The magic of magnetic shape memory... at Helsinki University of Technology 1999-2006

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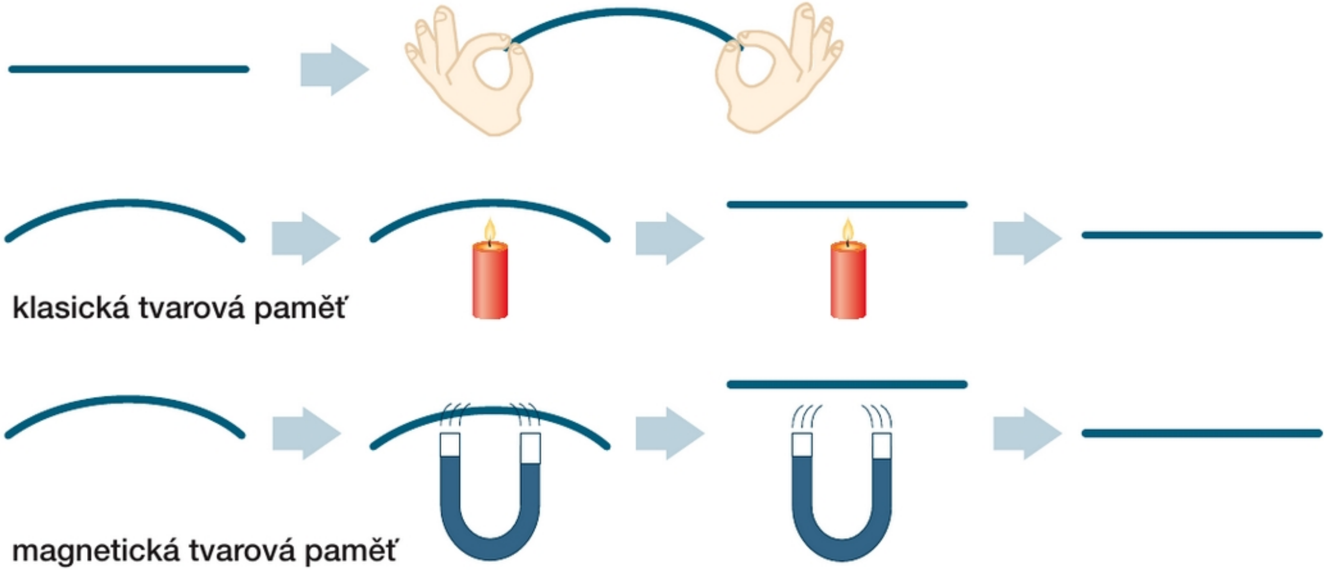
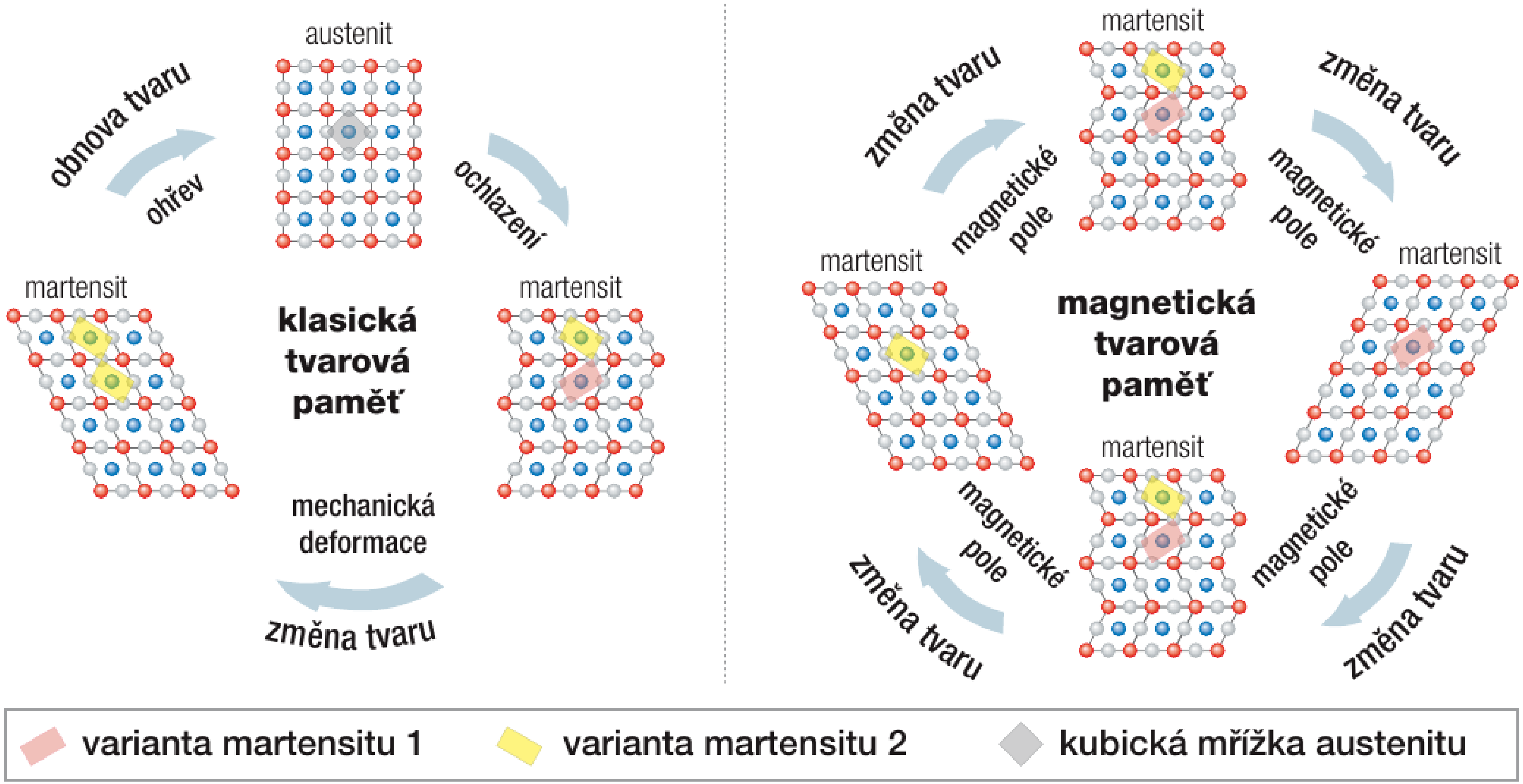
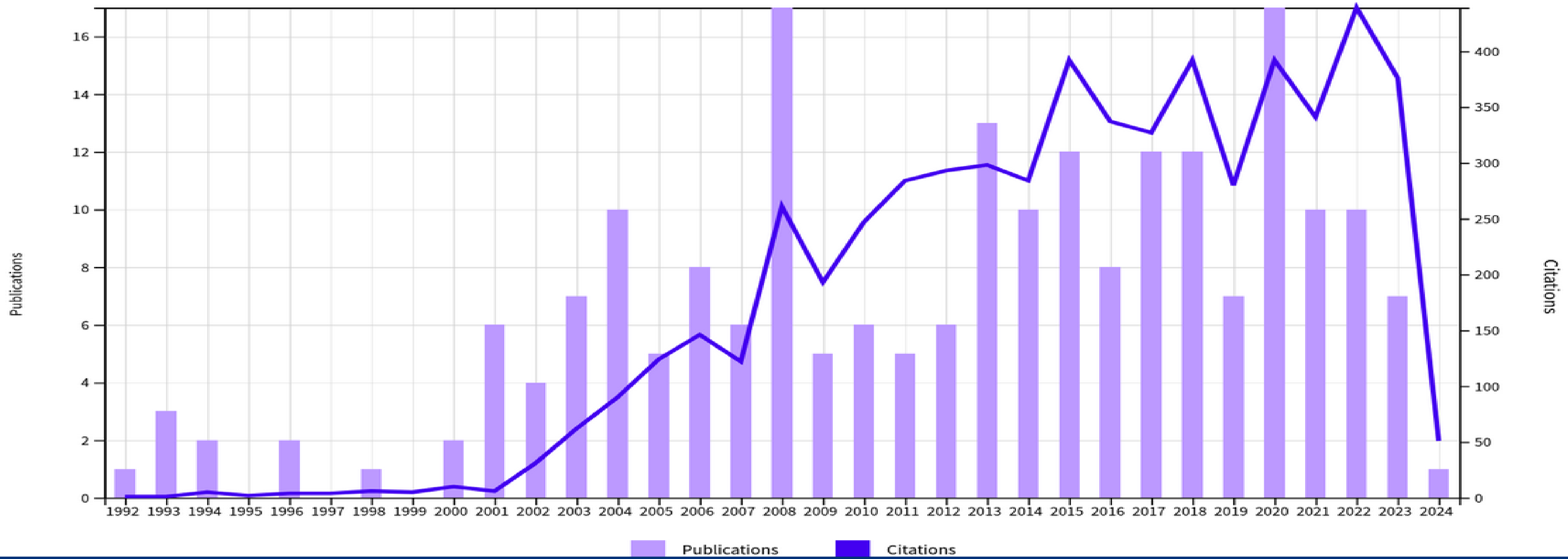


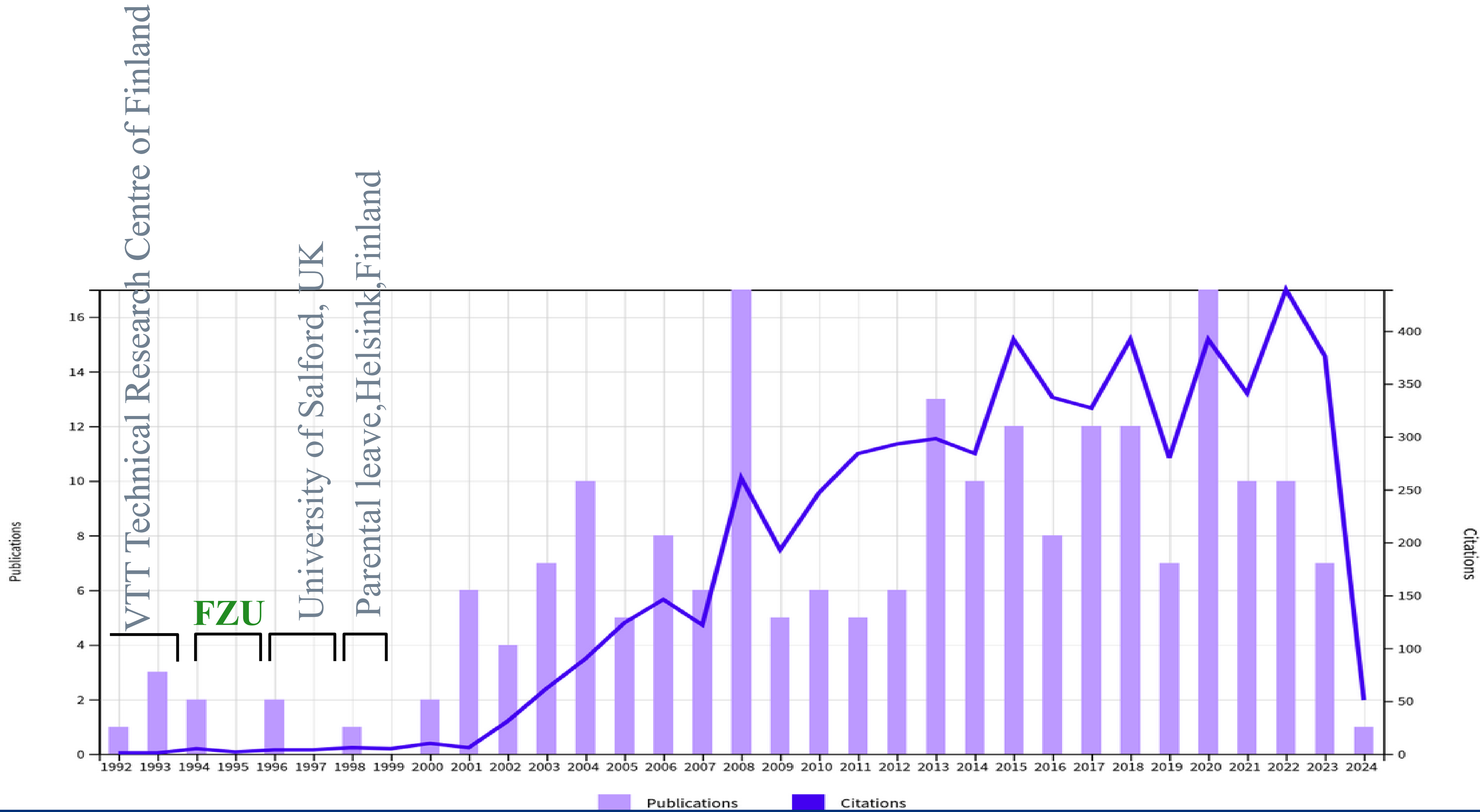
1. **TYPICKÁ DEMONSTRACE** jevu tvarové paměti – původní tvar deformovaného drátku je obnoven ohřevem. Při jevu magnetické tvarové paměti je obnova anebo změna tvaru vyvolána magnetickým polem.

