

Magnetic Properties of Sc-doped M-type Hexaferrite Thin Films

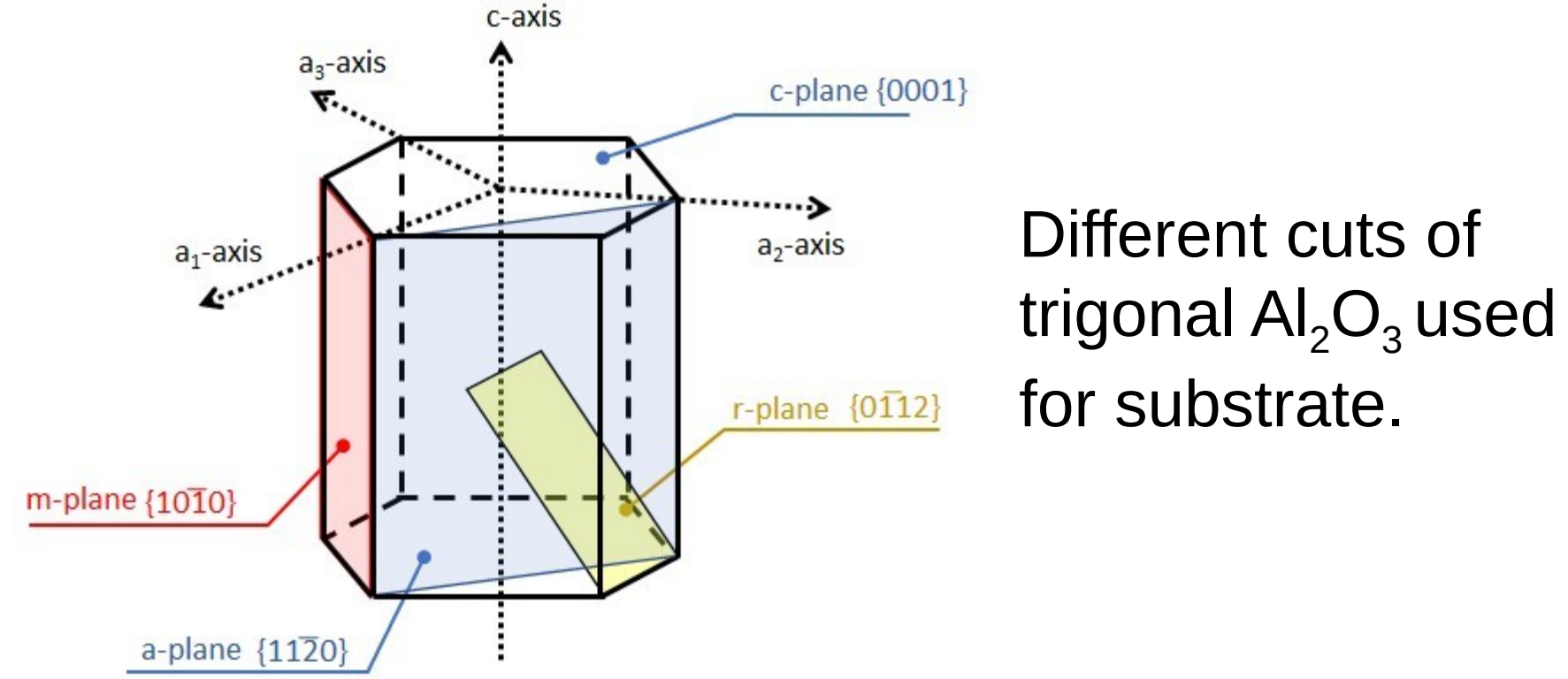
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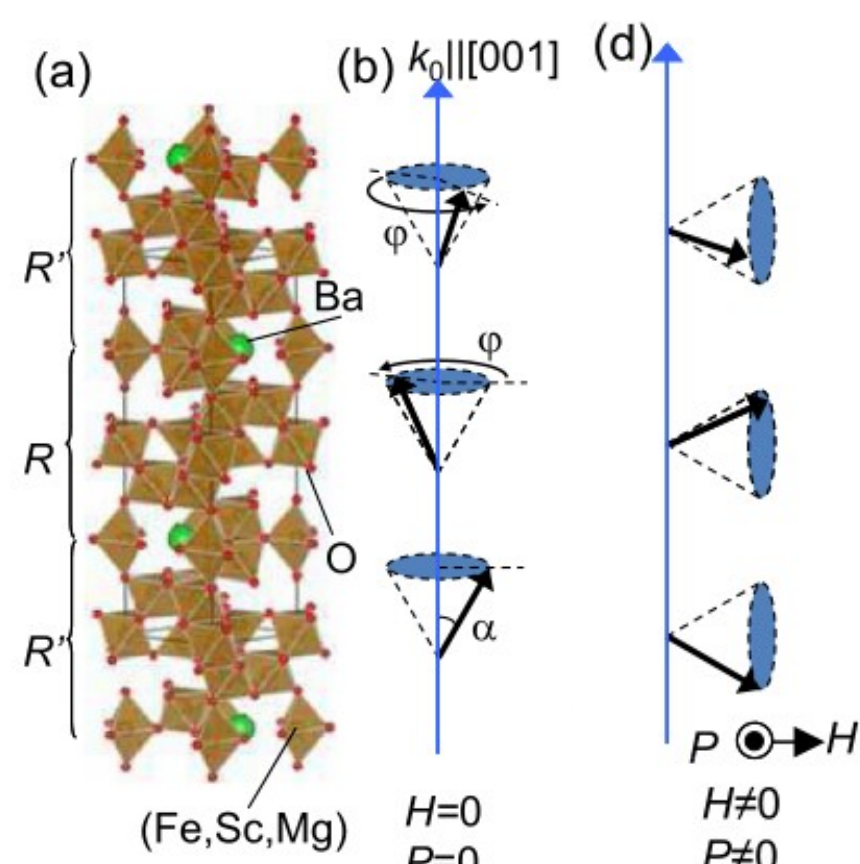
Abstract

