Materiais Magnéticos Nanocristalinos contendo Nióbio

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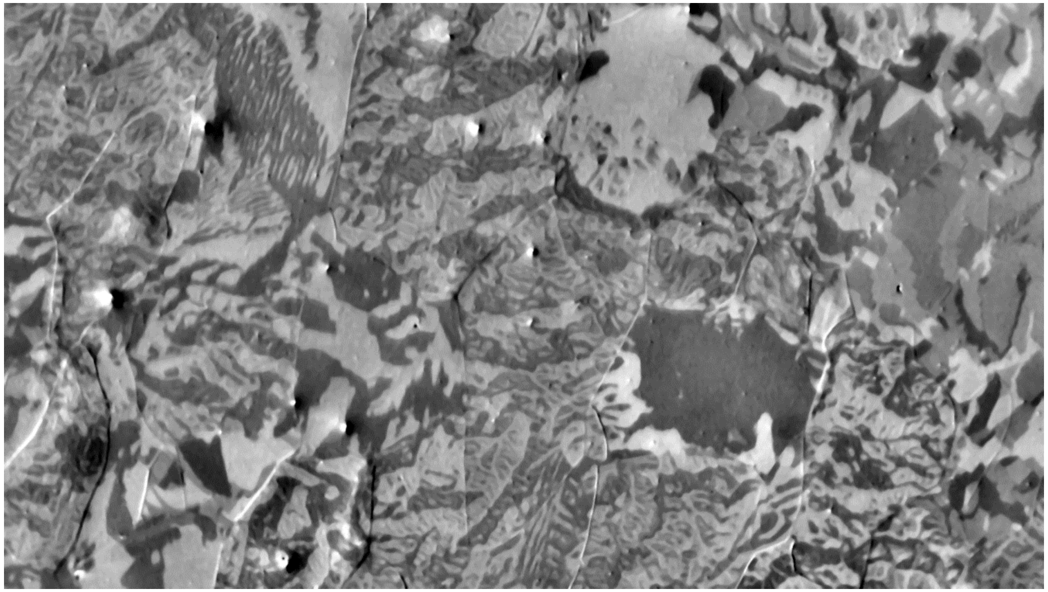
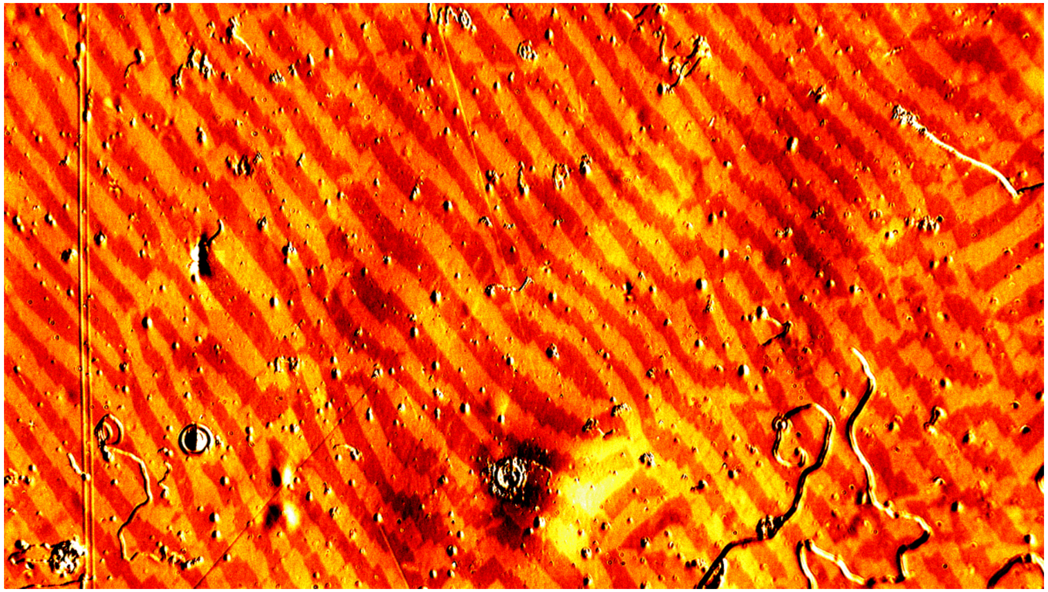
O Nb pode ser substituído?