The magic of magnetic shape memory... at Helsinki University of Technology 1999-2006



Oleg Heczko – citation report

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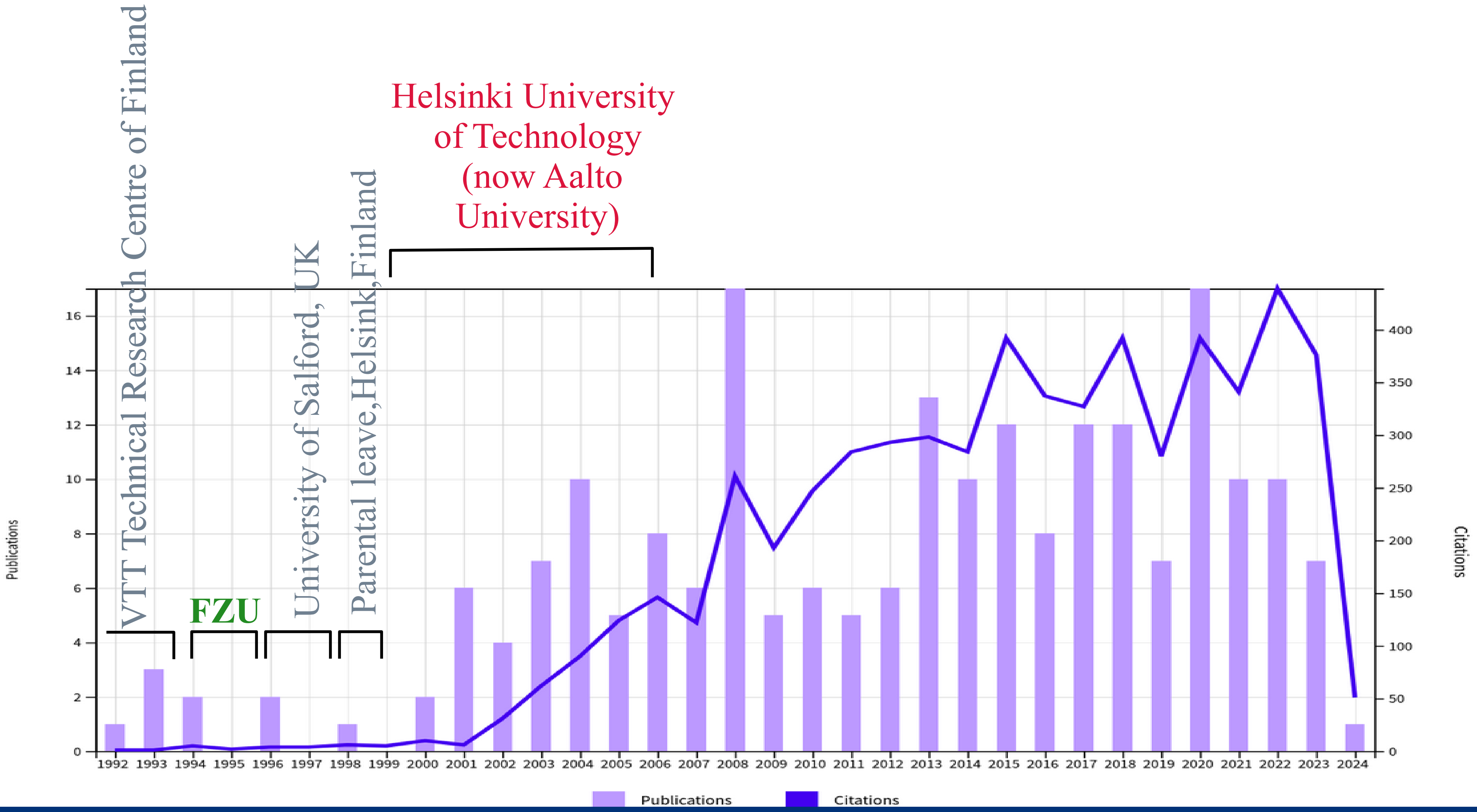
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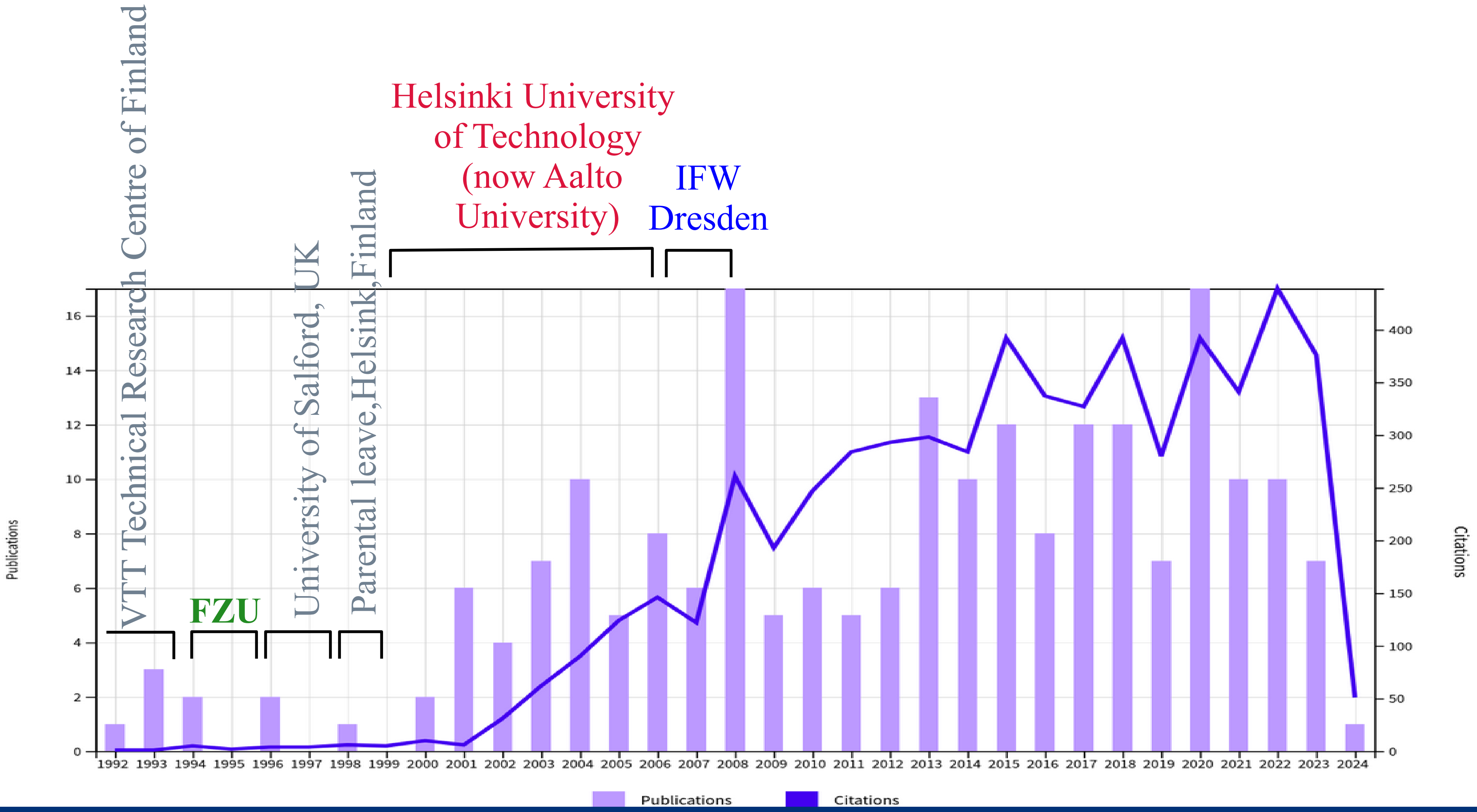
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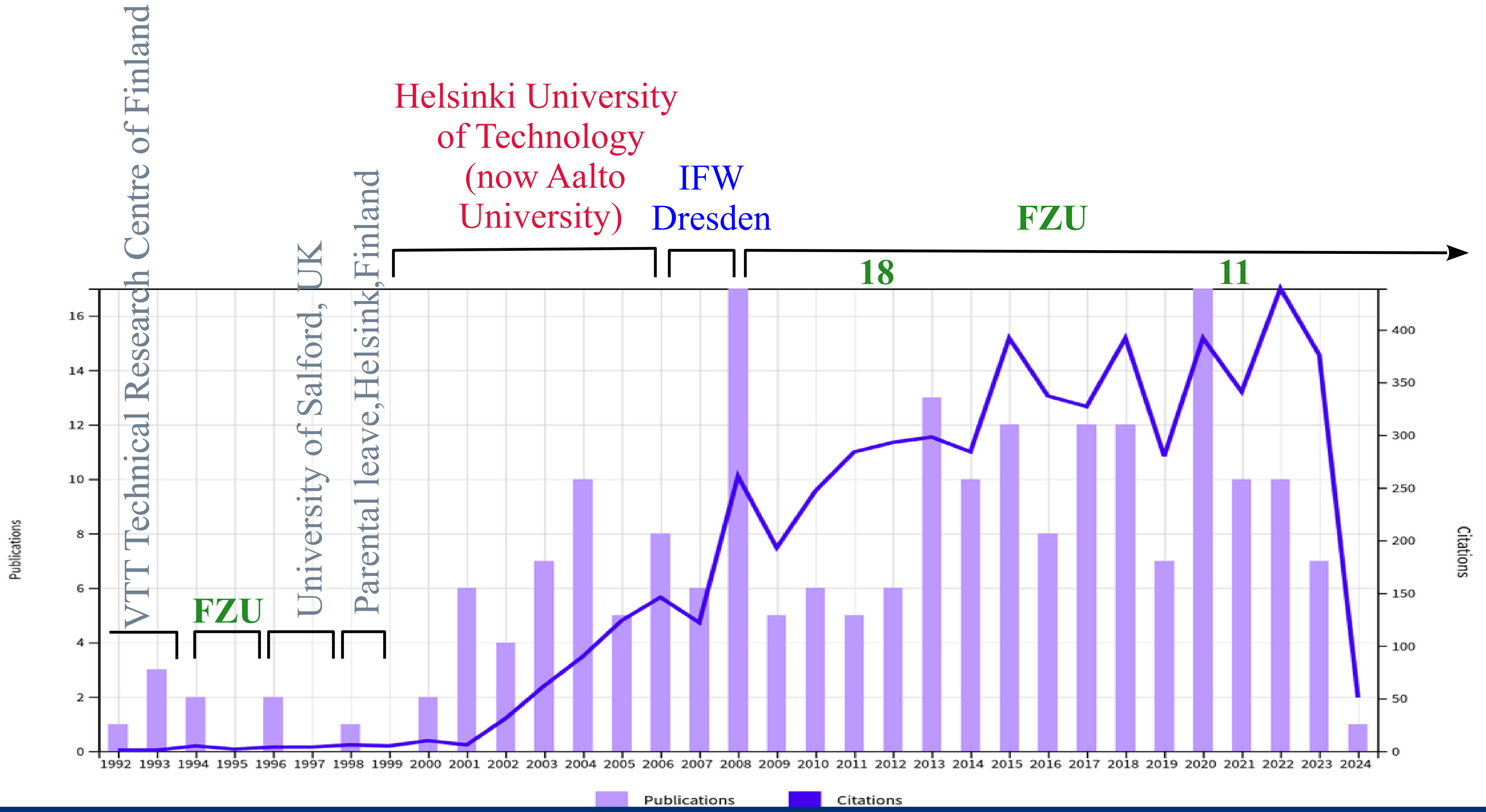
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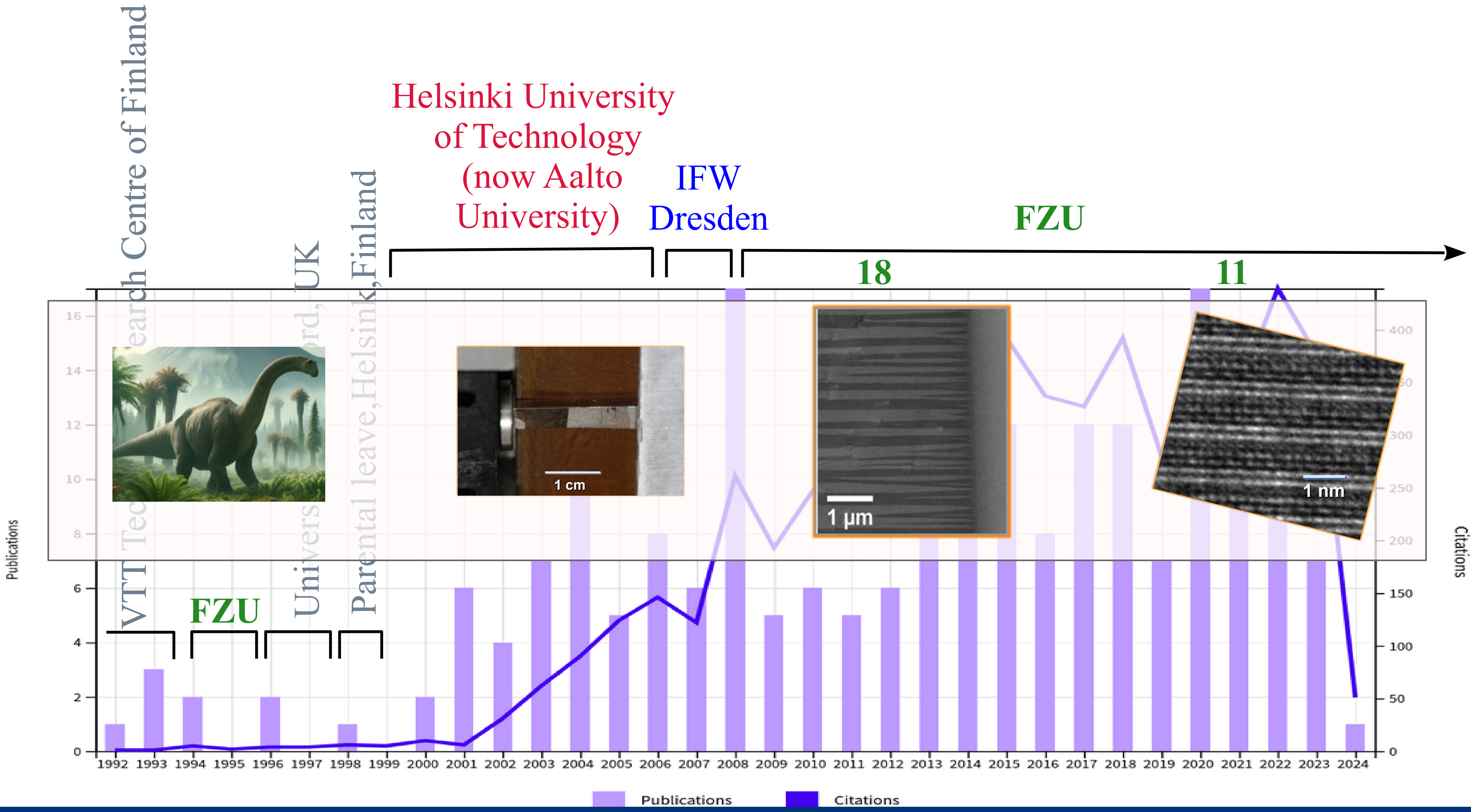
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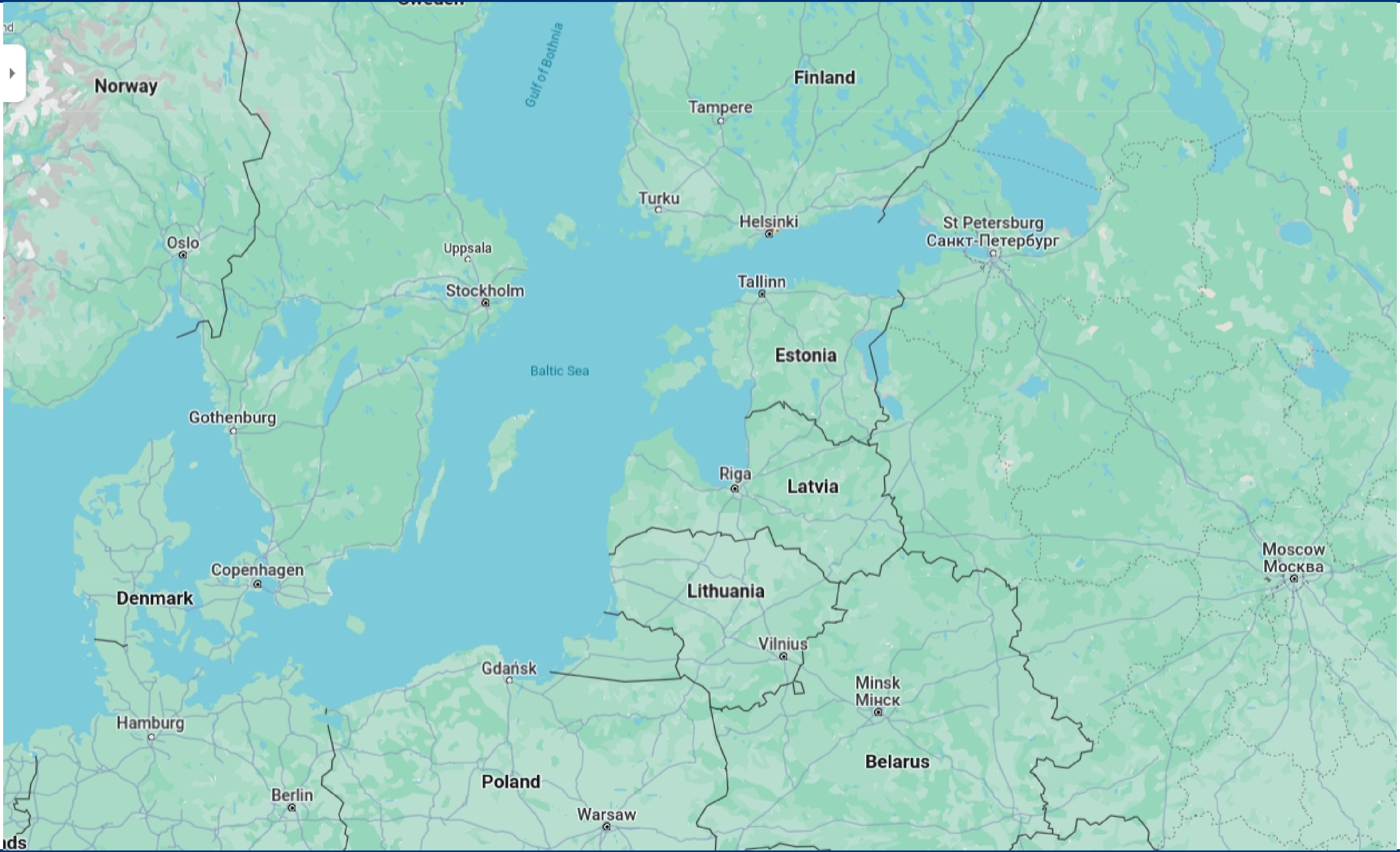
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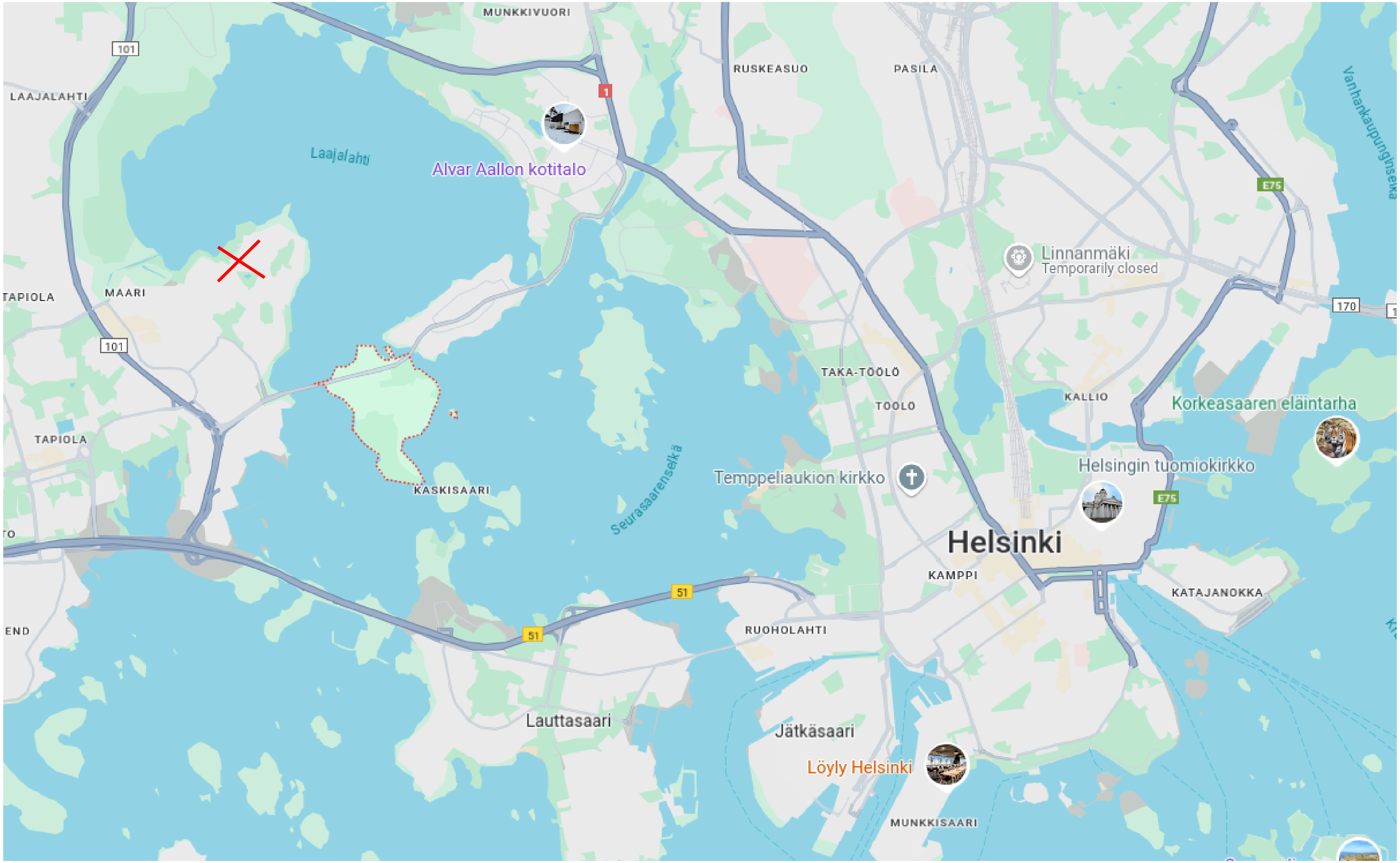
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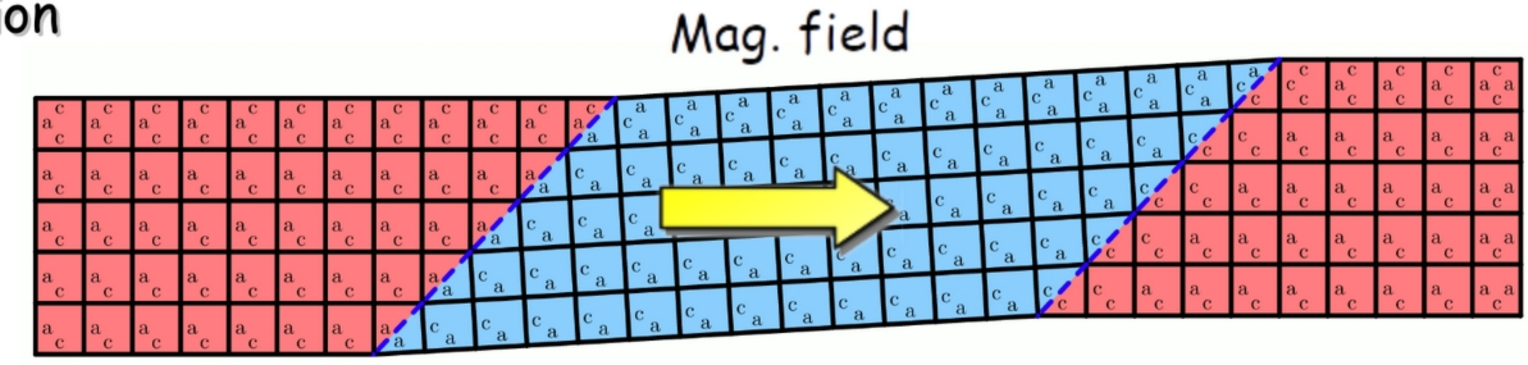
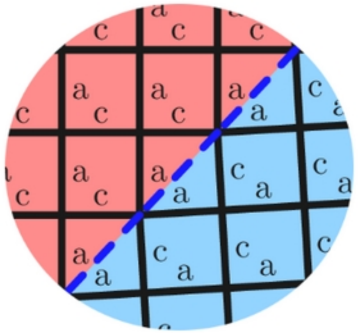
Motivation