Hexaferrites, magnetic iron-containing oxides, are superior materials with respect to the large magnetoelectric effect at elevated temperatures, coming from their frustrated noncollinear magnetic structures. Common in forms of ceramics, hexaferrites are only rarely developed in forms of crystals or thin layers. Latter are successfully grown predominantly with *c*-axis oriented along the film normal, which is inconvenient for applications. Their magnetoelectric properties can be stilted or further enhanced by substitutions within their crystallographic structure, subsequently altering their magnetic structure and anisotropy. In the presented study this enhancement of magnetic structure was explored by preparation of potentially magnetoelectric M-type hexaferrites in thin film form with various Sc doping and different orientations and the ensuing measurements of magnetic properties. The Fe positions in the M-type $\text{SrFe}_{12}\text{O}_{19}$ are partially substituted by Sc atoms causing a noncollinear conical magnetic structure to form in place of the original collinear magnetic structure. The thin film samples of $\text{SrFe}_{12-x}\text{Sc}_x\text{O}_{19}$ were prepared by chemical solution deposition method on sapphire Al_2O_3 single-crystal substrate. The measured temperature-dependent magnetic anisotropy is similar to that of magnetoelectric ceramics with $x(\text{Sc})=1.5$, which suggests a possibility to observe a magnetoelectric effect in the prepared films.

Structure and magnetism



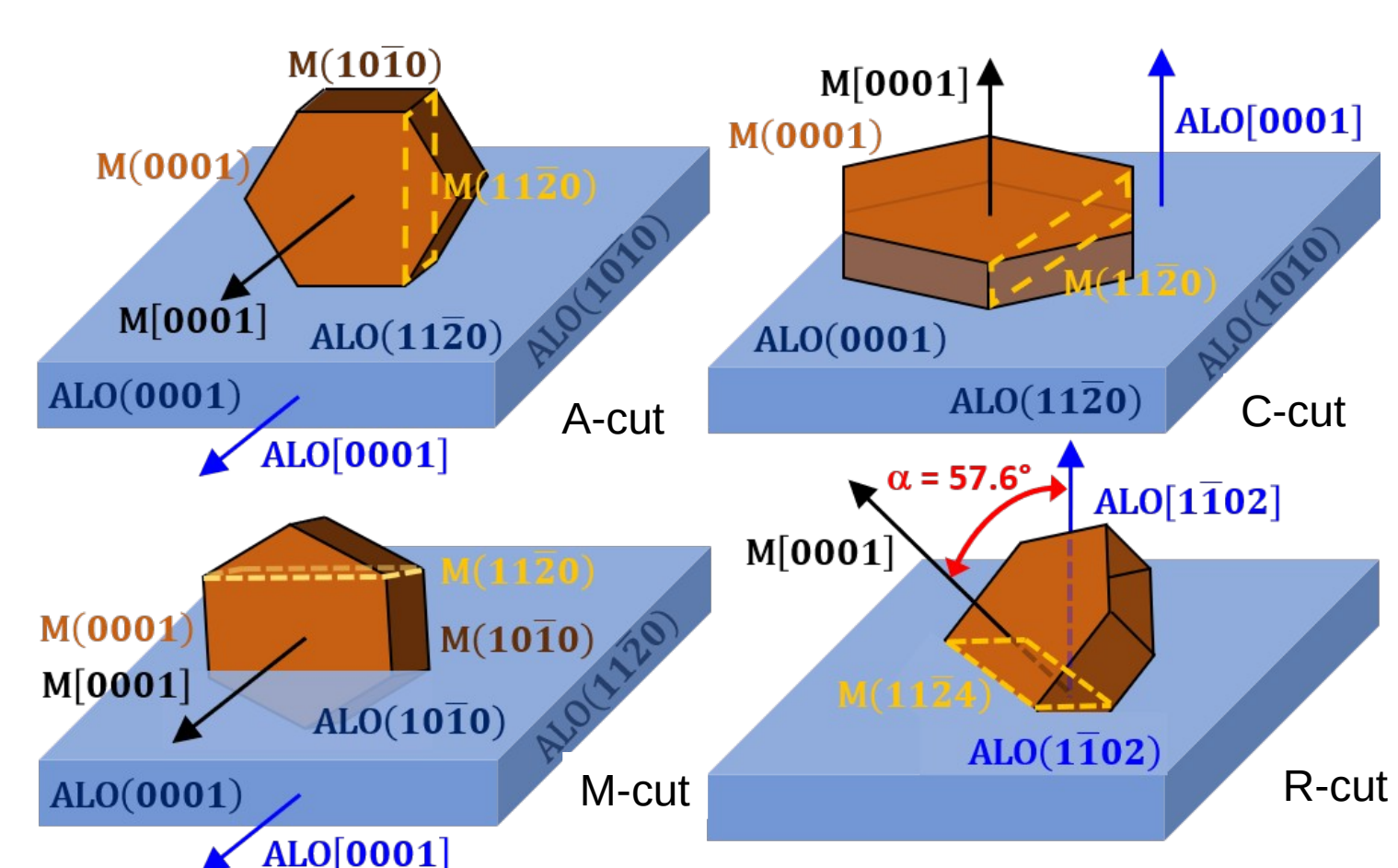
Different cuts of trigonal Al_2O_3 used for substrate.



