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IMPROVE OF MAGNETIC PROPERTIES OF FERRITIC Fe-Si STEELS BY PULSE AND CONTINUOUS FIBER LASER PROCESSING.

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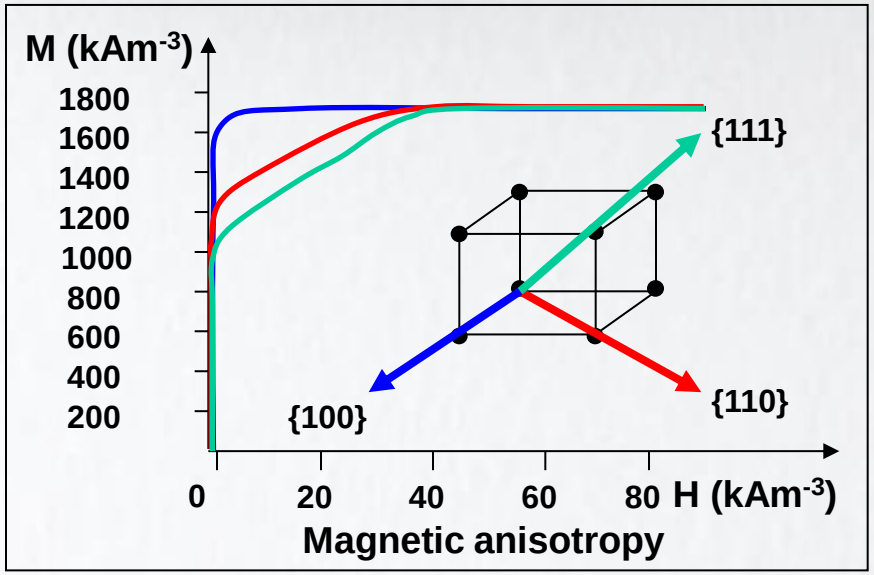
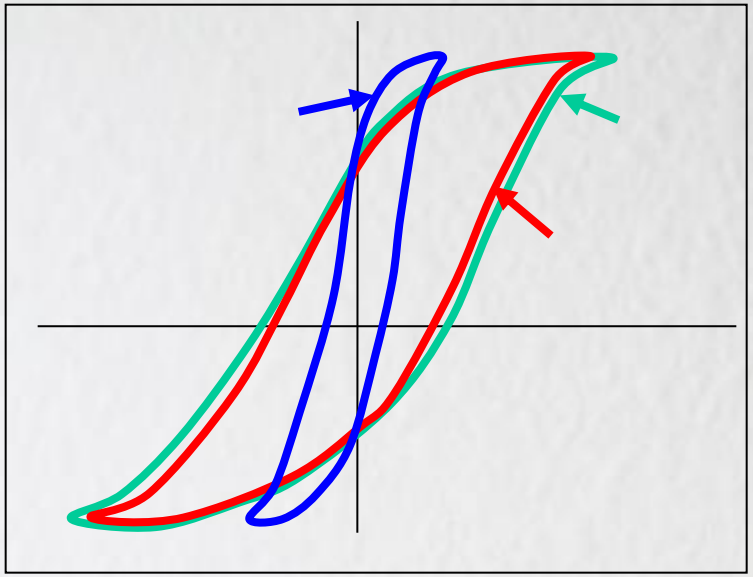
Electrotechnical steels

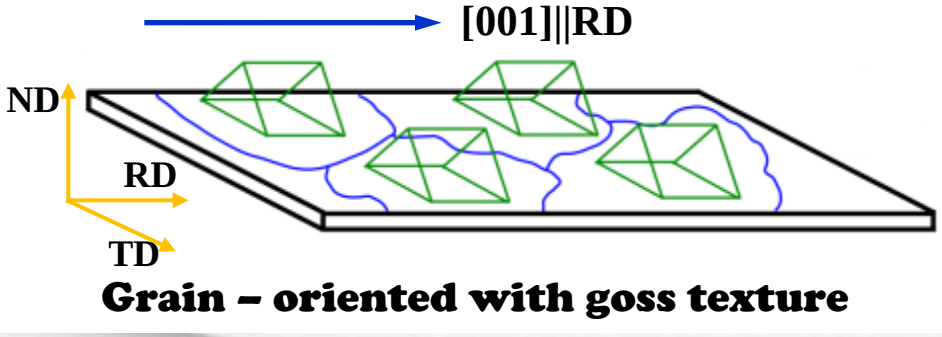
Scientific background

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

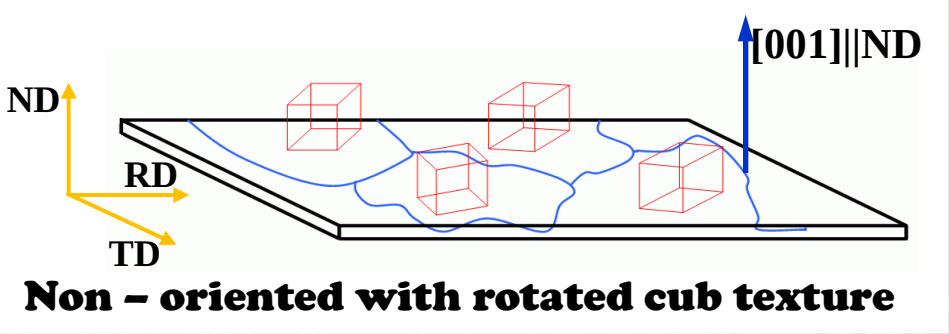
❖Magnetic properties (core losses) are also very depended on the direction of magnetization in the crystal lattice.