Magnetic Domains



Fe + 3% Si

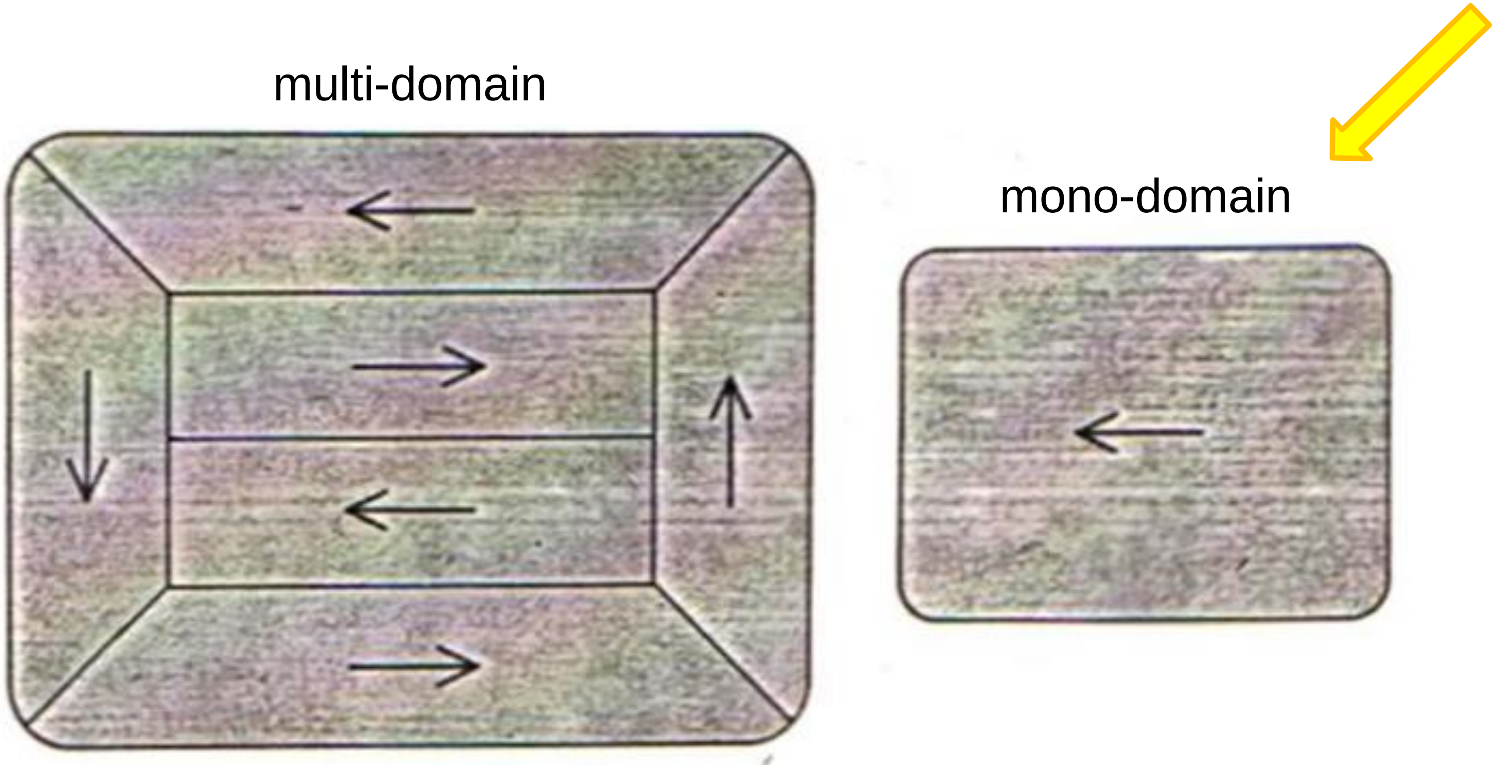
Magneto-crystalline anisotropy



Amorphous ribbon of Fe-Si-B

There is only shape anisotropy

Size dependence

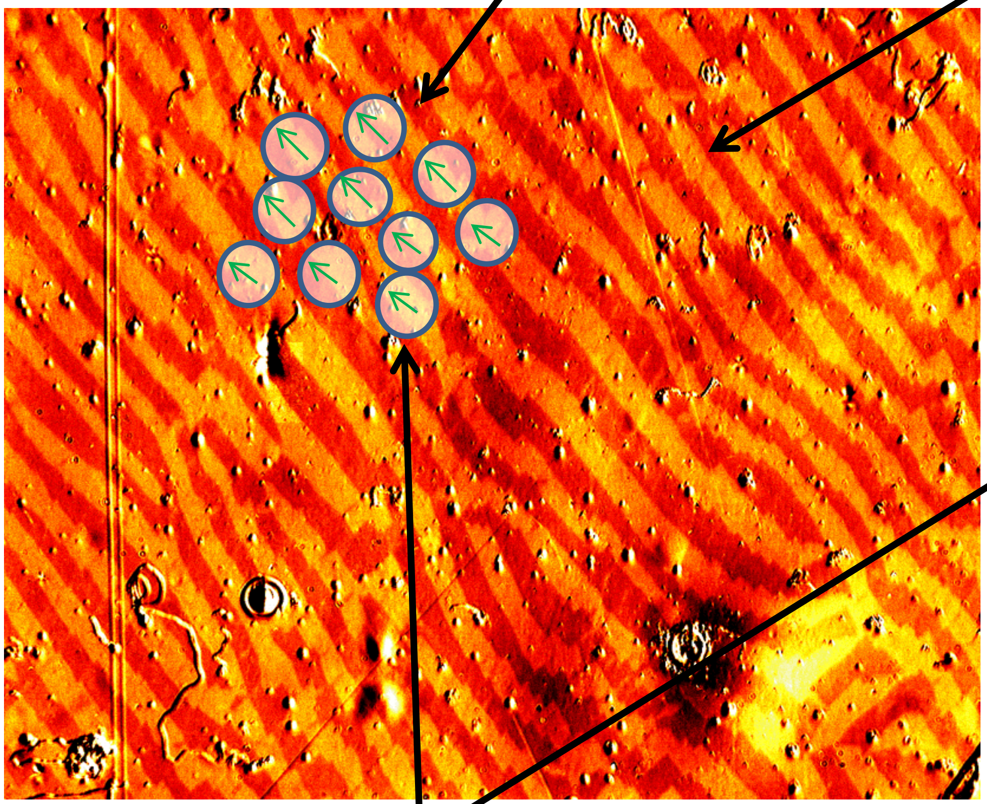


The size for mono-domain particles is typically below 500 nm.

But, the threshold depends strongly on the material.

Magnetic Nanocrystalline

Magnetic Nanocrystalline is a kind of magnetic composite:
Nanometric particles of Fe-23%Si + Cu, and an amorphous matrix of FeSiB + Nb



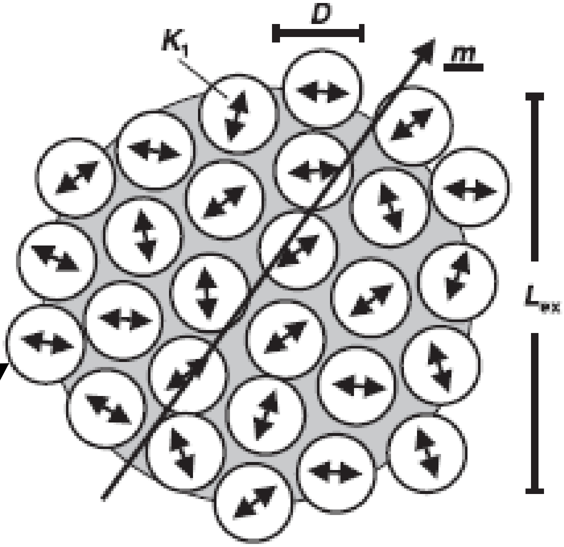


Fig. 6. Schematic representation of the random anisotropy model for grains embedded in an ideally soft ferromagnetic matrix. The double arrows indicate the randomly fluctuating anisotropy axis, the hatched area represents the ferromagnetic correlation volume determined from the exchange length L_{ex} within which the orientation $\underline{m}$ of the magnetization is constant. (After Herzer [2].)

