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Specialists in Rare Earth Magnets and Magnet Systems

Temperature-Compensated High Temperature SmCo Magnets for Traveling Wave Tubes

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INTRODUCTION

Why High Temperature Magnets?

High temperature magnets

- Conventional SmCo magnets have maximum operating temperature (T_M) up to 300°C
- Magnets with maximum operating temperature (T_M) up to 550°C developed in the late 1990s
- Enabled use of magnets in high temperature applications
- RTC of B_r about -0.035%/°C between -50°C to +150°C

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Why Low Temperature Coefficient?

Reversible temperature coefficient (RTC) of Br (α)

- Rate of change in residual induction, B_r, within a specified temperature range
- Calculated between –50°C to +150°C in this presentation
- $\alpha = \Delta B_r/B_r/\Delta T$, where $\Delta T = (T_2 - T_1)$, $B_r = B_r(T_1)$, $\Delta B_r = B_r(T_2)-B_r(T_1)$

The best zero TC magnets currently available were:

- EEC 2:17TC-16 - $RE(Co,Fe,Cu,Zr)_z$ magnets with α (-50°C to +150°C) = -0.001%/°C
- B_r= 8.3 kG, H_{ci}>25 kOe, H_c= 7.8 kOe, $(BH)_{max}$= 16 MGOe
- But the maximum operating temperature is 300°C

Why High Temperature Magnets With Low Temperature Coefficient?

- Reduce the loss in axial field with corresponding increase in operating temperature
- Can be used in applications beyond 300°C with lower rate of change in B_r
  - traveling wave tubes and inertial devices

APPROACH

- 4f-3d exchange interaction

  Light rare earths have ferromagnetic coupling with Co/Fe
  - Ce, Pr, Nd, Sm
  - higher saturation magnetization ($4\pi M_s$)
  - negative value of α (decrease in B_r with increase in temperature)

  Heavy rare earths have antiparallel coupling with Co/Fe
  - Gd, Tb, Dy, Er
  - lower saturation magnetization ($4\pi M_s$)
  - positive value of α (increase in B_r with increase in temperature)

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APPROACH

- Partial substitution of Sm with heavy rare earths
  - Partial substitution of Sm with Gd
  - $(Sm_{1-x}Gd_x)(Co_yFe_uCu_vZr_w)_7$
  - $0 \leq x \leq 0.55$
  - Retain high temperature stability ($T_M = 400^oC$)
  - Achieve near-zero RTC of B_r

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Typical Demagnetization Curves of TC400-22 Magnets
$(Sm_{1-x}Gd_x)(Co_yFe_uCu_vZr_w)_7$ (x=0)

α= -0.035%/°C *

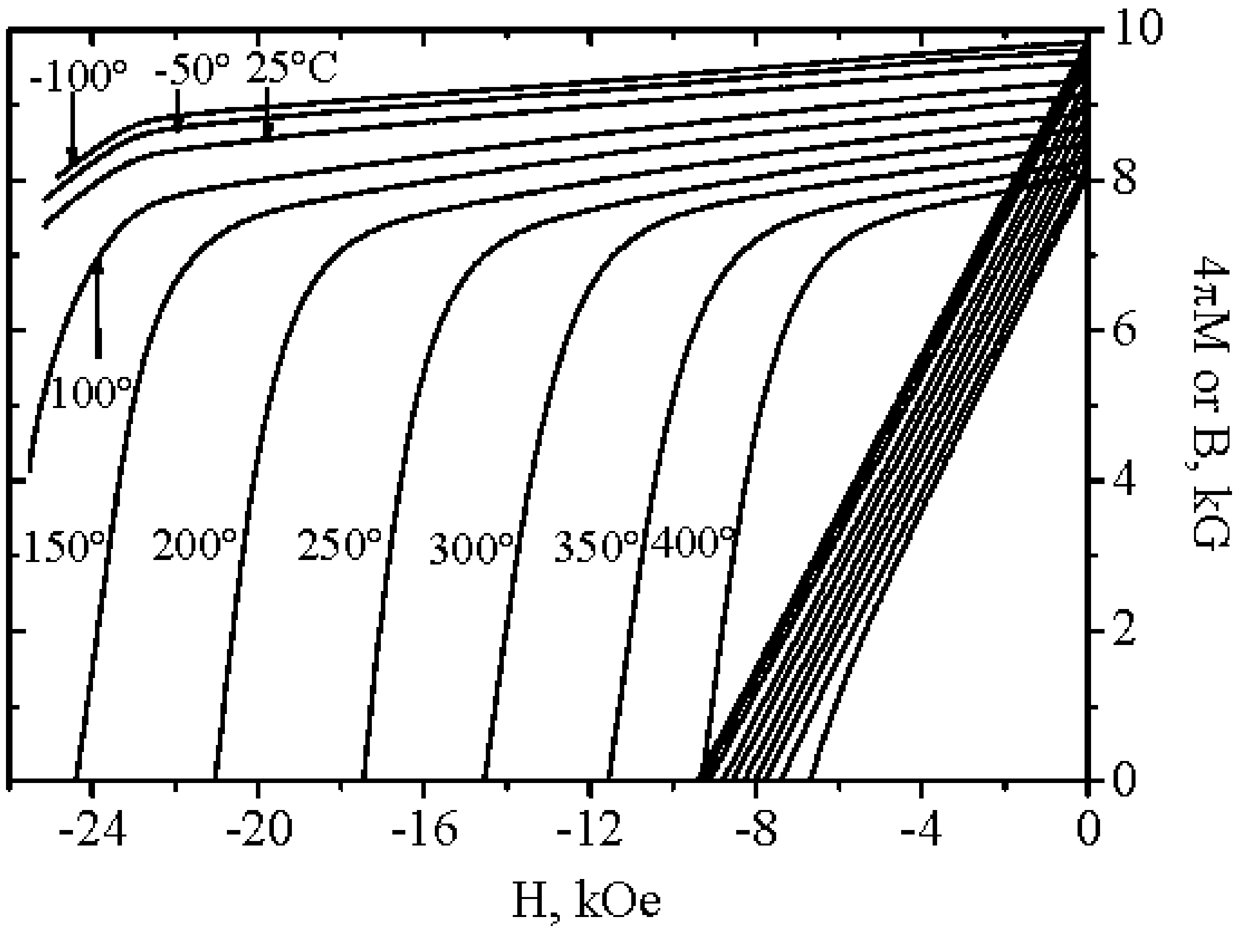
At Room Temp.:

B_r = 9.6 kG

H_{ci} > 25 kOe

$(BH)_{max}$ = 21.9 MGOe

* The value α is calculated between –50°C to +150°C

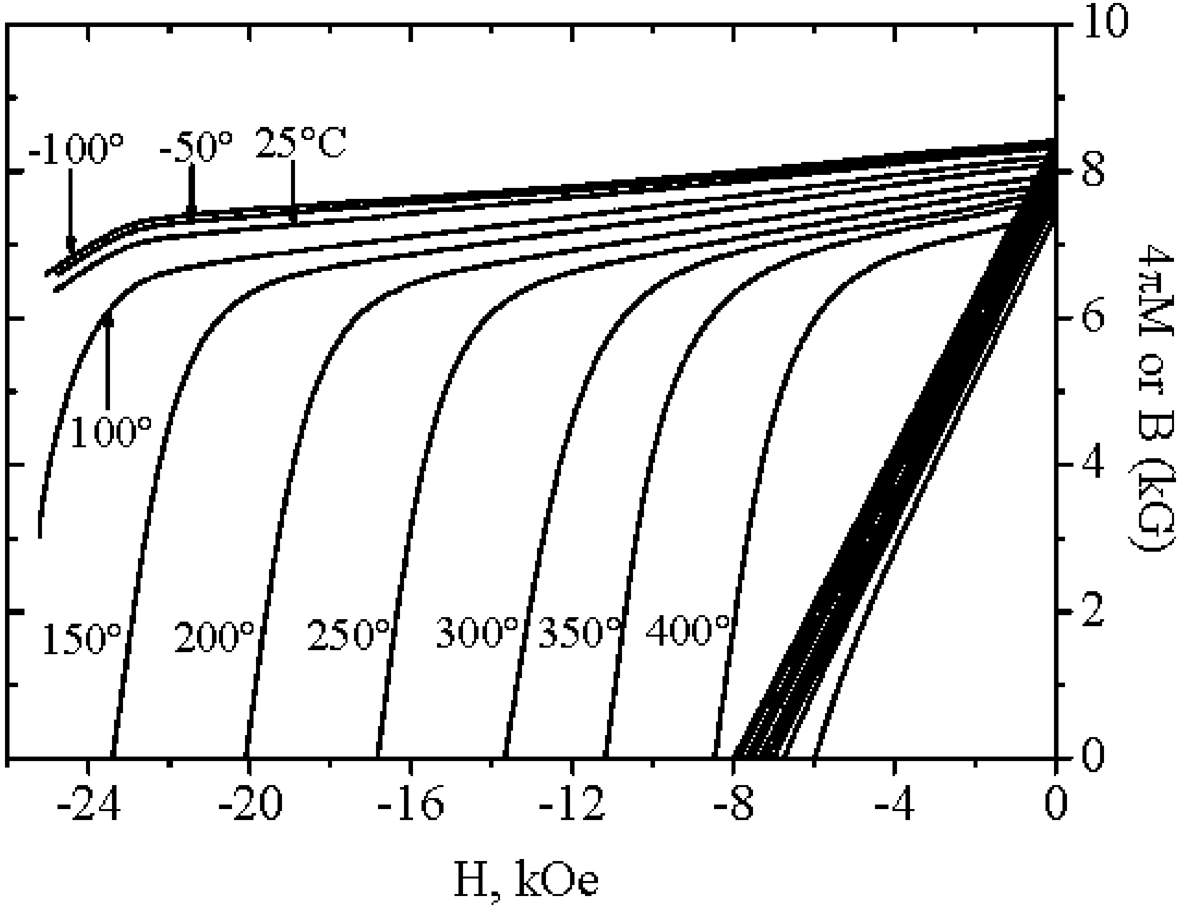


Typical Demagnetization Curves of TC400-16 Magnets
$(Sm_{1-x}Gd_x)(Co_yFe_uCu_vZr_w)_7$ (x=0.28)

α= -0.020%/°C *

At Room Temp.:

B_r = 8.3 kG
H_{ci} > 25 kOe
$(BH)_{max}$ = 16.5 MGOe



* The value α is calculated between –50°C to +150°C

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Typical Demagnetization Curves of TC400-11 Magnets

$(Sm_{1-x}Gd_x)(Co_yFe_uCu_vZr_w)_7$ (x=0.55)

