Modification of domain structures at Fe-Si alloy surface via the laser scribing technology

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COST Action no. MP1401

Advavced fibre laser and coherent source as tools for society, manufacturing and lifescience.

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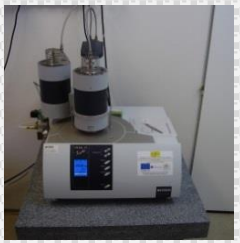
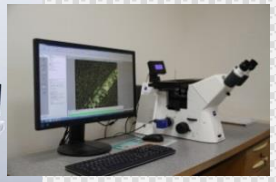
Laboratories

Laboratory for the Preparation of TEM Samples
Laboratory of Materials Thermal Analysis
Laser Laboratory
Laboratory of Mechanical Testing
SEM/FIB Laboratory
Laboratory of Progressive Alloys
SPS Laboratory
Laboratory of Sintering and Heat Treatment
Laboratory of Micro-Nanoindentation
Laboratory of Environmental SEM
Nanotechnological Laboratory
Laboratory of Light Microscopy
Laboratory of Chemical Surface Analysis
Laboratory of PVD Technologies







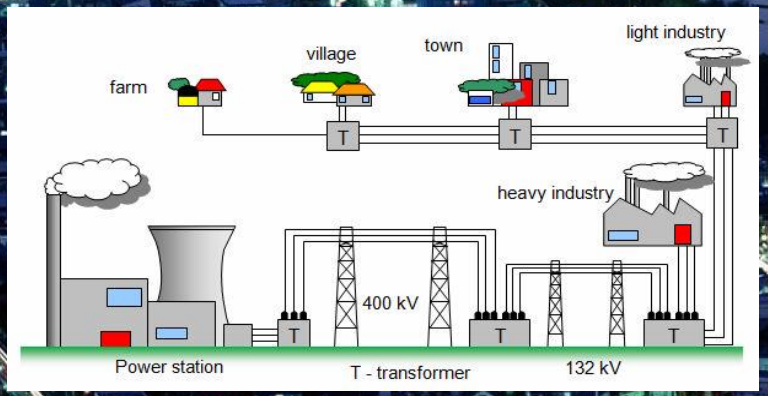


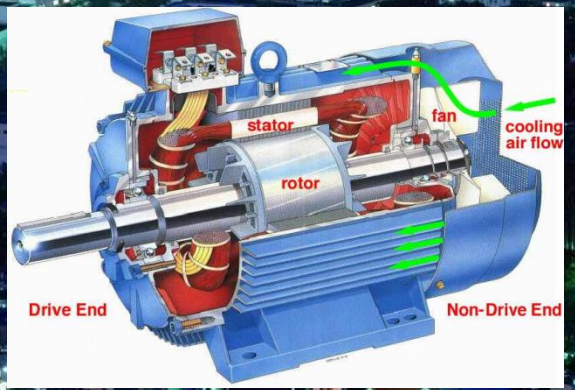


M O T I V A T I O N

Almost all power energy is transported for a long distances and then distributed, by transformers, to electrical devices. Both transformers as well as electrical machines consist of a particular type of electrical steels. These steels are produced by a different way from different basses materials called Grain-oriented and Non-oriented steels and used in transformers and rotating equipments respectively.

ELECTRIC POWER SERVES THE MANKIND



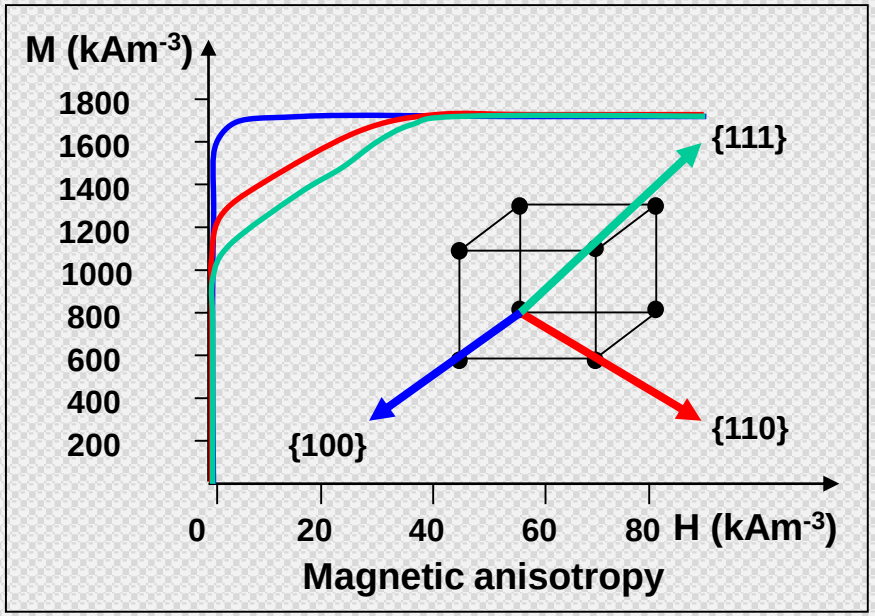


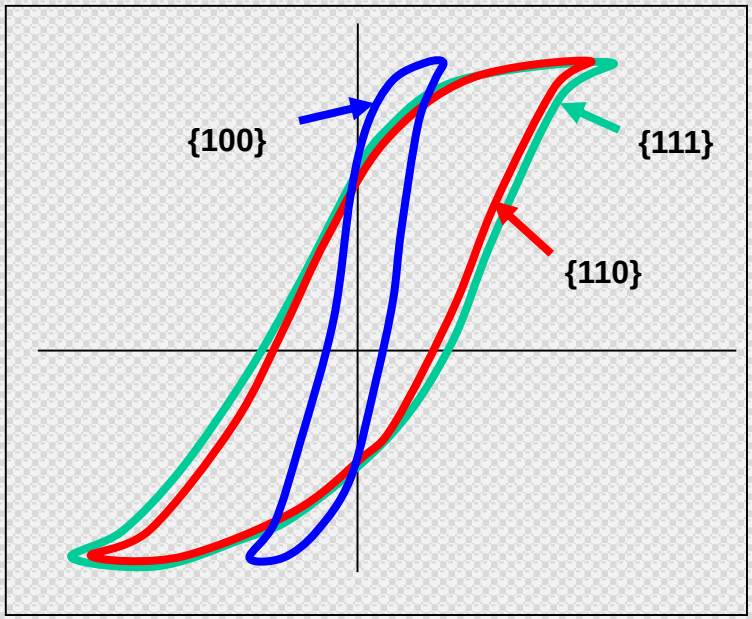
ELECTRICAL STEELS PLAY VITAL ROLE IN THIS SERVISE

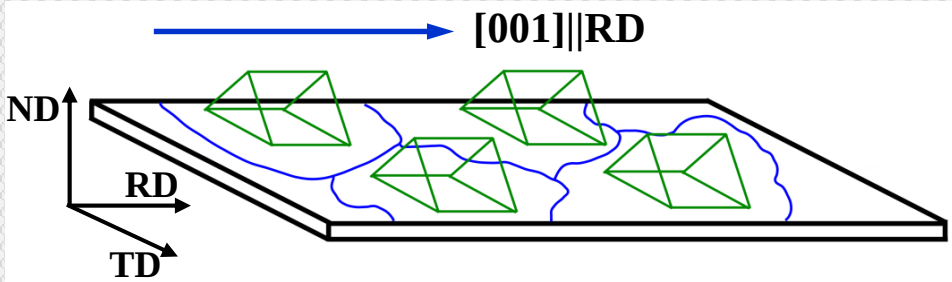
Scientific background

❖Minimization in magnetic losses in electrical steels improves electrical equipments efficiency.