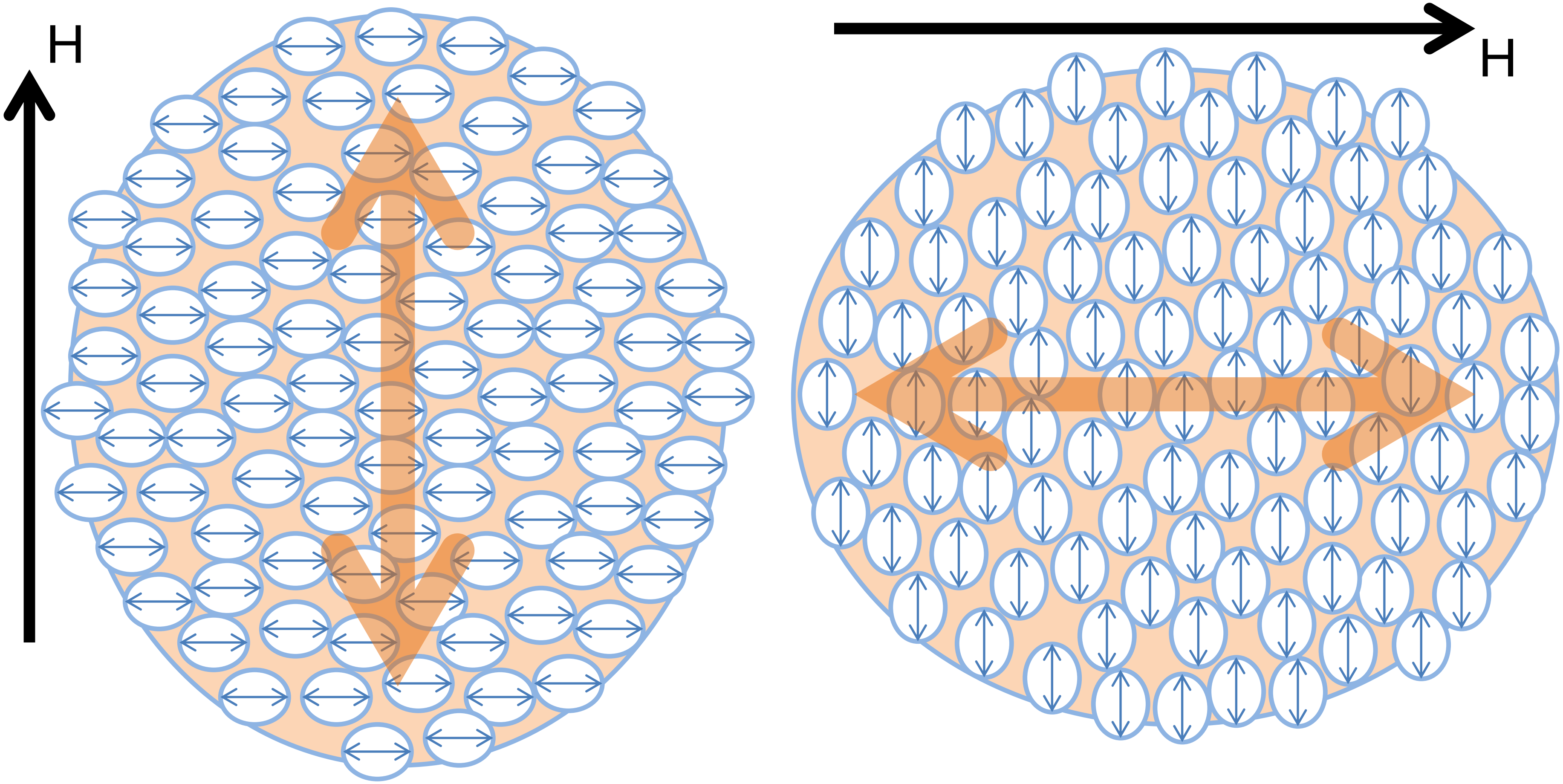
G. Herzer / Acta Materialia 61 (2013) 718–734

Each MNC is a mono-domain, and its anisotropy has random direction. But inside the magnetic composite it will align to the magnetization direction of the amorphous matrix.

Magnetostriction

λ_s (NC) < 0 contraction in the direction of H

λ_s (amorphous) > 0 enlargement in the direction of H



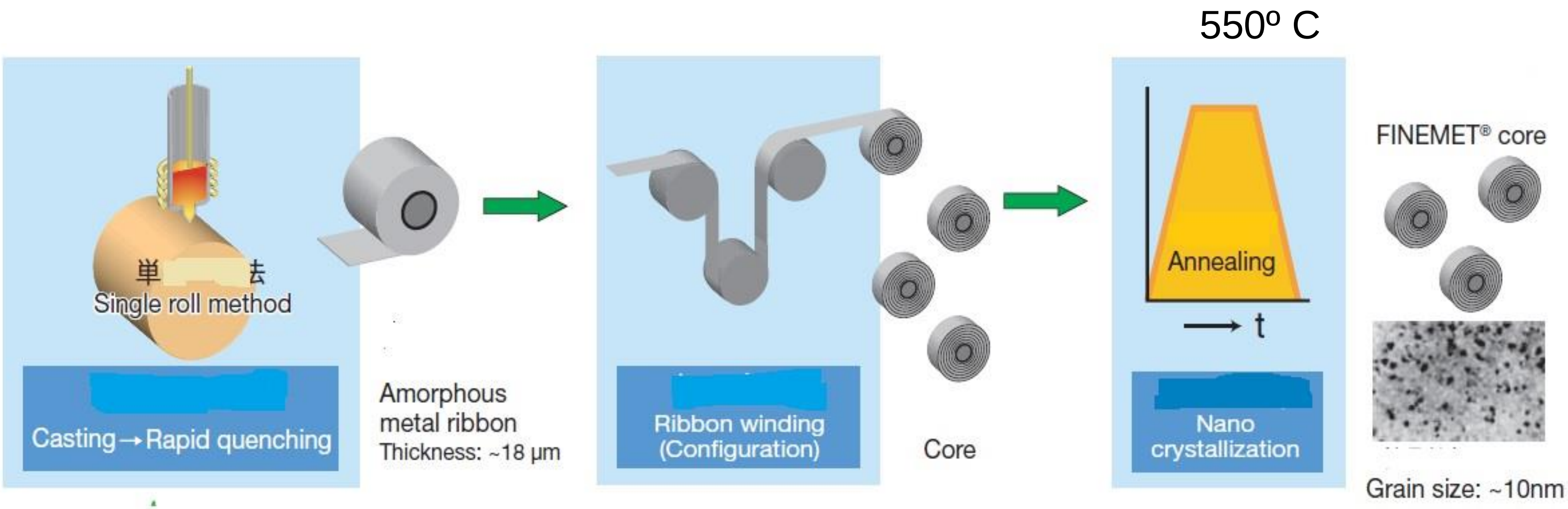
Magnetostriction is closed to zero ➔ **No external size variation.**