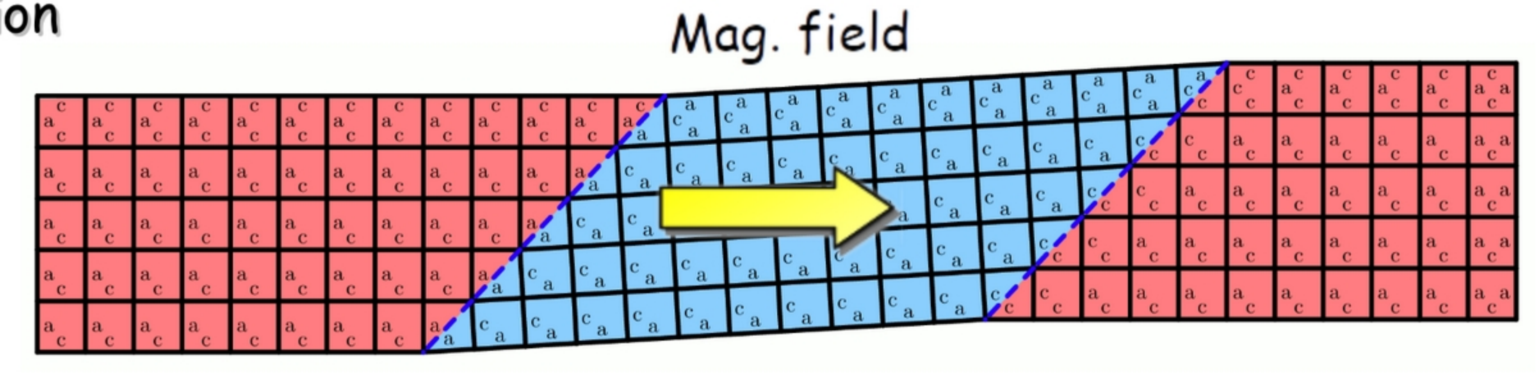
$$W_{MECH} = \sigma_{TW} \cdot \varepsilon_0$$