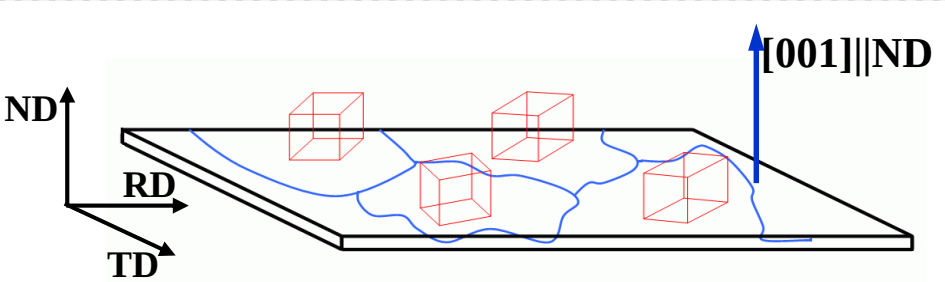
❖Magnetic properties (core losses) are also very depended on the direction of magnetization in the crystal lattice.





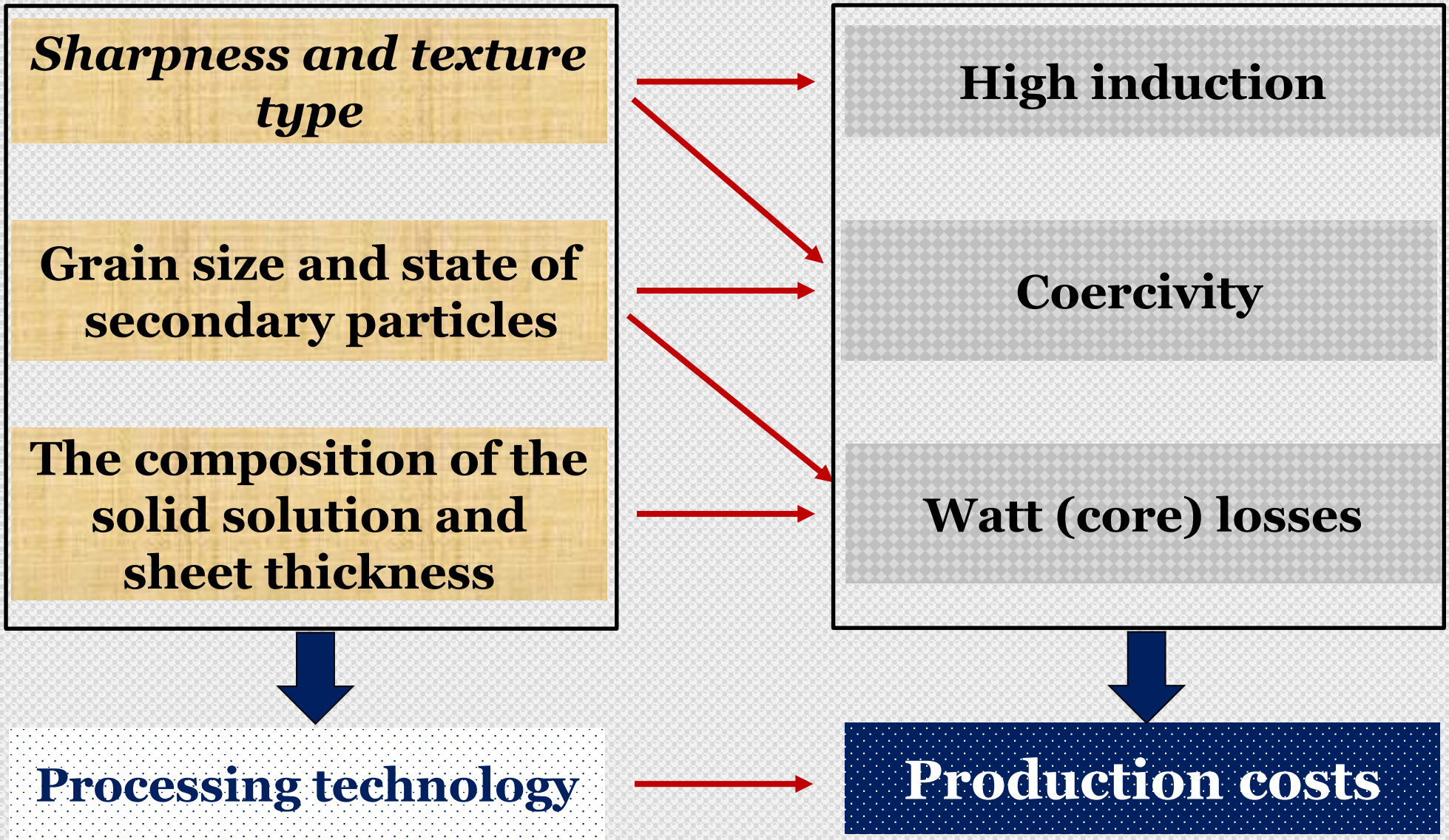


Grain – oriented with goss texture



Non – oriented with rotated cub texture

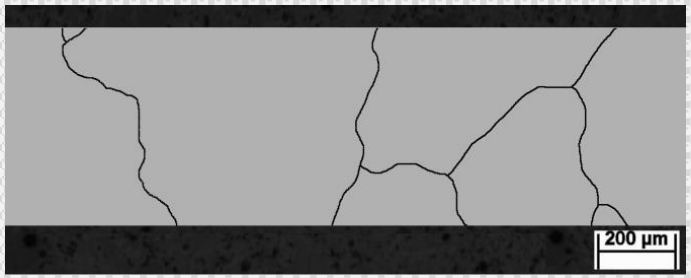
Factors which influence on the magnetic properties



Factors which influence on the magnetic properties

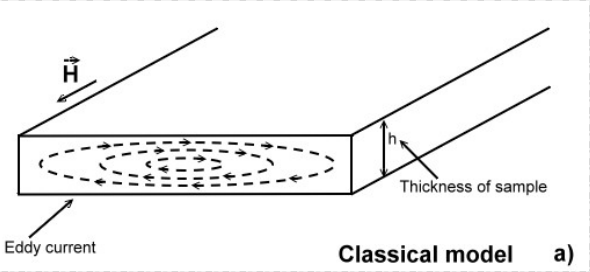
Core losses

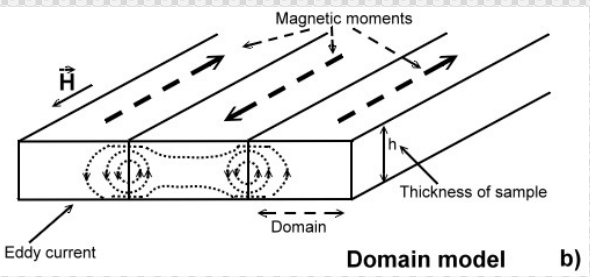
- **Eddy current**
  - High alloy content
  - Small grain size
  - Thin material
  - Good texture
- **Hysteresis**
  - Low impurity level
  - Large grain size
  - Surface quality
  - Sharpness texture