λ_s (Fe-23%Si) < 0 + λ_s (Fe-Si-B) > 0 = λ_s (MNC) ≈ 0

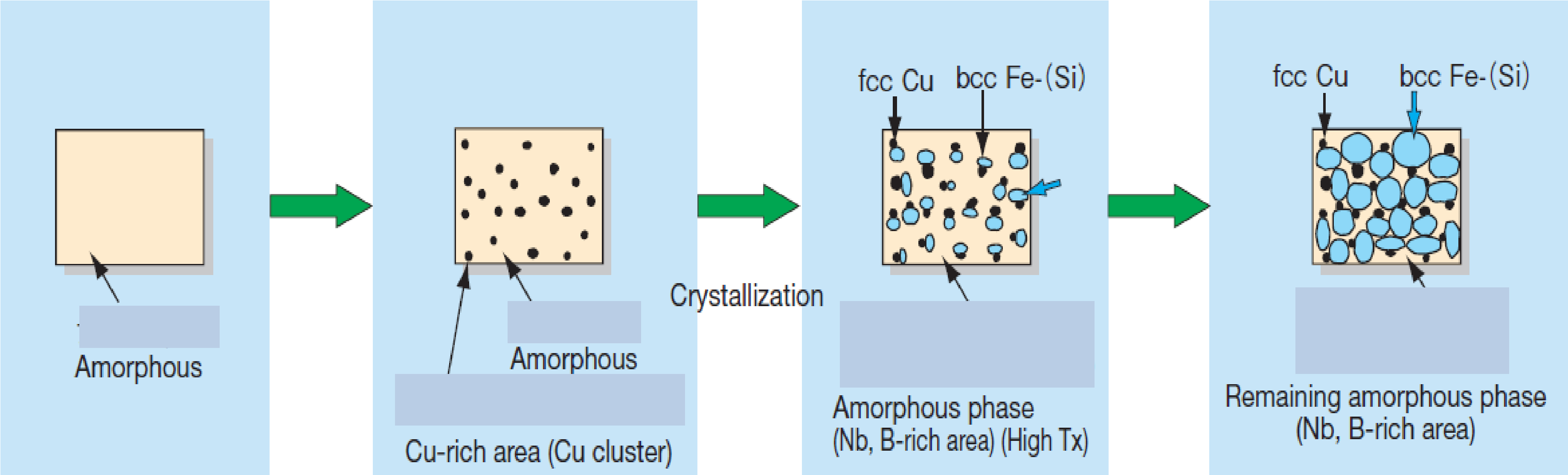
Most used is Finemet , patented by Hitachi in 1985

- Originally the chemical composition was **$Fe_{73.5}Nb_3Cu_1Si_{13.5}B_9$** (Finemet and Vitroperm)
- It may have changed a little, as Hitachi now differentiates FT-1 and FT-3.
- Literature says that microstructure is composed of three phases
  - 65% (approximately), in volume, of Fe_3Si crystals,
  - 1% in volume of fcc copper clusters inside the Fe-Si crystals
  - 34% of an amorphous matrix that surrounds the FeSi crystals, containing $70\%_{at}$Fe, $23\%_{at}$B and $7\%_{at}$Nb.

Finemet Processing



Microstructural evolution during heat treatment



Hitachi catalog

The importance of niobium

- Nb is the element that most improves magnetic permeability

- It does so, by two reasons:
  - Avoiding grain size growth during crystalization treatment and
  - allowing for the ideal combination of the magnetostriction of the two phases.

- Avoids grain growth by stabilizing the amorphous phase:
  - niobium is rejected from the growing grain into the amorphous phase.
  - Increasing Nb in amorphous phase stabilizes it, interrupting growth.

- Niobium is the strongest stabilizer of the amorphous phase

Nb promotes the highest initial permeability

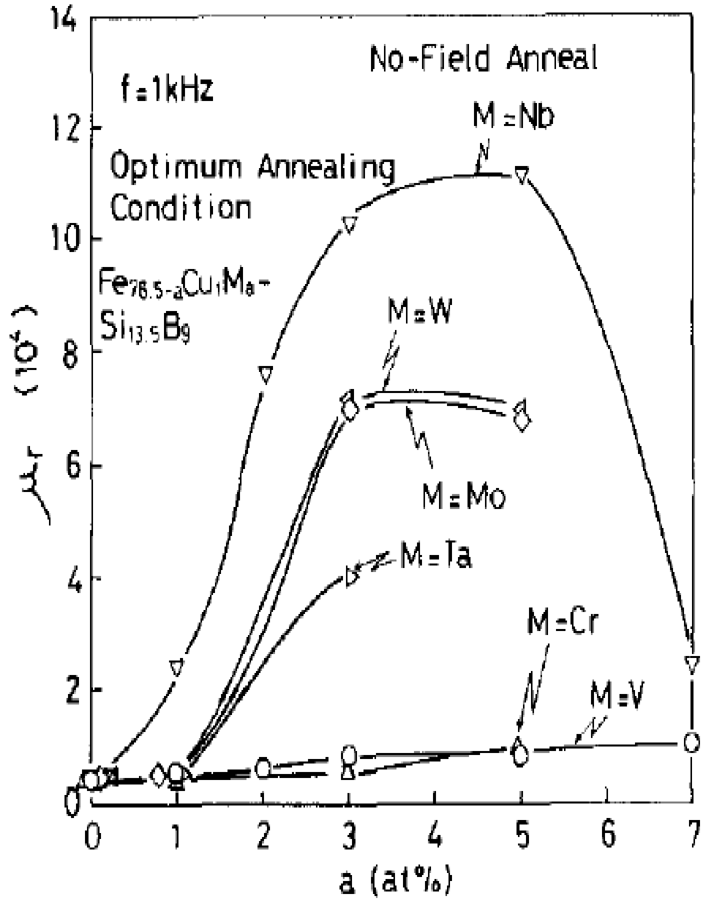


Fig. 2. M content dependence of μ_r at 1 kHz in $Fe_{76.5-a}$-$Cu_1M_aSi_{13.5}B_9$ alloys annealed optimum annealing temperature.