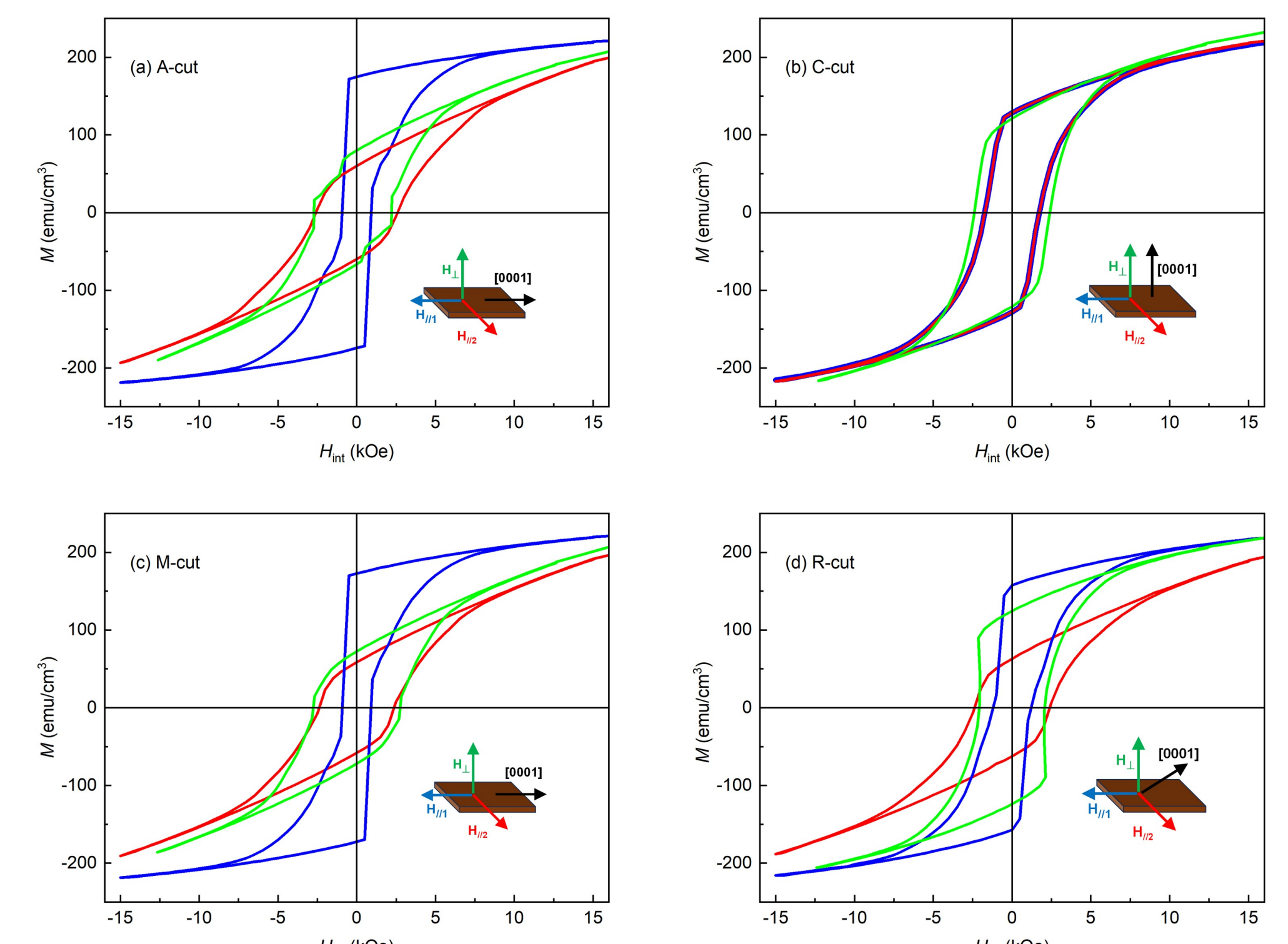
(a) Crystal and (b,d) possible magnetic structures of Sc-doped M-hexaferrite. [2] The transverse-conical magnetic structure (d) shows magnetoelectric effect.

Figure adopted from Ref. [2].

M-type hexaferrite $\text{SrFe}_{12}\text{O}_{19}$



Respective orientation of hexaferrite layer and Al_2O_3 substrate is always such that *c*-axes are parallel to each other.