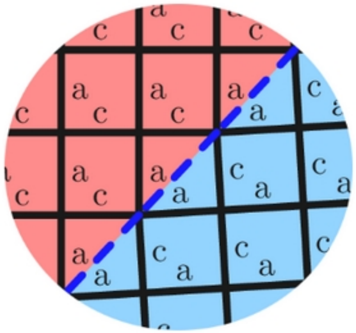
$$\Delta W_{MAG} = K_U$$

$$\Delta W_{MAG} > W_{MECH}$$

$$\sigma_{TW} < K_U / \varepsilon_0$$

Motivation





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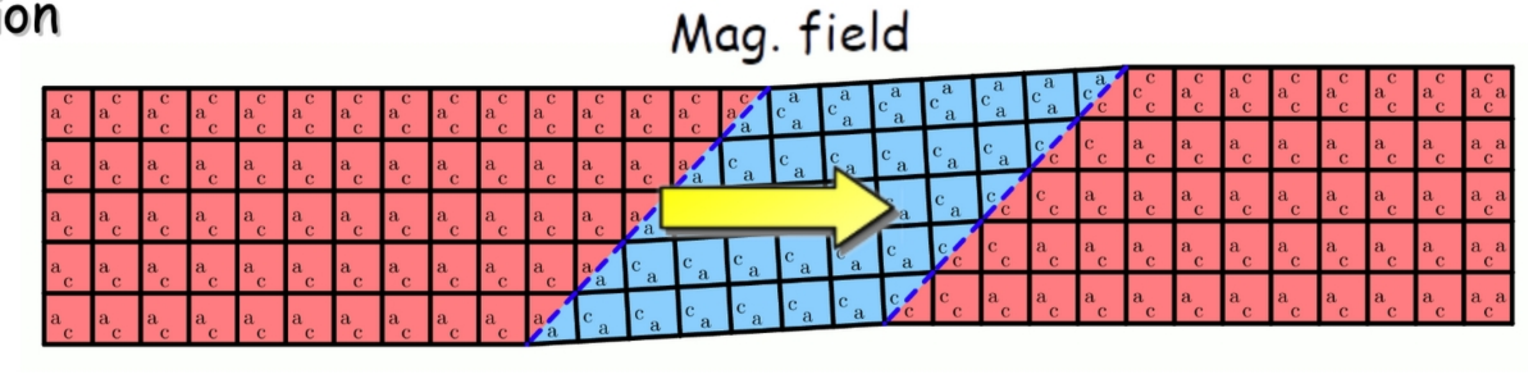

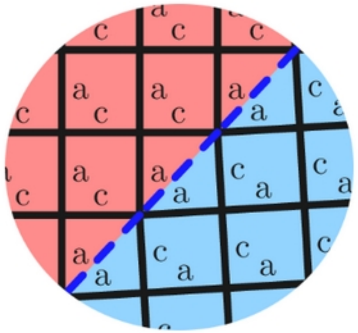

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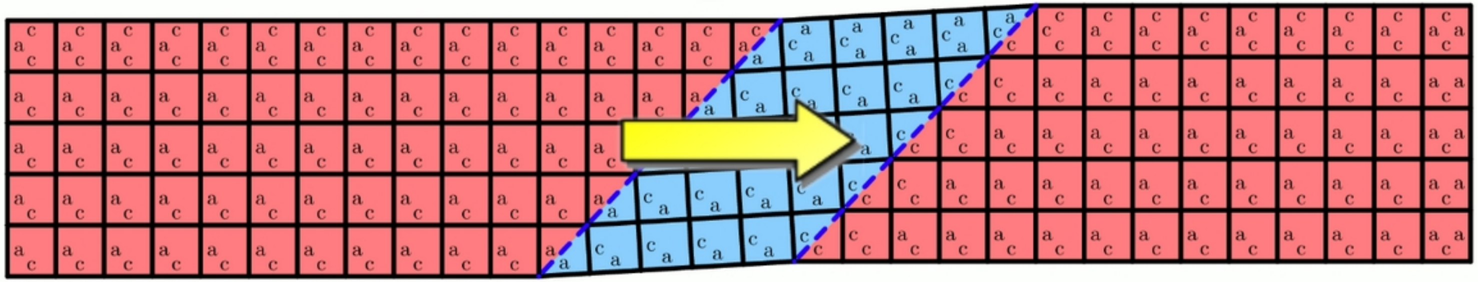
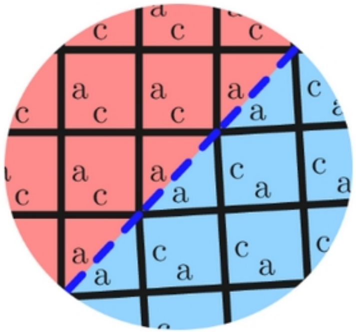
Motivation

Mag. field





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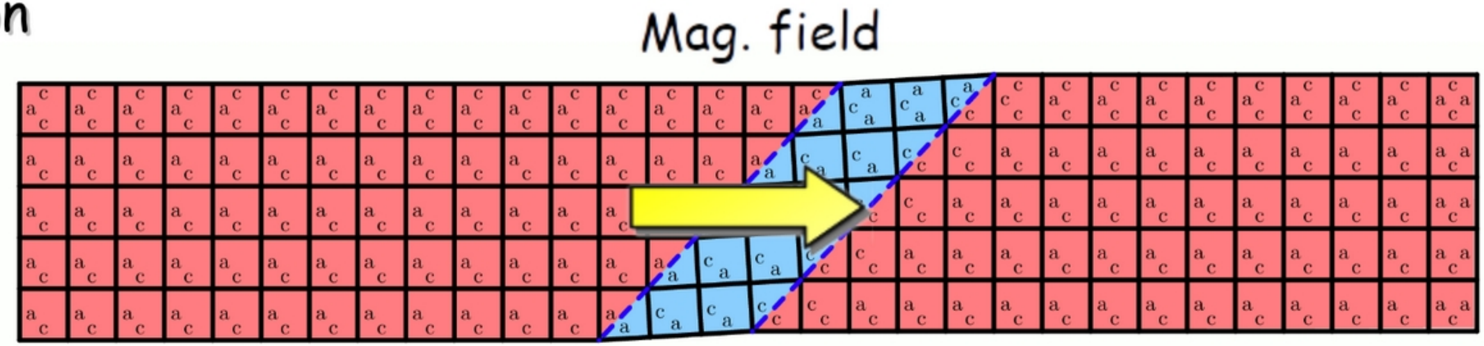

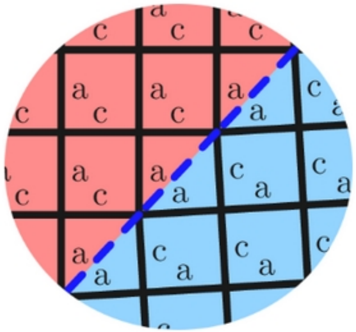

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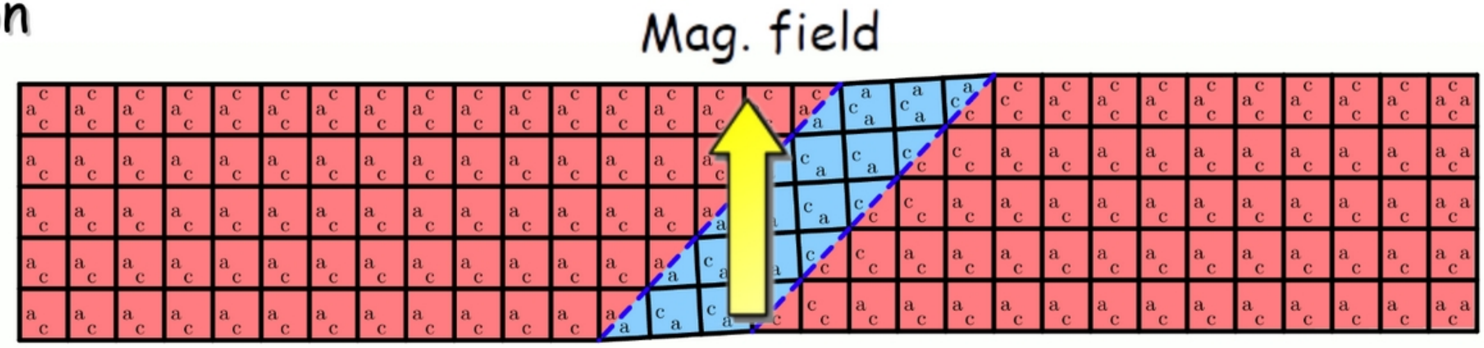

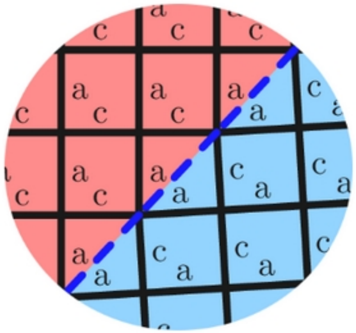

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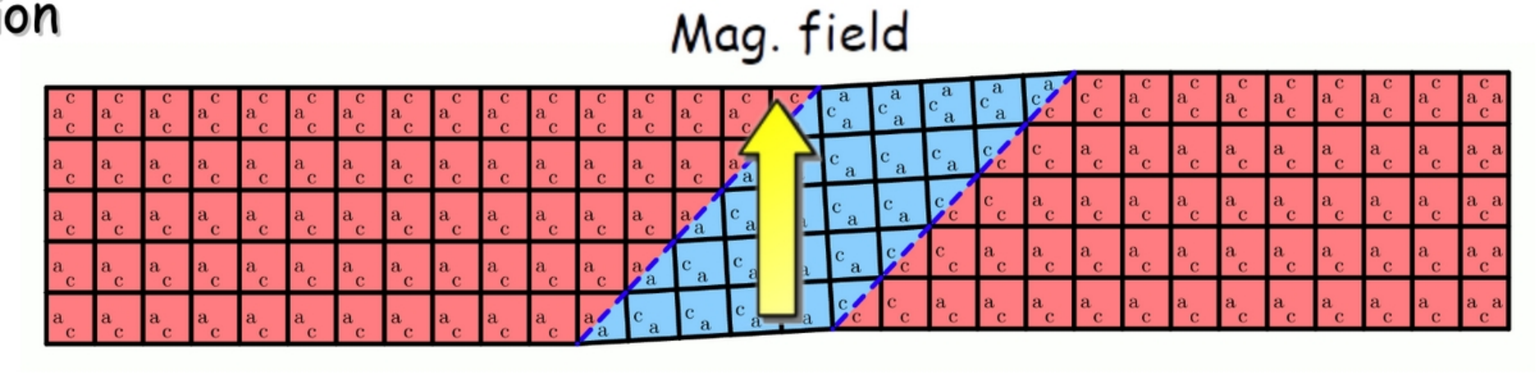

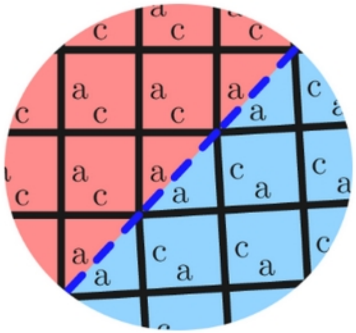

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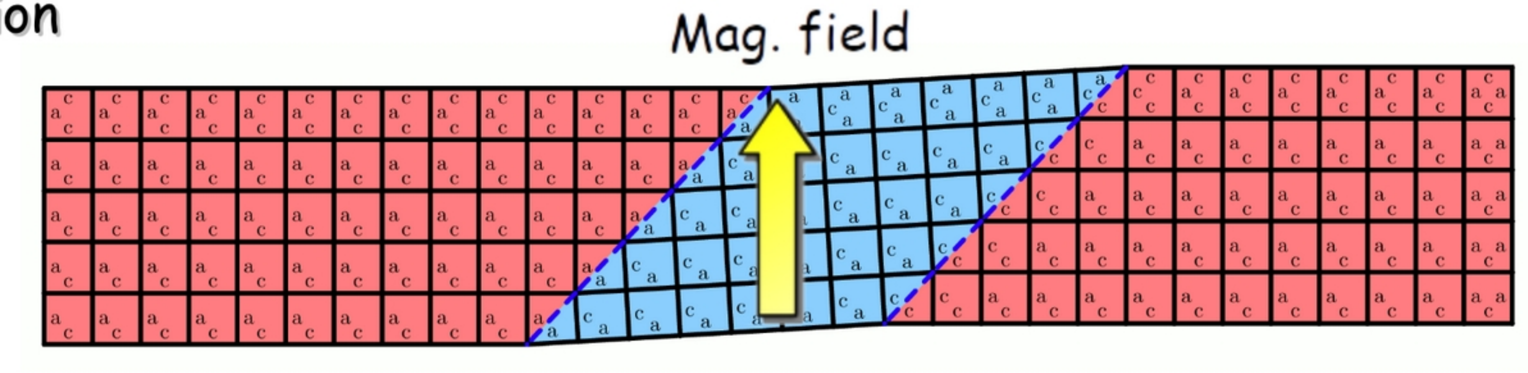

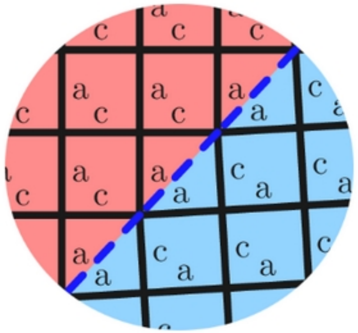

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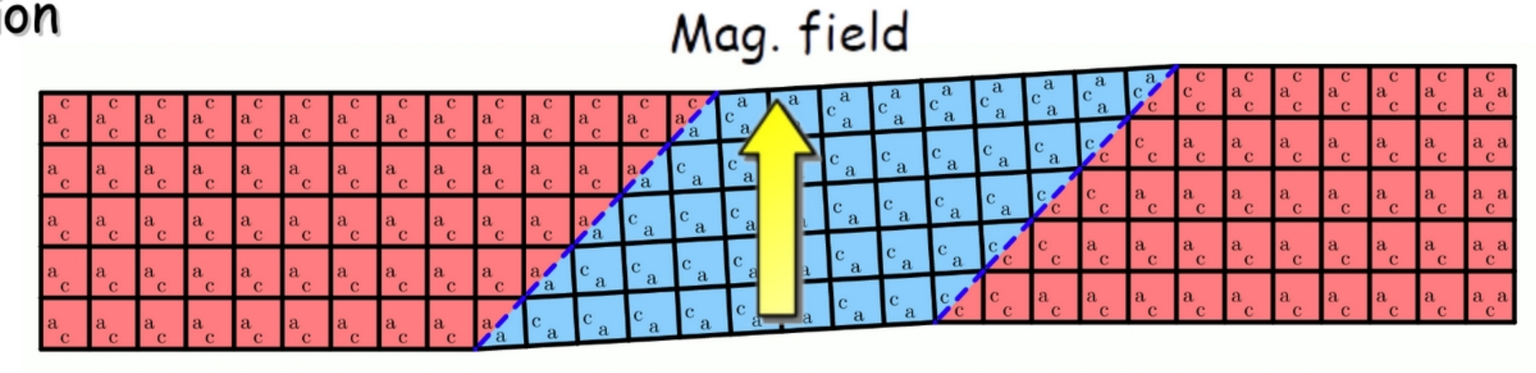