According to Yoshizawa (Hitachi), the best element for maximum permeability is niobium, and 3at% is enough!

yoshizawa

Materials Science and Engineering, A133 (1991) 176–179

Grain size is the critical parameter:

Maximum permeability is acchieved with nanocrystals of 15nm

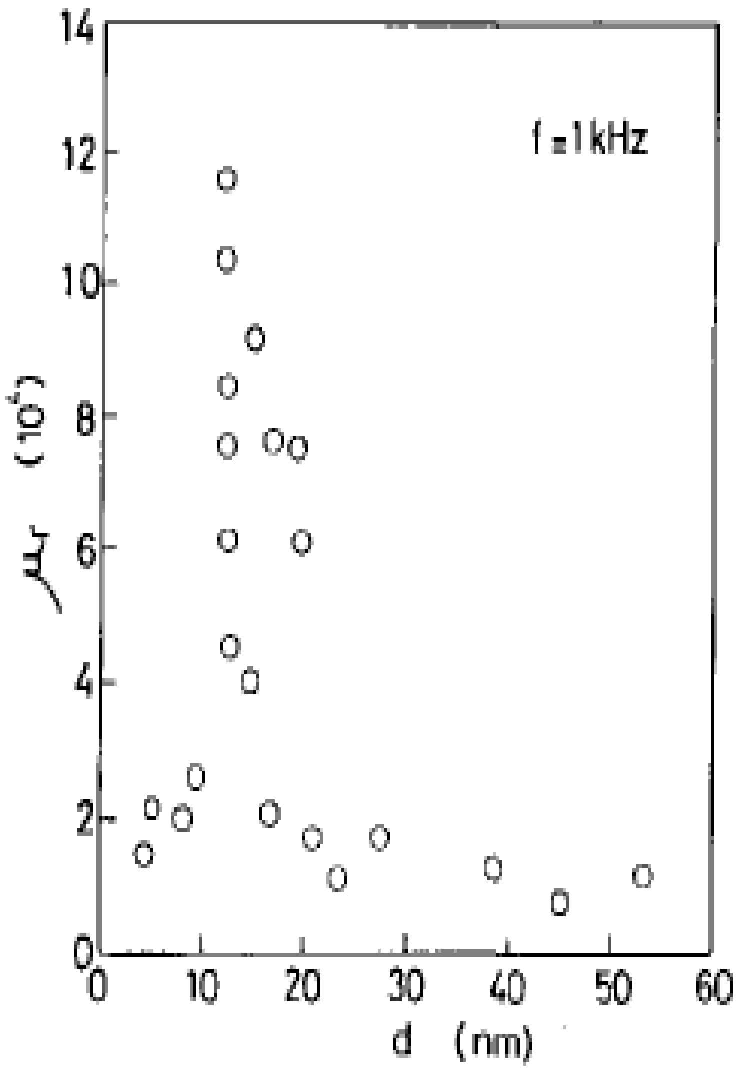
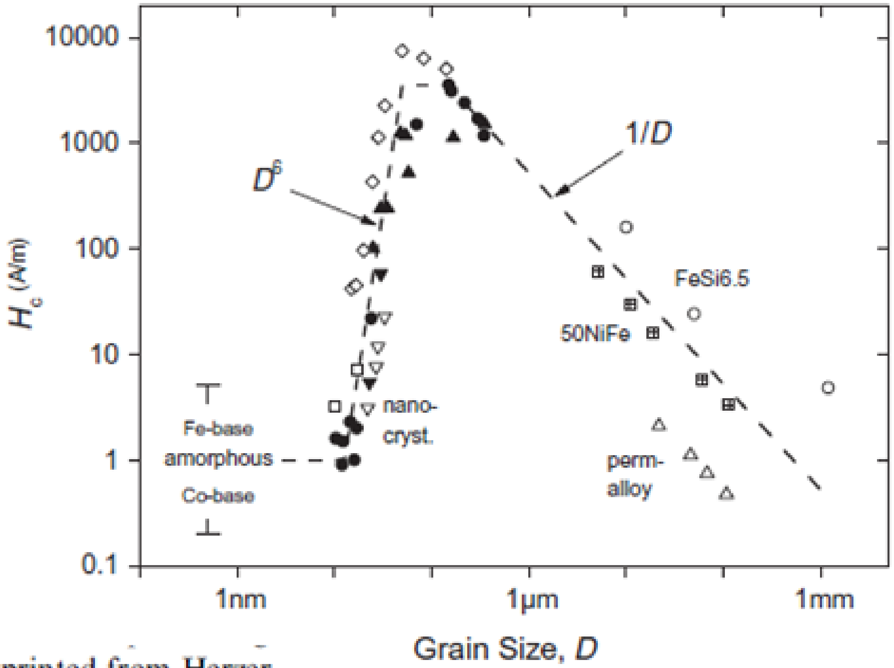
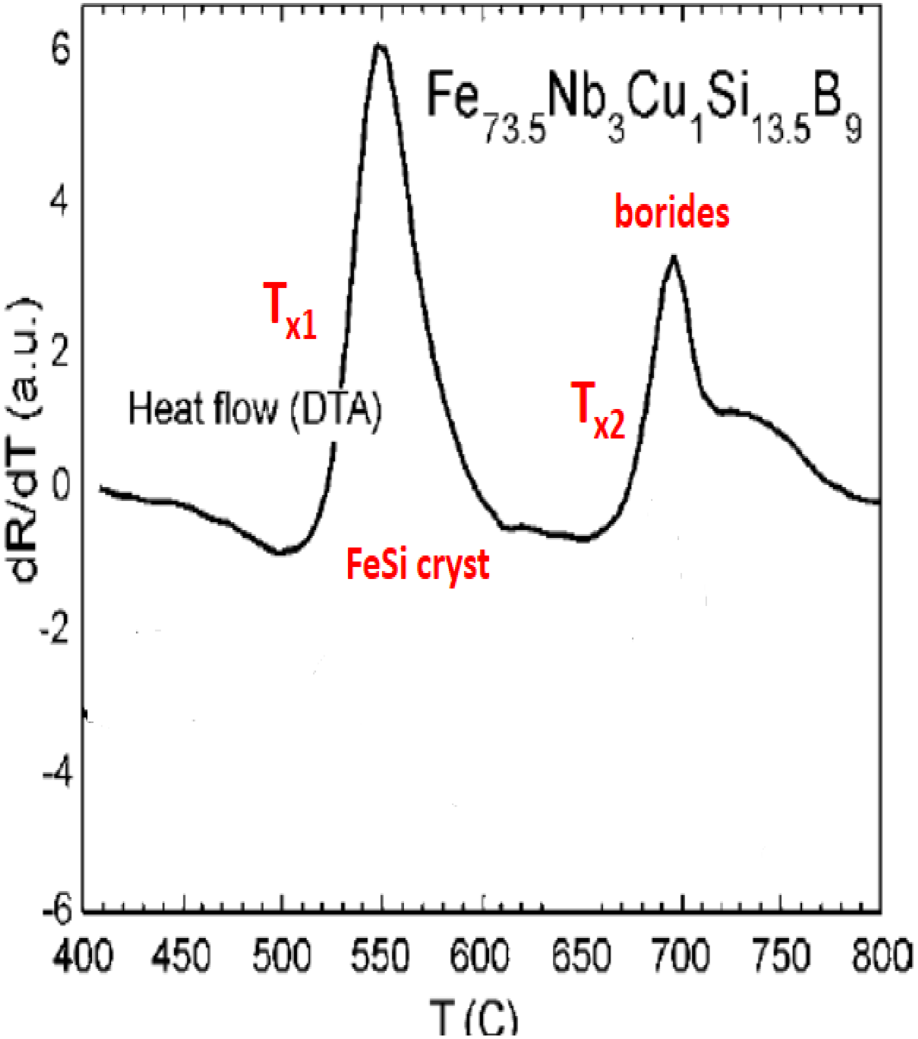