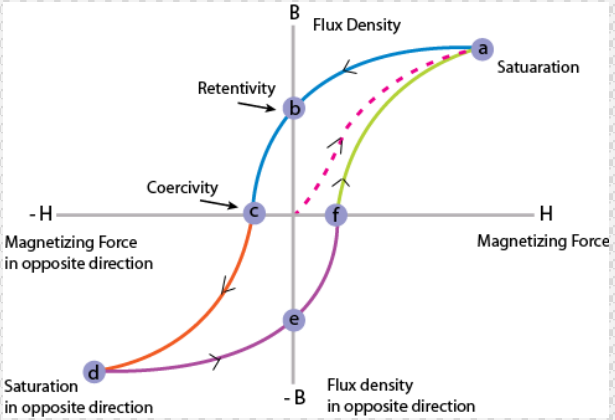


Microstructure of non-oriented electrical steel

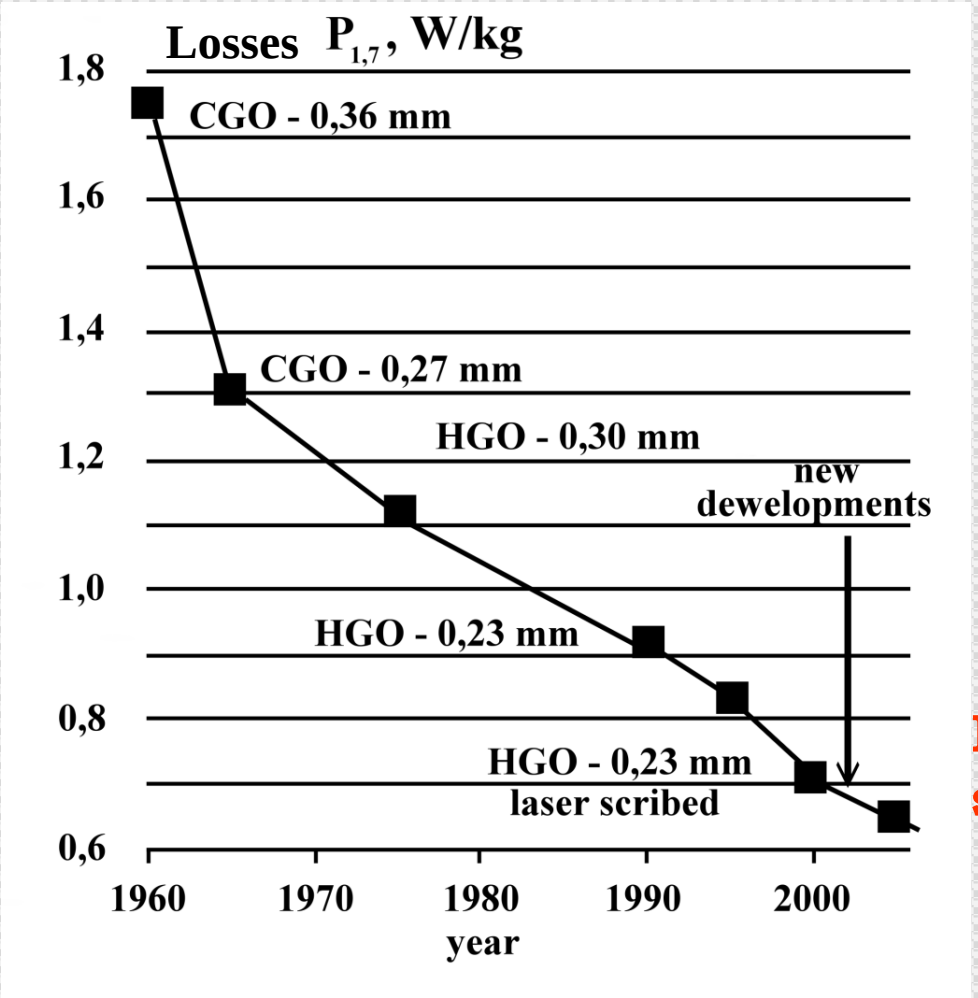
Microstructure of grain-oriented electrical steel







Current status



Magnetic properties:

B_{800}=1,8-1,93 T; H_C=5-10 A/m

Texture:

Deviation for CGO ~ 7°

Deviation for HGO ~ 3°

Heat tretmen during the box annealing : 90-120 hod

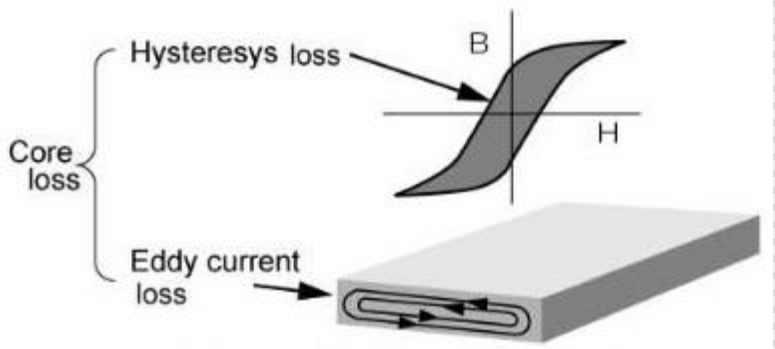
Future directions

Perfectly oriented transformer sheets: B_{800}=2,03 T

Reduce production costs

Electrical steels and eddy current losses

-VEGA - 2/0120/15: "The modification of domain structure of silicon electrotechnical steels by laser beam."



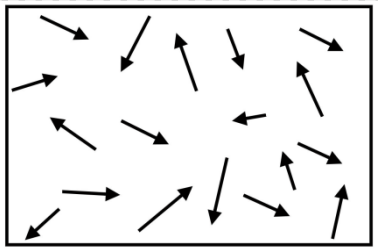
Factors and methods which influence on the reduction of eddy current losses

Sheet thickness ↓ **... rolling**

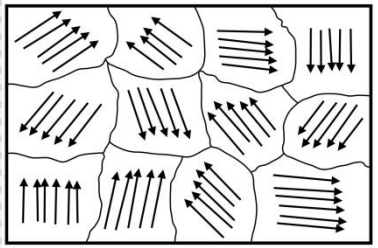
Electrical resistance ↑ **... addition of Si**