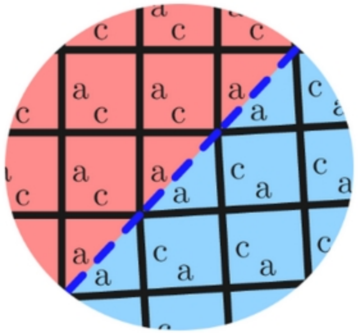

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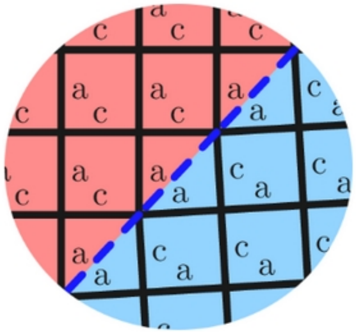

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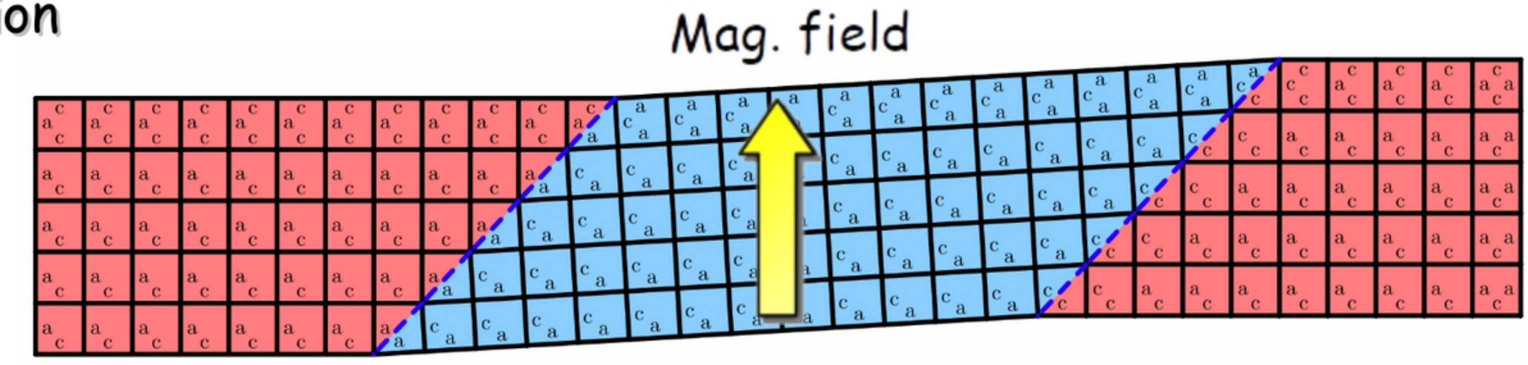

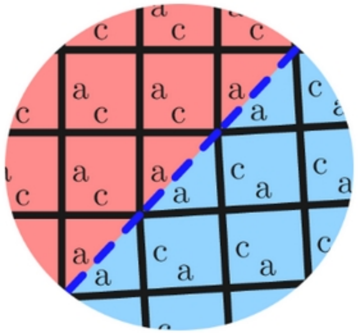

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42 Publications — Sort by: Citations: highest first — 1 of 1

	Title	2020	2021	2022	2023	2024	Average per year	Total
	Total	83	65	97	55	7	91.2	2,280
1	Giant field-induced reversible strain in magnetic shape memory NiMnGa alloy Heczko, O; Sozinov, A and Ullakko, K International Magnetics Conference (INTERMAG 2000) Sep 2000 | IEEE TRANSACTIONS ON MAGNETICS 36 (5), pp.3266-3268	11	14	18	7	1	13.16	329
2	Coexistence of ferromagnetic and antiferromagnetic order in Mn-doped Ni_2MnGa -: art. no. 212405 Enkovaara, J; Heczko, O; (...); Nieminen, RM Jun 1 2003 | PHYSICAL REVIEW B 67 (21)	9	9	8	5	0	9.77	215
3	Magnetic shape memory effect and magnetization reversal Heczko, O 2nd Joint European Magnetic Symposia (JEMS 04) Apr 2005 | JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS 290, pp.787-794	8	4	6	3	1	7.6	152
4	Magnetic anisotropy in Ni-Mn-Ga martensites Straka, L and Heczko, O May 15 2003 | JOURNAL OF APPLIED PHYSICS 93 (10), pp.8636-8638	5	8	6	1	0	6.45	142
5	Temperature dependence and temperature limits of magnetic shape memory effect Heczko, O and Straka, L Dec 1 2003 | JOURNAL OF APPLIED PHYSICS 94 (11), pp.7139-7143	2	5	9	2	0	6	132
6	Superelastic response of Ni-Mn-Ga martensite in magnetic fields and a simple model Straka, L and Heczko, O International Magnetics Conference Sep 2003 | IEEE TRANSACTIONS ON MAGNETICS 39 (5), pp.3402-3404	1	3	2	0	2	4.14	91
7	Magnetic properties and domain structure of magnetic shape memory Ni-Mn-Ga alloy Heczko, O; Jurek, K and Ullakko, K International Conference on Magnetism May 2001 | JOURNAL OF MAGNETISM AND MAGNETIC MATERIALS 226, pp.996-998	3	1	3	2	0	3.54	85

3266 IEEE TRANSACTIONS ON MAGNETICS, VOL. 36, NO. 5, SEPTEMBER 2000

Giant Field-Induced Reversible Strain in Magnetic Shape Memory NiMnGa Alloy

O. Heczko, Alexei Sozinov, and Kari Ullakko

***Abstract*—A room temperature extensional strain of 5.1% was observed in martensitic $Ni_{48}Mn_{31}Ga_{21}$ alloy in the magnetic field of 480 kA/m. The magnitude of field-induced strain decreases with increasing external compressive stress applied in the direction of expansion. The compressive stress of about 3 MPa prevents the development of the substantial field-induced strain. Magnetization curves obtained by VSM exhibit an abrupt magnetization change and a transient hysteresis in the first quadrant. Large reversible field-induced strain and the abrupt magnetization change are due to the rearrangement or redistribution of martensitic twin variants by the applied magnetic field. It was confirmed by optical observation of movement and nucleation of martensitic twin boundaries.**

***Index Terms*—Magnetic shape memory, magnetoelastic deformation, martensitic transformation, NiMnGa alloys.**

redistribution of martensitic twin variant fractions. This structural rearrangement is accompanied with the changes of magnetization curve. Additionally the strain dependence on external compressive stress was studied. The measured magnitude of the strain is quite close to theoretical limit given by tetragonal distortion of the lattice of the particular composition.

II. Experimental Procedure

Textured bars of composition $Ni_{48}Mn_{31}Ga_{21}$ were prepared from high purity elements by a directional solidification method. After annealing the grain size was so large that it was possible to cut single crystalline samples from the grain.

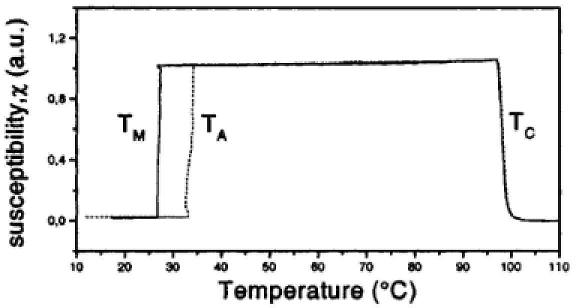

Fig. 1. Temperature dependence of low-field magnetic susceptibility measured during cooling (solid line) and heating (dash line). The transformations are marked with the corresponding temperatures.

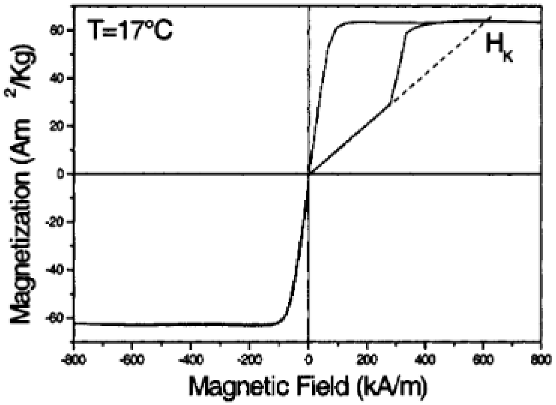

Fig. 2. Magnetization curve of stress-free Ni-Mn-Ga sample at room temperature.

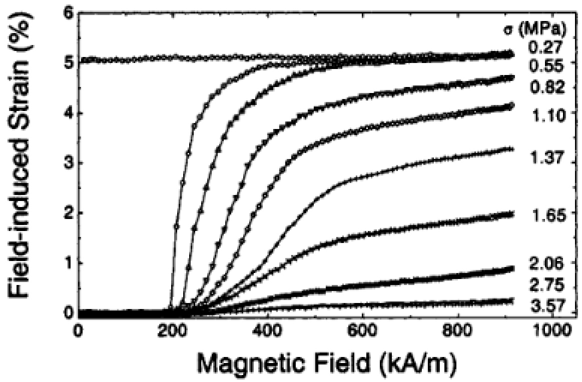

Fig. 3. The field-induced strain for various loads at room temperature. The magnitudes of compressive stresses are marked next to the corresponding curves.

process is pure rotation, one obtains the value of magnetic anisotropy constant of martensite $K_u = 1.7 \times 10^5$ J/m^3, which is lower than the value 2.45×10^5 J/m^3 reported by Tickle and James [5] for $Ni_{51.3}Mn_{24}Ga_{24.7}$ but higher than the value 1.2×10^5 J/m^3 reported by Ullakko [2] for nonstoichiometric Ni_2MnGa composition.

In Fig. 3 the field-induced strain under different loads is shown as a function of the magnetic field. In the experiment the direction of variable magnetic field was along the long sample axis and fixed constant compressive stress was applied along the short sample axis, i.e. the field and loading directions were normal to each other. The expansion was measured in the stress direction. The contraction was observed in the field direction.

JOURNAL OF APPLIED PHYSICS VOLUME 93, NUMBER 10 15 MAY 2003

Magnetic anisotropy in Ni–Mn–Ga martensites

Ladislav Straka[a] and Oleg Heczko
Laboratory of Biomedical Engineering, Department of Engineering Physics and Mathematics, Helsinki University of Technology, P.O. Box 2200, 02015 HUT, Espoo, Finland

(Presented on 15 November 2002)

We study the temperature dependence of the magnetic anisotropy of three different martensites known to exist in the Ni–Mn–Ga alloys. The anisotropy constants were determined from magnetization curves measured at different temperatures. The anisotropy of five-layered modulated tetragonal martensite is uniaxial with easy magnetization direction along short crystallographic axis. At room temperature $K_1(\mathrm{rt}) = 1.65\times10^5\ \mathrm{J\,m^{-3}}$ and K_2 is negligible. Seven-layered modulated orthorhombic martensite exhibits easy magnetization direction along the shortest crystallographic axis. $K_1(\mathrm{rt}) = 1.7\times10^5\ \mathrm{J\,m^{-3}}$ and $K_2(\mathrm{rt}) = 0.9\times10^5\ \mathrm{J\,m^{-3}}$ referring to hard and mid-hard magnetization axes. Nonmodulated tetragonal martensite possesses a uniaxial anisotropy with easy plane and hard magnetization direction along the long crystallographic axis with $K_1(\mathrm{rt}) = -2.3\times10^5\ \mathrm{J\,m^{-3}}$ and $K_2(\mathrm{rt}) = 0.55\times10^5\ \mathrm{J\,m^{-3}}$. The temperature dependence of $K_1(T)$ of five-layered martensite follows magnetization power law with exponent $n = 3$ suggesting a single ion origin of the magnetic anisotropy in Ni–Mn–Ga martensite.
[DOI: 10.1063/1.1555982]

JOURNAL OF APPLIED PHYSICS VOLUME 93, NUMBER 10 15 MAY 2003

Magnetic anisotropy in Ni–Mn–Ga martensites

Ladislav Straka[a] and Oleg Heczko
Laboratory of Biomedical Engineering, Department of Engineering Physics and Mathematics, Helsinki University of Technology, P.O. Box 2200, 02015 HUT, Espoo, Finland

8638 J. Appl. Phys., Vol. 93, No. 10, Parts 2 & 3, 15 May 2003 L. Straka and O. Heczko

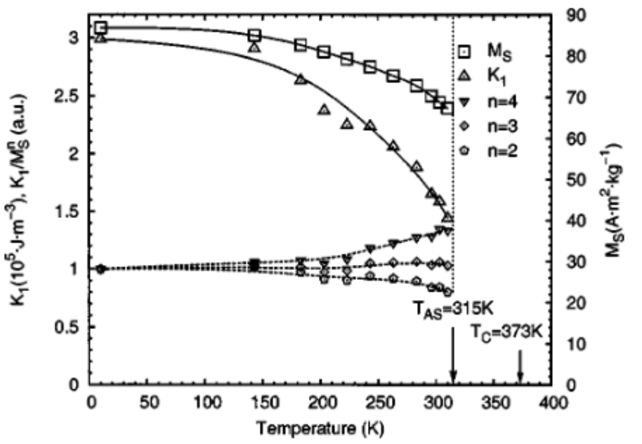

FIG. 2. Magnetization and anisotropy constant of five layered tetragonal martensite (sample 5M). Lower curves present dependence of normalized K_u/M_S^n for $n=2$, 3, and 4. A dotted vertical line marks the transformation temperature from martensite to austenite.