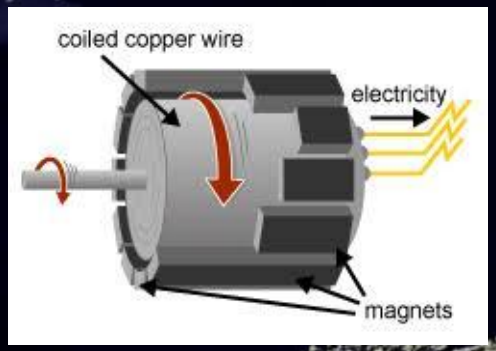


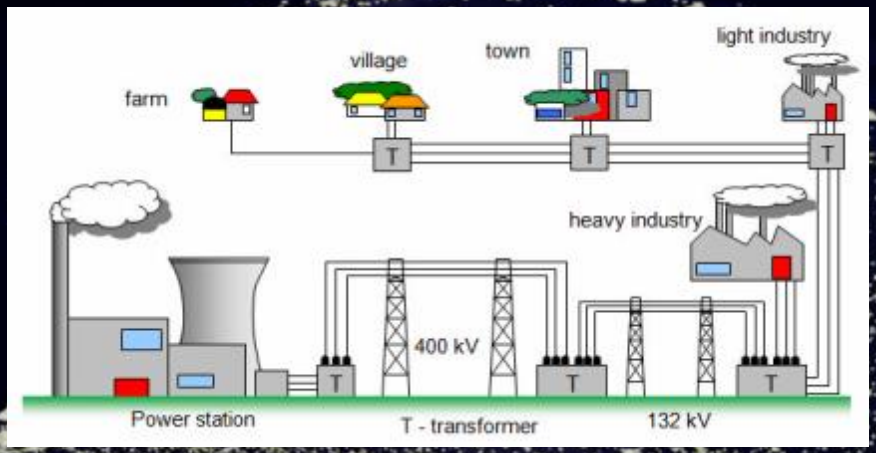
Grain – oriented with goss texture

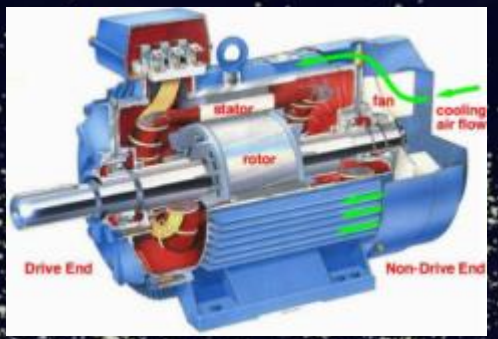


Non – oriented with rotated cub texture

ELECTRIC POWER SERVES THE MANKIND

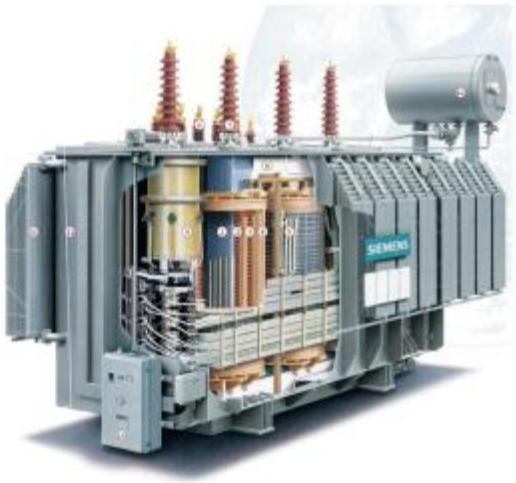






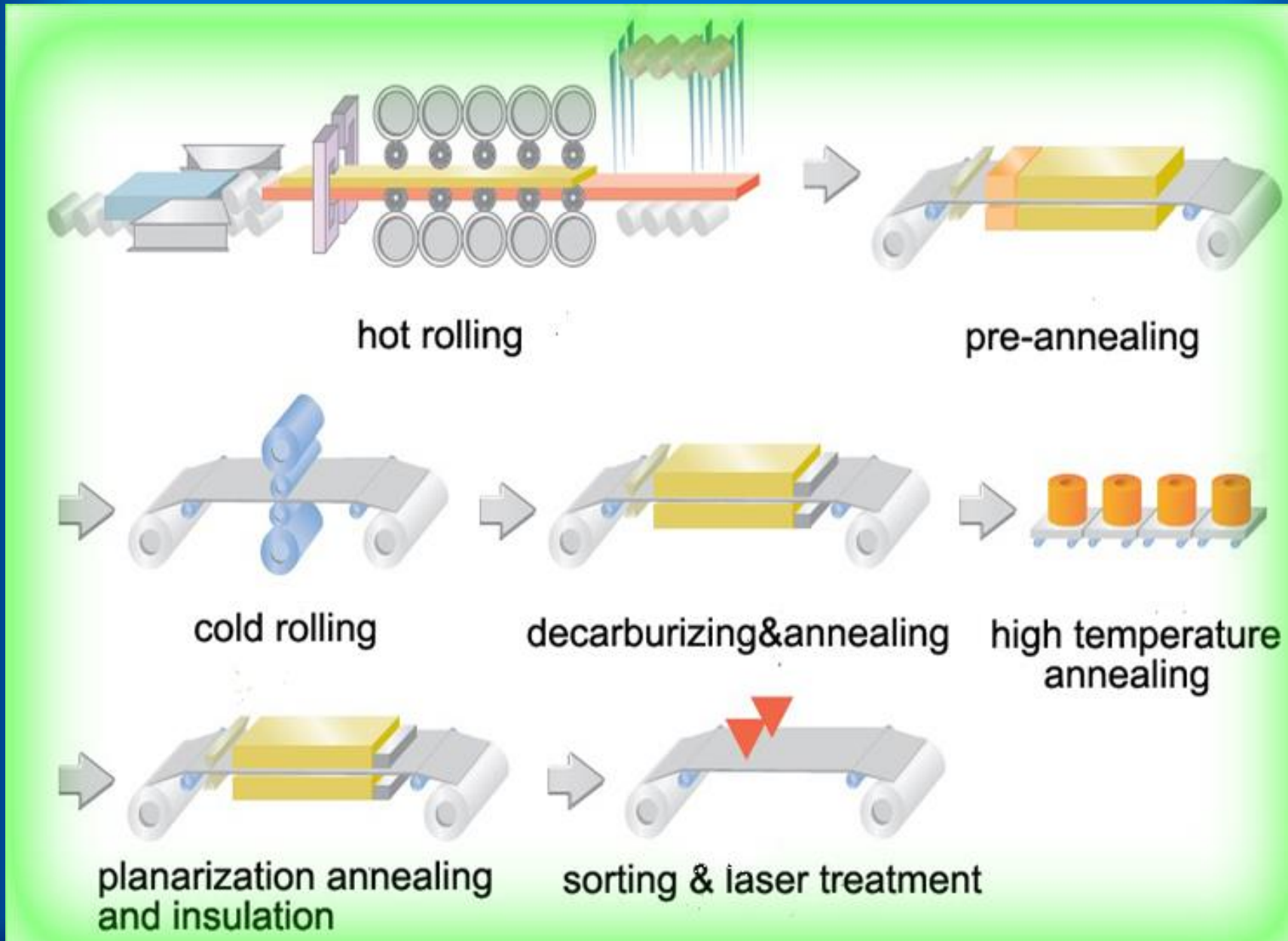
Transformer Main Parts

1. Three-limb core
2. LV Winding
3. HV Winding
4. Tapped Winding
5. Tap Leads
6. LV Bushings
7. HV Bushings
8. Clamping Frame
9. On-Load Tap Changer
10. Motor Drive
11. Tank
12. Conservator
13. Radiators