Domains wall ↔ **... refinement**

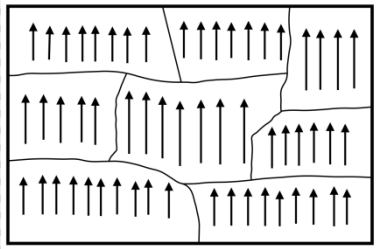
laser scribing



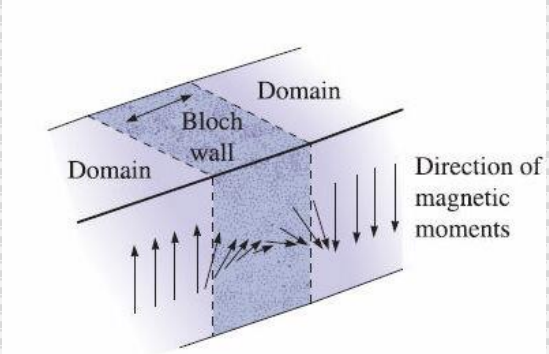
Non-magnetic material



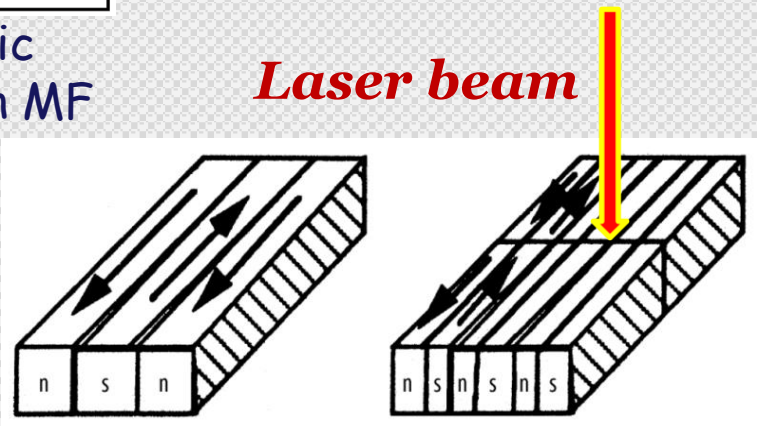
Magnetic material



Magnetic material in MF

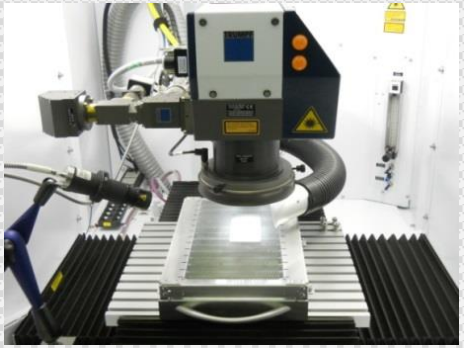


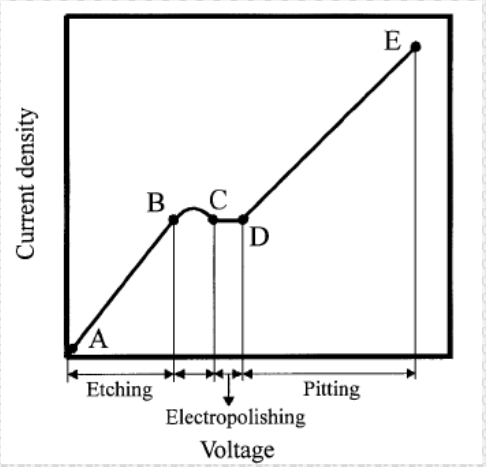
Laser beam

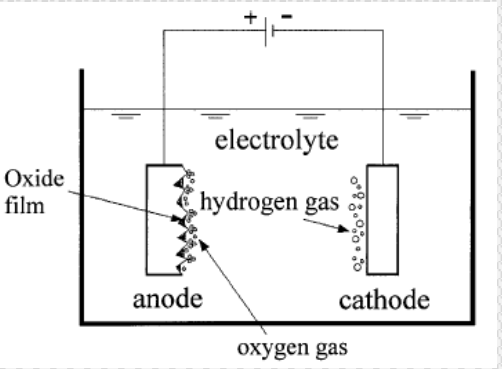


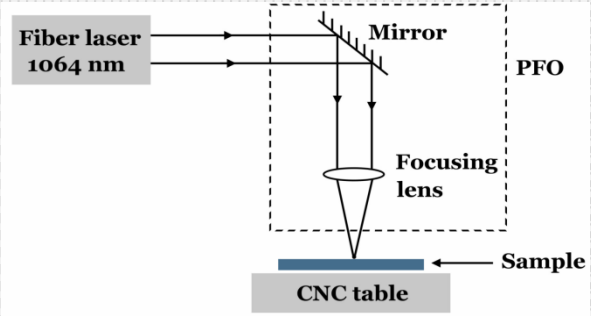
Scheme of domain refinement

Laser scribing process









Technical specifications

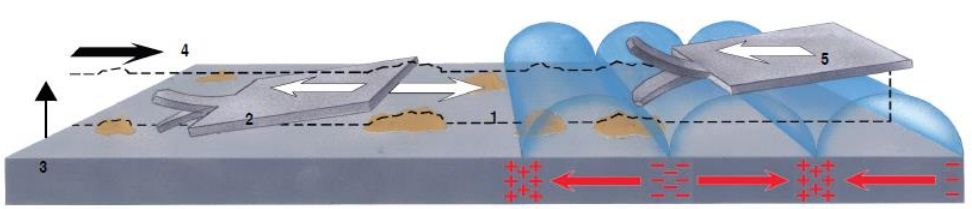
- Power of the beam: from 3 to 400 W
- Wavelength :1070 nm
- Beam diameter in focus :17µm - 200µm

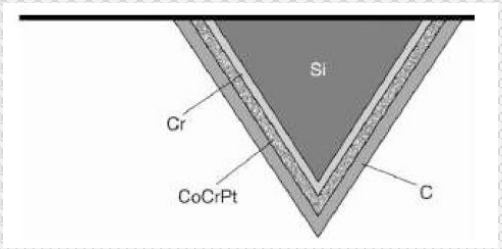
Apparatus for electrolitical polishing LectroPol-5

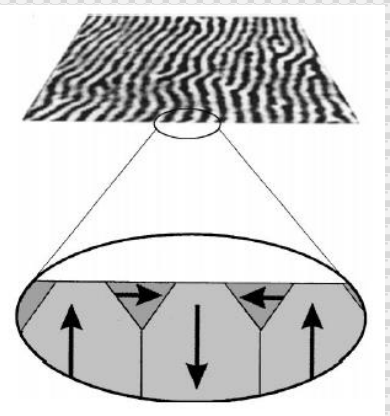
Domains imaging by three different methods

1) *Bitter observation technique: combine magnetic colloid suspension and classical optical microscope*

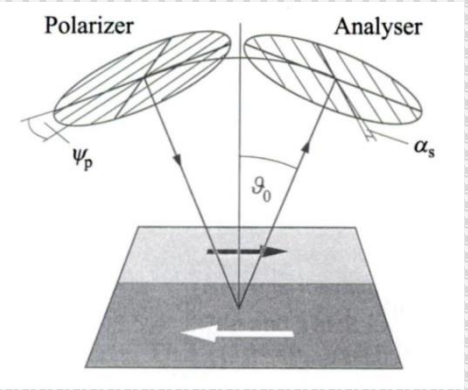
2) MFM method include - Domains made visible by AFM

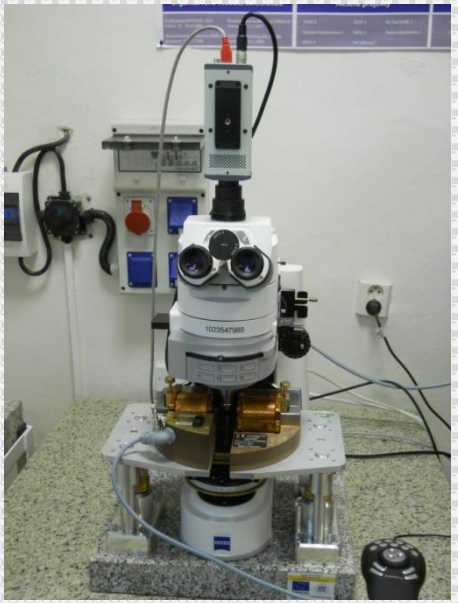




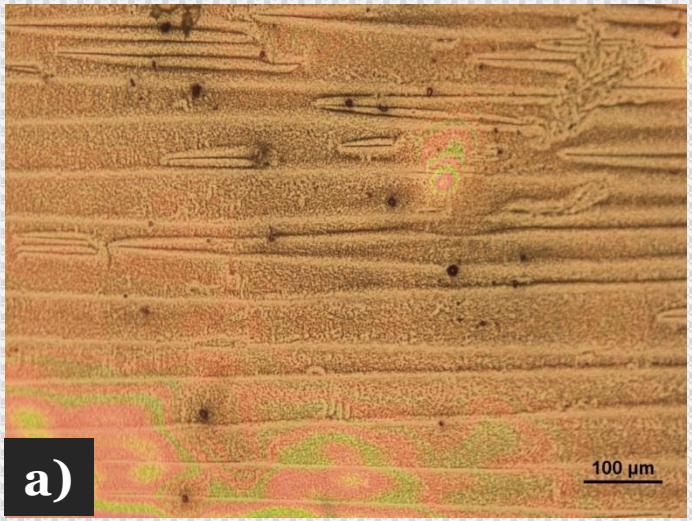


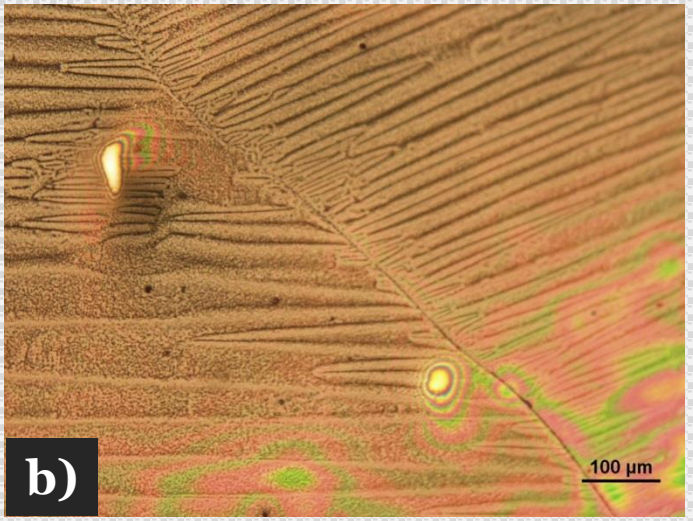
3) *Kerr method:* domain imaging by scanning magneto-optical microscope