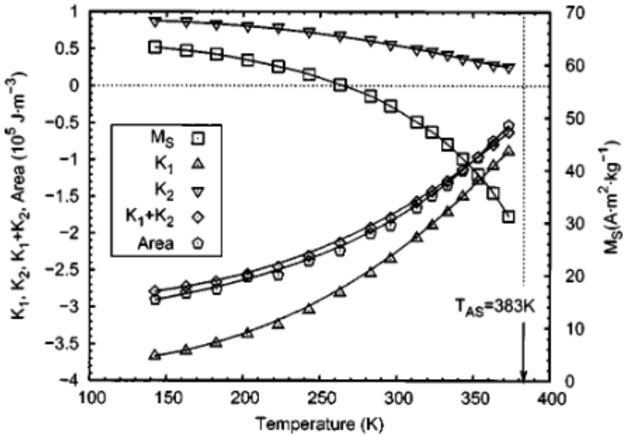

FIG. 4. Magnetization and anisotropy constants K_1 and K_2 of nonmodulated tetragonal martensite (sample T). For comparison the sum of the magnetization constants (rhombuses) and the negative value of integrated area between the hard and easy magnetization curves are also shown (pentagons). A vertical dotted line marks the transformation to austenite and Curie point.

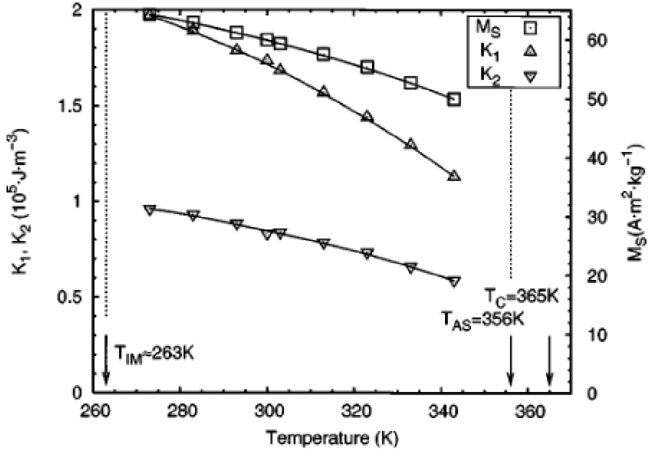

FIG. 3. Magnetization and anisotropy constants K_1 and K_2 of seven-layered orthorhombic martensite (sample 7M). Dotted vertical lines mark the transformation temperatures to other phases.

JOURNAL OF APPLIED PHYSICS VOLUME 94, NUMBER 11 1 DECEMBER 2003

Temperature dependence and temperature limits of magnetic shape memory effect

Oleg Heczko[a)] and Ladislav Straka
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(Received 23 June 2003; accepted 23 September 2003)

We study the temperature dependence and low and high temperature limits of the magnetic shape memory effect (MSME) in five-layered tetragonal Ni–Mn–Ga martensite. Using a simple model we show that, additionally to the limits posed by transformation to austenite or an intermartensitic transformation, the temperature dependence of the magnetic anisotropy, tetragonality of the lattice, and twinning stress play important role when considering the temperature limits of the MSME. With decreasing temperature, the lattice distortion and magnetic anisotropy increase, but saturate in a low temperature region. The twinning stress does not saturate and its temperature dependence has exponential-like character that increases rapidly in the low temperature region. The model predicts that the low-temperature limit of the MSME is 165 K for $Ni_{49.7}Mn_{29.1}Ga_{21.2}$ composition. This agrees very well with the value of 173 K determined from direct measurements. The high temperature limit is transformation to austenite at 315 K. The interval of the MSME existence is therefore 173–315 K. Quasistatic measurements of the MSME in the range 203–313 K up to the 1.15 T magnetic field show that the onset of the MSME shifts to a higher field and that a maximum field-induced strain increases with decreasing temperature.
[DOI: 10.1063/1.1626800]

Temperature dependence and temperature limits of magnetic shape memory effect

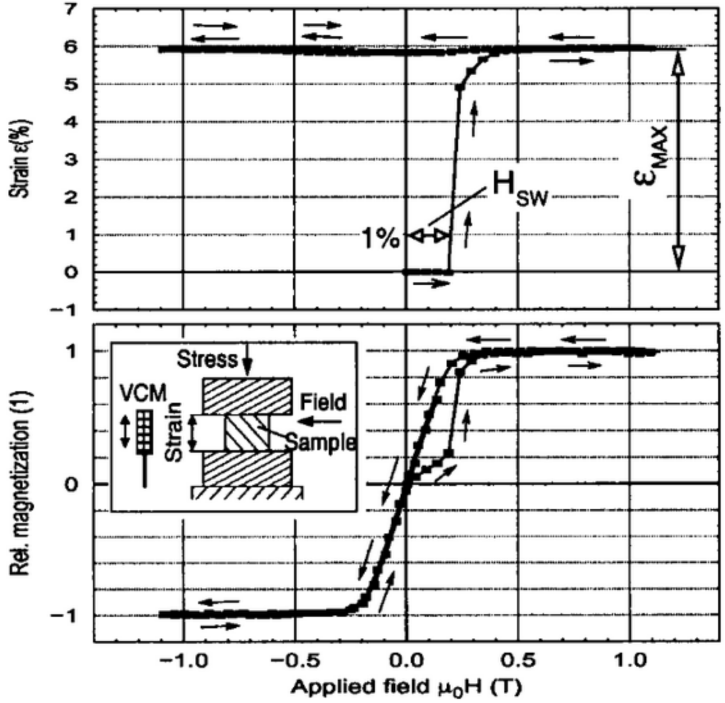


FIG. 1. Simultaneous measurements of the strain and magnetization at 301 K. The changes on the magnetization curve clearly reflect the strain changes. The first quadrant hysteresis on the magnetization curve is a typical mark of the MSME occurrence. Switching field H_{SW} and maximum strain ϵ_{MAX} are defined in the figure. Inset shows the experimental arrangement.

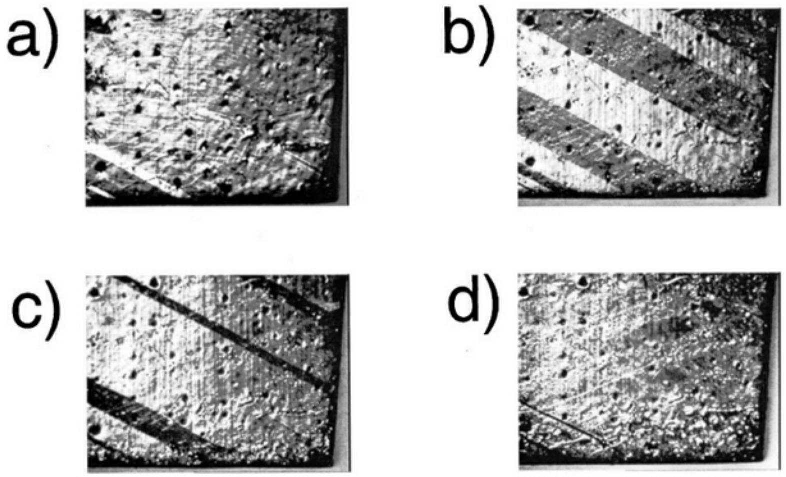
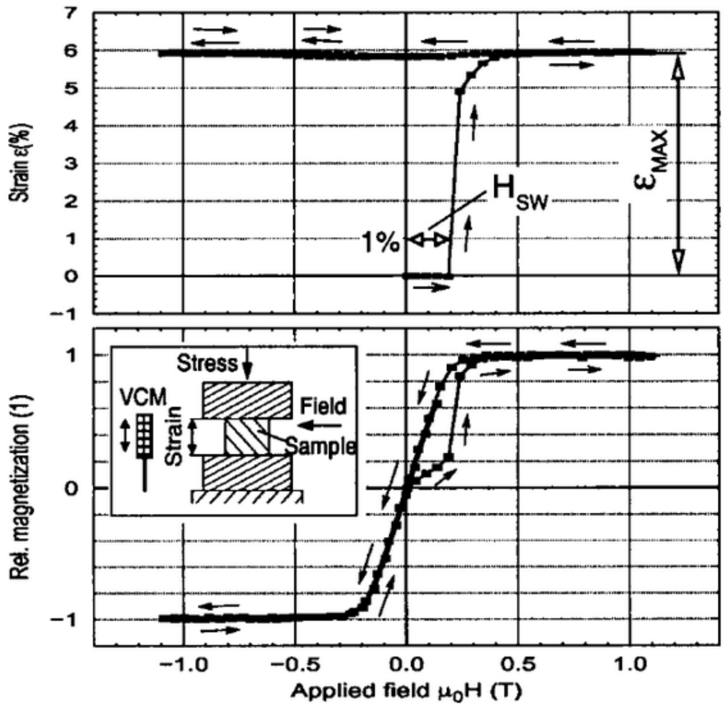


FIG. 2. Typical morphology observed on the 5M samples during compression: (a) initial configuration with mostly one variant, (b), (c) development of the morphology during compression, and (d) final state after 14 MPa compression. A similar morphology is obtained by application of magnetic field. The face of the sample shown is the (110) plane of the parental cubic phase. The width of the micrographs corresponds to 3 mm.

Temperature dependence and temperature limits of magnetic shape memory effect



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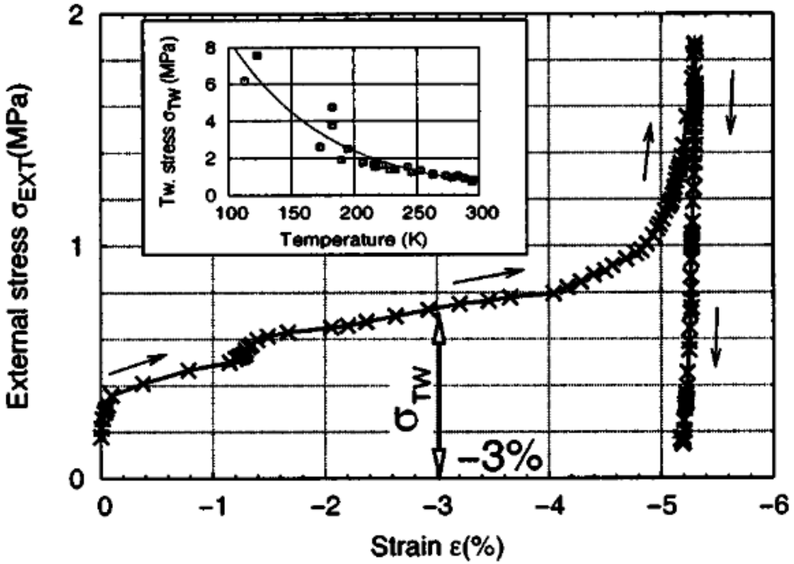
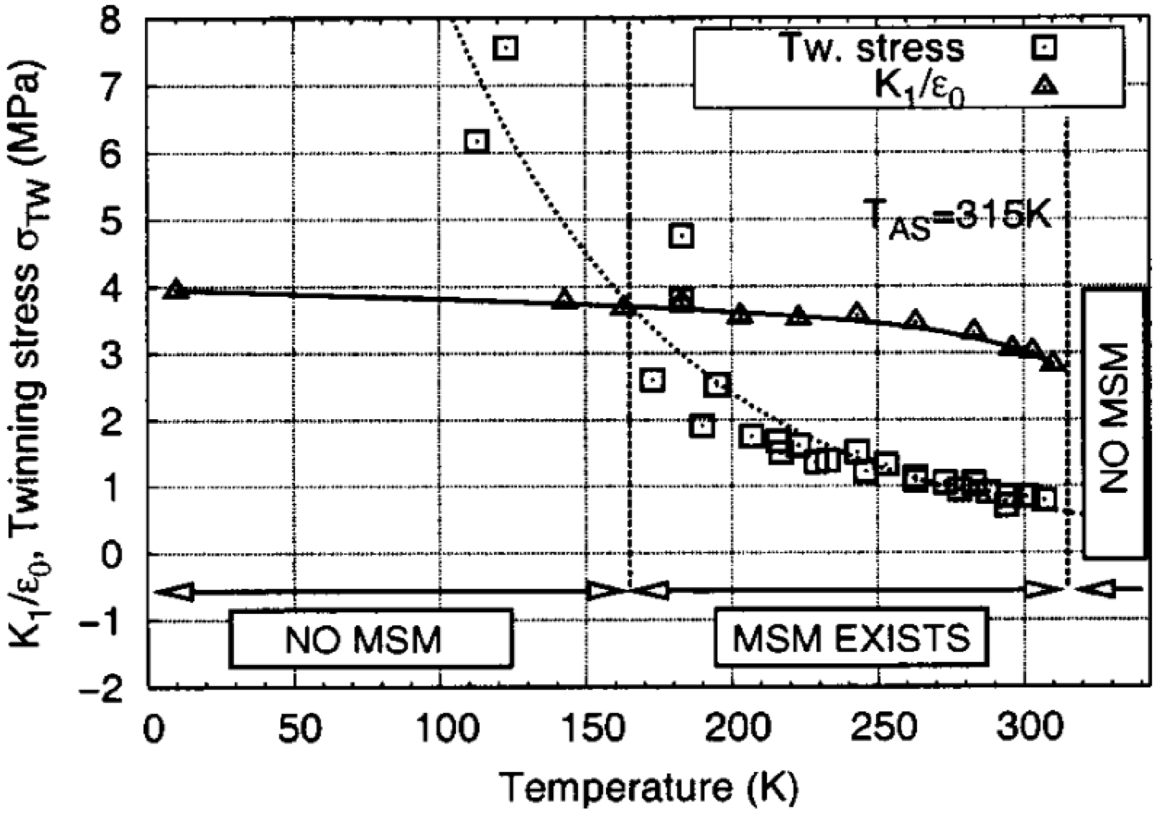


FIG. 3. Stress-strain curve measured at room temperature after MSME measurement. Twinning stress σ_{TW} is defined as an external stress necessary to induce -3% strain. Inset shows twinning stress as a function of temperature. The curve is an exponential fit of the measured data.