Fig. 6. Relation between grain diameter and μ_r of nanocrystalline alloys annealed in the condition which does not form Fe–B compounds.



Reprinted from Herzer

The crystallization temperature is measured by heat evolution in a DTA



Tx is temperature when crys. begins

Tx1 FeSi crystals form around 550ºC
Tx2 Borides form around 700ºC

This is why annealing is done at 550ºC

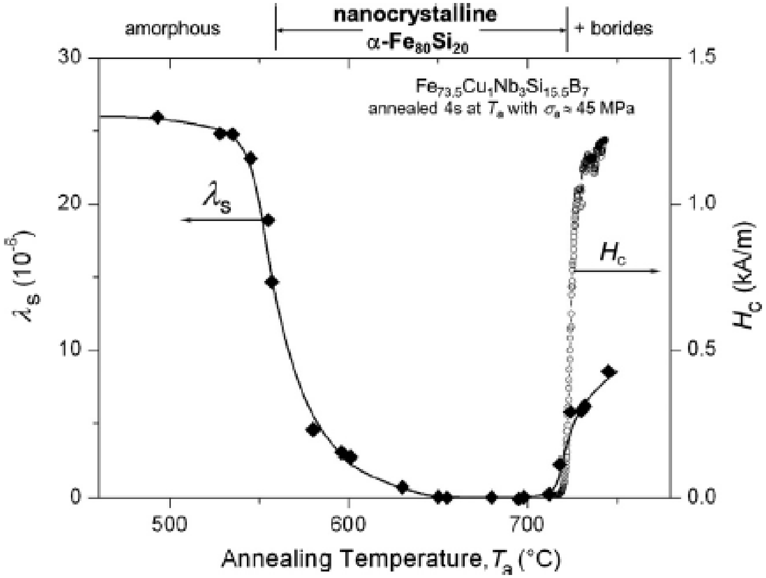
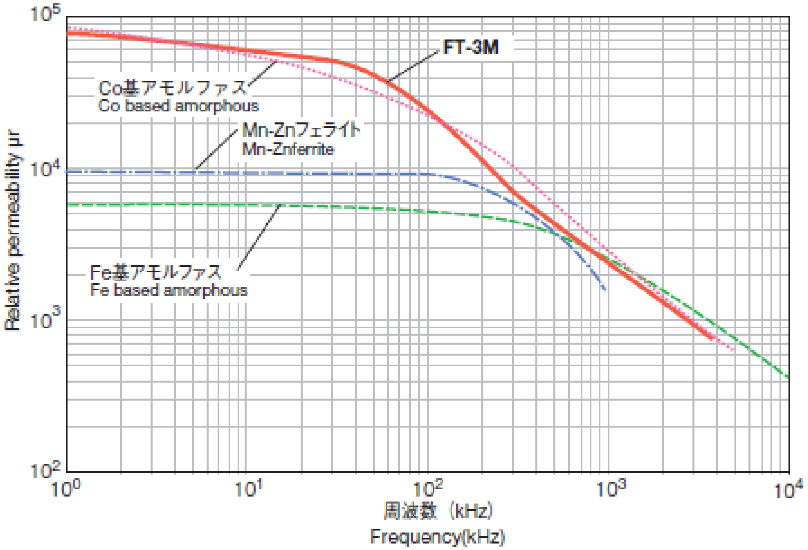


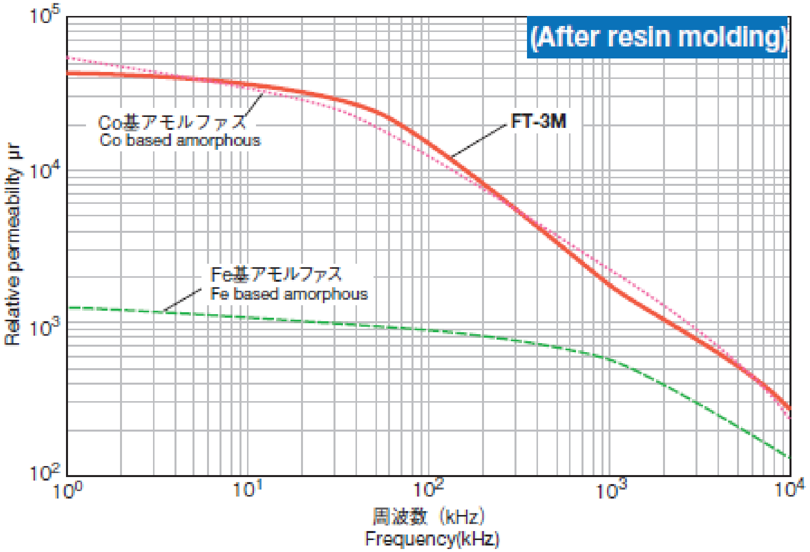
Fig. 1. Variation in saturation magnetostriction λ_s and coercivity H_c as a function of annealing temperature, indicating the various stages from as prepared amorphous to primary Fe–Si nanocrystallization to secondary Fe–B compound formation. Data adapted from Ref. [13].

