Structure and phases of low Neodymium NdFeB Permanent magnets

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Introduction

- $Nd_2Fe_{14}B$ is the most famous hard magnetic material on the Nd-Fe-B basis
- Low Nd content ($Nd_{4.5}Fe_{77}B_{18.5}$) nanocrystalline multiphase magnetic materials are cheaper
- Their magnetic properties are highly influenced by the microstructure and phase composition (hard and soft magnetic phases)
- They depend mainly on starting composition, method of synthesis and heat treatment

Magnetic properties

Material	Coercivity H_{ci} [kOe]	Remanence B_r [kG]	Energy product $(BH)_{max}$ [MGOe]
S2	3.4	11.8	12.0
B2	2.8	10.9	10.7

- Different methods of preparation
- Melt-spinning and 600°C/2 min. (S2)
- Centrifugal atomization and 660°C/5 min. (B2)
- Aim of the work is to elucidate the difference in magnetic qualities of given materials

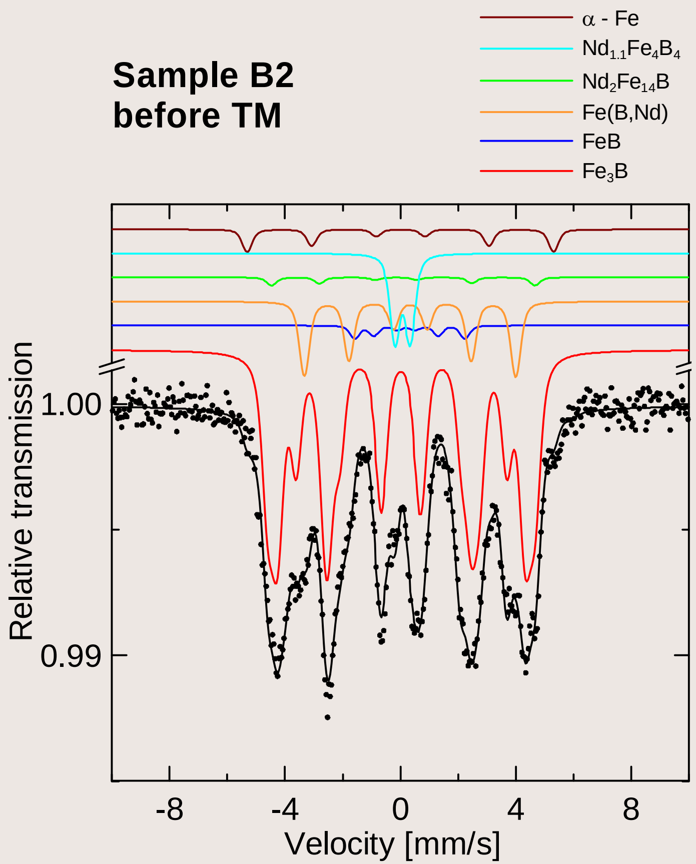
Experimental

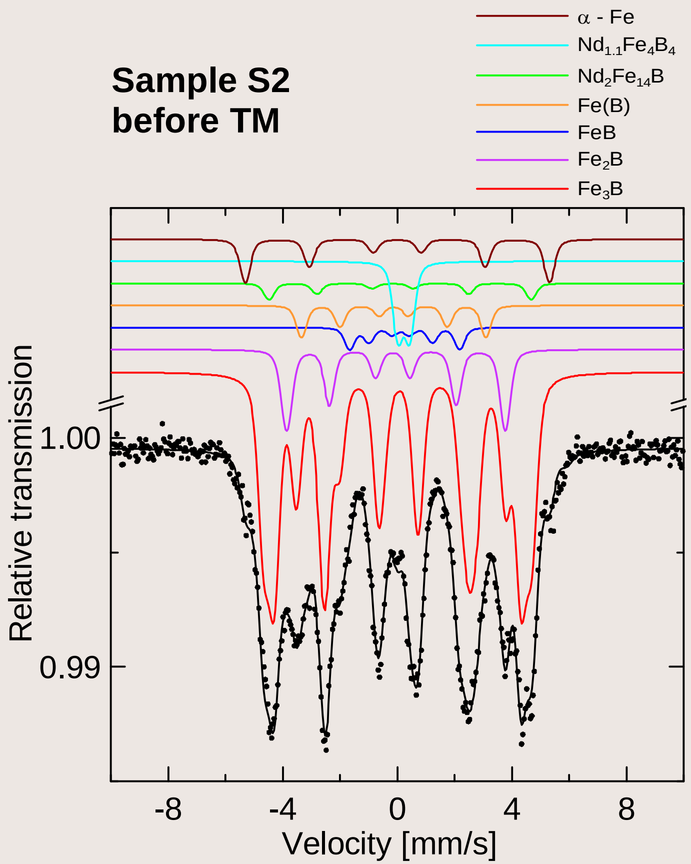
- Material was gained in the form of powder, suitable for Mössbauer and X-ray spectra
- Transmission RT Mössbauer spectroscopy using Co^{57}(Rh) source, calibration against α-Fe foil data
- Amount of iron containing phases is supposed to be equal to intensities of corresponding spectral components
- X-ray diffraction (XRD) performed using X'pert device using CoKα radiation
- Thermomagnetic (TM) measurements on EG&G VSM at 50 Oe, 4 K/min., small cold-pressed tablets were used
- Subsequent Mössbauer and X-ray measurement done on softly manually crumbled material