α= +0.002%/°C *

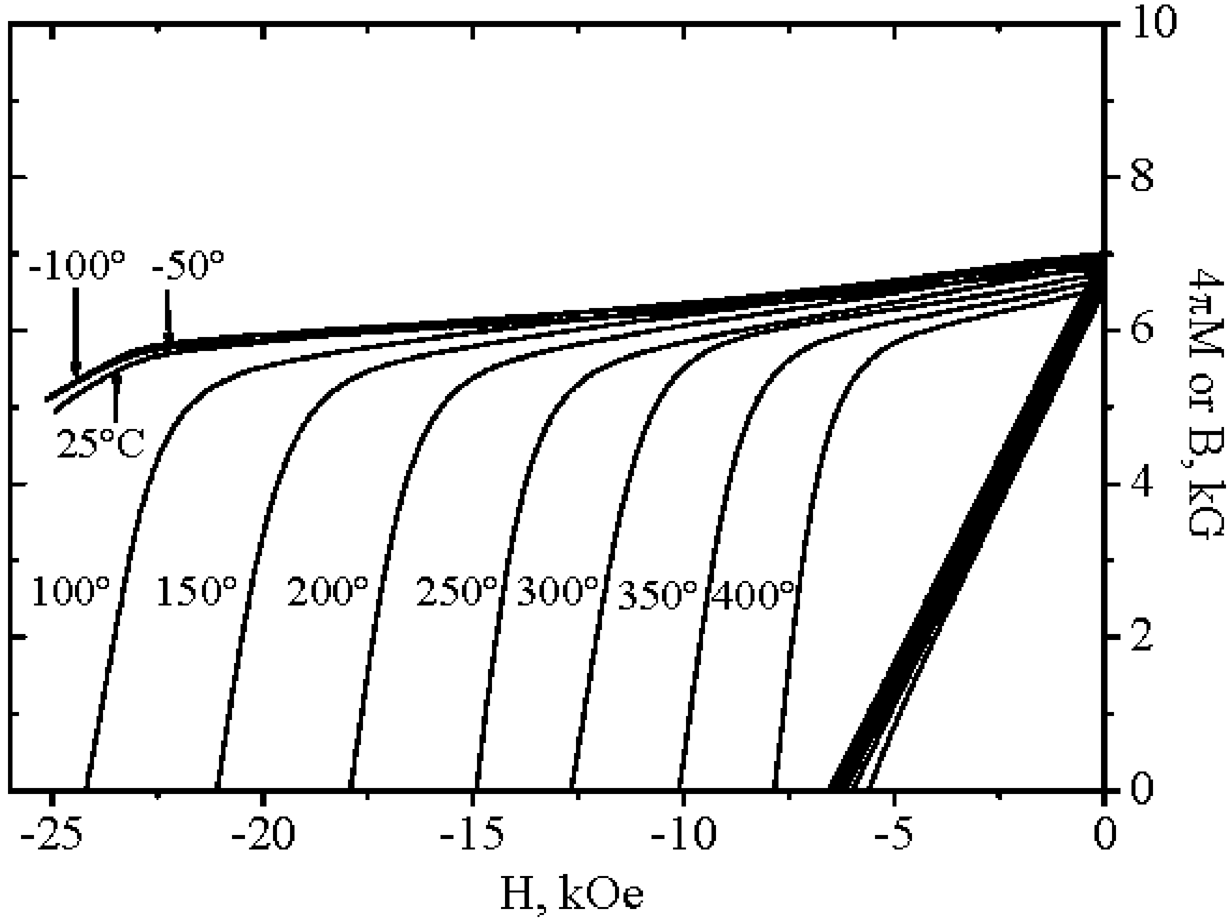
At Room Temp.:

B_r = 6.9 kG

H_{ci} >25 kOe

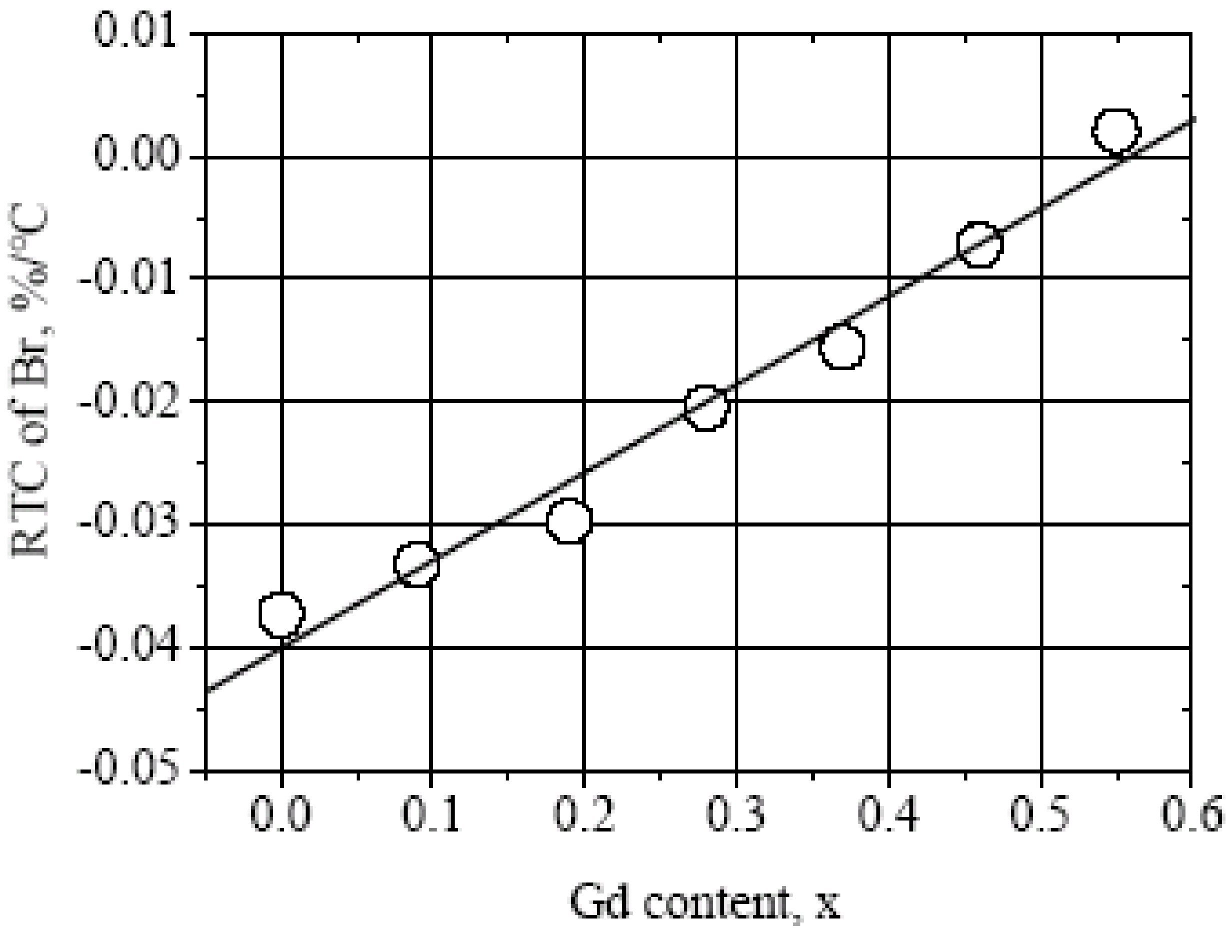
$(BH)_{max}$ = 11.5 MGOe

* The value α is calculated between –50°C to +150°C

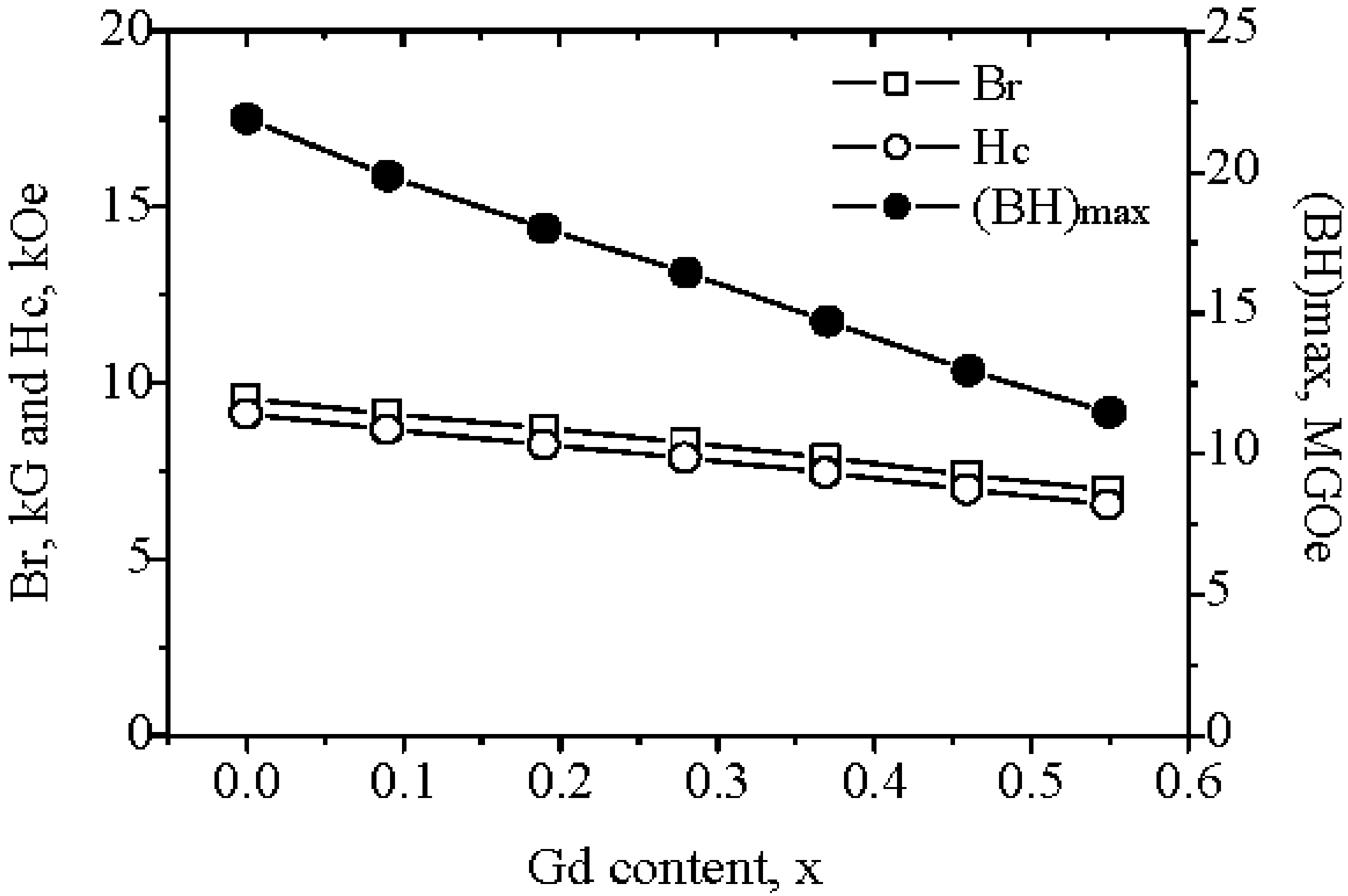


RESULTS & DISCUSSION

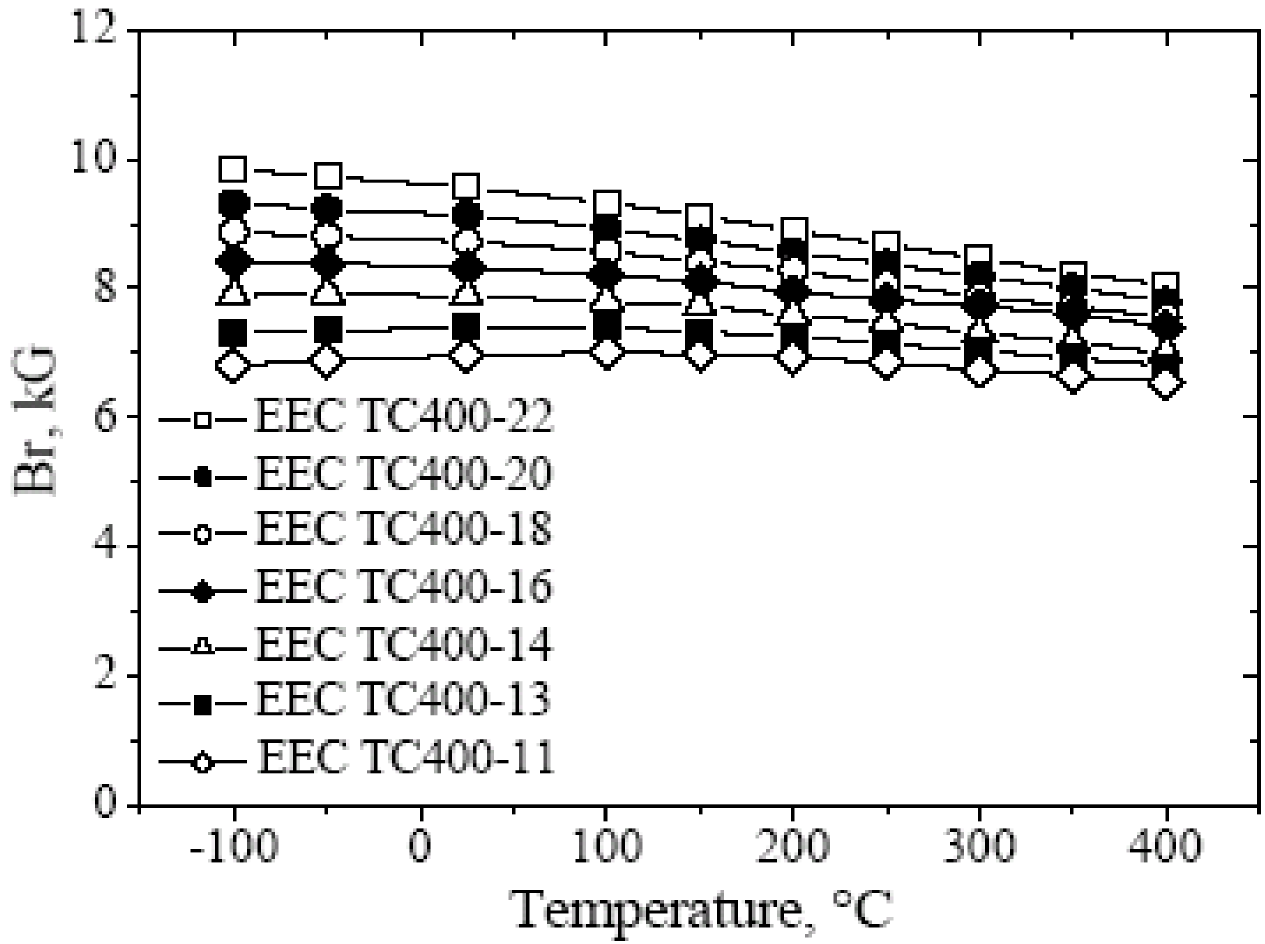
Effect of Gd on Temperature Coefficient



Effect of Gd on TC400 Series Magnetic Properties



B_r as a Function of Temperature For TC400 Series Magnets



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Summary of Typical Magnetic Properties of TC400 Series High Temperature Magnets

TC400 Series	Br	Hc	(BH)max	Hci	RTC Of Br
	(kG)	(kOe)	(MGOe)	(kOe)	%
TC400-9500H	9500	9.03	21.3	>25	-0.032
TC400-9250H	9250	8.79	20.2	>25	-0.029
TC400-9000H	9000	8.55	19.2	>25	-0.025
TC400-8750H	8750	8.27	18.0	>25	-0.021
TC400-8500H	8500	8.03	17.0	>25	-0.018
TC400-8250H	8250	7.80	16.0	>25	-0.014
TC400-8000H	8000	7.56	15.1	>25	-0.011
TC400-7750H	7750	7.32	14.1	>25	-0.007
TC400-7500H	7500	7.05	13.2	>25	-0.003
TC400-7250H	7250	6.82	12.3	>25	0.000
TC400-7000H	7000	6.58	11.5	>25	0.004
TC400-6750H	6750	6.35	10.7	>25	0.008

