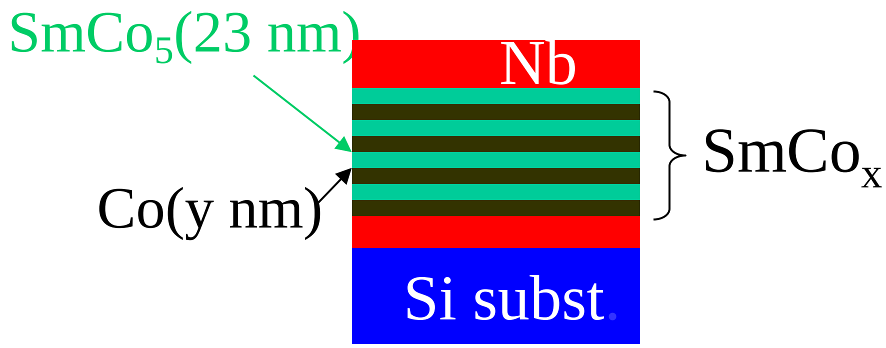
compare properties

Homogeneous



x: 5 –25

Multilayer



y: 0 – 20 nm
equivalent to x: 5 – 12.3

Anneal to crystallize Sm-Co

Vacuum anneal (20 minutes)
Or
Rapid thermal anneal (30 seconds)

Sputter Deposition

Homogeneous $SmCo_5$:

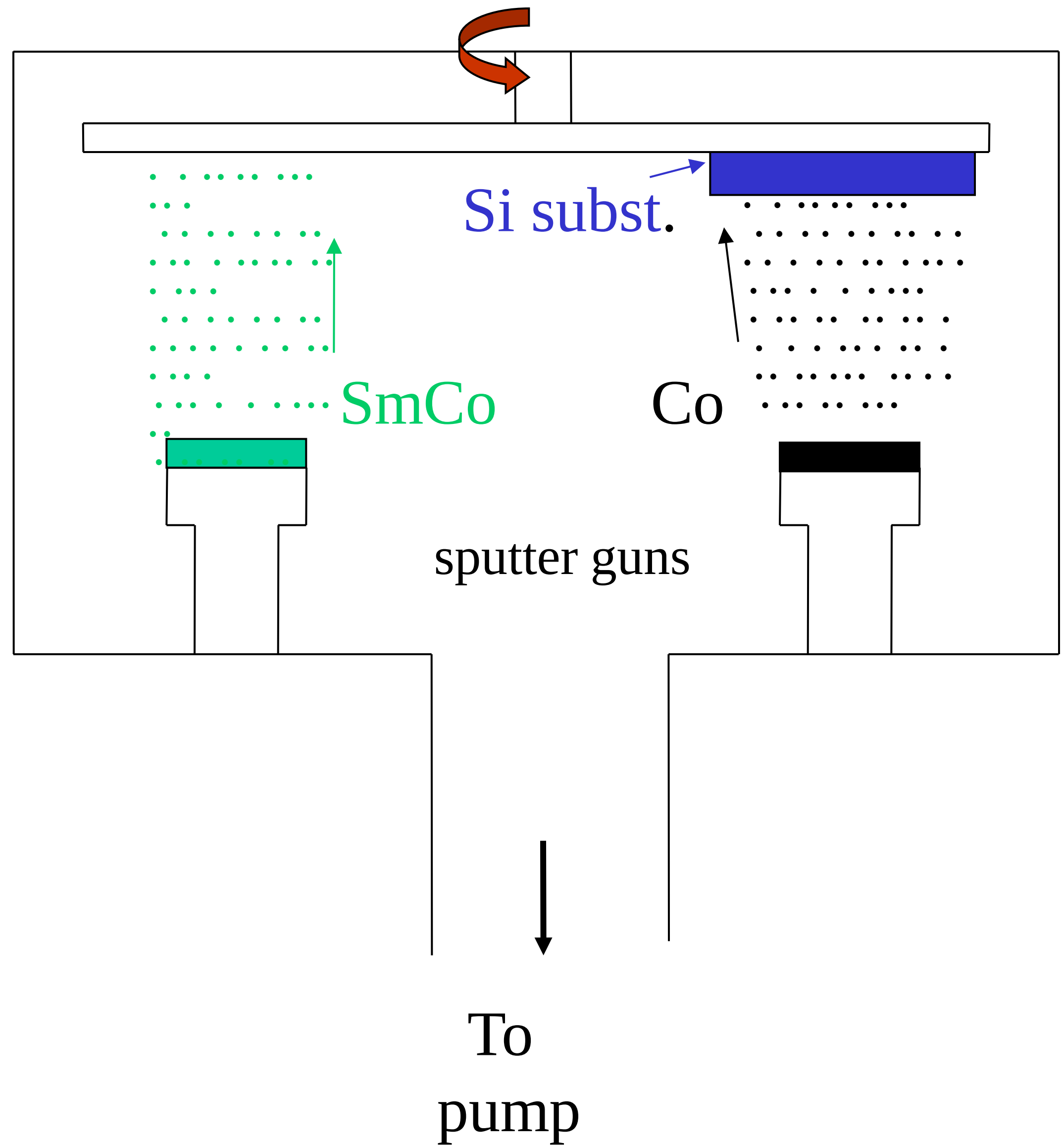
Sputter directly from a $SmCo_5$ target

Multilayers of $SmCo_5$/Co:

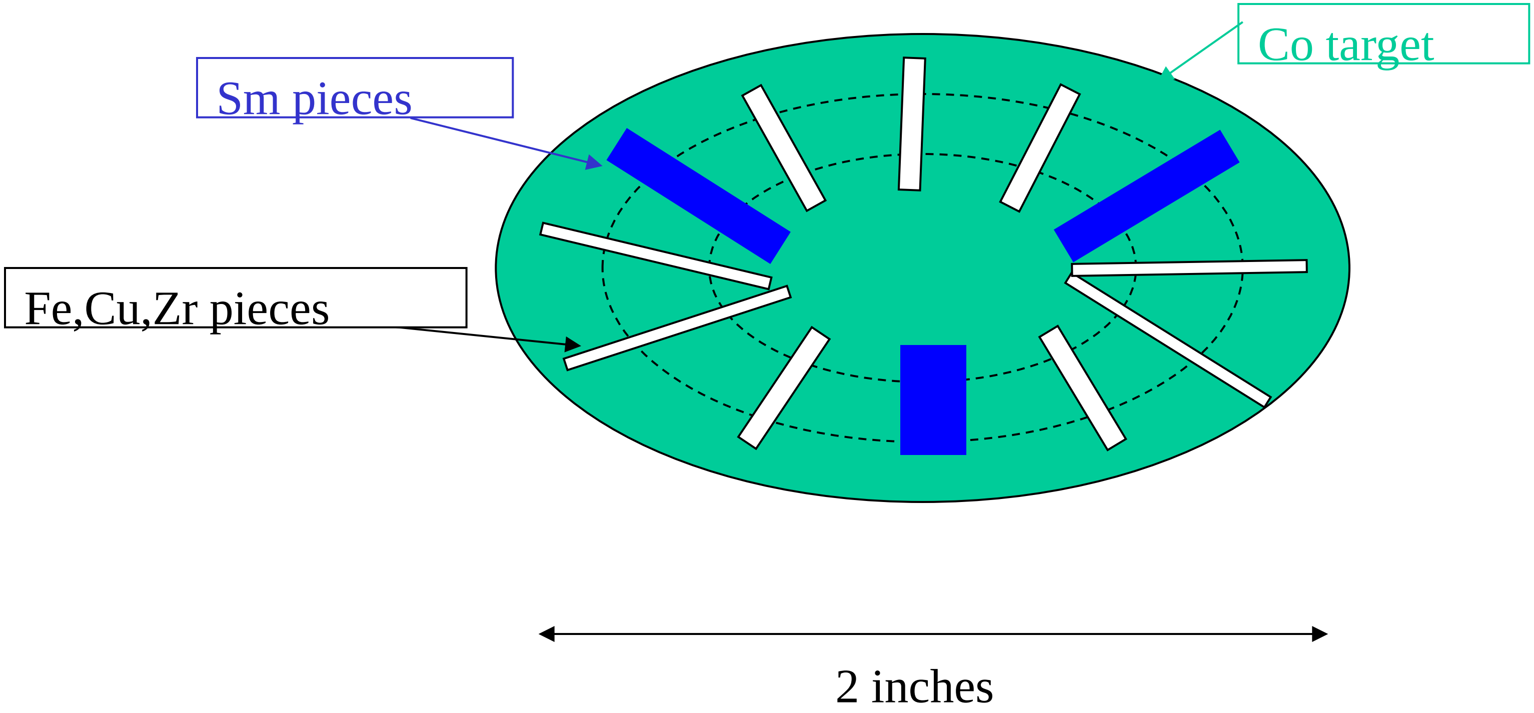
Si substrate switched between SmCo and Co sputter guns

Homogeneous $SmCo_x$:

Add pieces of Co to $SmCo_5$ target



Sputter target: $SmCo_{12}$(Fe,Cu,Zr)



X-ray diffractograms for the 540 nm initially homogeneous $SmCo_5$ sample

$SmCo_5$ films - $SmCo_5$ and trace of elemental Co phases identified

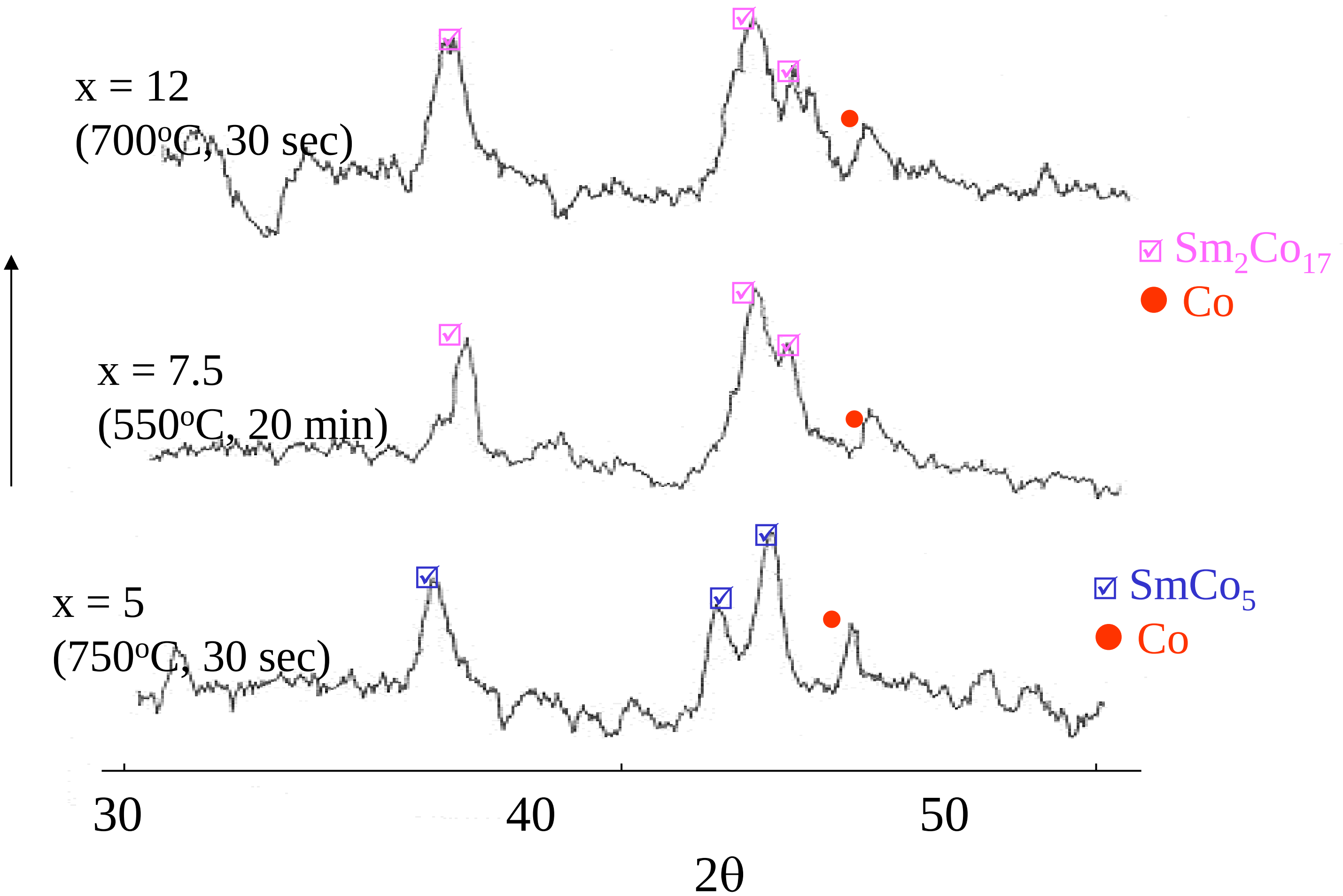
$SmCo_x$ films - $SmCo_5$ and elemental Co phases identified