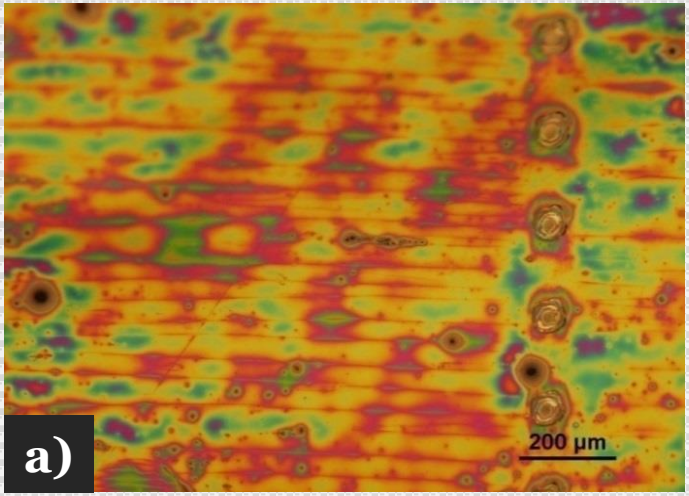


Bitter method



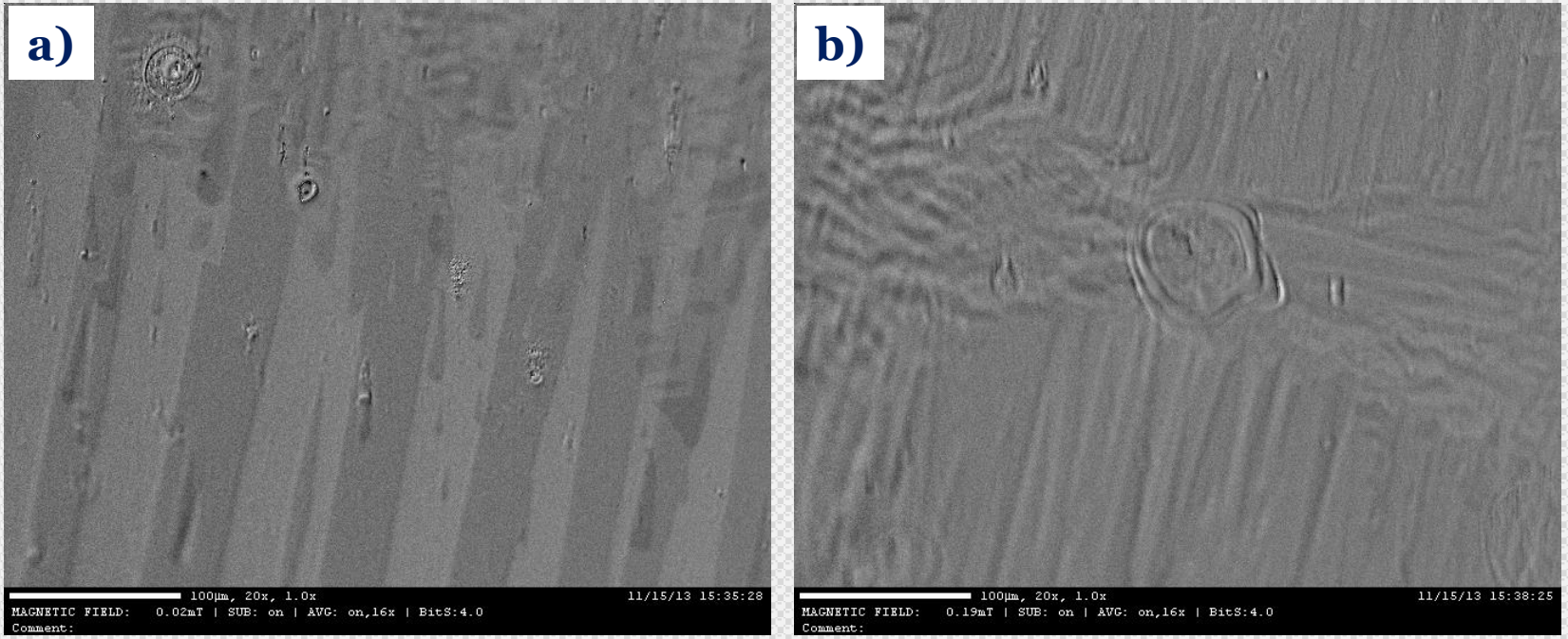


Domains made visible by *Ferrofluid* in the GO silicon steel without laser treatment: a) in frame of grain, b) grain boundarie



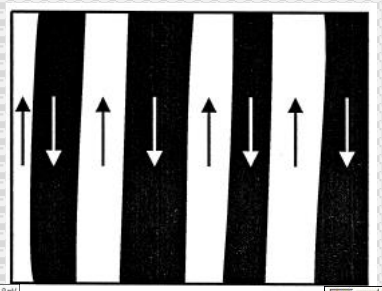
Domains refinements of GO electrotechial steel by laser beam: a) pulse mode, 5 mJ and b) continuous mode, 10mJ