Room-temperature M-H curves of $\text{SrFe}_{12}\text{O}_{19}$ films grown ALO single crystal substrates presented in 3 perpendicular orientations of external magnetic field. All samples (except for C-cut with poor texture) are easy-axis magnets.

T-dependence of magnetic anisotropy

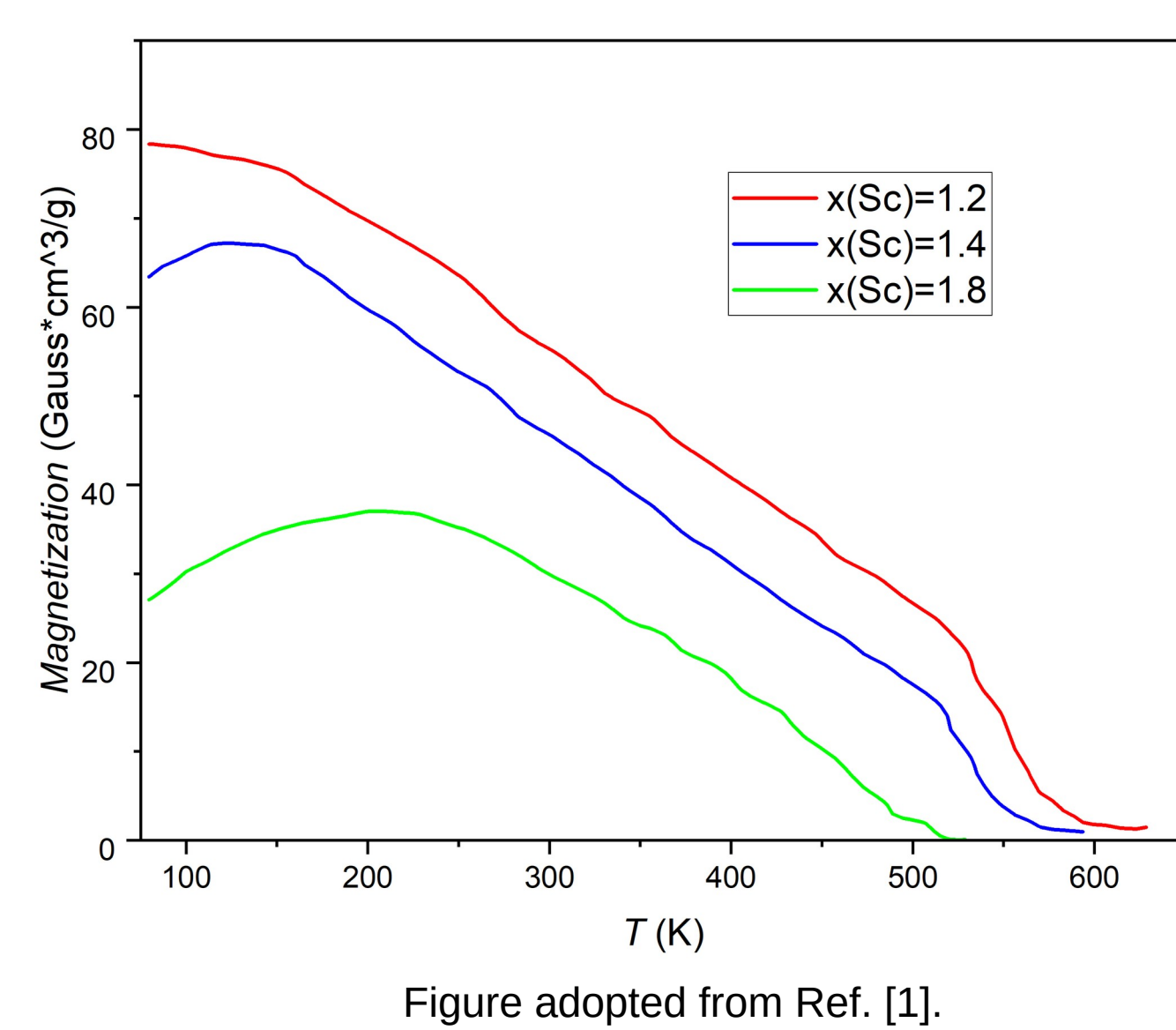
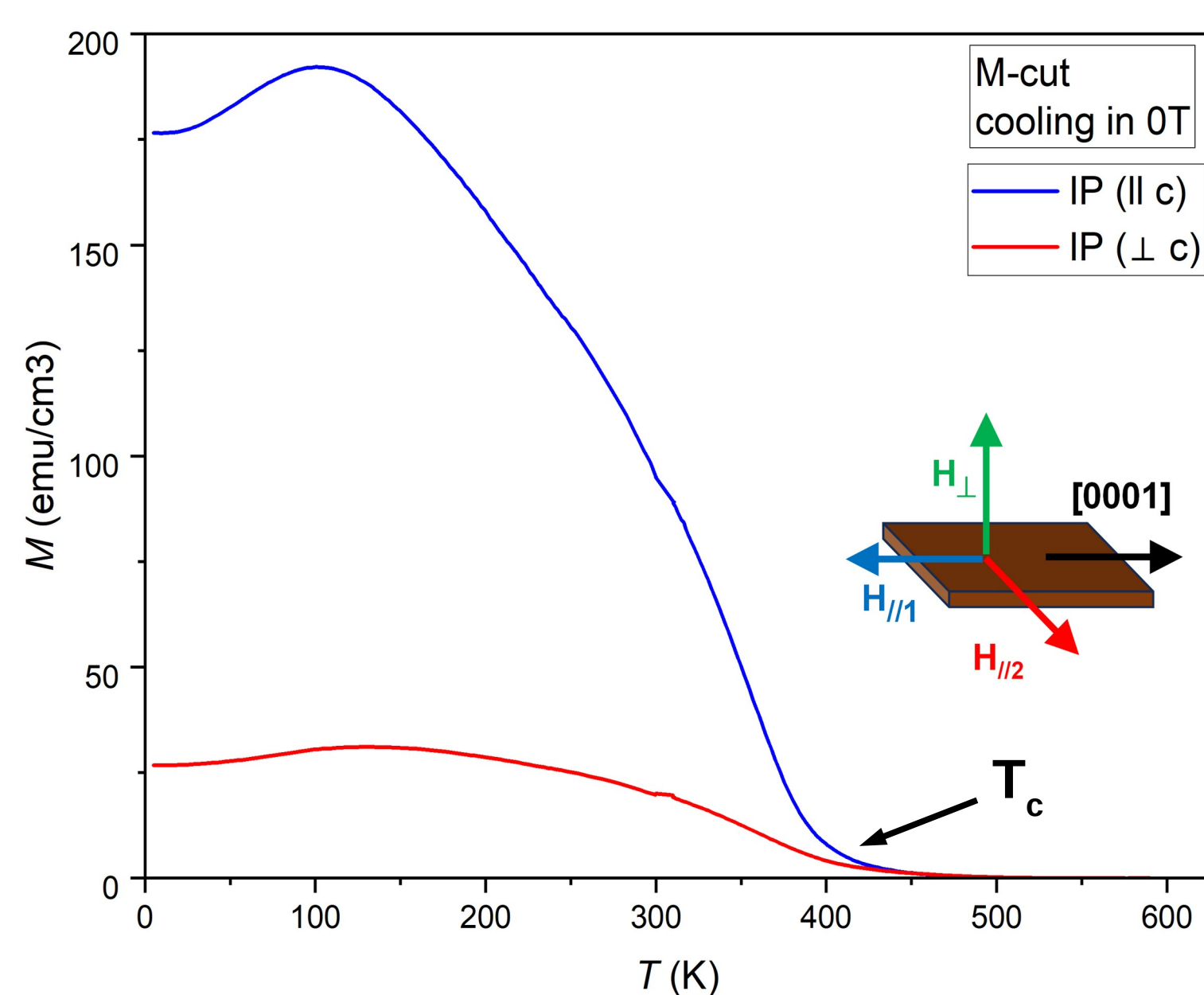