Texture – No significant texture found

Grain size – 12 → 25 nm

Structure of annealed homogeneous films-

Nb/$SmCo_X$/Nb

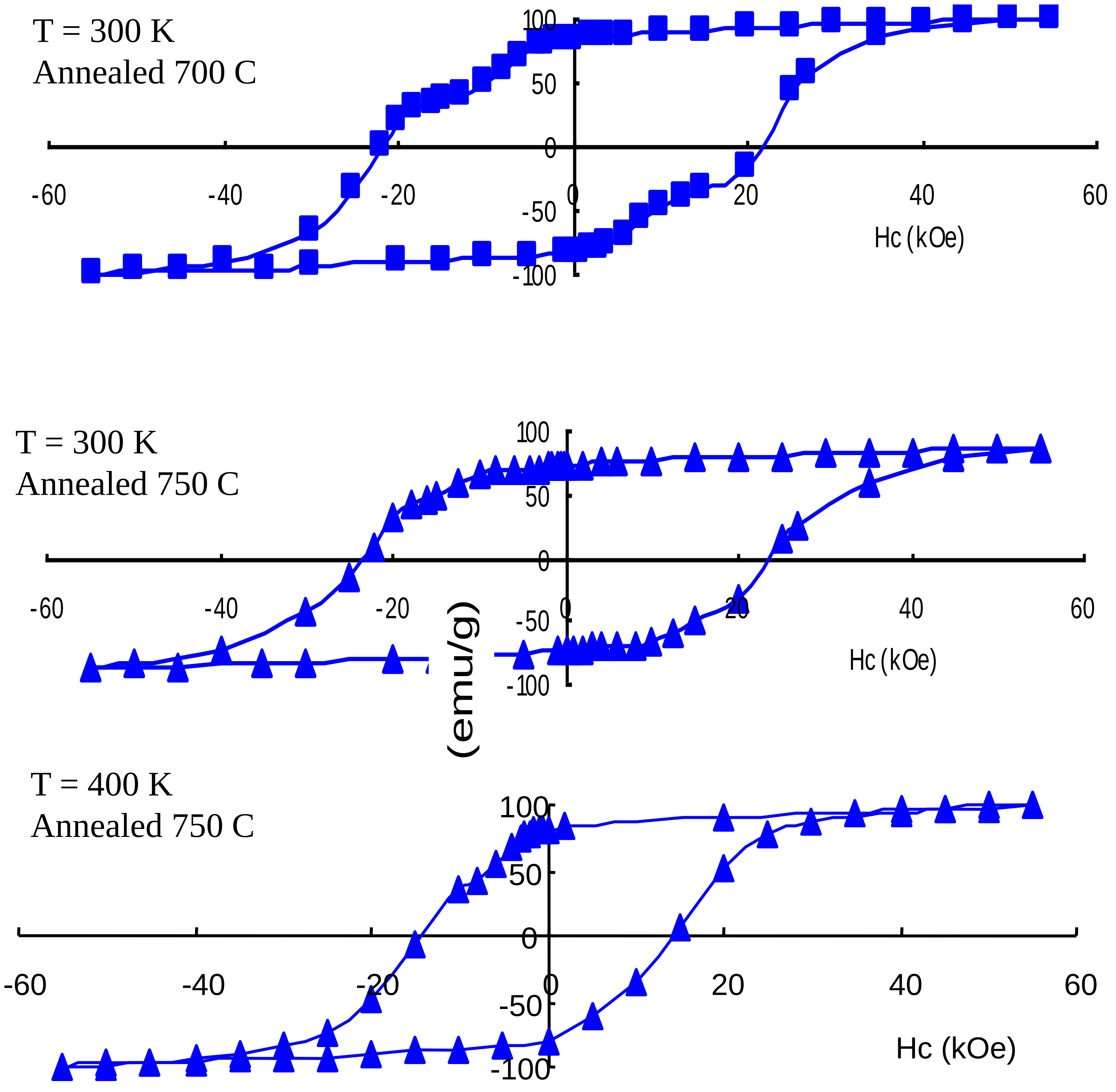


Magnetization isotherms at selected measurement temperatures for an initially homogeneous $SmCo_{12}$ film after an anneal at 700 °C for 30 seconds.