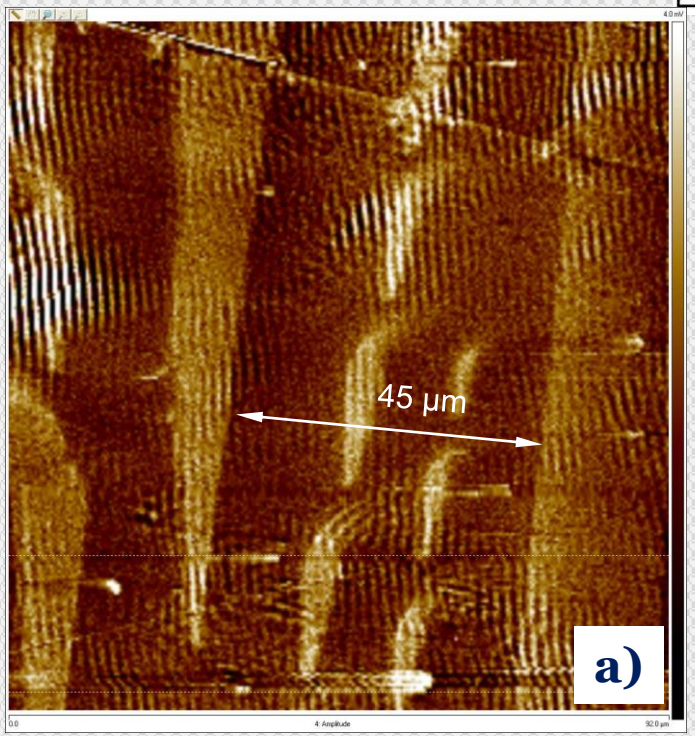
KERR method

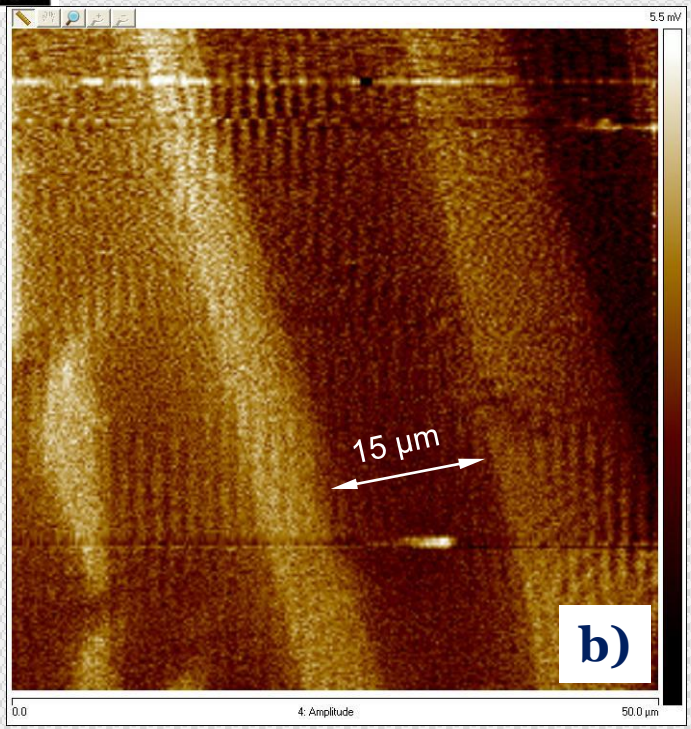


Primary magnetic domains made visible by *KERR microscopy in the silicon steel without laser treatment, (b) refined domains in the 0.6 mJ laser treated silicon steel - labyrinthine structure near the laser spot*

MFM method

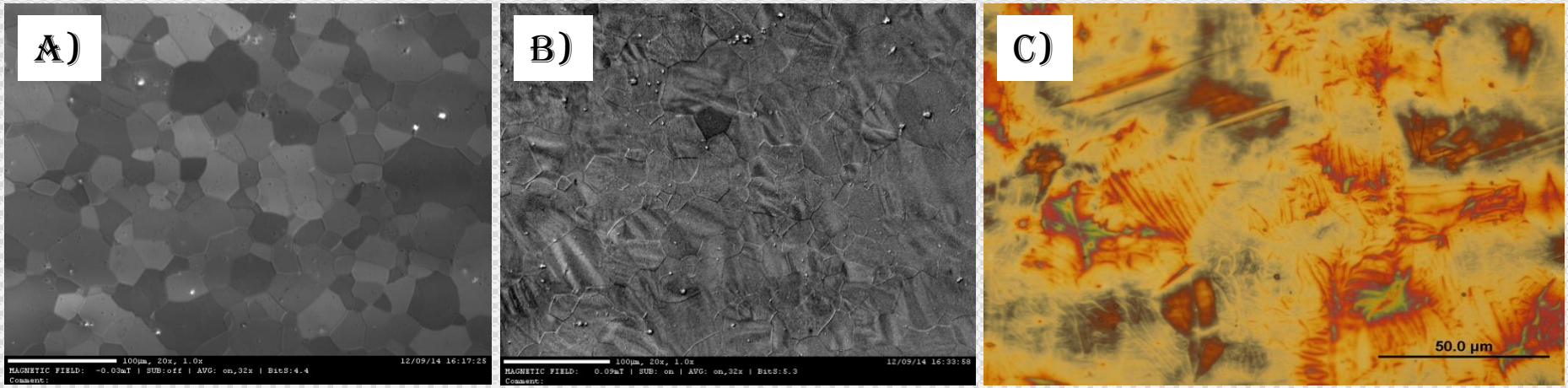




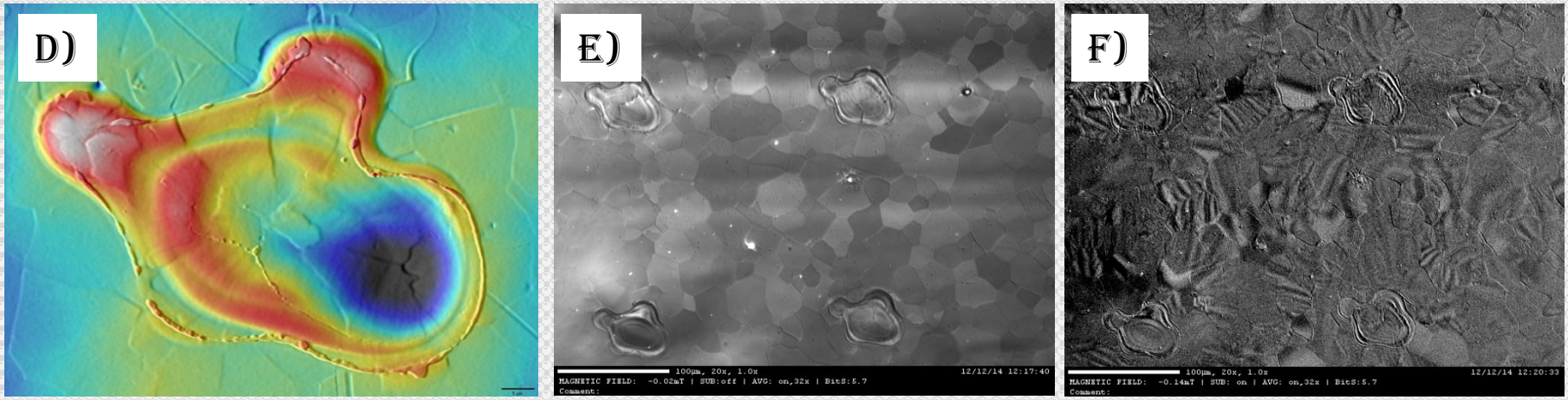


Domains made visible by AFM in the silicon steel without laser treatment (area 90x90µm) - magnetic domain sub-structure - lancet domains (arrow), (b) domains in the 0.6 mJ laser treated silicon steel (area 50x50µm)