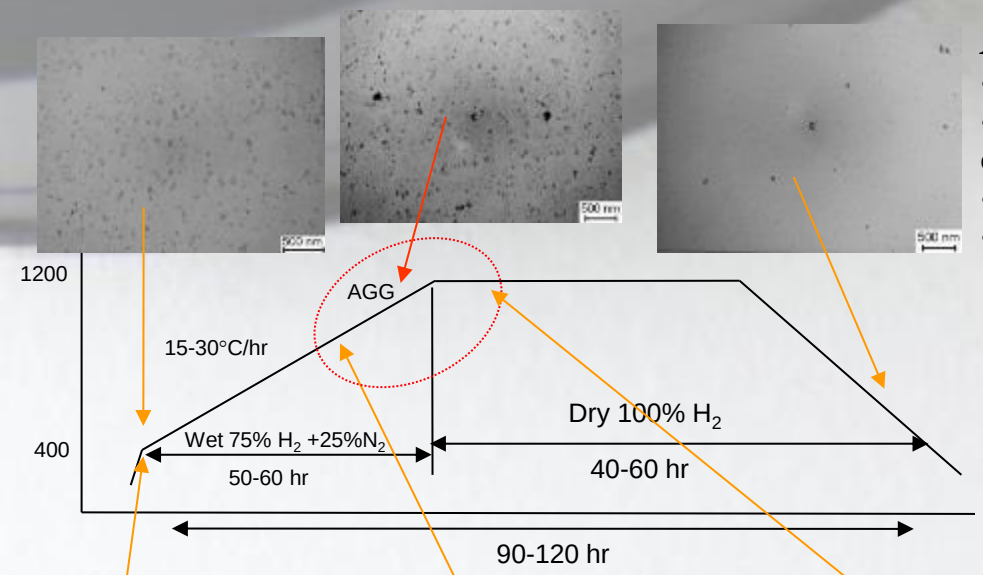


ELECTRICAL STEELS PLAY VITAL ROLE IN THIS SERVISE

Manufacturing process of GO steels



CONVENTIONAL (STATIC) PROCESS TO OBTAIN AGG IN GO STEELS



Principal schema of the box annealing

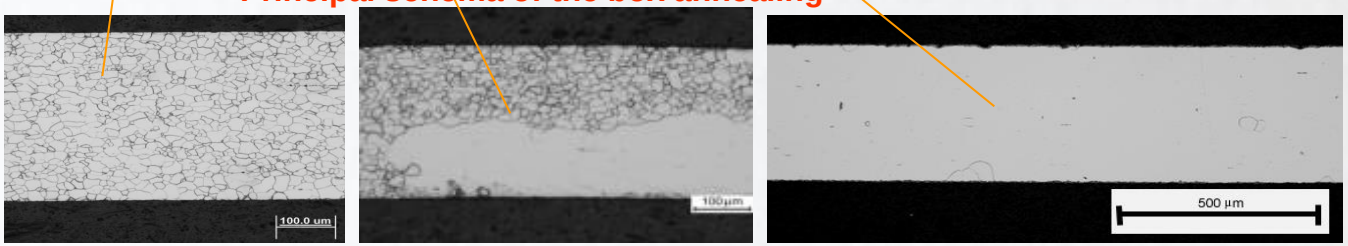
AGG v Fe-3%Si oceli:

- incubation period
- interaction between grains and precipitates has selective character
- bimodal grain size distribution onset of abnormal grain growth
- texture of the final state is characterized by sharp Goss texture

Because of slow heating 15-30°C/hour, *E*, F_V *are change very slowly with the temperature*

Low kinetic

$$\frac{dR}{dt}$$



PR OAGG AGG

Hence it is based on the selective interaction with the nanoprecipitates.

THE SECONDARY RECRYSTALLIZATION TEXTURE FORMATION IN GO STEELS EXPLAINED BY ONE OF THE TWO MODERN COMPETING MODELS: ORIENTED NUCLEATION AND ORIENTED GROWTH

ORIENTED GROWTH MODEL: CSL BOUNDARY, HIGH ENERGY BOUNDARY THEORIES

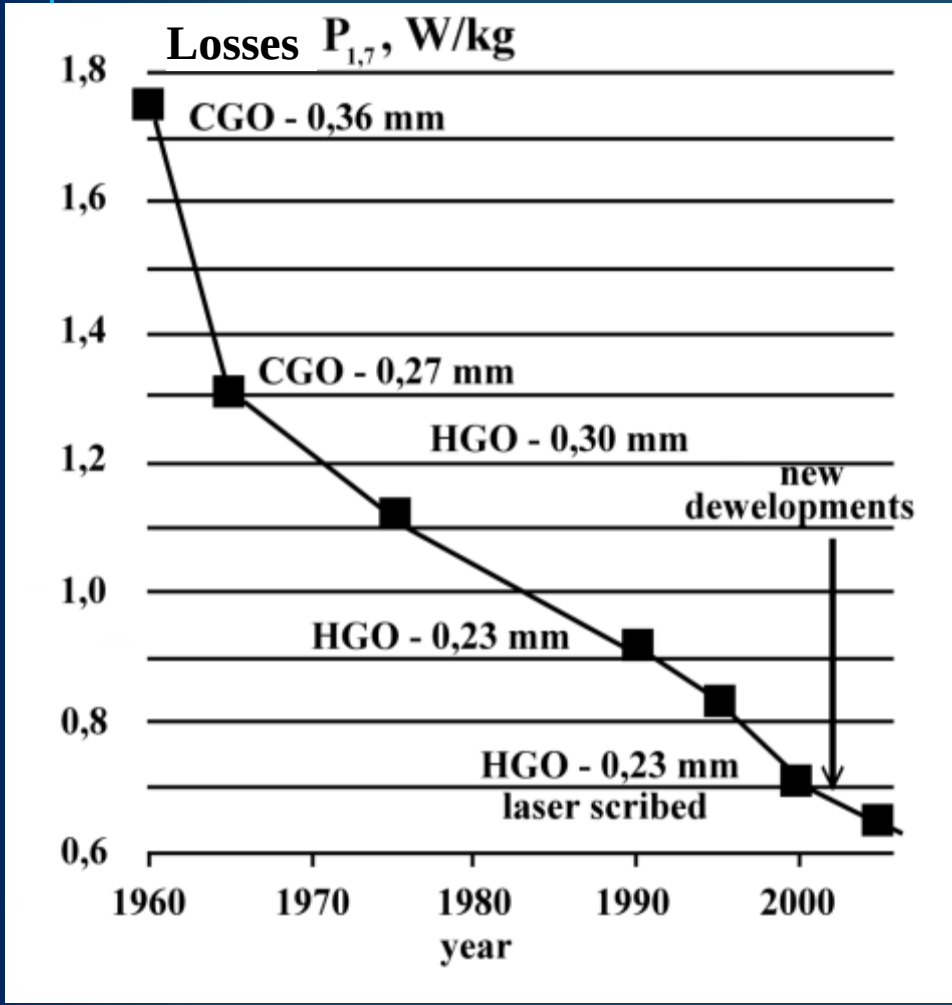
?