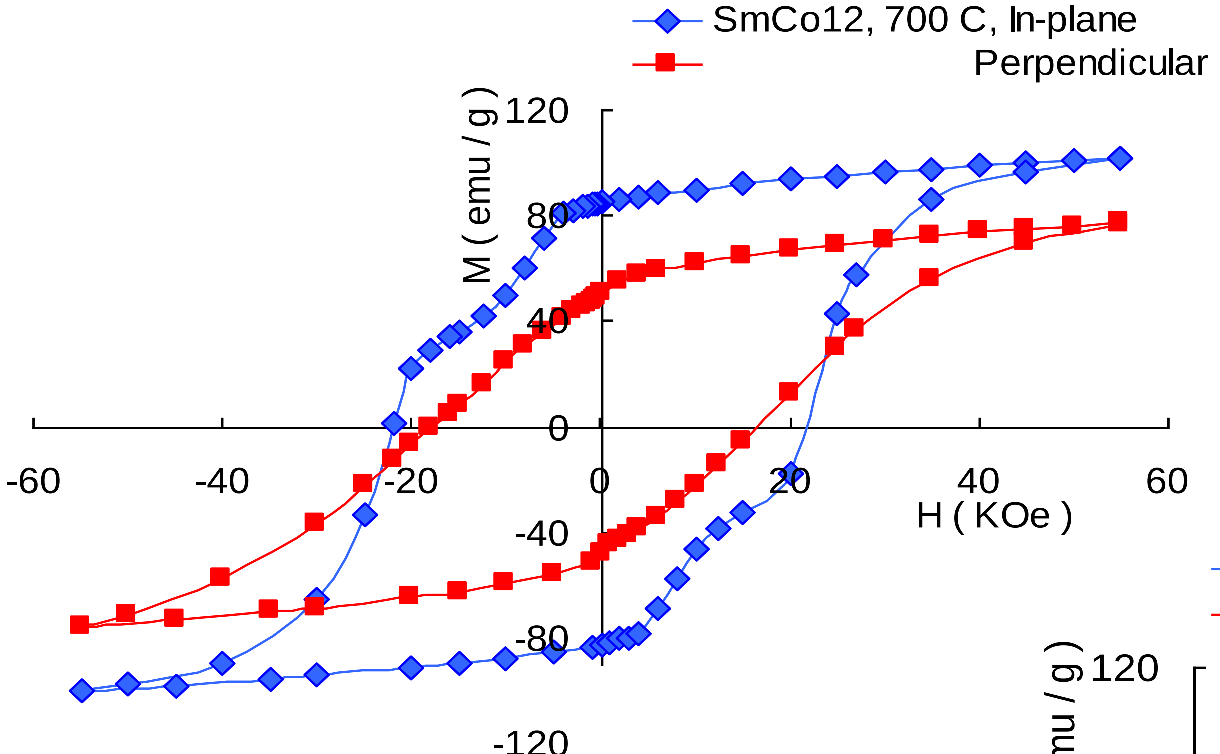
The slight constriction centered on -20 kOe indicates the soft and hard phases are not completely coupled on reversal in this sample

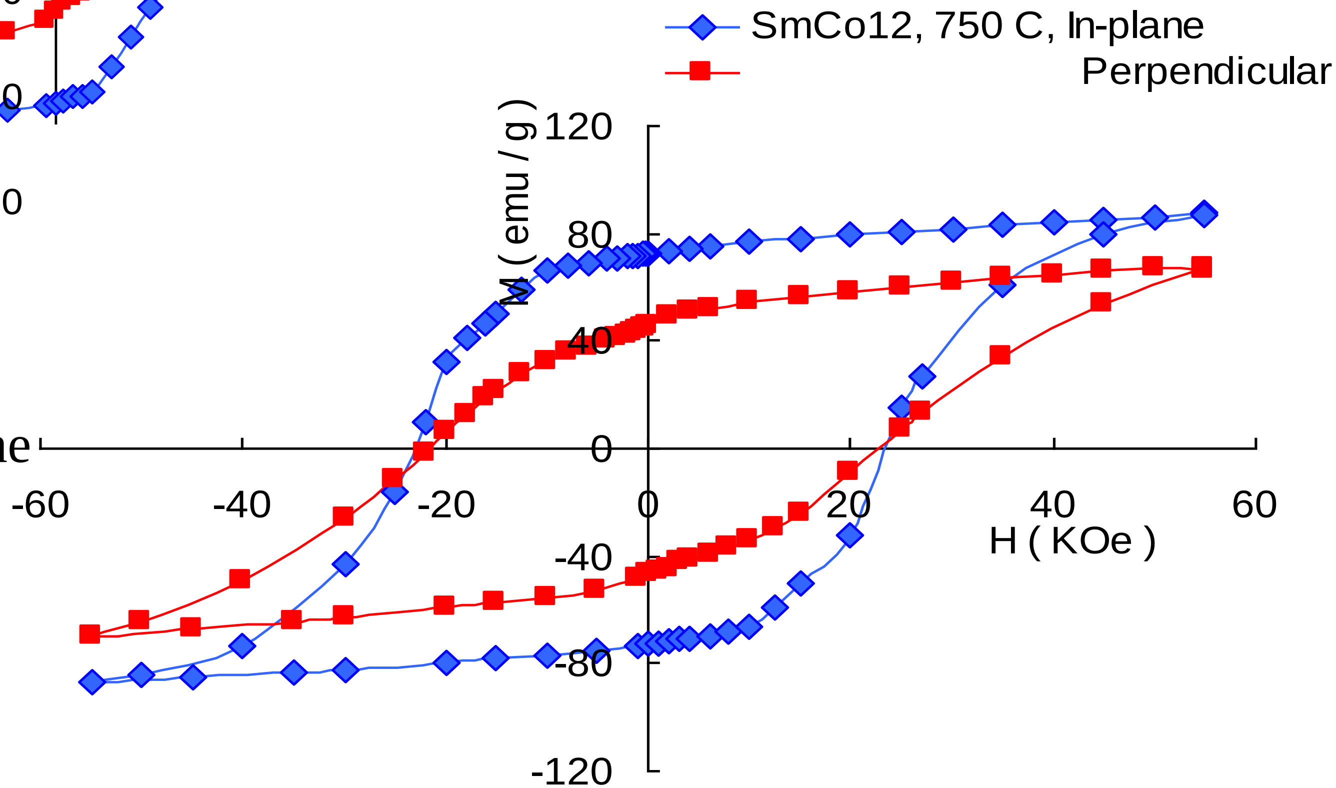
Coercivity shows a strong dependence on temperature (analyzed later)

