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Exceptional dimensional stability of non-ferromagnetic Invar alloy for advanced semiconductor manufacturing equipment

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Blooming innovation in metal casting

To elucidate the thermal and magnetic dimensional stability of Cr-based Invar, the effects of various alloying elements on thermal expansion and magnetic properties were investigated. The Cr-Fe-Mn alloys exhibit low thermal expansion characteristics near room temperature, with the addition of Mn significantly elevating the Néel temperature. Specifically, the addition of approximately 0.89% Mn adjusted the low thermal expansion region to be close to room temperature, while 3.2% Sn raised it to temperatures below 0ºC. The average thermal expansion coefficient (CTE) of Cr-based Invar at a temperature range between 20 and 30ºC was found to be 1.7 ppm/ºC, comparable to the 0.90 ppm/ºC of conventional Invar, and approached nearly zero around 50 - 60ºC. Magnetic measurements indicated that Cr-based Invar exhibits negligible magnetization compared to conventional Invars, with magnetization less than one-thousandth of Invar 36. This low magnetization results in minimal magnetostriction, making Cr-based Invar suitable for applications requiring both thermal and magnetic stability. Under a magnetic field strength of 796 kA/m, Cr-based Invar showed a slight contraction behavior, unlike other Invars which expanded. This contraction is attributed to the antiferromagnetic nature of Cr, where magnetic moments align in opposite directions, leading to a net magnetization of zero.

INTRODUCTION

As ultra-precision manufacturing technologies continue to advance, the demand for structural support components with exceptional dimensional stability has become increasingly critical.

Invar alloy

Invar has been extensively utilized in optical components due to its renowned low thermal expansion

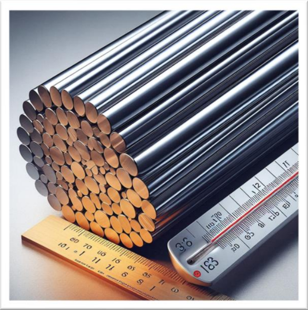
The most significant drawbacks
- Inherent ferromagnetism
- Substantial magnetostriction

Challenges associated with magnetism

Dimensional changes due to magnetostriction
- High-precision optical systems

Magnetic noise
- Electron microscope
- Medical diagnostics

Magnetic induction
- Electrolytic refining furnace
- Power transmission facilities



Invar alloy

This study aims to comprehensively evaluate the thermal expansion and magnetic properties, including magnetostriction, of Cr-based Invar for high-precision applications in semiconductor lithography equipment.