Figure adopted from Ref. [1].

Temperature-dependent magnetization as compared to Ref. [1]. Nonmonotonic behavior at low temperatures shows smooth transition into a noncollinear magnetic structure, in which magnetoelectric effect can be observed.

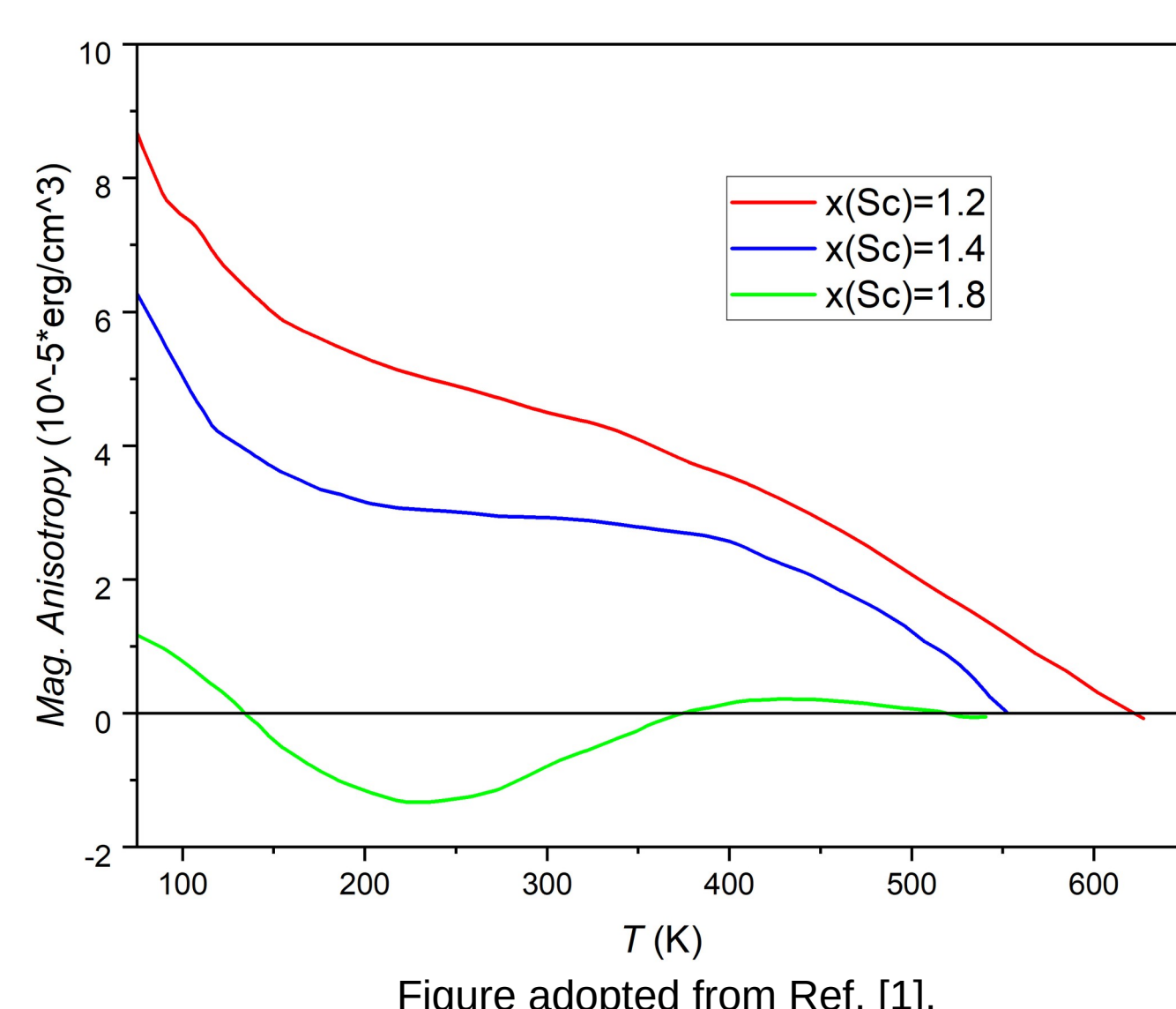
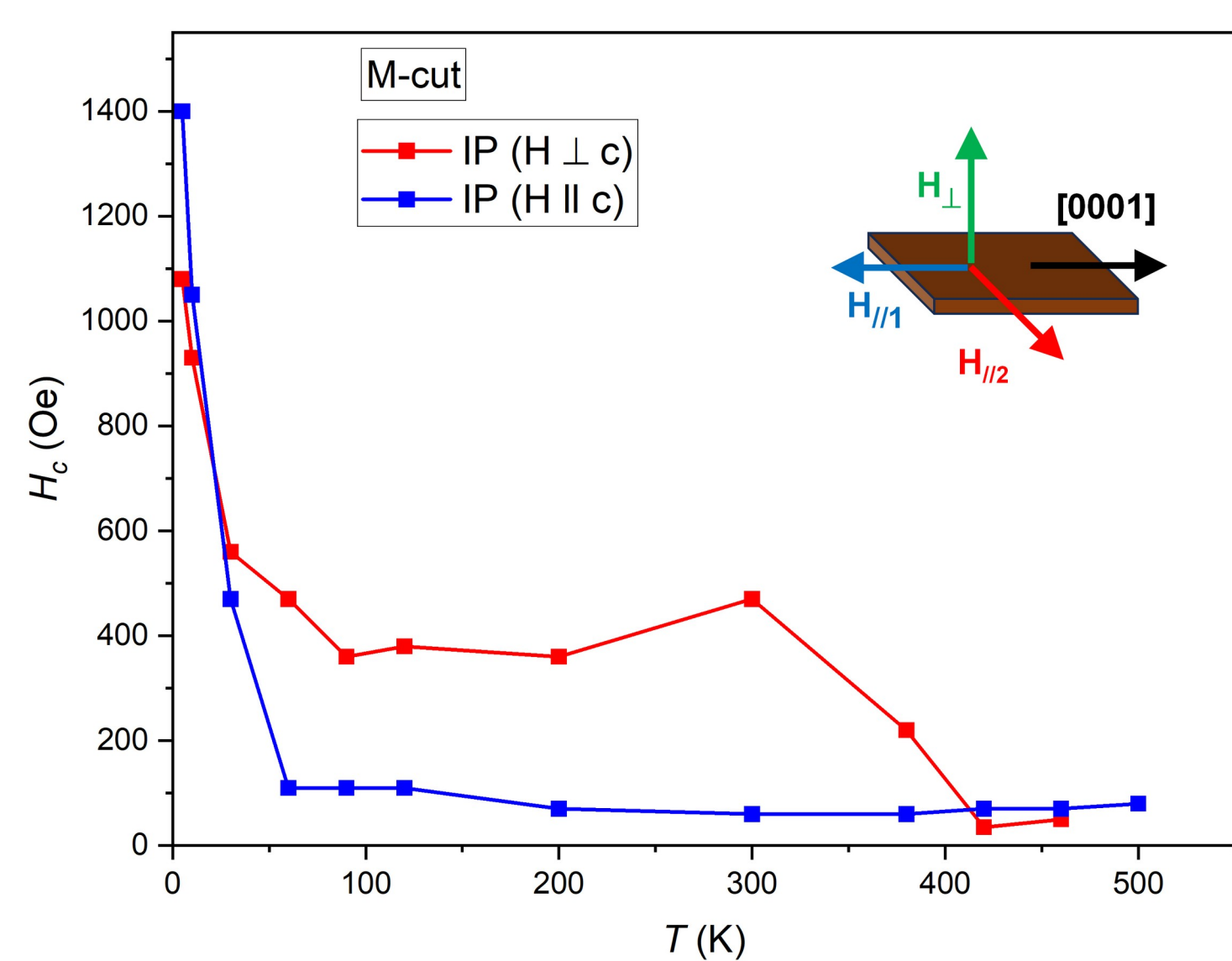