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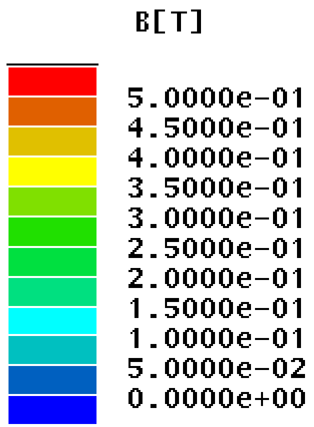
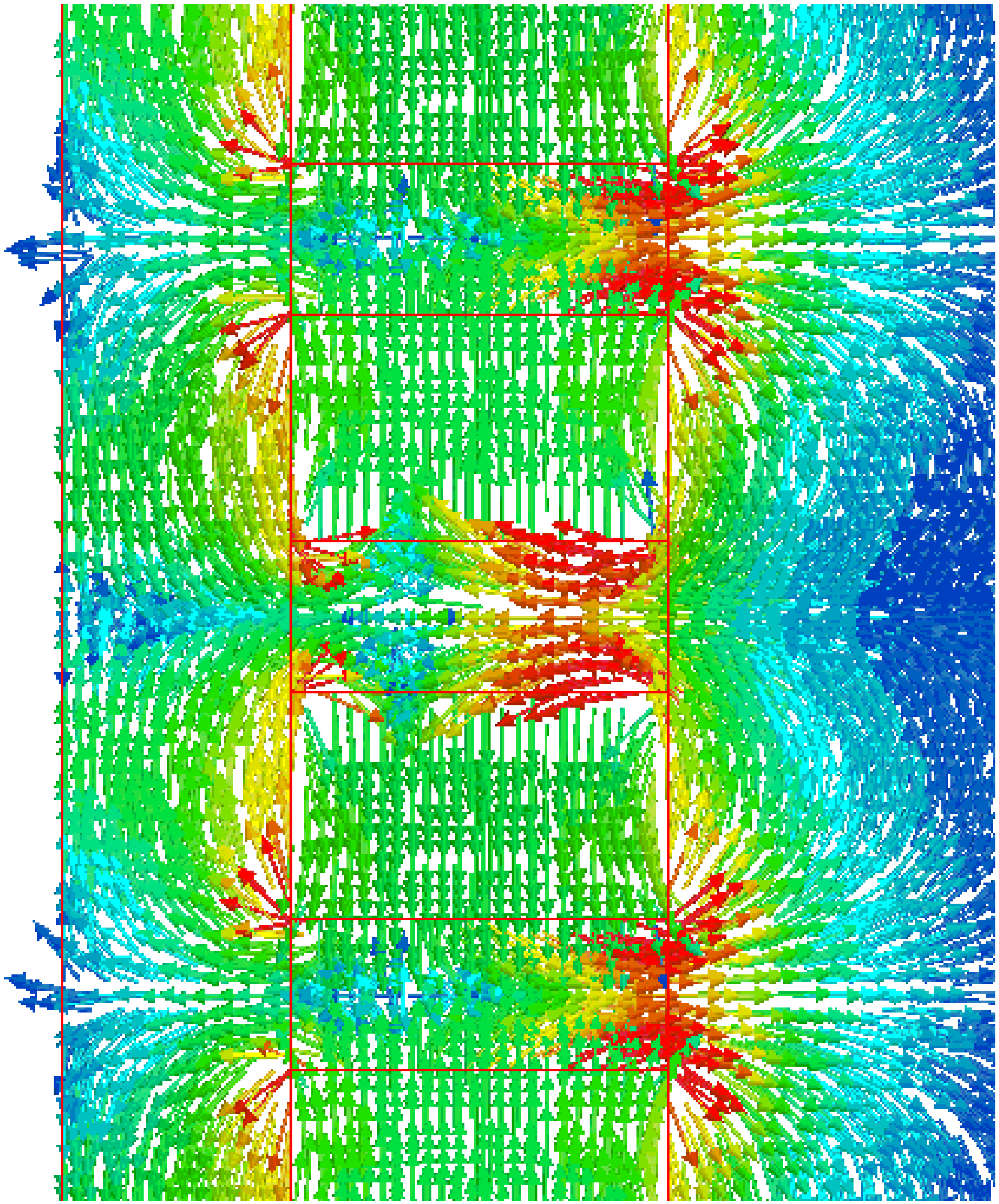
PPM Stack ---- A Case Study

Dimensions

	OD	ID	THK	Material
Magnet	0.800”	0.300”	0.150”	Sm-Co
Pole Piece	0.800”	0.300”	0.100”	Iron

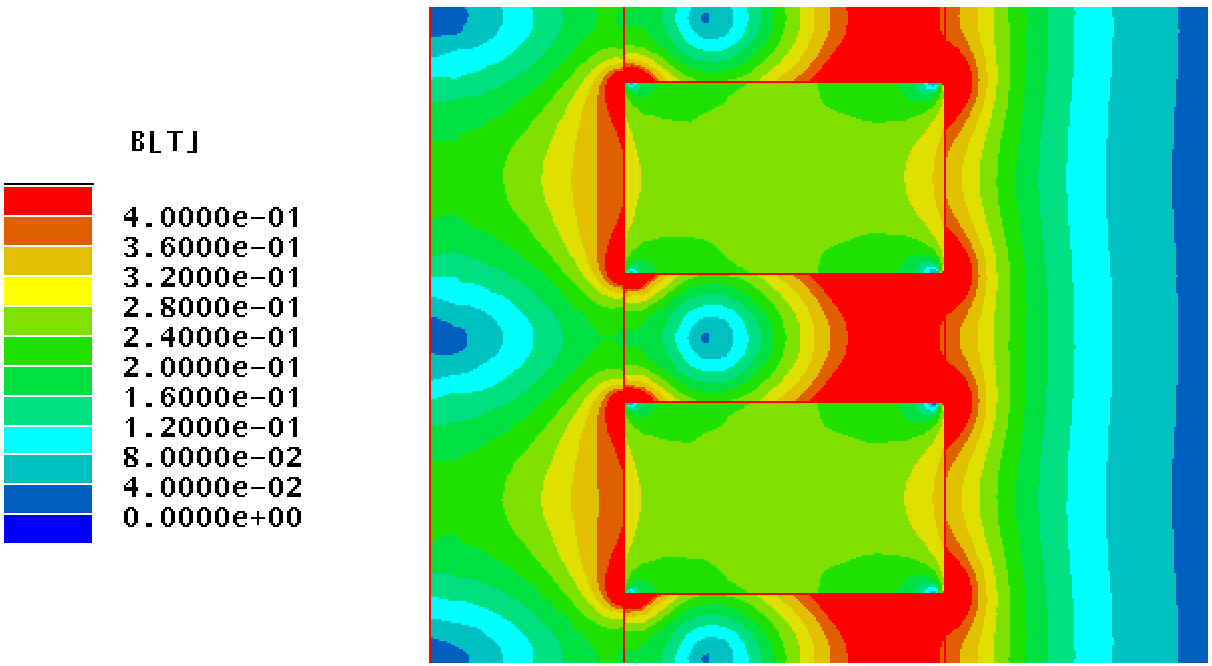
Flux Lines


B[T]
5.0000e-01
4.5000e-01
4.0000e-01
3.5000e-01
3.0000e-01
2.5000e-01
2.0000e-01
1.5000e-01
1.0000e-01
5.0000e-02
0.0000e+00