ORIENTED NUCLEATION MODEL: SIZE ADVANTAGE THEORY

There are meny experimental facts questioning the proposed theories

The recent research activities were directed mainly to optimalization of the static box annealing process.

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

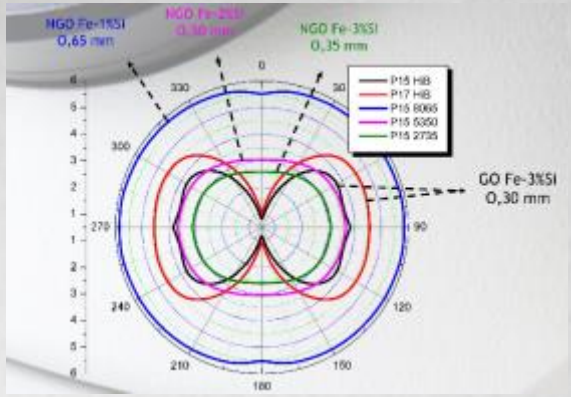
Perfectly oriented transformer sheets: B_{800}=2,03 T

Reduce production costs

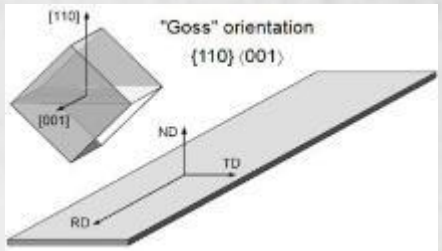
Factors which influence on the magnetic properties

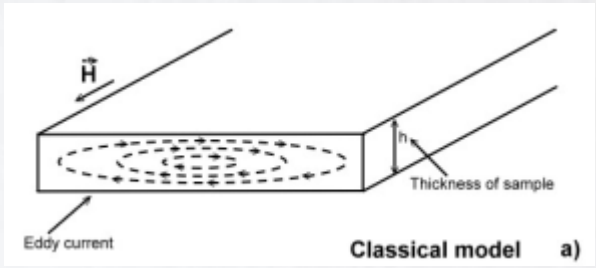
Core losses

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

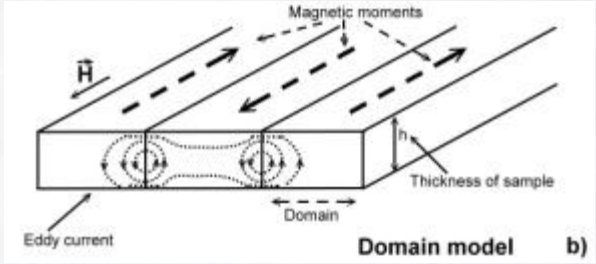


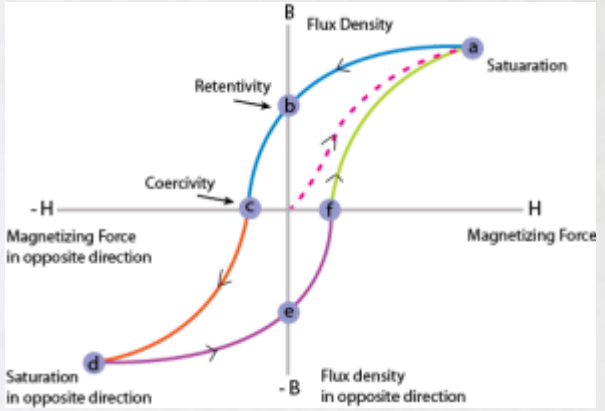
Microstructure of non-oriented electrical steel