Homogeneous $SmCo_{12}$



In-plane and Perpendicular Magnetization





In some cases there is a small amount of in-plane anisotropy

High field magnetization (M_s), coercivity (H_{ci}) and energy product (BH_{max}) as a function of anneal temperature for several thicknesses of initially homogeneous $SmCo_5$ as indicated.

Generally the thickest samples (540 nm) have the best values of M_s, H_{ci} and energy product BH_{max}

For thin samples a 30 sec anneal is more effective than a 20 min anneal for high values of M_s, H_{ci} and energy product BH_{max}

Once more M_s decreases and H_c increases with increasing anneal temperature. This leads to a maximum in energy product at intermediate anneal temperature

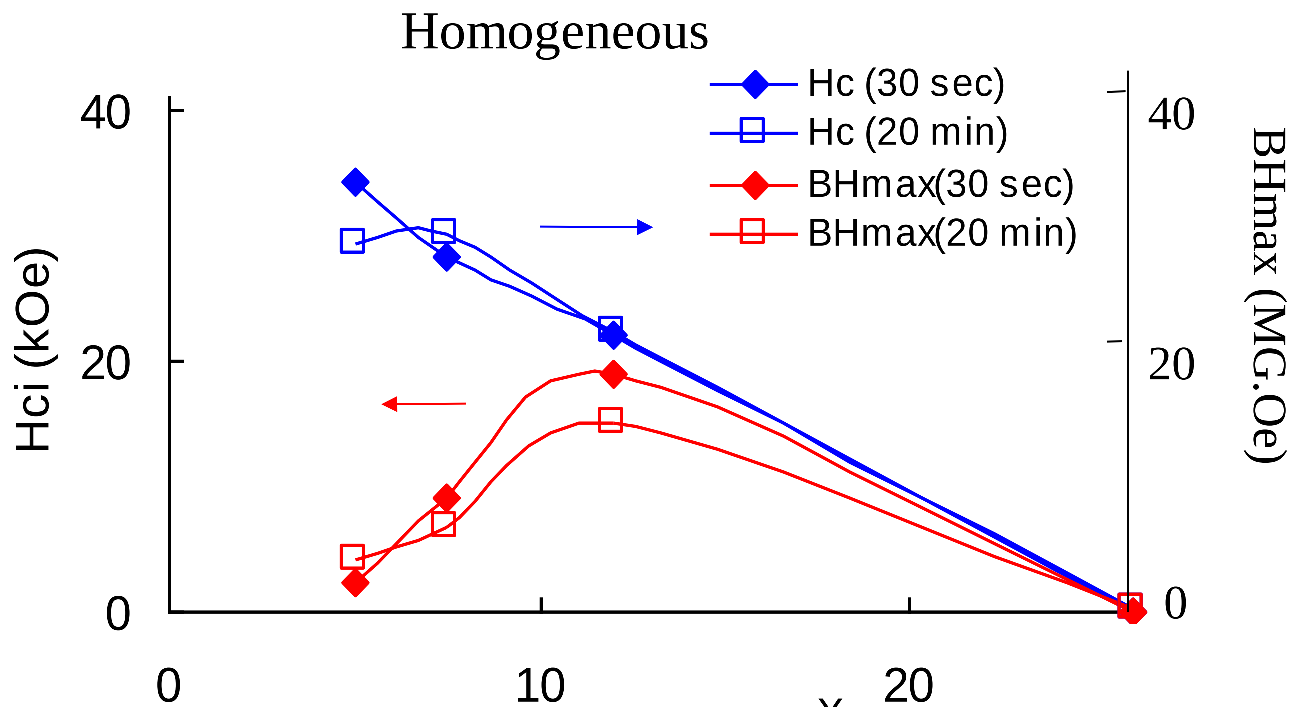
H_c, BH_{max} versus composition x

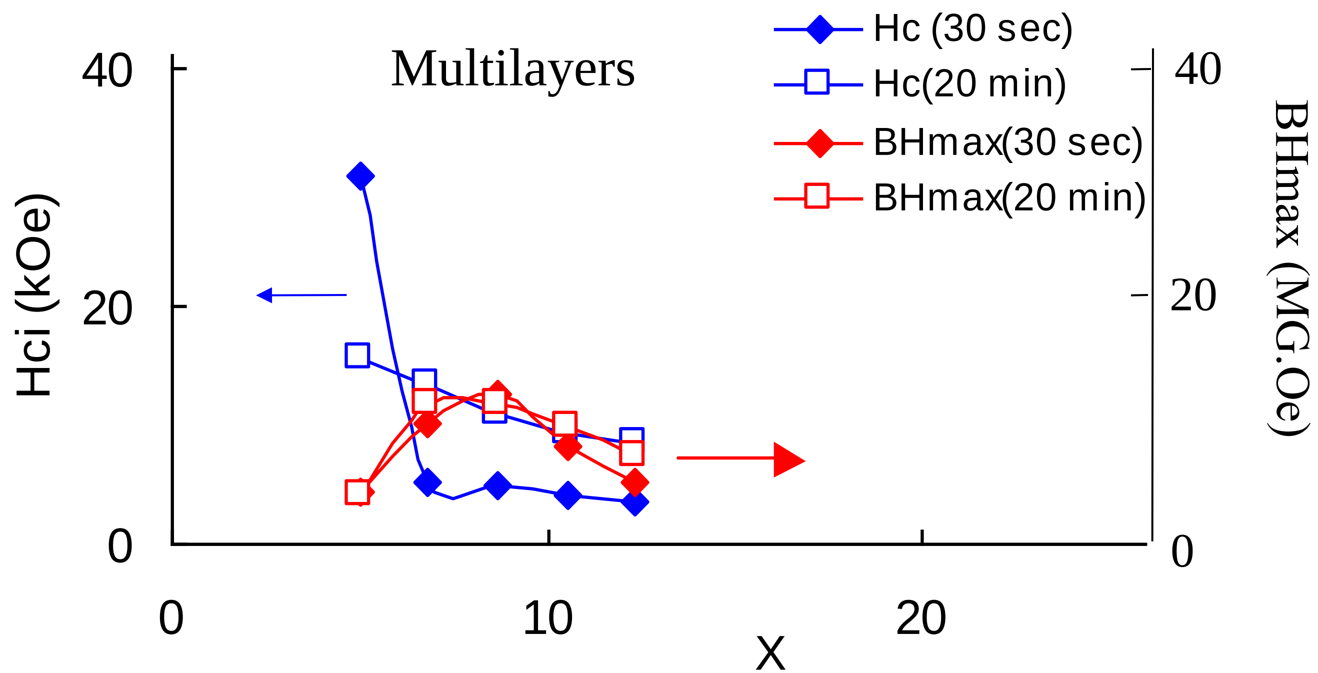
•Initially homogeneous samples, best H_{ci} and BH_{max}