The magnetic domains structure of non-oriented steel

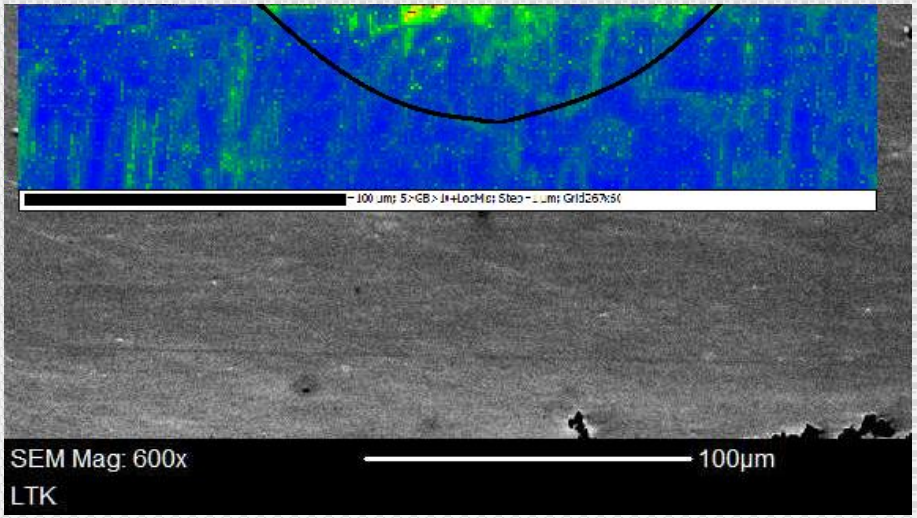


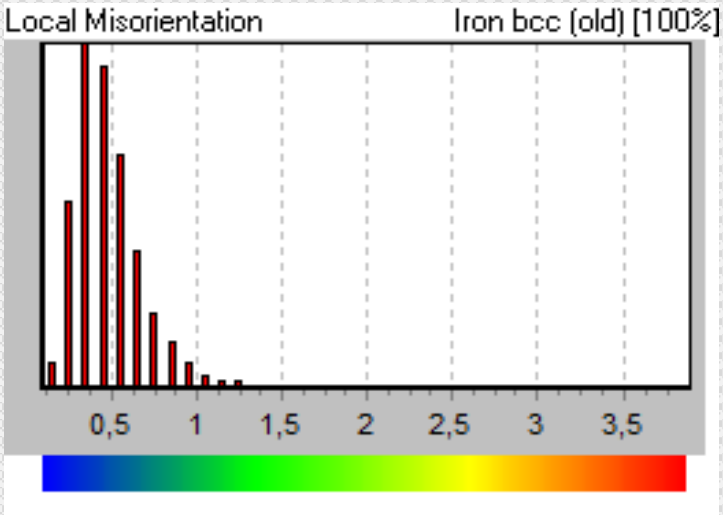
Non-oriented electrical steel: a) microstructure, b) domains structure in individual grains (*Kerr microscope*), c) Domain structure of steel with averige size of domains - 10µm (*Bitter methods*)



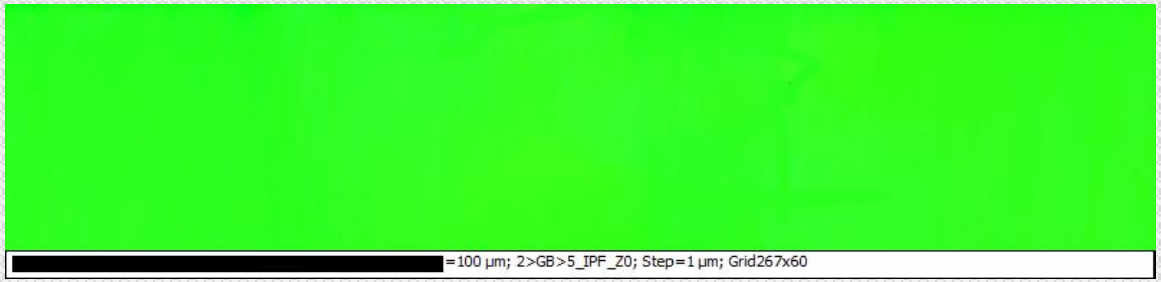
d) profile of the laser pulse 50W, 20µs (*Konfocal mikroscope*), e) microstructure of steel with laser pulse, f) domain structure of steel around the laser pulse.

Texture of GO steel after laser scribing

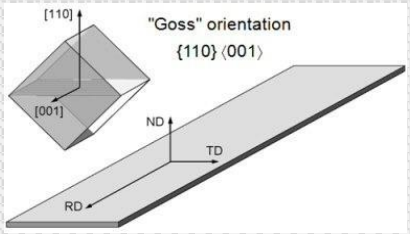


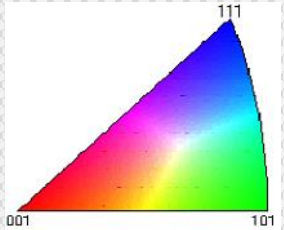


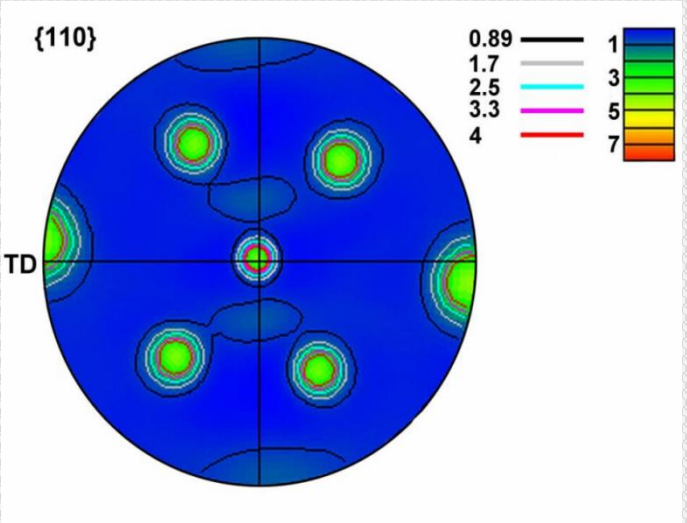
SEM image of microstructure of GO steel after laser treatment with local misorientation map obtained from EBSD analysis