PPM Stack ---- A Case Study

Flux Map



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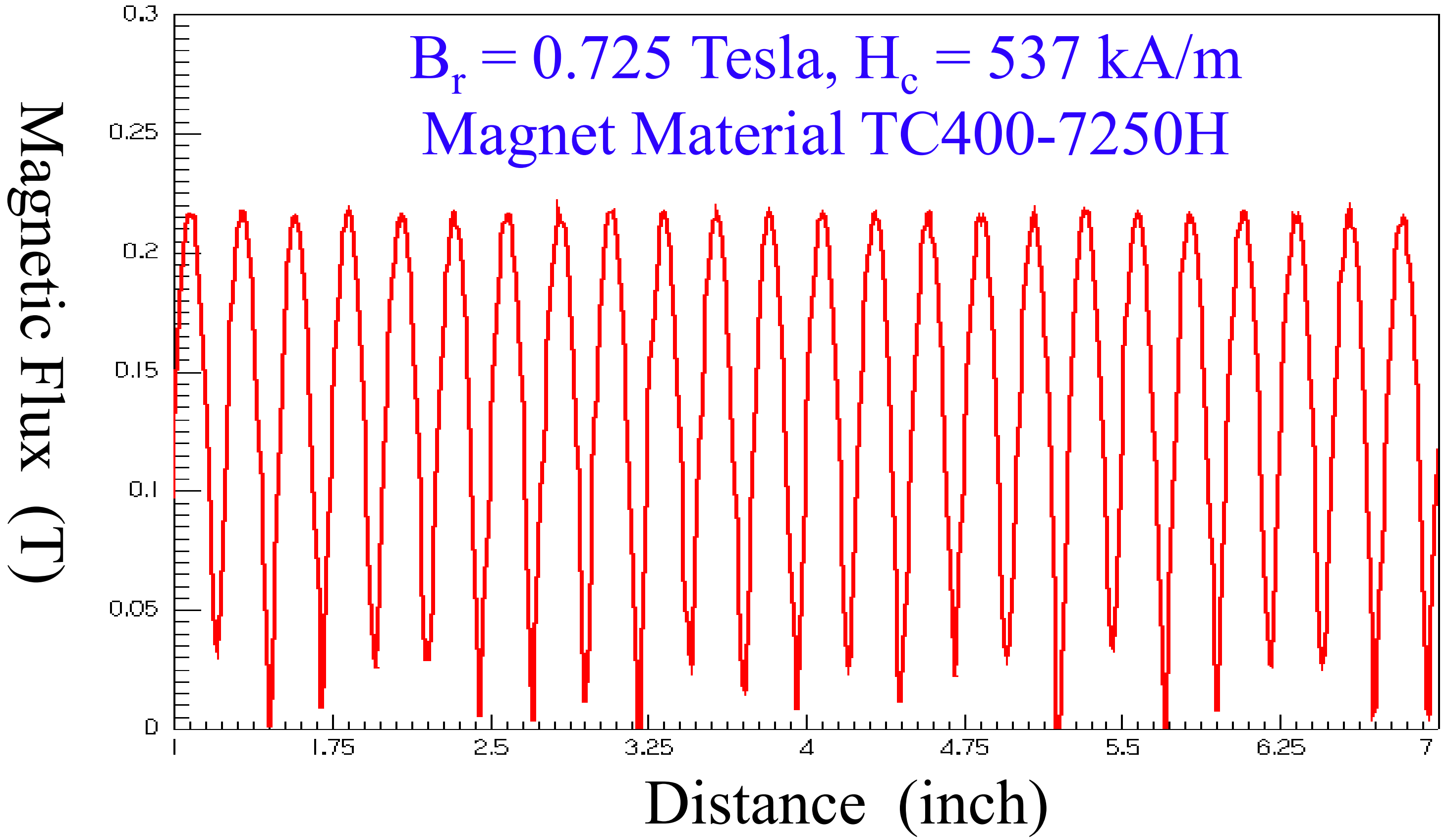
PPM Stack ---- A Case Study