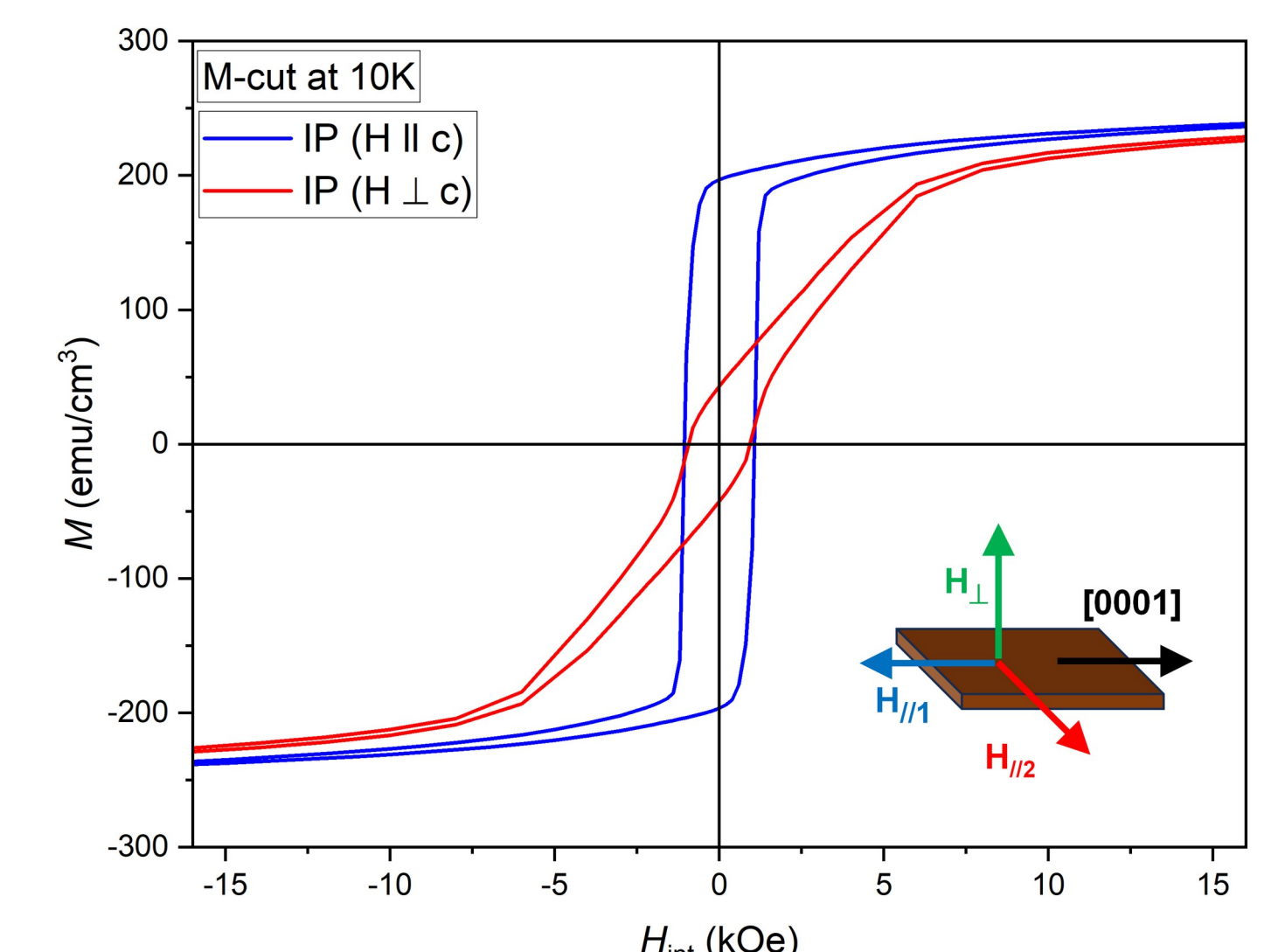
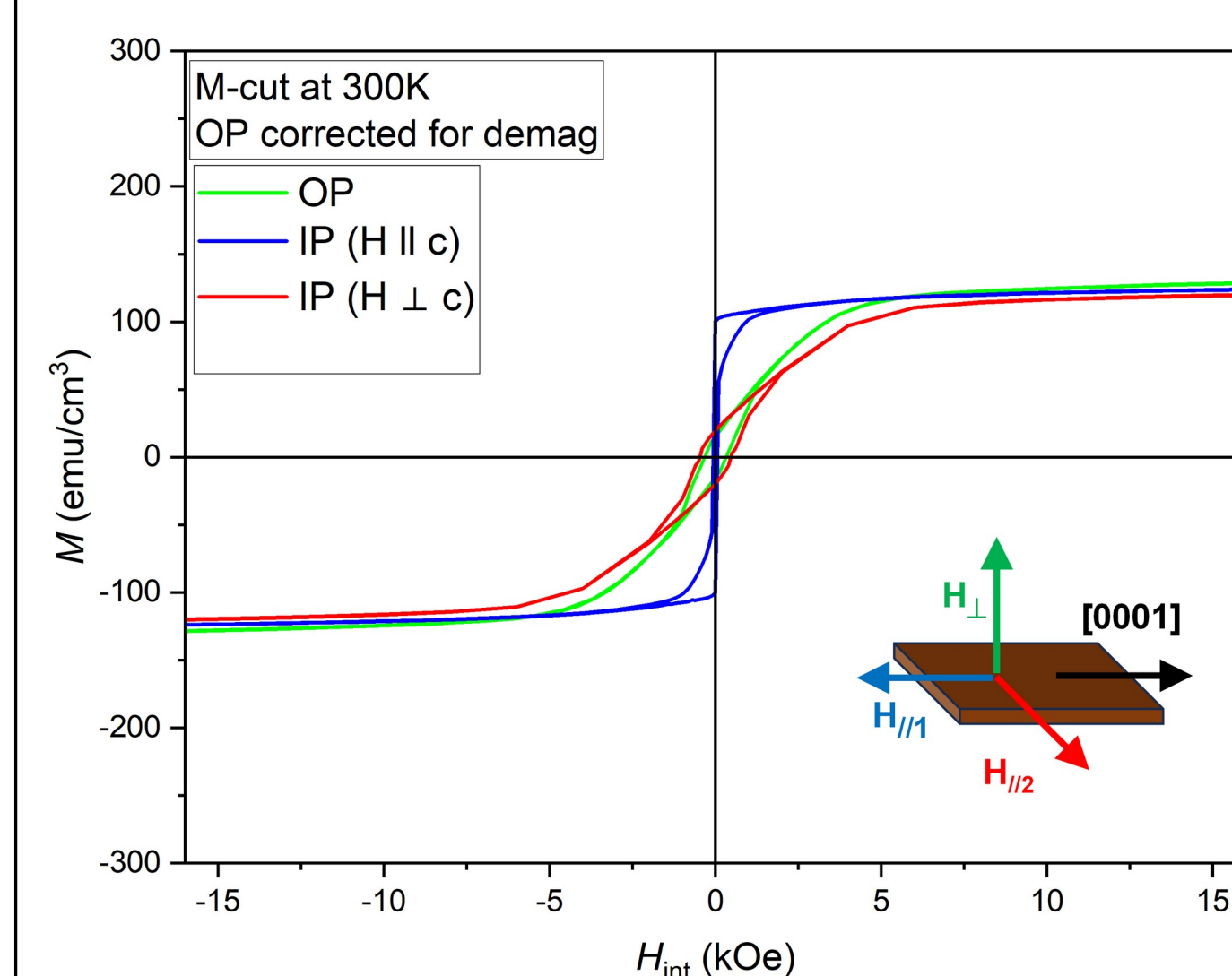
Figure adopted from Ref. [1].