IPF map of cross – section plane in GO steel laser scribing

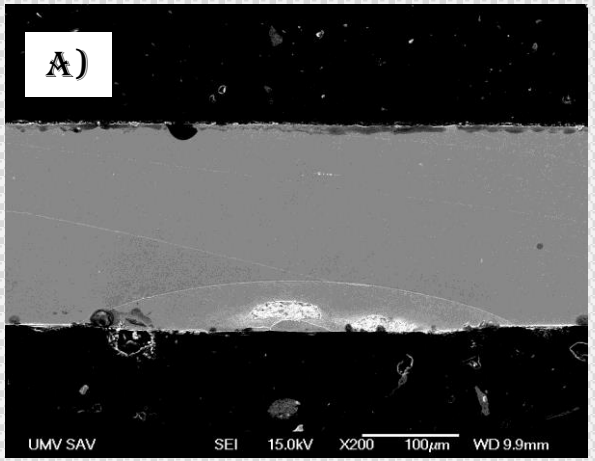


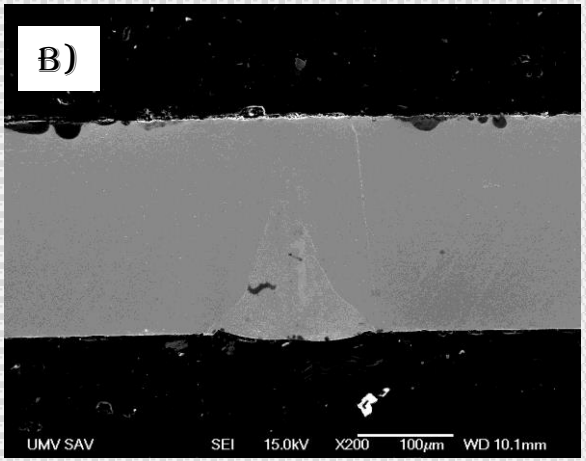


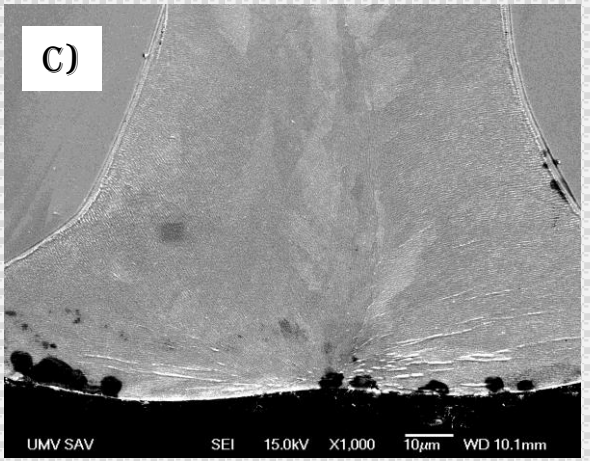


The pole figure taken at φ2 = 45° obtained from the sample after laser scribing

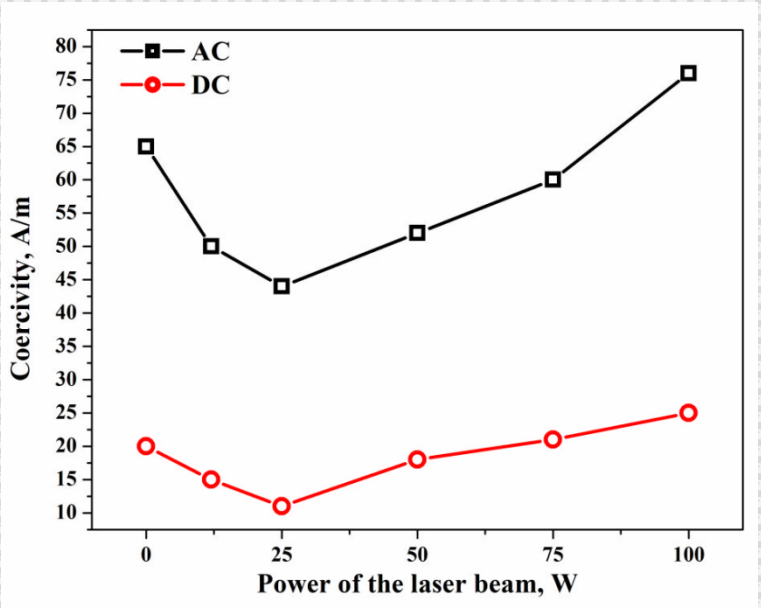
Magnetic domains and core losses





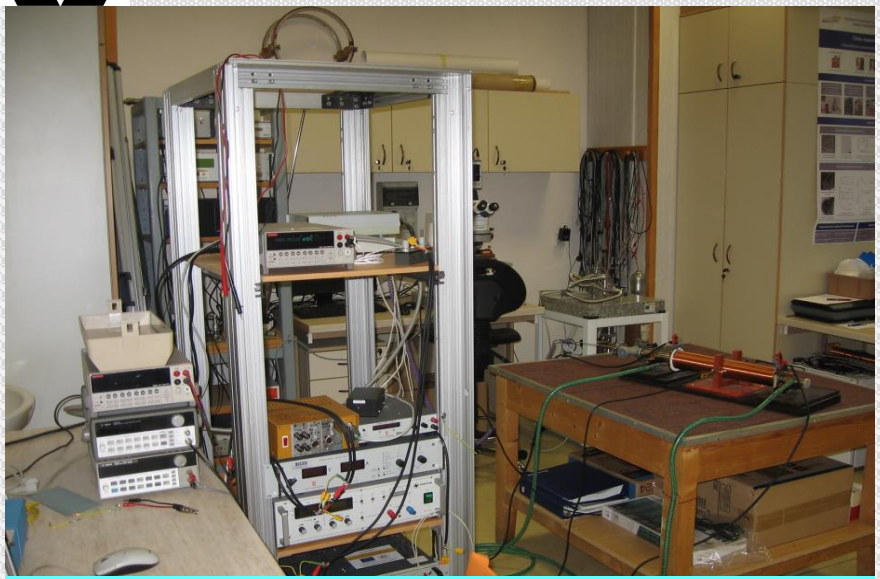


Laser pulse a) 100W, 5ms, defocus +10mm, b), c) 100W, 5ms beam focused on the sample surface

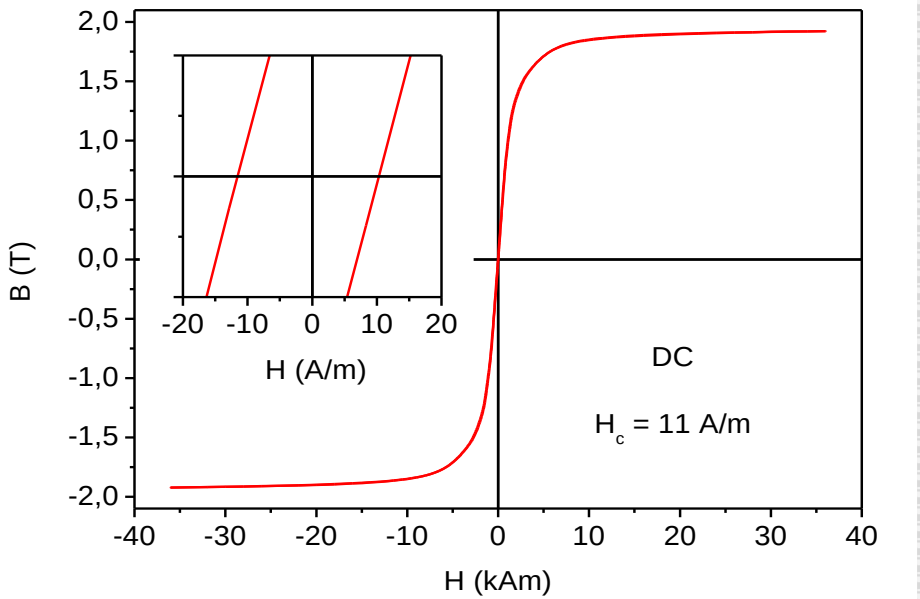


Sample	Interval of lines [mm]	Pulse energy [mJ]	Coercivity [A/m]	Magnetic domain width [μm]
1			21,0	45±4,2
2	3,75	0,6	14,0	23±2,9
3		5,0	20,5	38±3,6
4		50	22,5	50±4,1
5	5	0,6	11,0	16±2,1
6		5,0	21,5	39±3,8
7		50	23,0	50±5,5
8	7,5	0,6	15,0	25±3,4
9		5,0	21,0	43±4,1
10		50	2,15	47±4,4

Coercivity

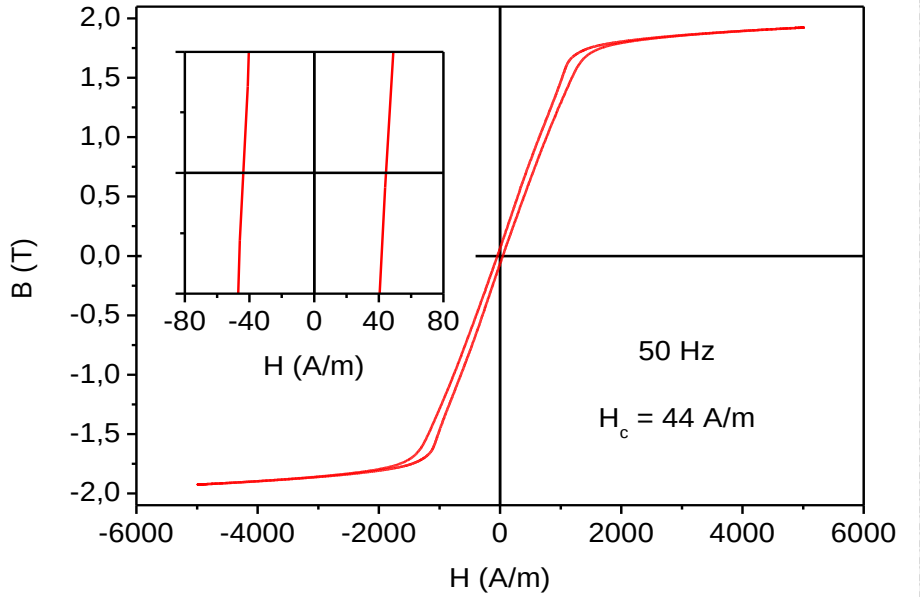


Förster type hysteresis loop tracer developed at the Institute of Experimental Physics SAS, Košice



DC hysteresis graph

Remagraph-Remacomp combination C-710, Magnet-Physik, Dr. Steingroever GmbH



AC hysteresis graph

Thank you for your attention!

The M-ERA.NET Call 2016

1. Topic: Nanobainite induced by laser surface modifications of steels

2. Topic: Investigation of thermoelectric properties of materials: Mg2Si and FeSi2

Deadline for pre-proposal submission 14th of June 2016, 12:00 noon Brussels time!