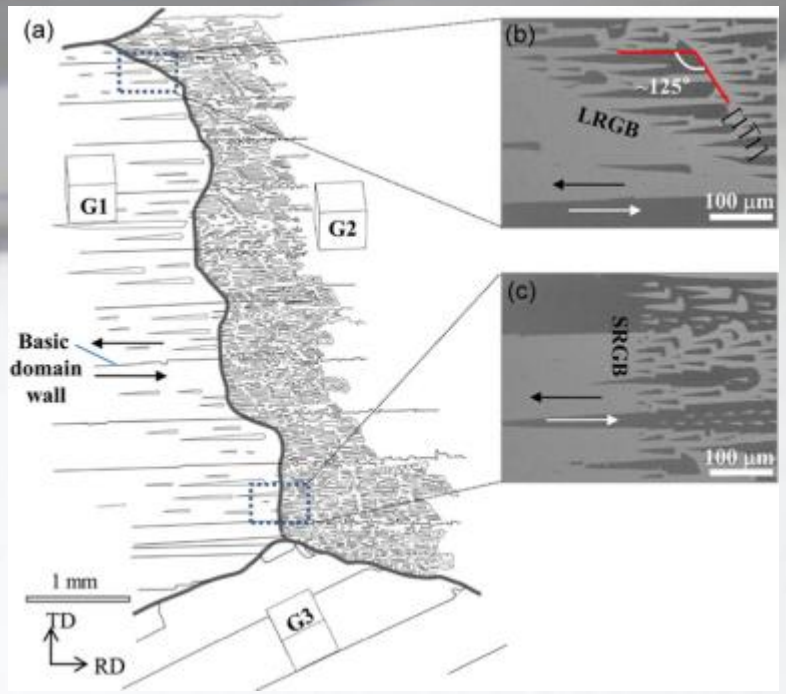


Microstructure of grain-oriented electrical steel





Electrical steels and eddy current losses



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

Sheet thickness ↓ … rolling

Electrical resistance ↑ … addition of Si

Domains wall ↔ … refinement

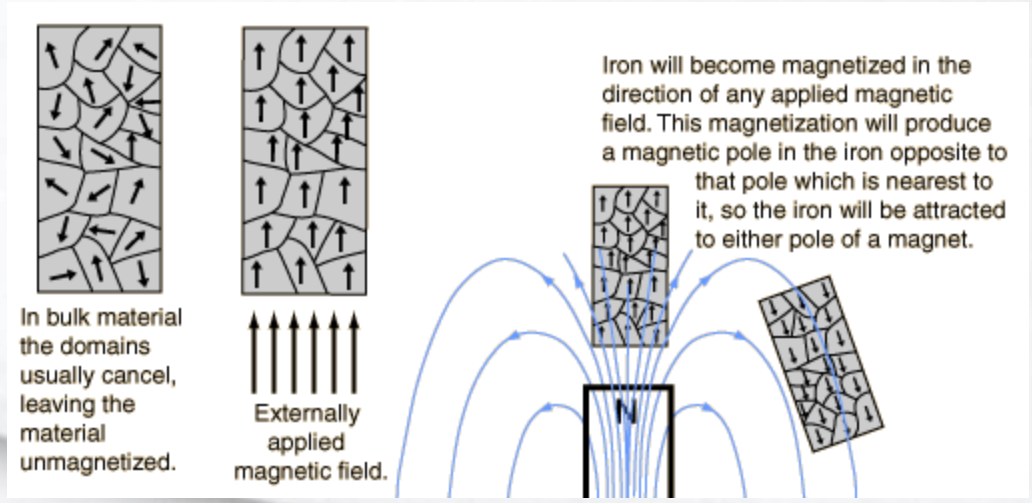
Domain refinement techniques

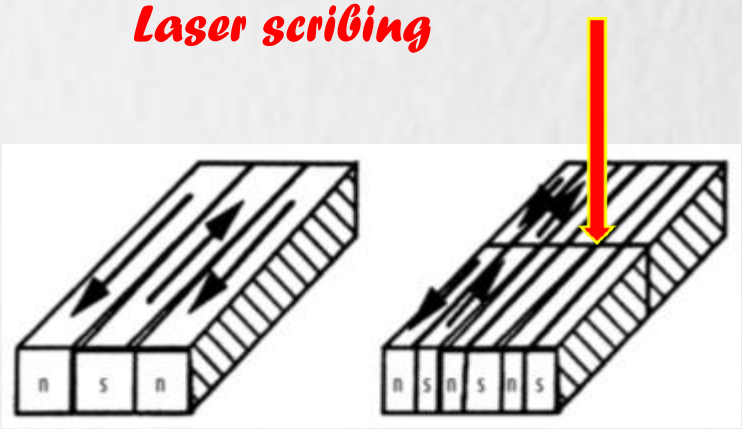
Mechanical scratching

Plasma irradiation

Spark ablation

Laser scribing





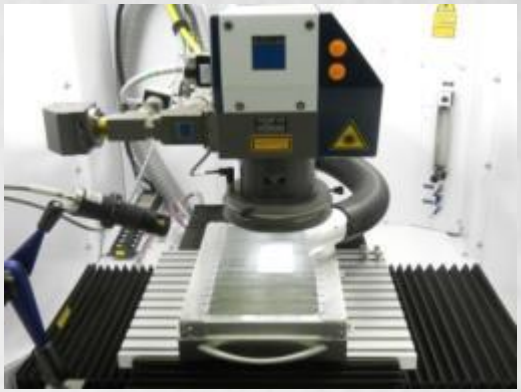
Scheme of domain refinement

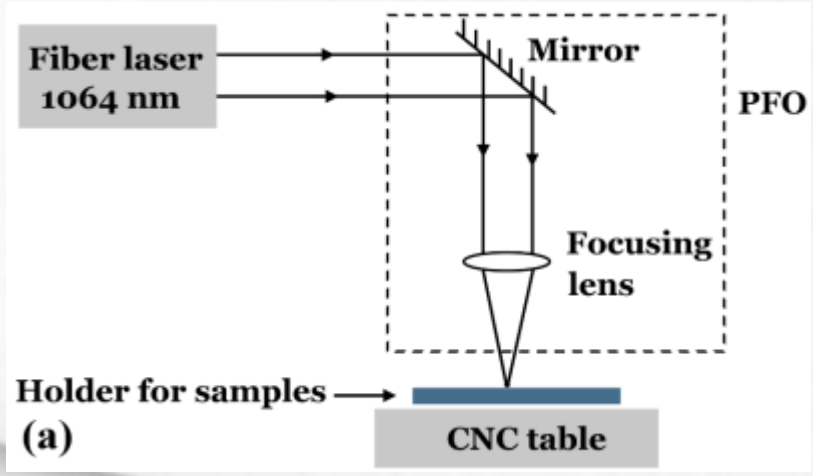
Chemical content of experimental steel

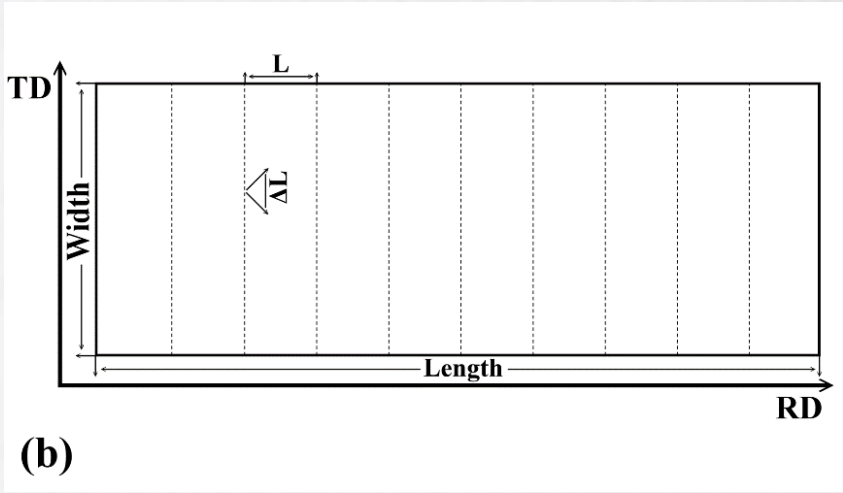
EXP. MATERIAL	C, %	Mn, %	Si, %	Cu, %	P, %	S, %	Al, %	N, %	V, %	Cr, %
	0.04	0.18	3.2	0.54	0.003	0.003	0.004	0.003	0.046	0.008

Technical specifications of steel samples

Thickness: 0.28 mm
Length: 80mm
Width: 30mm
Watt losses: 368 J/m
Prepared by electric spark cutting







Parameters of laser scribing process

Technical specifications

- Distance between the scribed lines: **4mm, 6mm, 8mm and 10mm**
- Wavelength :**1064 nm**
- Beam diameter in focus: **30μm**