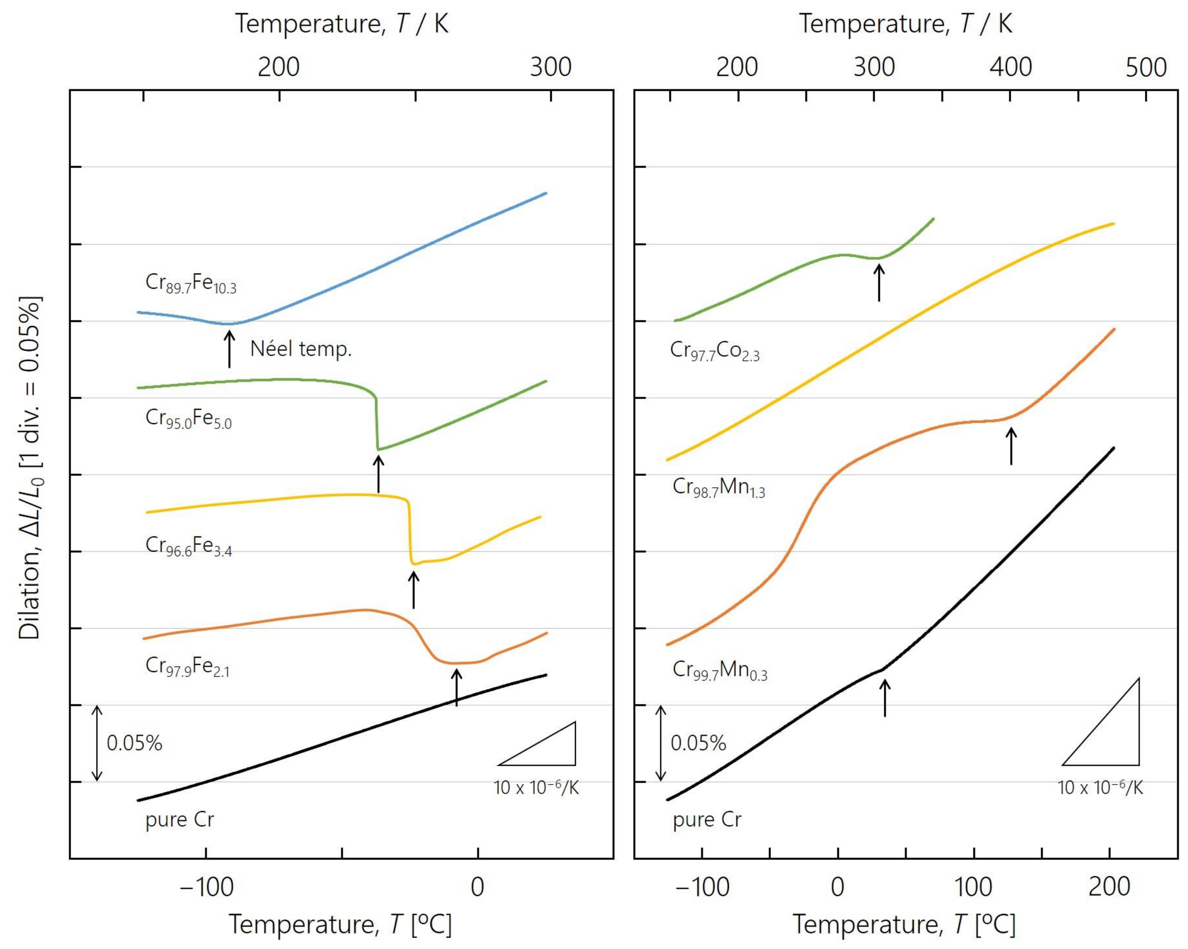
EXPERIMENTAL

Sample preparation
- ✓ Materials: pure Cr, Cr-Fe, Cr-Mn, Cr-Fe-Mn
- ✓ Processes; Arc melting and casting in Ar gas atmosphere

Evaluation of materials properties
- ✓ Precise dilatometer (Thermal expansion)
- ✓ Vibrating sample magnetometer (Magnetization hysteresis loop)
- ✓ Strain gage method and magnetic measurement (Magnetostriction)

RESULTS

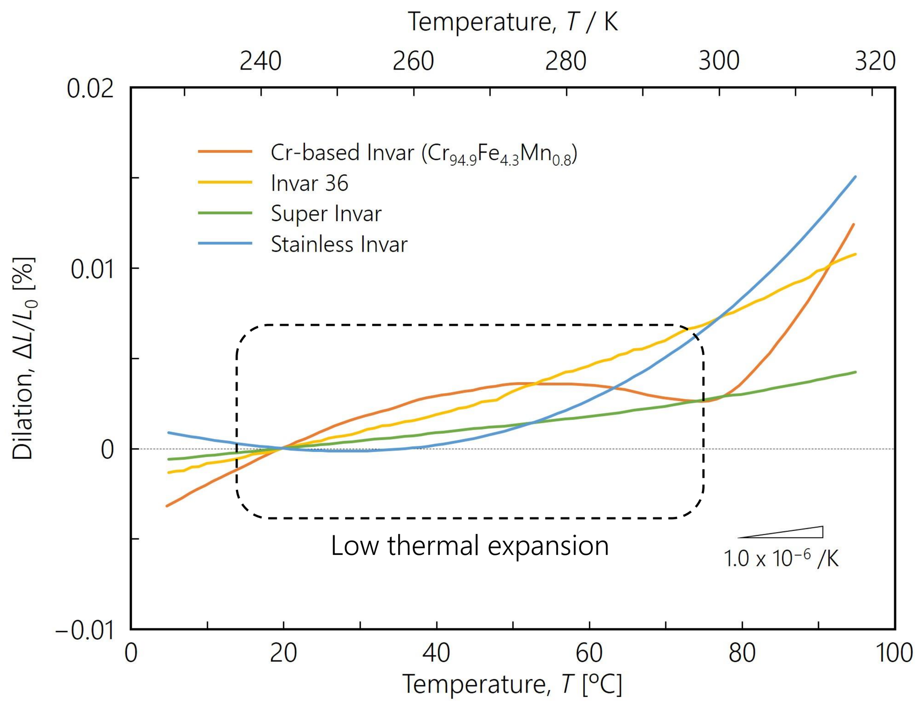
Low thermal expansion behavior in antiferromagnetic Cr-based alloys