SOME ASPECTS OF THE CRYSTALLIZATION
OF FINEMET- AND NANOPERM-LIKE ALLOYS

J.M. BARANDIARAN

Magnetic Nanocrystalline





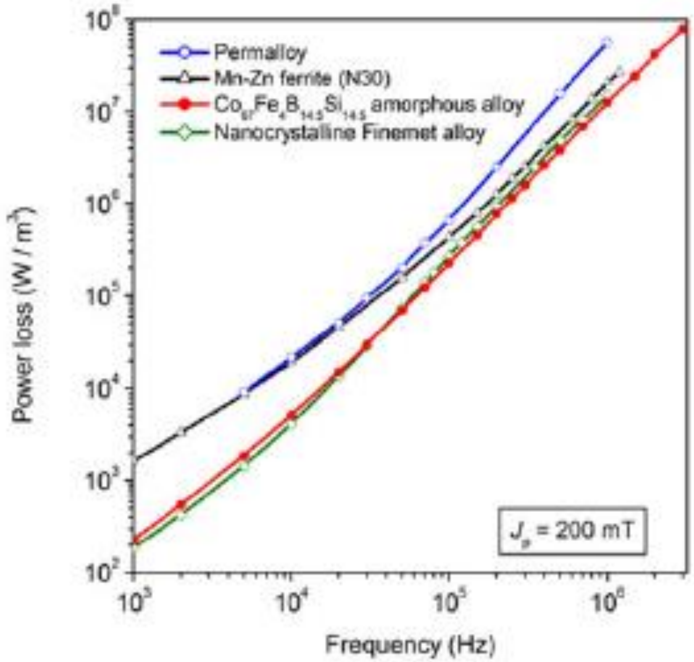


FIG. 2. Power loss at intermediate and high frequencies and peak polarization value J_p = 200 mT in tapewound ring samples of $Fe_{15}Ni_{80}Mo_5$ Permalloy (ribbon thickness d = 25 μm), amorphous $Co_{67}Fe_4B_{14.5}Si_{14.5}$ alloy (d = 13.7 μm), nanocrystalline (Finemet) $Fe_{73.5}Cu_1Nb_3B_9Si_{13.5}$ alloy (d = 20.3 μm), and in a sintered Mn–Zn ferrite. The tapewound samples have been annealed under a transverse saturating field.

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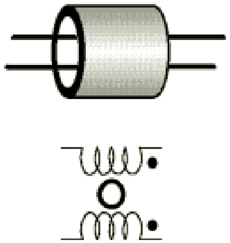
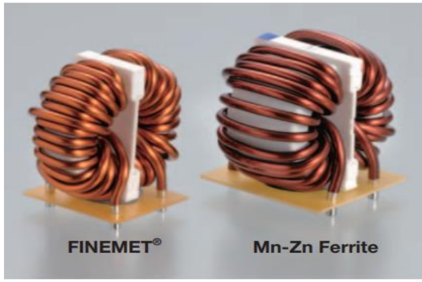
Typical filter: applications

CMC (common mode choke)



CMCs FOR HIGH POWER CENTRAL AND UTILITY GRADE PHOTOVOLTAIC-INVERTERS UP TO THE MW-RANGE

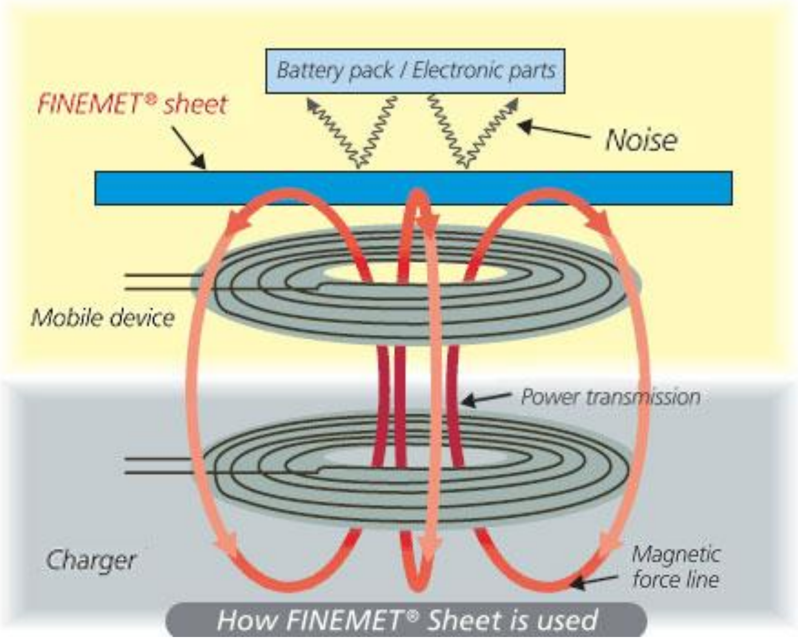
[1] Design example: $I_{rms} = 2 \times 400$ A, $L = 2 \times 1.5$ mH, $U_{is} = 1000$ V_{rms},
mechanical dimension 276 mm x 287 mm
(without cable and cable lugs)



- "All" the electric equipment connect to the grid need to have one. The use on connection to the electrical machine is growing to rise the insulator and bearing life.
- Important properties: 1)high initial permeability at high frequency, 2)High DC immunity (high B), 3)high thermal immunity
- Materials: ferrite, nanocrystalline.

Shielding: Irradiated EMI

- Filter for conducted EMI
- Shielding for irradiated



How FINEMET® Sheet is used

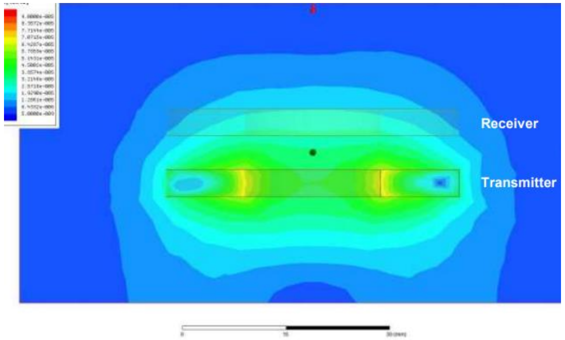


Figure 6 Magnetic flux density distribution without shielding (software simulation)