Continuous regime

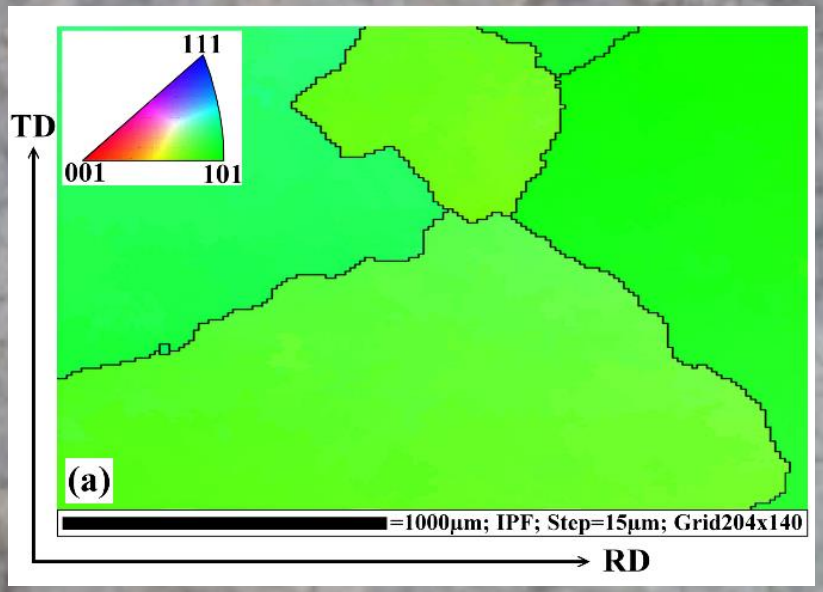
The power density : **12W, 18W, 24W and 30W**
Velocity of laser treatment: **100mm/s**

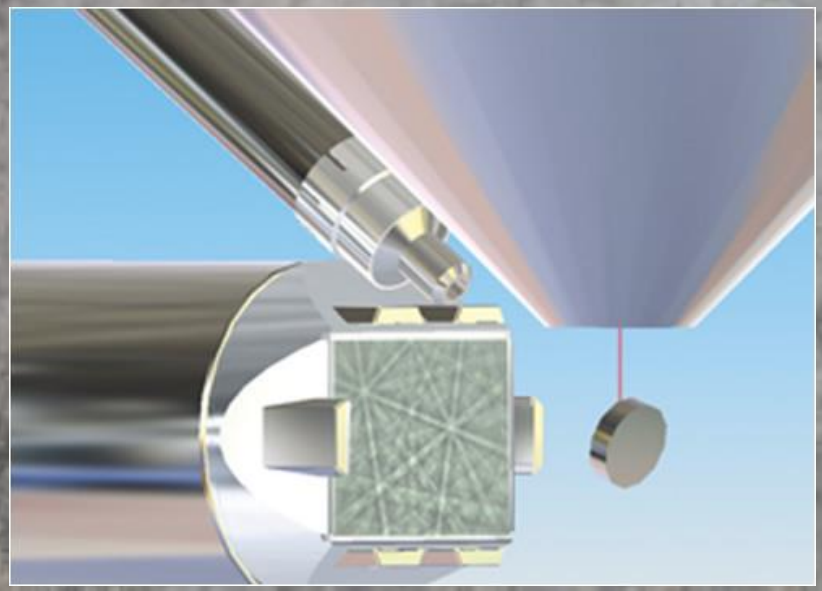
Pulse regime

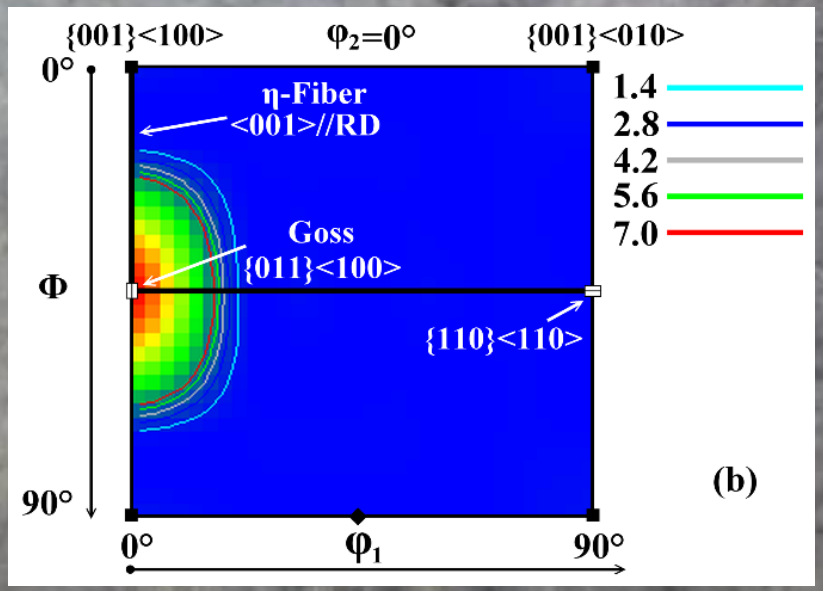
Power of beem: **60W, 120W, 180W and 240W**
Pulse duration: **100μs**
Frequency: **100Hz**
The distance between the neighboring pulses was **ΔL=0,3mm**