Room Temperature Field Profile



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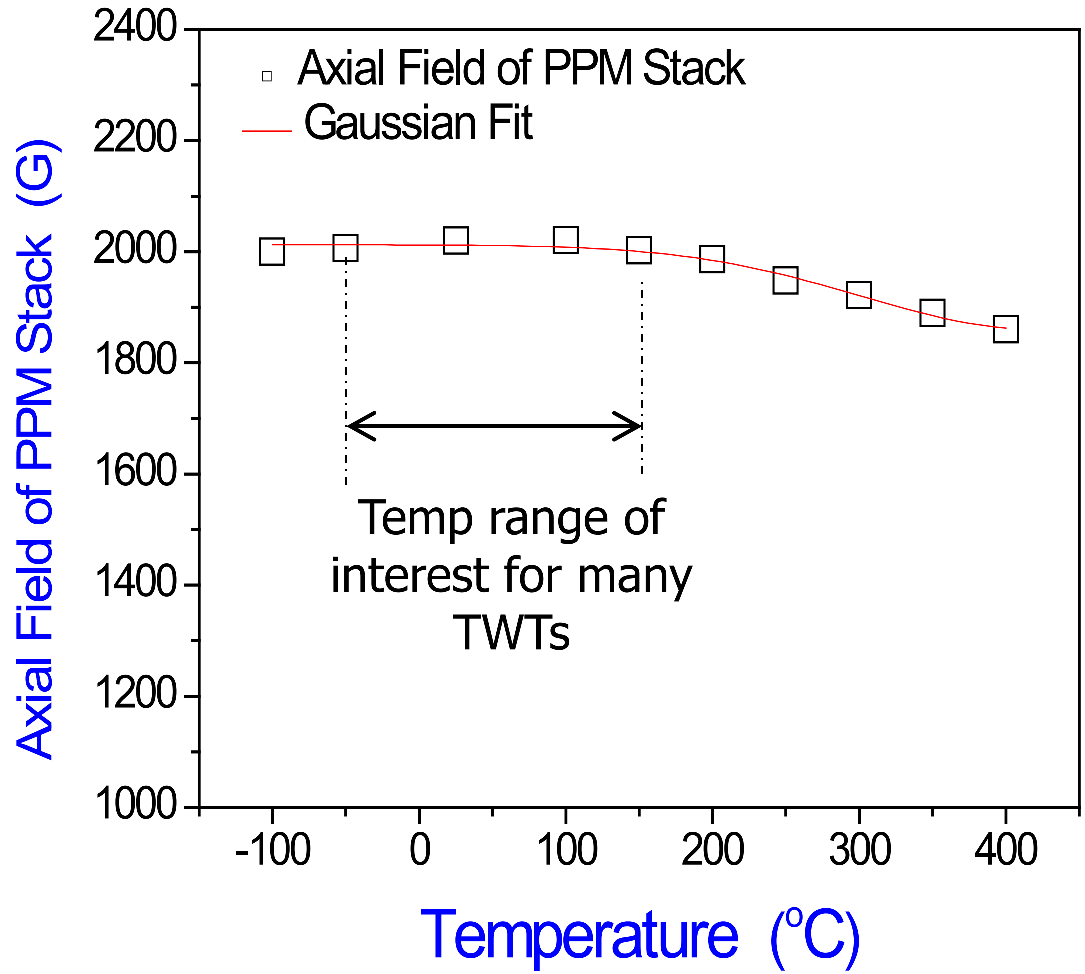
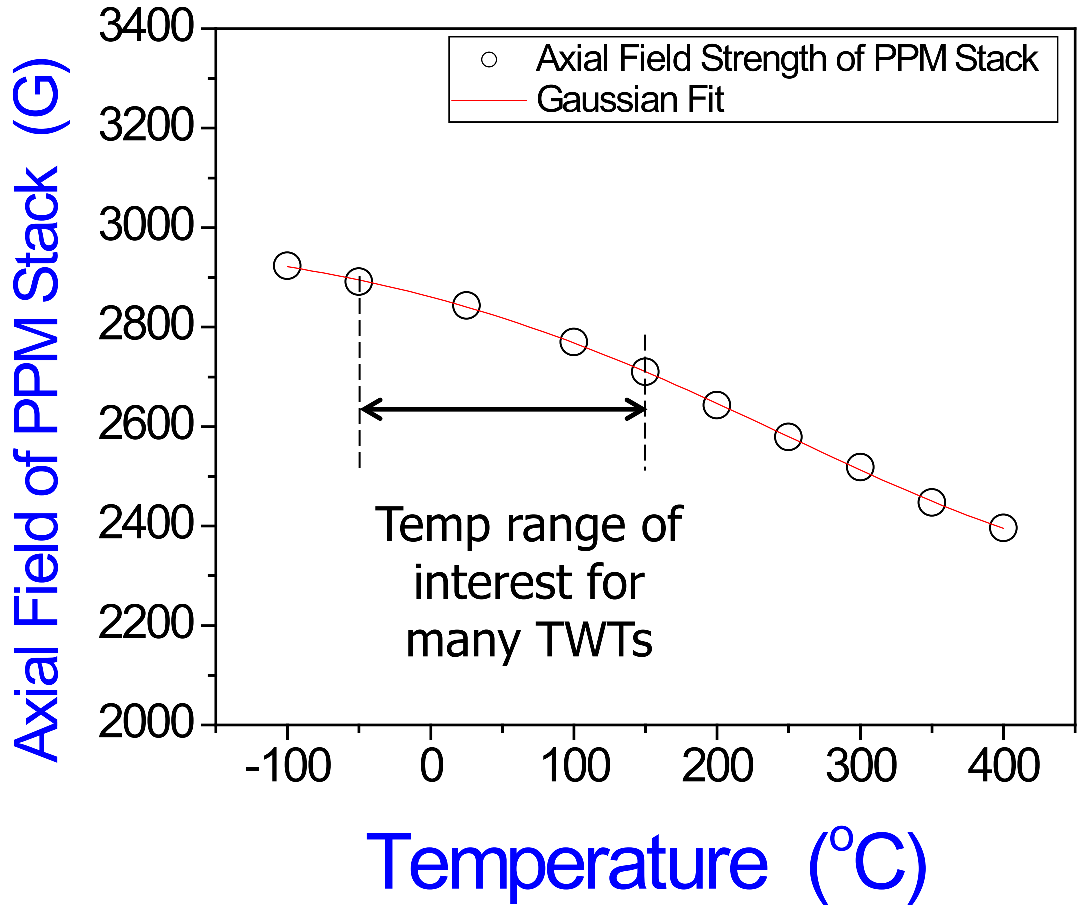
Temperature Dependence of the Axial Field of PPM Stack

TC400-7250H



Temperature Dependence of the Axial Field of PPM Stack

TC400-9500H



SUMMARY

- Near-zero Reversible Temperature Coefficient of Br (α) is achieved by partial substitution of Gd in **high temperature** (T_M = 400°C) $RE(Co,Fe,Cu,Zr)_z$ magnets
- At x = 0.55, the reversible temperature coefficient α = +0.002%/^{o}C (-50^{o}C to 150^{o}C), and α = -0.01%/^{o}C (-50^{o}C to 400^{o}C)
- The change in axial field strength of a PPM stack made of TC400-7250H is significantly smaller with increase in temperature, compared to that of TC400-9500H
- Significant improvement on PPM stacks with high-temperature low-RTC magnets has been observed by TWT companies.
- The remarkable combination of high temperature stability and low α over such a broad temperature window could lead to new applications