Temperature-dependent coercivity compared to temperature-dependent anisotropy constant from Ref. [1], measured by torque magnetometry.

Magnetic characteristics are consistent with Ref. [1], showing that:

- Sc content in our samples is $x \approx 1.5$
- Our samples are promising for exhibiting magnetoelectric effect

Magnetization curves of $\text{SrFe}_{12-x}\text{Sc}_x\text{O}_{19}$



Magnetization curves for Sc-doped M-hexaferrites. The coercivity remarkably decreased upon Sc doping, still keeping weak easy-axis anisotropy.

Future plans: magnetoelectric effect measurements

Conditions for magnetoelectric effect in hexaferrites:

→ Magnetoelectric polarization $P \perp c$ ($H \perp c$, $P \perp H$)
→ THz absorption (electromagnon) if $E \parallel c$

hexaferrite film

substrate (must be **insulating**)

C-cut

M-cut

substrate (must be **insulating**)

Low-frequency magnetic field sensor (according to Ref. [3])

substrate (must be **conductive**)

To Wheatstone bridge

Conductive M-seed layer must be developed.

Silver contact (top electrode)
ME film
ITO (bottom electrode)
Si substrate

Dynamic magnetoelectric effect in THz frequencies (in Y- and Z-hexaferrites): absorption (electromagnon) tunable by magnetic field

substrate (must be **transparent in THz**)

$H > 20$ kOe transparent
 $H = 0$ highly absorbing $\alpha > 30 \text{ mm}^{-1}$ [4]

References:

- [1] T. M. Perekalina and V. P. Cheparin, Fiz. Tverd. Tela **9**, 3205 (1967).
- [2] Y. Tokunaga, et al., Phys. Rev. Lett. **105**, 25 (2010).
- [3] A. Si, F. Lombardi and C. Vittoria, IEEE SENSORS JOURNAL **19**, 1, 129-137 (2019)
- [4] J. Vít et al., Phys Rev. B **97**, 134406 (2018)

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