Samples texture before laser scribing

IPF maps taken from sheet plane of GO steel and related ODF at φ1=0°; φ2=45°

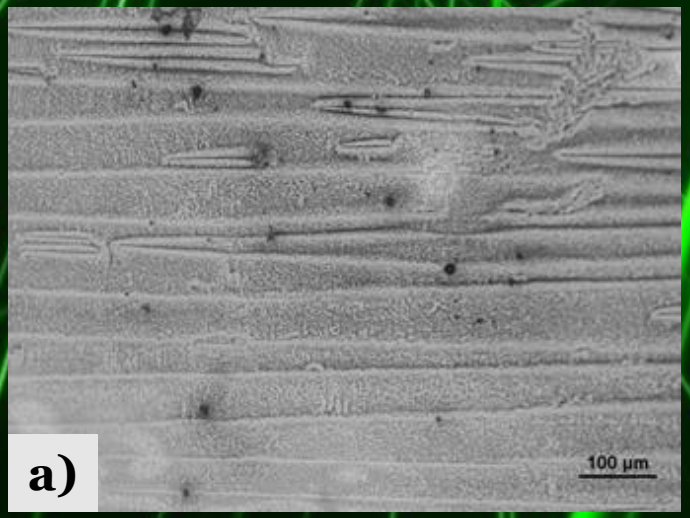


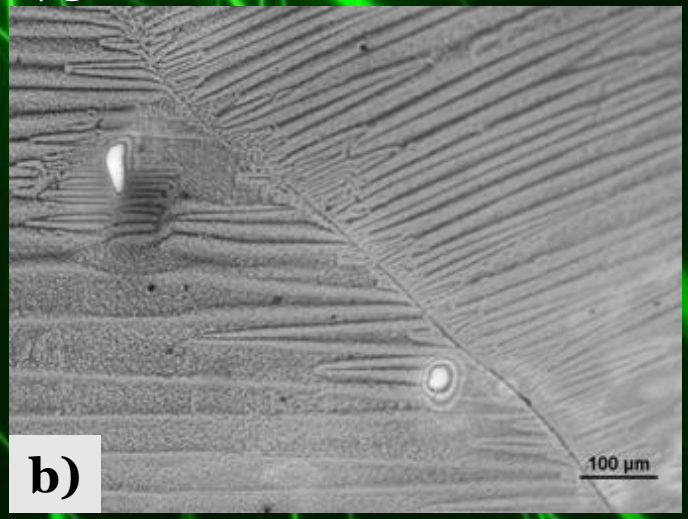




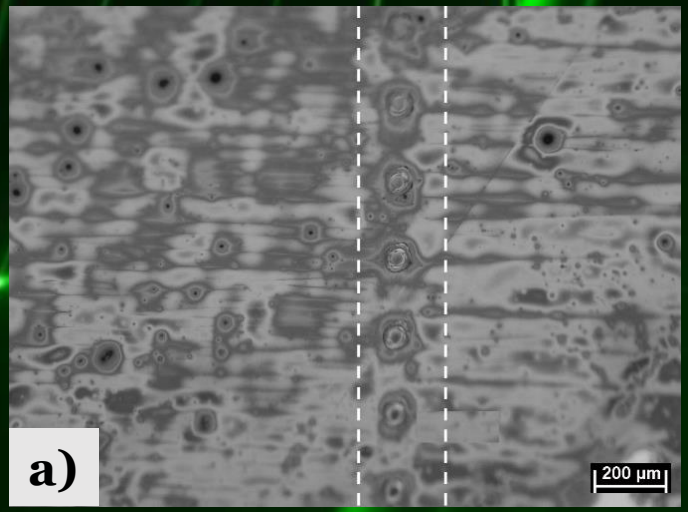
The surface domain structure

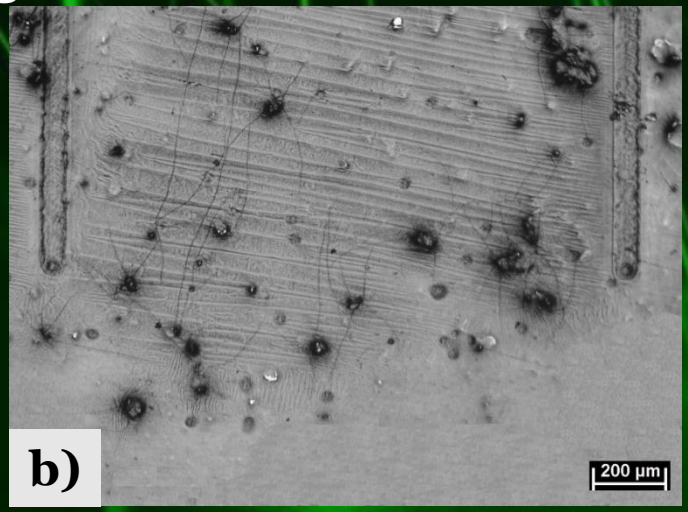
Domains made visible by *Ferrofluid* in the GO silicon steel without laser treatment: a) in frame of grain, b) grain boundarie



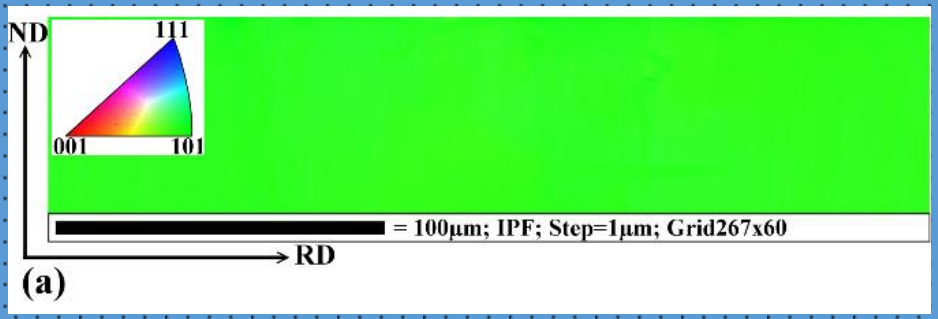


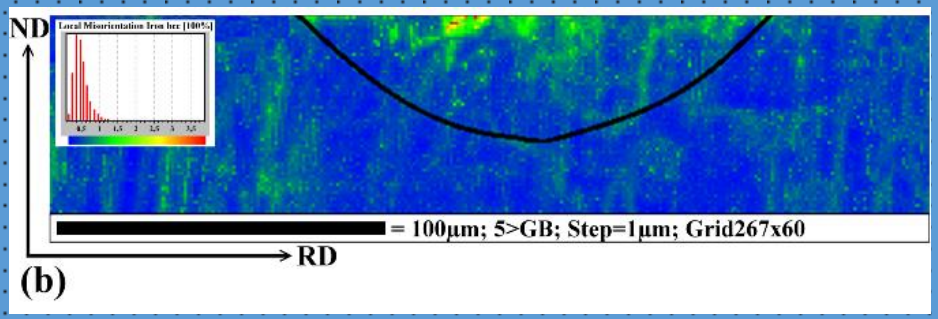
The surface domain structure state of investigated steel after laser scribing a) in pulse regime (marked by white dashed line) and b) in continuous regime.