•Rapid anneal preferable to longer time anneal

•Anneal temperatures for

•homogeneous samples < multilayers

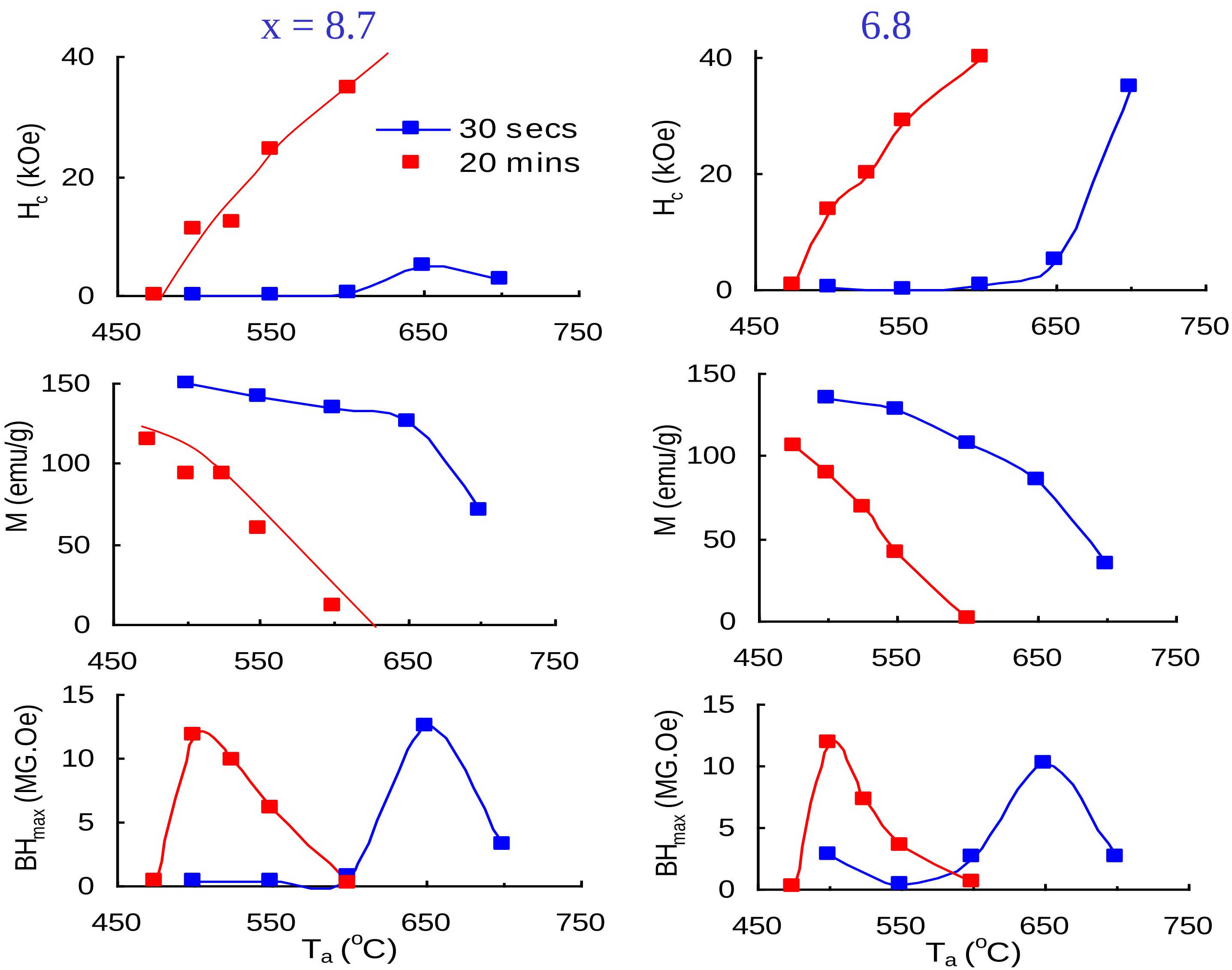




High field magnetization (M_s), coercivity (H_{ci}) and energy product (BH_{max}) as a function of anneal temperature and anneal time for several compositions of initially multilayered $SmCo_x$.

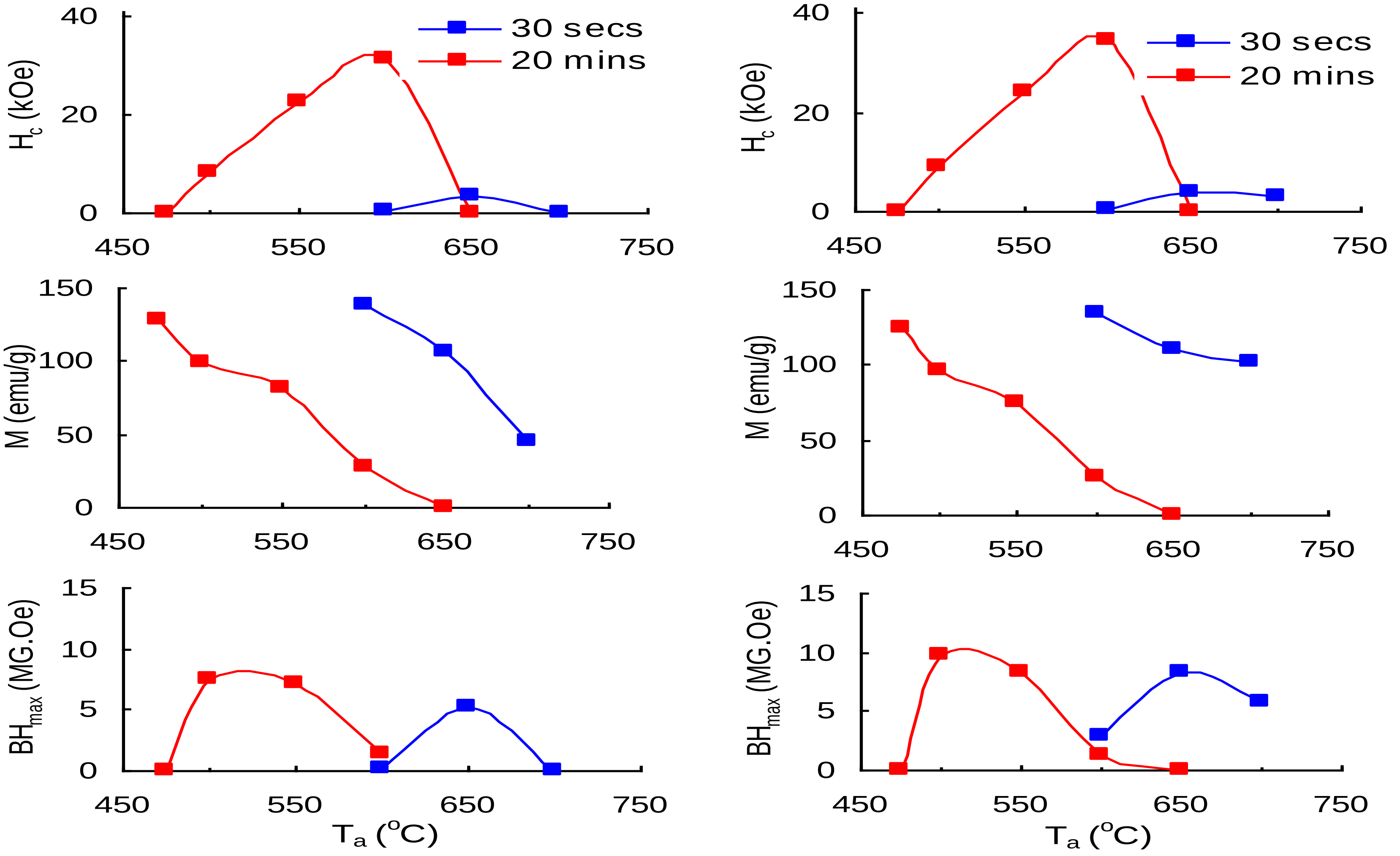
Once more M_s decreases and H_c increases with increasing anneal temperature. This leads to a maximum in energy product at intermediate anneal temperature

Multilayers (RT)



Multilayers (RT)

x = 12.3 10.5



Coercivity and energy product as a function of measurement temperature for three selected Sm-Co samples

In going from 10 K to 400 K a 60% decrease in H_{ci} and a 4% decrease in M_s (not shown) occur.

These produce a roughly 20% decrease in BH_{max}.

Modified magnetization plot (see axes labels) for homogeneous $SmCo_5$ annealed at 600 °C for 20 minutes, and initially multilayered $SmCo_{6.8}$ annealed at 500 °C for 20 minutes.

A linear behavior is expected if the coercivity is determined by domain walls pinned by narrow inhomogeneities [Kronmuller et al, Jour. Magn. Magn. Mater. 74, 291 (1988)].

A fit yields a homogeneity size of about 0.5 nm.