Temperature dependence and temperature limits of magnetic shape memory effect



$$\sigma_{TW} < K_U/\varepsilon_0$$

3402 IEEE TRANSACTIONS ON MAGNETICS, VOL. 39, NO. 5, SEPTEMBER 2003

Superelastic Response of Ni–Mn–Ga Martensite in Magnetic Fields and a Simple Model

Ladislav Straka and Oleg Heczko

***Abstract*—The irreversible and reversible straining (superplasticity and superelasticity) of the single crystal $Ni_{49.7}Mn_{29.1}Ga_{21.2}$ sample stressed compressively under a static magnetic field up to 1 T is described and successfully modeled. The sample possesses a five-layered martensitic structure at room temperature and it becomes almost fully superelastic (reversible strain close to 6%) for values of field higher than 0.3 T. The maximum sensitivity of the stress-strain curve to the magnetic field determined from the model is 6.8 MPa/T (7.2 MPa/T from measured data). Knowledge of magnetization curves of the single variant sample and stress-strain curve in zero magnetic field is sufficient to predict the stress-strain behavior in an arbitrary static magnetic field.**

***Index Terms*—Magnetic shape memory, magnetic shape memory (MSM) effect, martensite, MFIS, NiMnGa, Ni–Mn–Ga, smart alloys.**

I. Introduction

FERROMAGNETIC Ni–Mn–Ga alloys in the martensitic state are promising magnetically active materials due to the existence of a giant magnetic-field-induced strain (magnetic

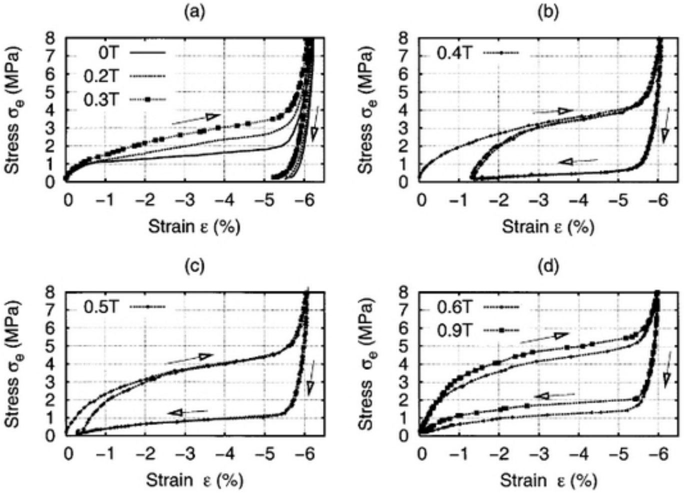


Fig. 1. Stress-strain curves for different values of the applied magnetic field. (a) For zero or small field, the sample is superplastic. (b) For a few cycles in the field of 0.4 T, the process is partly reversible. (c) Further increasing of field to 0.5 T brings more reversibility. (d) Strain is fully reversible for the field of 0.6 T and above.

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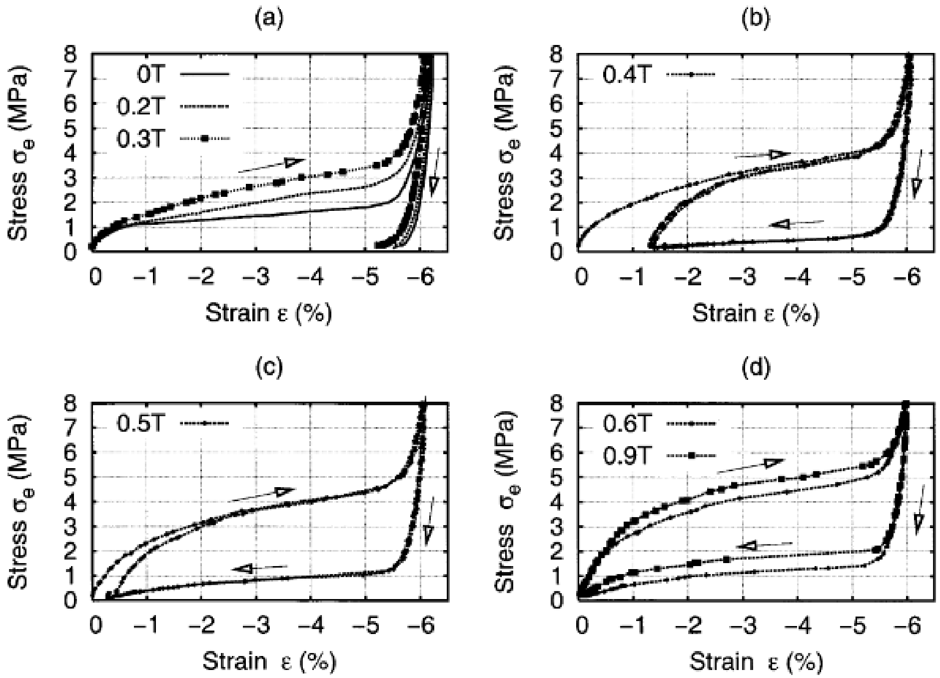

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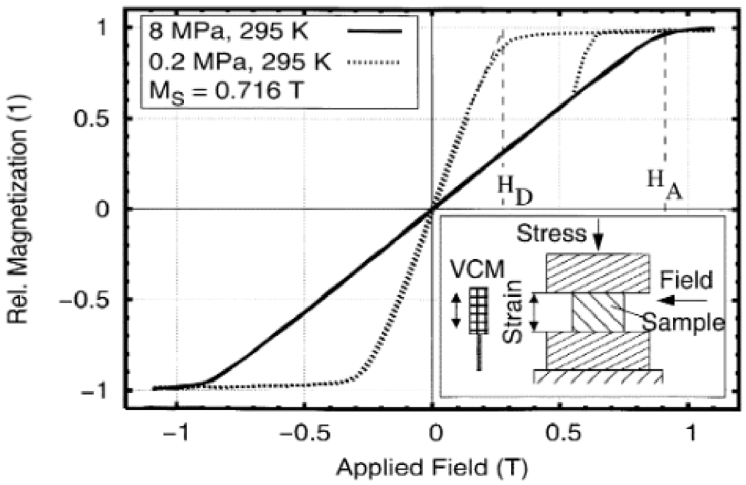

Fig. 2. Solid line shows magnetization curve of the sample constrained in single variant state measured in hard direction and dotted curve shows magnetization measurement after removing the constraint. Switching from one variant to another (MSM effect) is visible as the first-quadrant hysteresis of the dotted curve. Inset shows experimental arrangement.

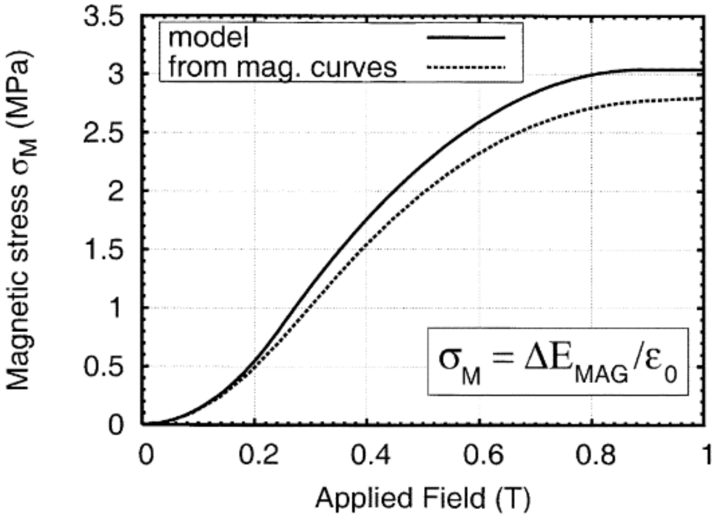

Fig. 3. Magnetic stress as a function of the applied field calculated from linearly approximated (solid line) and measured (dotted line) magnetization curves. The difference between curves is 0.2 MPa at the field 1 T.

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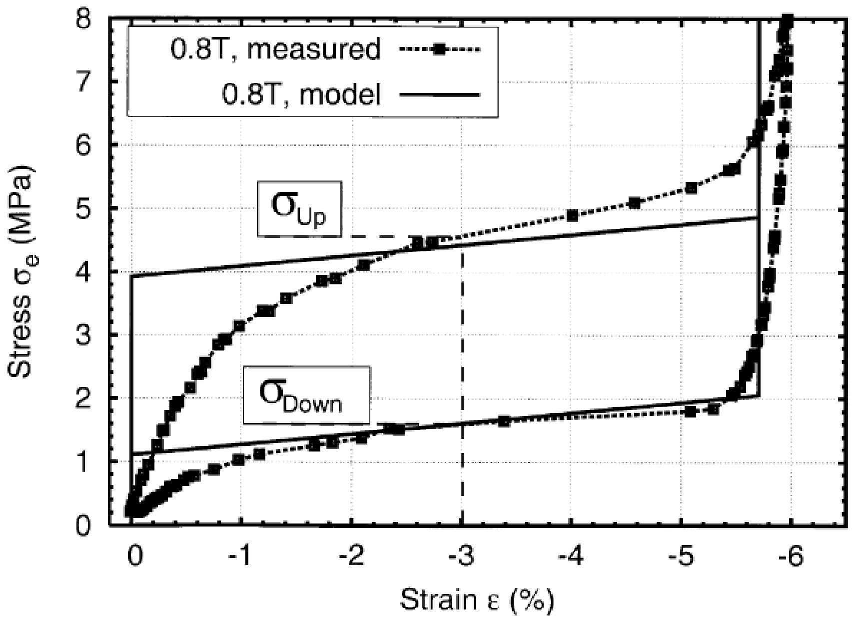

Fig. 4. Comparison of measured stress-strain curve (squares and dotted line) and model calculation (solid line) for the applied field of 0.8 T.

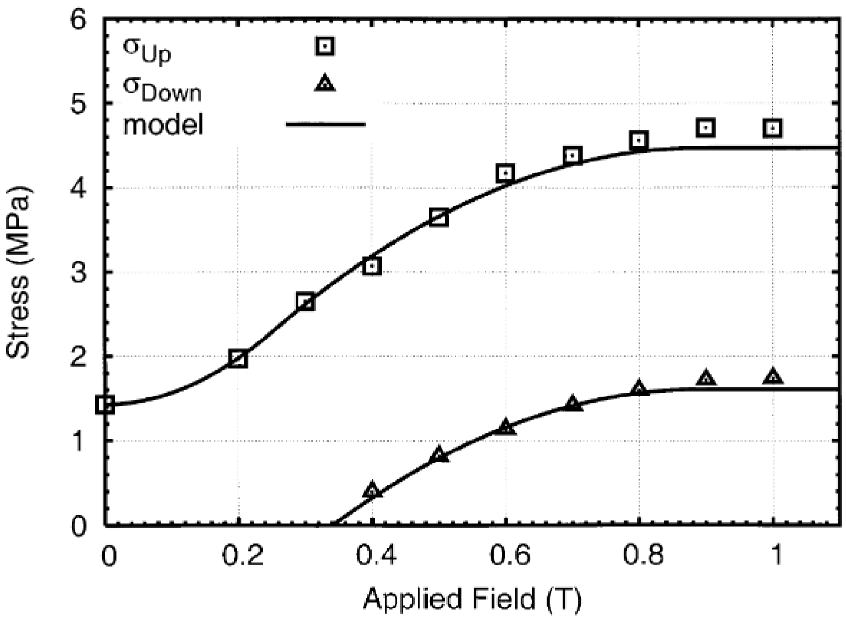

Fig. 5. External stress necessary to induce strain 3% (σ_{Up}, squares) and stress induced by magnetic field at strain 3% (σ_{Down}, triangles) during sample unloading as functions of the applied field. Solid line shows calculation from the model.

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Coexistence of ferromagnetic and antiferromagnetic order in Mn-doped Ni_2MnGa

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Ni-Mn-Ga is interesting as a prototype of a magnetic shape-memory alloy showing large magnetic-field-induced strains. We present here results for the magnetic ordering of Mn-rich Ni-Mn-Ga alloys based on both experiments and theory. Experimental trends for the composition dependence of the magnetization are measured by a vibrating sample magnetometer in magnetic fields of up to several tesla and at low temperatures. The saturation magnetization has a maximum near the stoichiometric composition and it decreases with increasing Mn content. This unexpected behavior is interpreted via first-principles calculations within the density-functional theory. We show that extra Mn atoms are antiferromagnetically aligned to the other moments, which explains the dependence of the magnetization on composition. In addition, the effect of Mn doping on the stabilization of the structural phases and on the magnetic anisotropy energy is demonstrated.