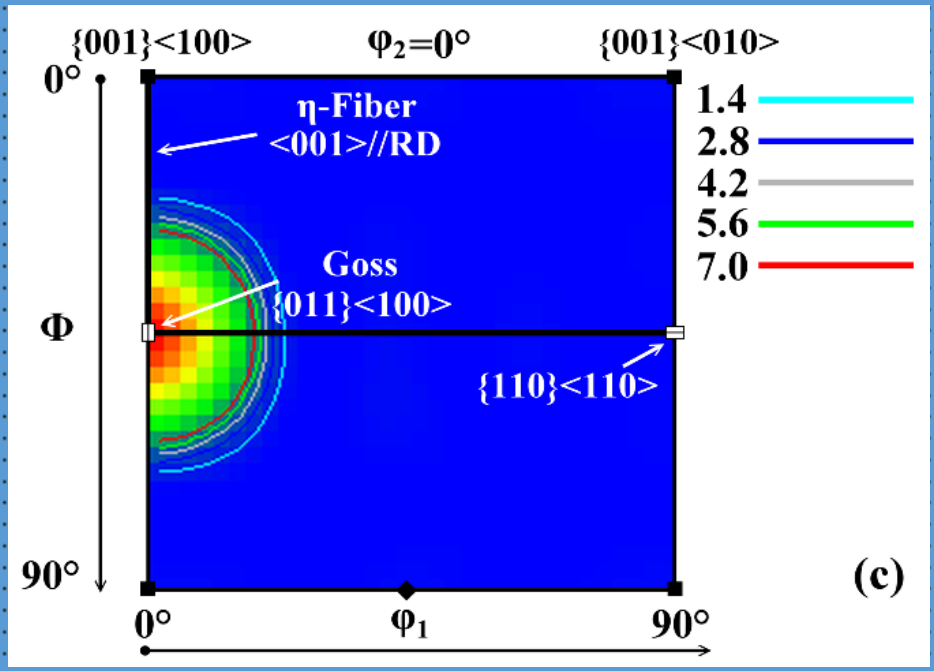




Texture of GO steel after laser scribing



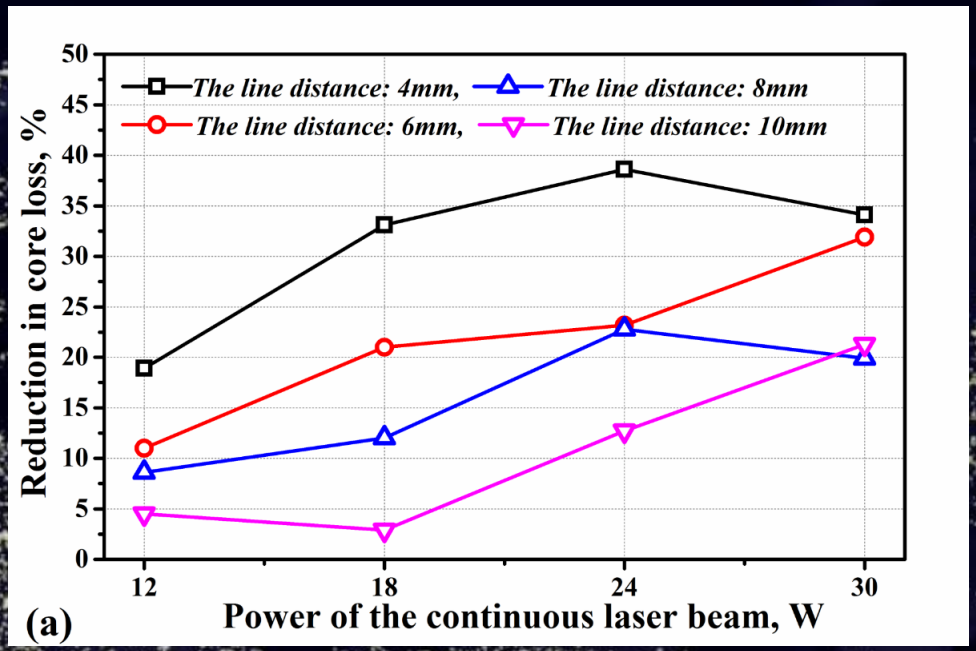


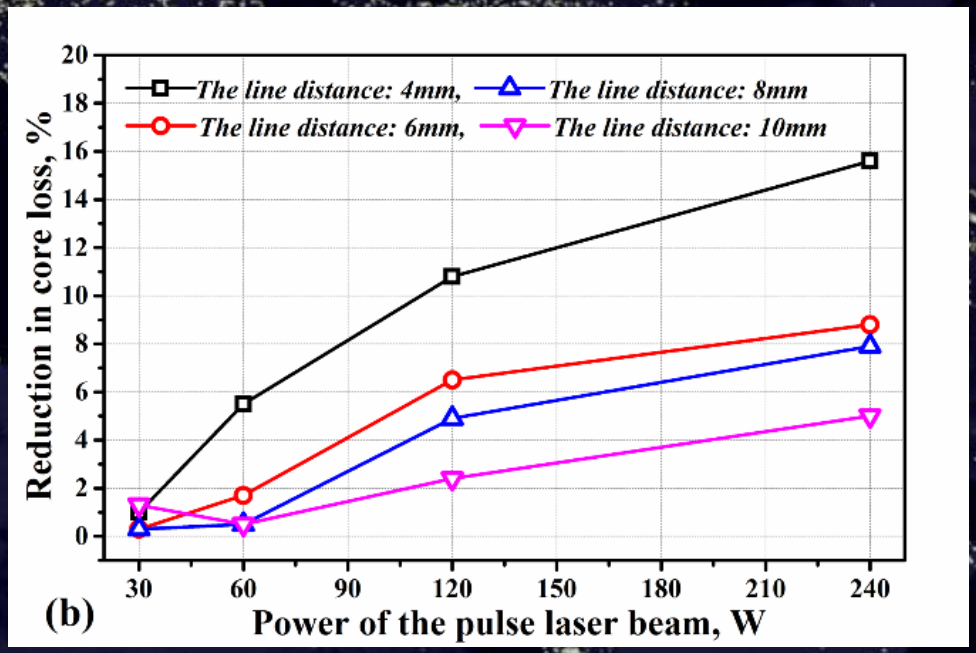


a) IPF map showing the crystallographic orientation of grain with heat affected zone obtained after scribing by continuous 24 W laser beam, b) local misorientation map of sample cross-section on which was carried out IPF map, c) the ODF sections at φ_2=0° represent the Goss crystallographic orientation of sample part with heat affected zone.

Measurement of final magnetic properties

LF AC hysteresisgraph up to 50 Hz





Conclusions

- The experimental results have clearly shown beneficial effect of laser scribing on the core losses reduction of GO steels. Both continuous and pulse laser scribing regimes were applied on the grain oriented steel strips.
- The optimal conditions of pulse and continuous laser scribing treatment resulted in core loss reduction from original 368 J/m^3 to newly obtained 312 J/m^3 and 226 J/m^3, respectively.
- The energy of laser beam induces thermal shock which in combination with correct density of scribe lines may decrease the samples core loss.
- The texture analysis demonstrated that small spots of thermal stresses do not influence the outgoing crystallographic orientation.
- Summarily, performed investigations revealed that the best soft magnetic properties improvements for the pulse and continuous regimes with the same scribe lines distances were related to 15% and 38% core loss reduction, respectively.

Thank you for your attention!