The largest values of coercivity H_{ci} and energy product BH_{max} are given for each sample type along with the composition where that value was obtained.

Initial sample form		H_{ci} (kOe)	BH_{MAX} (MG.Oe)
3x[$SmCo_5$(d nm)/Nb(36 nm)] Isolated homogeneous $SmCo_5$ layers		38 (x = 5)	5.5 (x = 5)
10x[$SmCo_5$(24nm)/Co(y nm)] Initially multilayered $SmCo_x$, x>5*		35 (x = 6.5)	12.5 (x = 8.7)
$SmCo_x$ (d nm) Initially homogeneous $SmCo_x$, x>5		34.8 (x = 6.8)	19 (x = 12)

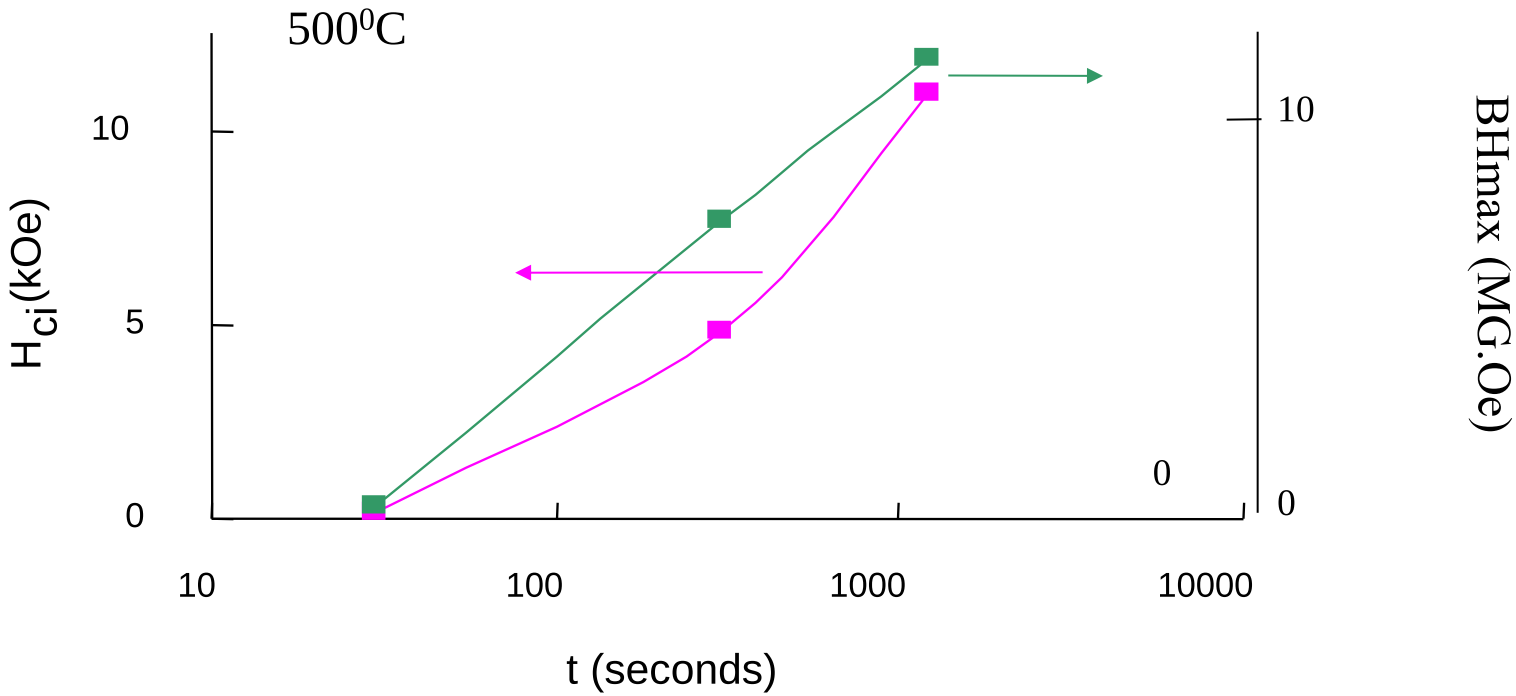
* x is calculated from the $SmCo_5$ and Co layer thicknesses

Comparison with other thin film work

Author	Ref.	Sample	Method	BH_{max} MG.Oe
Kato et al	J. Appl. Phys. 87, 6125 (2000)	$SmFe_{12}$/ α-Fe	Sputter, 1 μm	18.5
Cadieu et al	J. Appl. Phys. 76, 6059 (1994)	SmCo	Sputter, 118 μm	16
Our work	J. Appl. Phys, 91, 8183 (2002)	SmCo/Co	Sputter, 500 nm	19
Sabiryanov et	Phys. Rev. B 58, 12071 (1998)	SmCo5/ CoFe	Theory	65

Anneal time dependence of H_{ci}, BH_{max}

Multilayer $SmCo_{8.7}$



Conclusions

-Thicker samples have best permanent magnet properties.

-A 30 sec anneal is most beneficial, especially for thinner samples

-Best values of BH_{max} are:

T (K)	BH_{max} (MG.Oe)	(kJ/m^3)
10	21	166
300	19	150
400	17	134

Other Exp.

Kato et al, J. Appl. Phys. 87, 6125 (2000)-18.5 MG.Oe

Cadieu et al, J. Appl. Phys. 76, 6059 (1994)-16 MG.Oe

Zhou et al, Paper GD-10, this conference – 16.6 MG.Oe

Theory

Sabiryanov et, Phys. Rev. B 58, 12071 (1998)- 65 MG.Oe

-H_{ci}(T) is fitted well by a domain wall pinning theory and is consistent with a pinning inhomogeneity size of about 0.5 nm