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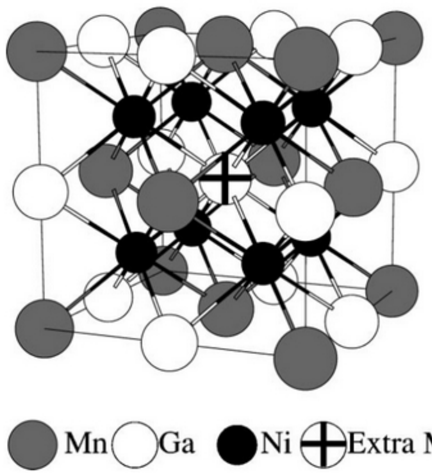
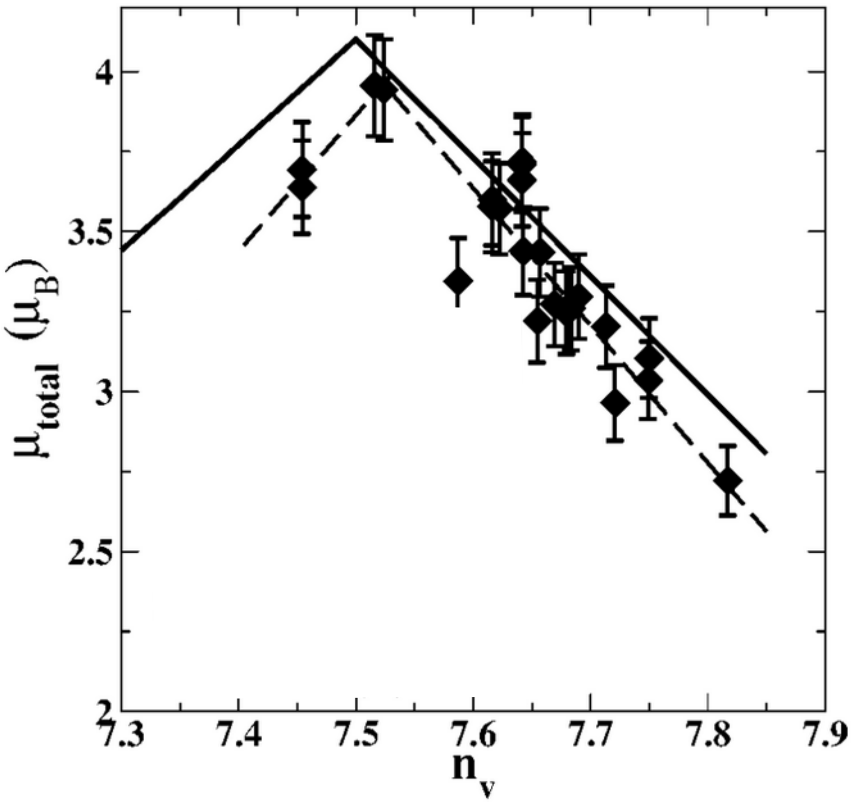


FIG. 1. $L2_1$ supercell of $Ni_2Mn_{1.25}Ga_{0.75}$.



JOURNAL OF APPLIED PHYSICS VOLUME 96, NUMBER 4 15 AUGUST 2004

Various magnetic domain structures in a Ni–Mn–Ga martensite exhibiting magnetic shape memory effect

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Magnetic domain structures of the Ni–Mn–Ga martensite were observed by means of type I and type II magnetic contrast in scanning electron microscope. The different configuration of magnetic domain patterns coupled together with the twin structures were studied in multivariant, two-variant, and single-variant martensite. The martensitic band contains broad stripelike magnetic domains following the easy axis of magnetization, i.e., the crystallographic *c* axis. These stripe domains are connected by 90° domain walls creating a staircaselike structure in the adjoining bands. It is found that the internal twins, substructures of the martensite twin domains, are distorted into a zig–zag shape in order to accommodate the main band magnetization. Furthermore, the dagger-shaped stripe domains occur only when the internal twins are present. When the sample exhibits the single-variant state, the internal twins disappear totally and the stripe magnetic domains spread over the whole specimen. The configuration observed here for the magnetic microstructure together with the crystallographic microstructure can help in understanding the magnetic shape memory effect.
 [DOI: 10.1063/1.1773381]

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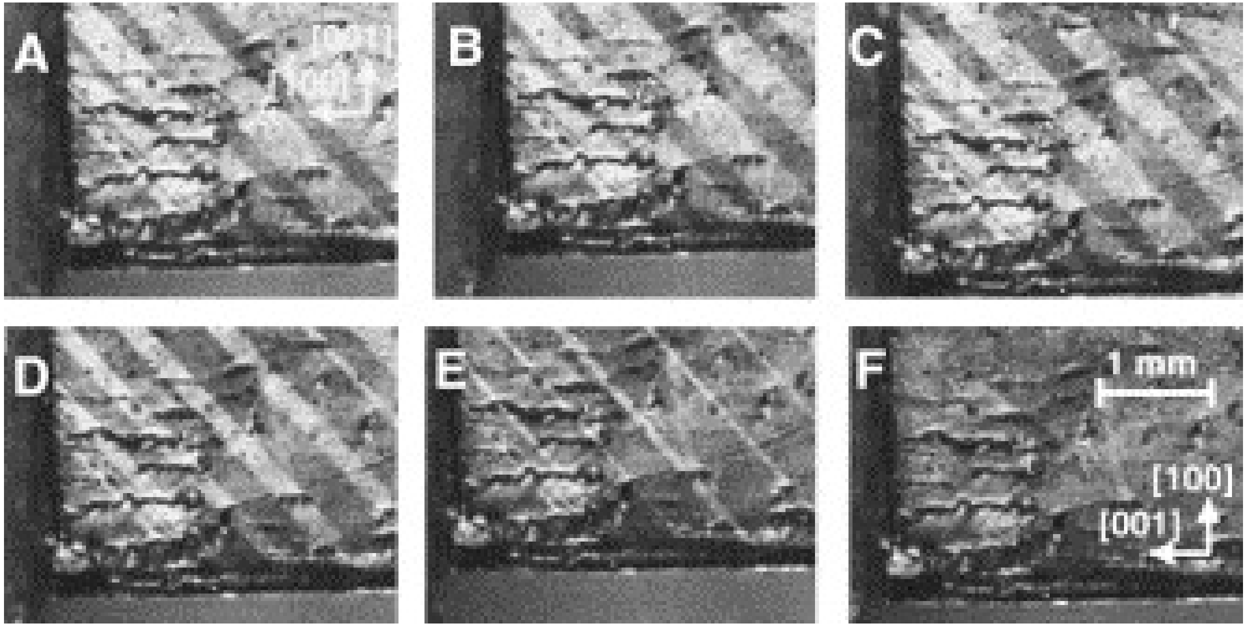

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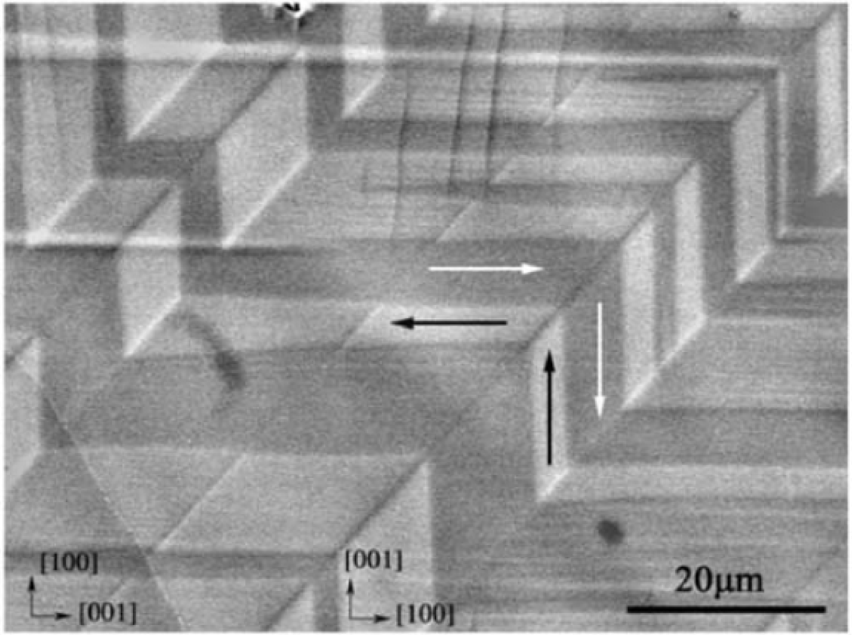

FIG. 2. The two-variant specimen with the magnetic stripe domain pattern coupled with the twin band (BEI).

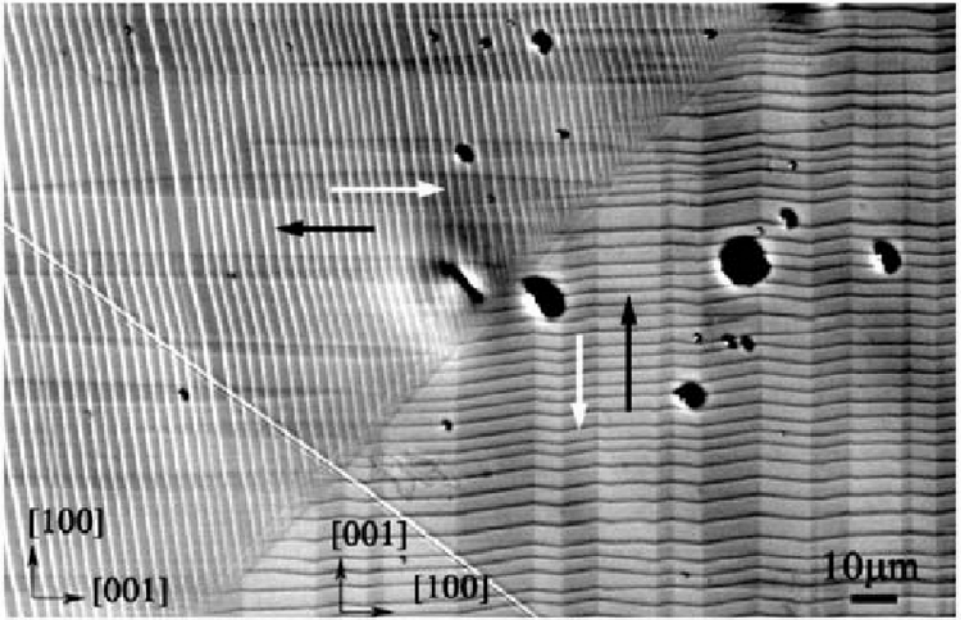

FIG. 4. The area in which the twin boundary and the internal twins are present in the two-variant specimen (BEI).

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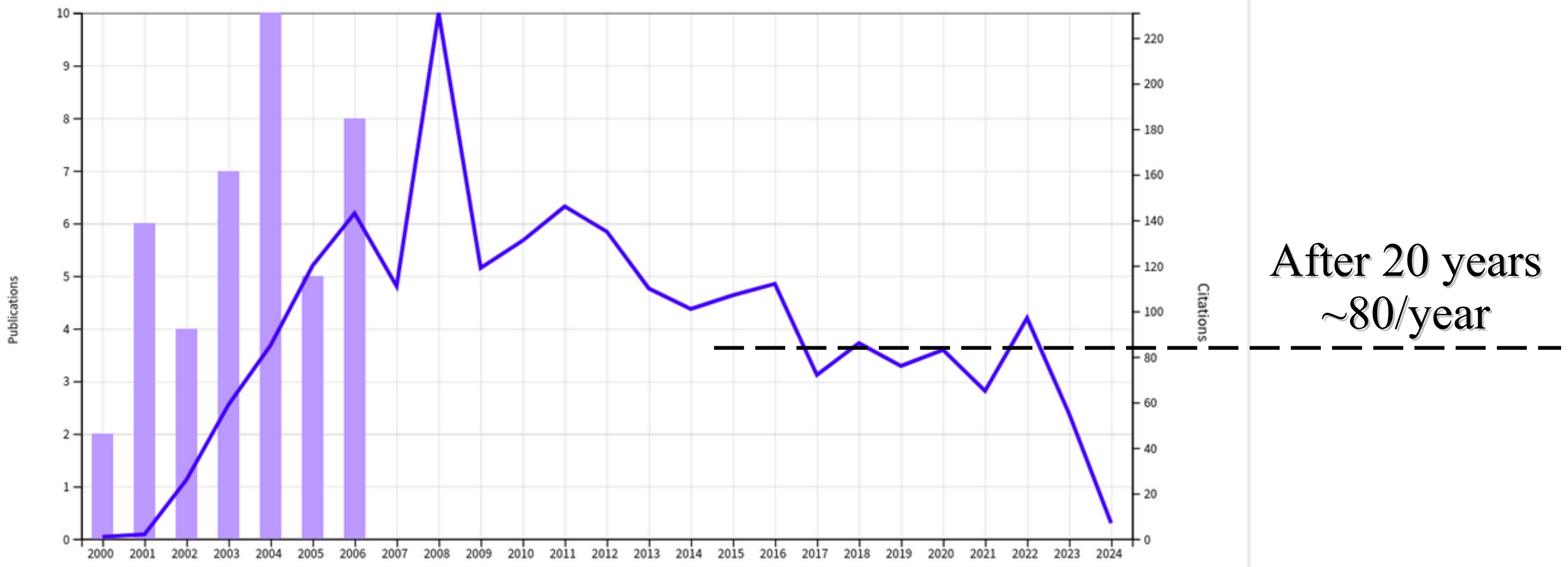

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