The shield reduces the external field

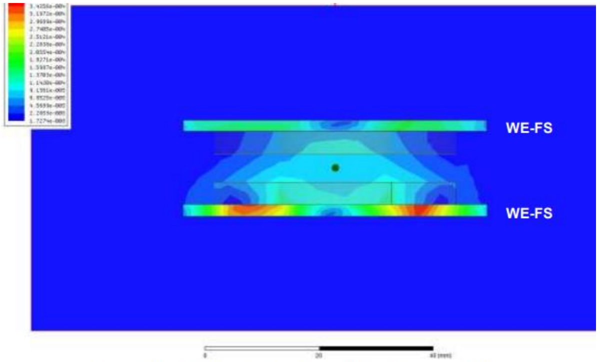
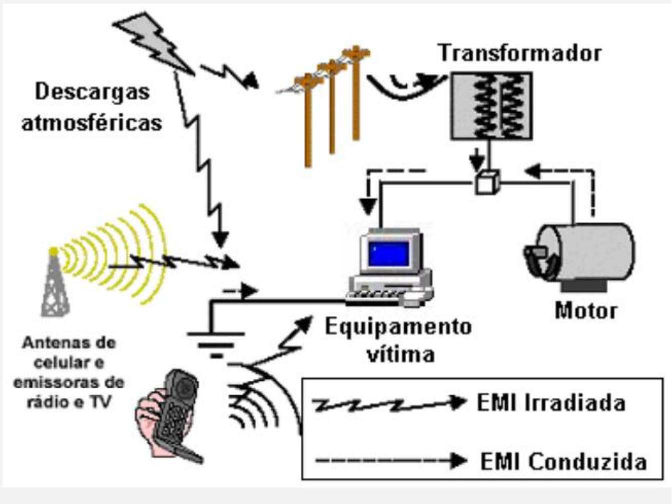


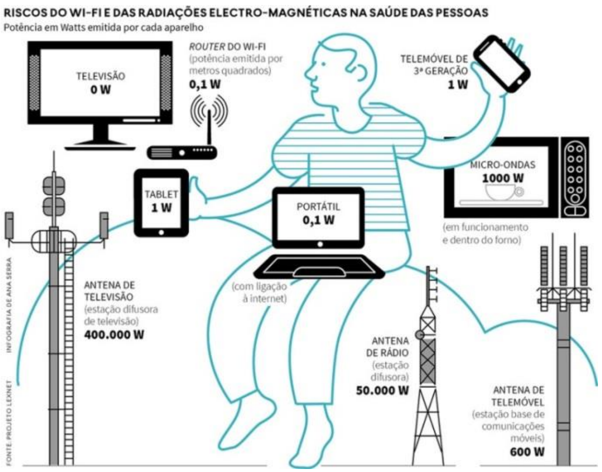
Figure 8 Magnetic flux density with shielding (software simulation)

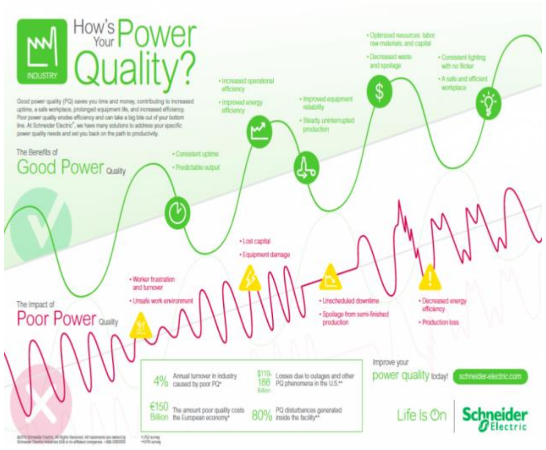
The shield rises the fied inside the “wire less charger” ⇔ better efficiency

The electrical energy and the “Electromagnetic pollution”

Inter(national) Standards assures an appropriate electromagnetic environment for equipment, people and electric grid







IEC 61000 series

ICNIRP Rules
(International Commission on Non-Ionizing Radiation Protection)

Brazil
ONS PRODIST 2018
IEC 1000, IEEE 519,NEMA etc

Road Map (Technological Drive)

	Solar inverter	Wind Power	Electricity installation	Power System Protection/Instrumentation	Inverter Welder machine	Electrostatic precipitator	Induction Heating	Industrial inverter	Consumer electronic (LED, Air conditioning	Electric locomotives	Automotive	Wireless charger
Miniaturization			X		X				X		X	
Higher power	X	X			X			X		X	X	X
Efficiency	X				X	X	X	X	X	X	X	X
Frequency	X			X		X	X	X	X	X	X	X
Linearity			X	X								
DC immunity			X	X				X				
Reliability		X		X				X	X	X	X	X

Keysight Technologies Challenges and Solutions for Power Testing in Automotive Applications Technical Overview

Key challenges facing vehicle electrification systems

– Must be reliable under a wide range of conditions/ Must function over a wide temperature range (e.g. -40 to +150°C)
– Employ large operating currents and voltages (e.g. 200 A, 650 V)
– Need high conversion efficiencies
– Need high operating frequencies to reduce module size and weight
– Need reliable sensors to provide critical safety information
– Must utilize SiC/GaN devices to increase efficiency and functional temperature range

Road Map (Important Properties)

	Solar inverter	Wind Power	Electricity installation	Protection/ Instrumentation	Inverter Welder machine Power System	Electrostatic precipitator	Induction Heating	Industrial inverter	Consumer electronic (LED, Air conditioning	Electric locomotives	Automotive	Wireless charger
High saturation	X	x	X	X	X	X	X	X	X	X	X	X
Low loss/Low coercive force	X	X	x	x	X	X	X	X	X	X	X	X
High (initial) permeability	X	X			X	X	X	X	X	X	X	X
Thermal, Mechanical stability		X		X				X	X		X	X

Road Map (Components using nanocristalline materials)

T: today (*)

F: future

T/F: some products today, the future is promissive.

	Solar inverter	Wind Power	Electricity installation	Power System Protection/Instrumentation	Inverter Welder machine	Electrostatic precipitator	Induction Heating	Industrial inverter	Consumer electronic (LED, Air conditioning	Electric locomotives	Automotive	Wireless charger
EMC Common mode Choke	T	T	T	T	T*	T*	T*	T	T	T	T	T
Transformer core: high power	F				T*	T*	T*	F				
Transformer core: low power (instrumentation)			F	T/F				F				
Other filters	F	F	F					F				
Shielding									T/F		F	T/F

Summary (Properties: comparison at high frequency)

Material	Bmax	µ	Losses	Mechanical Degradation	Thermal Degradation	B or µ linear/ Controlable
Fe-Si (at low freq) Only for reference	Highest	Medium	Medium	Medium	Low	No[1]
Fe-Si [2]	----	Too Low	Too High	----	----	----
Ferrite	Low	Medium	Medium	High	High	No[1]
Amorphous[3]	High	High	Medium	High		Yes
Permalloy	Medium	Medium	High	Low		No
Nanocrystalline	High	High	Low	Low	Low	Yes

O Nb pode ser substituído?