Mössbauer spectra of the raw material

- Material is obviously not very homogeneous because of its way of production, metastable phases and interfaces/surfaces cannot be excluded
- Very complex spectra, hard to fit
- Fit based on previously published results gained on similar materials and our experiences
- Processing of Mössbauer spectra using CONFIT program
- Identification of some components possible only in connection with other methods
- However, not perfectly identified components remained

Mössbauer spectra of the raw material

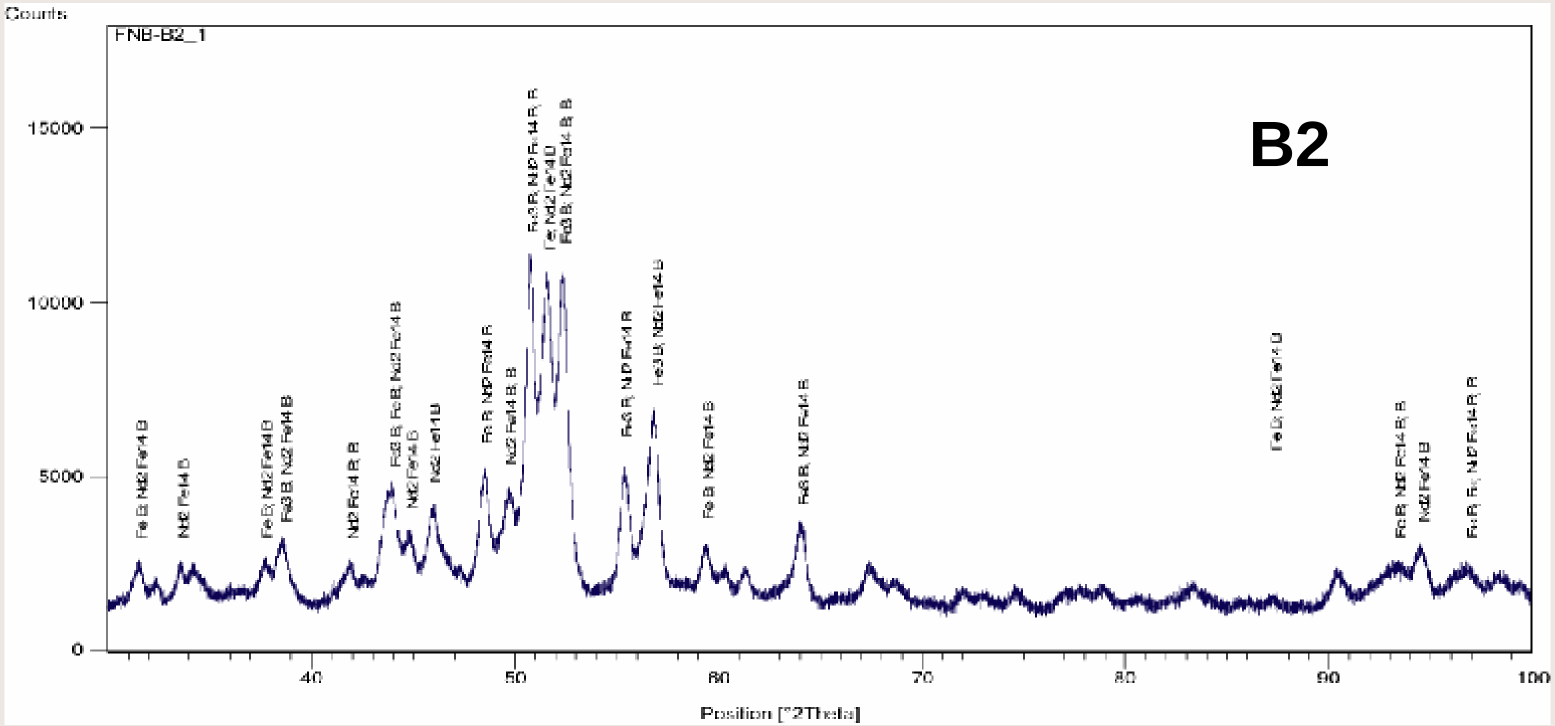




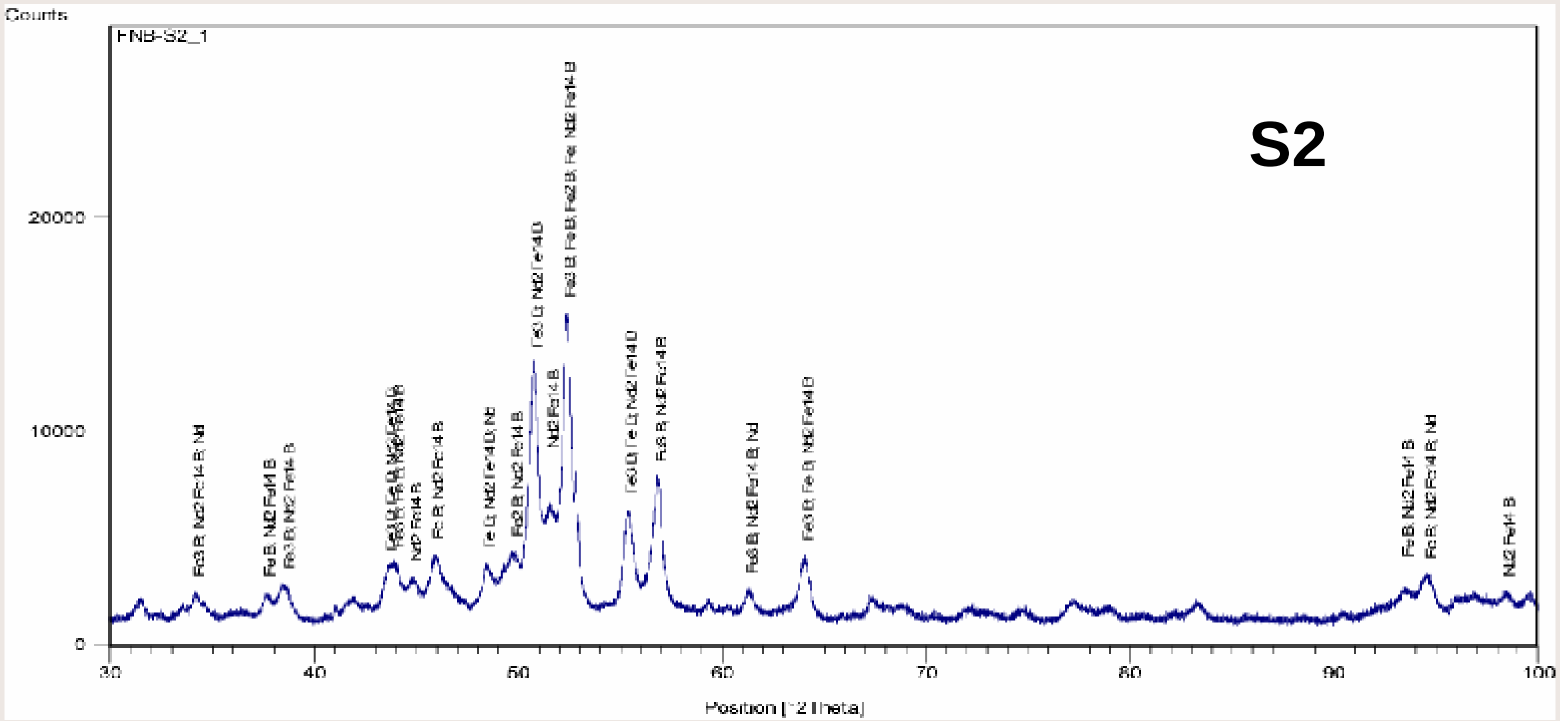
X-ray diffraction on the raw material

- Diffraction spectra approve the complexity of both materials
- Main components agree with Mössbauer phase analysis
- When interpreting XRD spectra also a coarse confirmation of Mössbauer phase analysis results was found
- XRD helps to identify differences appearing due to characteristics of preparation methods