Thermal expansion curves obtained from pure Cr, Cr-Fe, Cr-Mn and Cr-Co alloys. The inflection points of the curves correspond to the Néel temperatures, indicated by arrows. Additionally, the coefficient of thermal expansion is represented by slopes in the lower right corner of the figure.

By adding Fe to Cr, the region exhibiting low thermal expansion characteristics can be expanded, and by adding Mn, this region can be elevated to near room temperature.

Development of non-ferromagnetic low thermal expansion Cr-Fe-Mn alloy

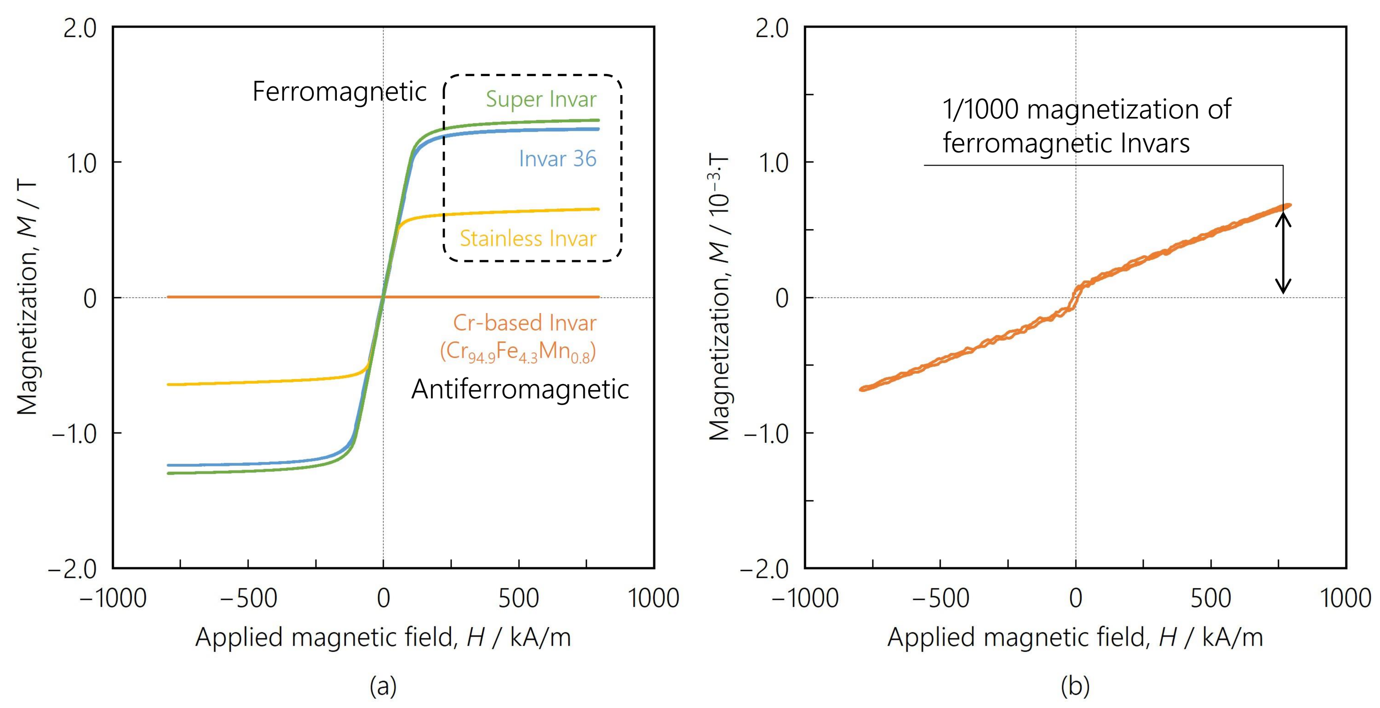


Thermal expansion curves obtained from Cr-based Invar and conventional Invars. These curves illustrate the change in length of each material relative to their respective lengths at 20ºC.

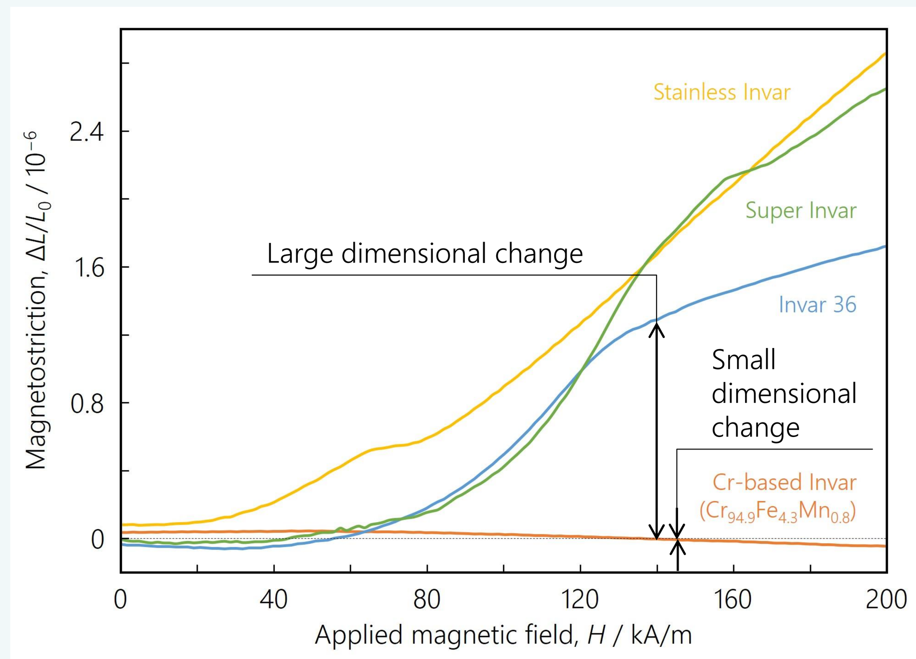
Material	Average CTE at each temperature [10⁻⁶/K]				
	283 – 293 K (10 - 20ºC)	293 – 303 K (20 - 30ºC)	303 – 313 K (30 - 40ºC)	313 – 323 K (40 - 50ºC)	323 – 333 K (50 - 60ºC)
Cr-based Invar	1.9	1.7	1.2	0.69	−0.053
Invar 36	0.84	0.90	1.0	1.3	1.4
Super Invar	0.40	0.42	0.45	0.41	0.48
Stainless Invar	−0.51	−0.15	0.32	0.90	1.6

The careful design and optimization of the alloy composition have resulted in a Cr-based Invar that rivals conventional Invars and offers improvements in specific temperature ranges.

Magnetic dimensional stability of Cr-based Invar



(a) Magnetization curves obtained from Cr-based invar, Invar 36, super Invar, and stainless invar.
(b) Enlarged view of the magnetization direction of the Cr-based alloy's magnetization curve from (a).



KEY POINTS

Magnetostriction response to external magnetic fields in Cr-based Invar, Invar 36, super Invar, and stainless Invar.

Cr-based Invar offers significant magnetostriction under a magnetic field, making it ideal for requiring high dimensional stability and minimal magnetic interference like optical devices.

CONCLUSIONS

This study shows that adding Fe and Mn to Cr improves their low thermal expansion by raising the Néel temperature. Cr-based Invars have lower magnetization and magnetostriction than conventional Invars, making them ideal for high-precision applications requiring dimensional stability and minimal magnetic interference, such as scientific instruments, satellite technology, and semiconductor manufacturing equipment.

REFERENCES

1. Saito H. and Fukamichi K., *IEEE, Trans. Mag.*, **8**, 687 (1972).
2. Fawcett E., *Rev. Modern Phys.*, **60**, 209-283 (1988).
3. Mohn P., Schwarz K., and Wagner D., *Phys. Rev. B*, **43**, 3318-3324 (1991).
4. Fujii H.T., Matsumura S., Sakaguchi N., Ohno H. and Ona K., *Proc. SPIE*, **13100**, 1311000L-1-11 (2024).

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