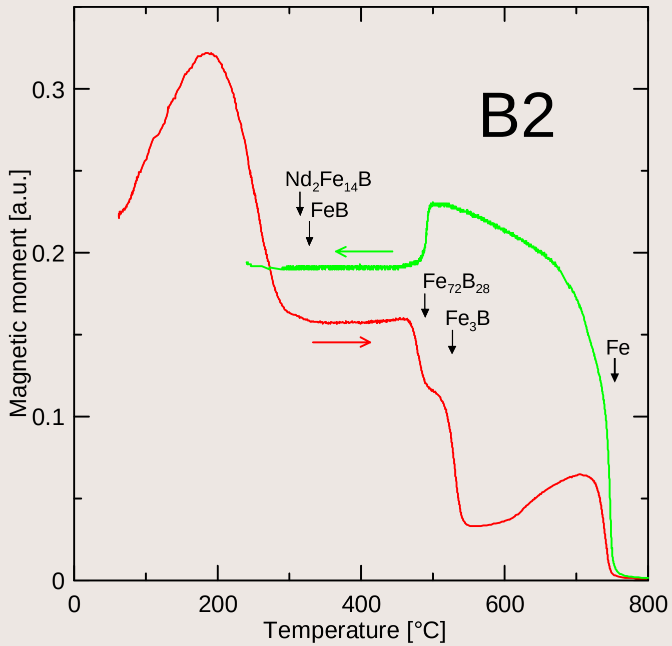
X-ray diffraction on the raw material

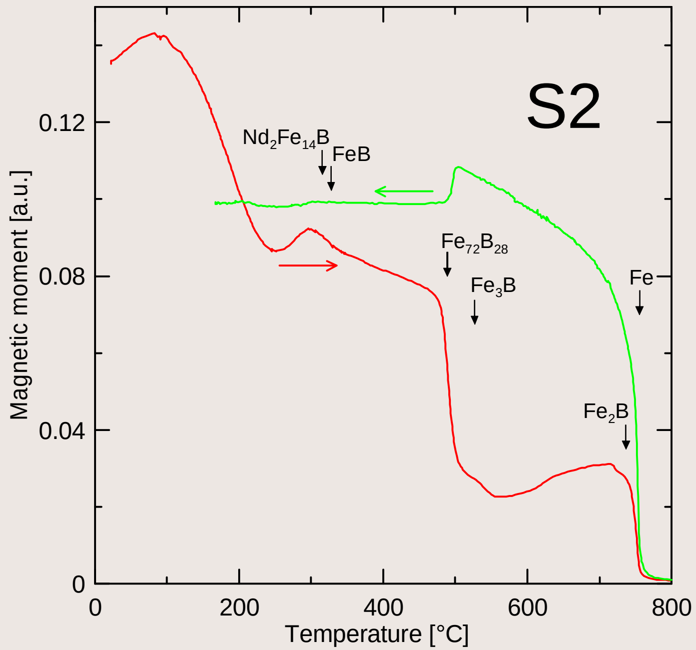


X-ray diffraction on the raw material



Thermomagnetic curves



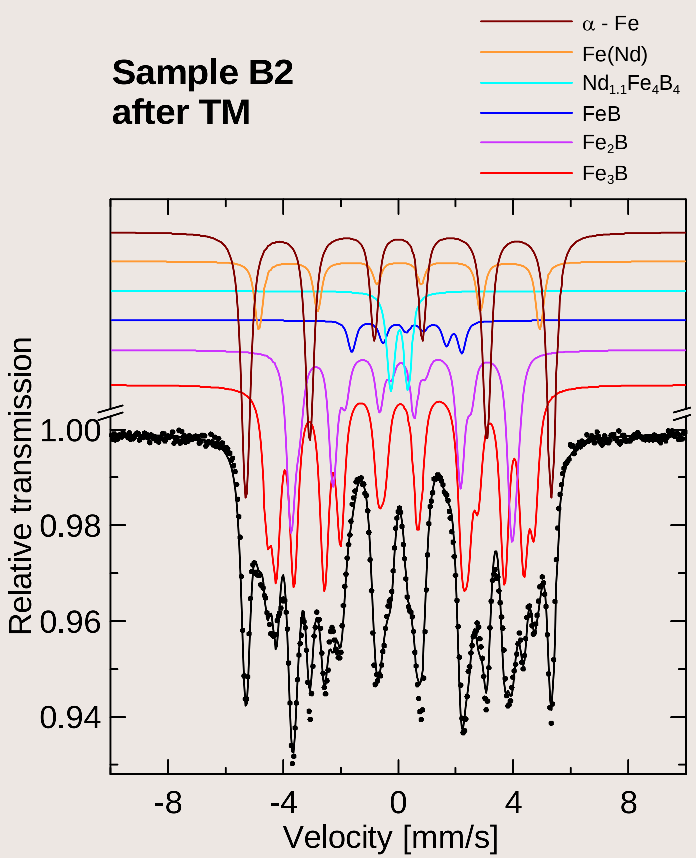


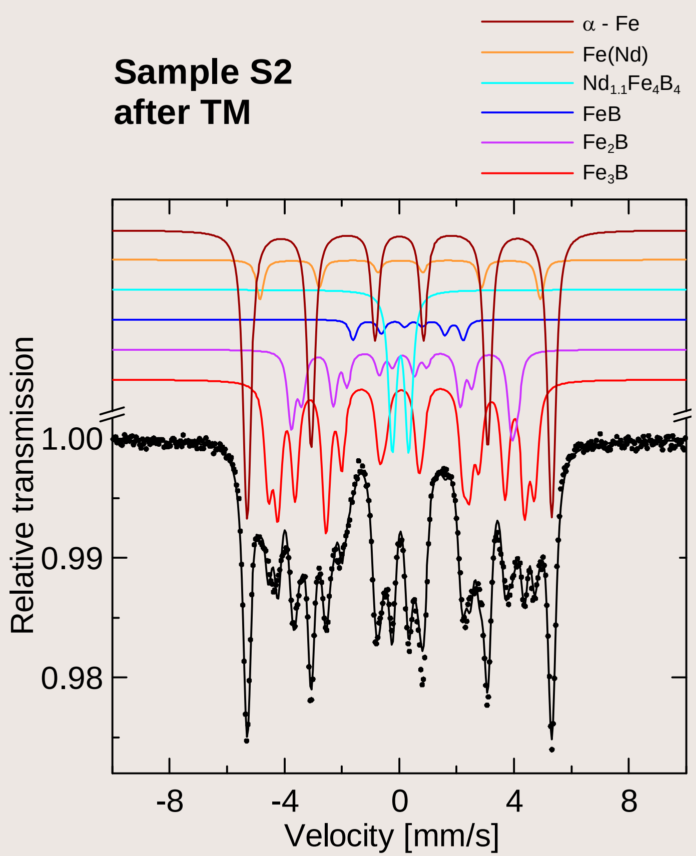
- Curie temperatures of individual phases are clearly visible
- With one exception, the phases are identical with those gained from the rest of methods
- Curie temperature of the $Fe_{72}B_{28}$ phase as found in the literature can identify some more complex structure in the reality

Mössbauer spectra after TM measurement

- Illustrate the process of thermal decomposition
- Conform the stage before TM measurement
- α-iron as most important product of decomposition
- The known decomposition process of Fe_3B to Fe_2B is present as well
- Total vanishing of the $Nd_2Fe_{14}B$ phase
- Very probably small amount of Fe-Nd solid solution can be identified

Mössbauer spectra after TM measurement

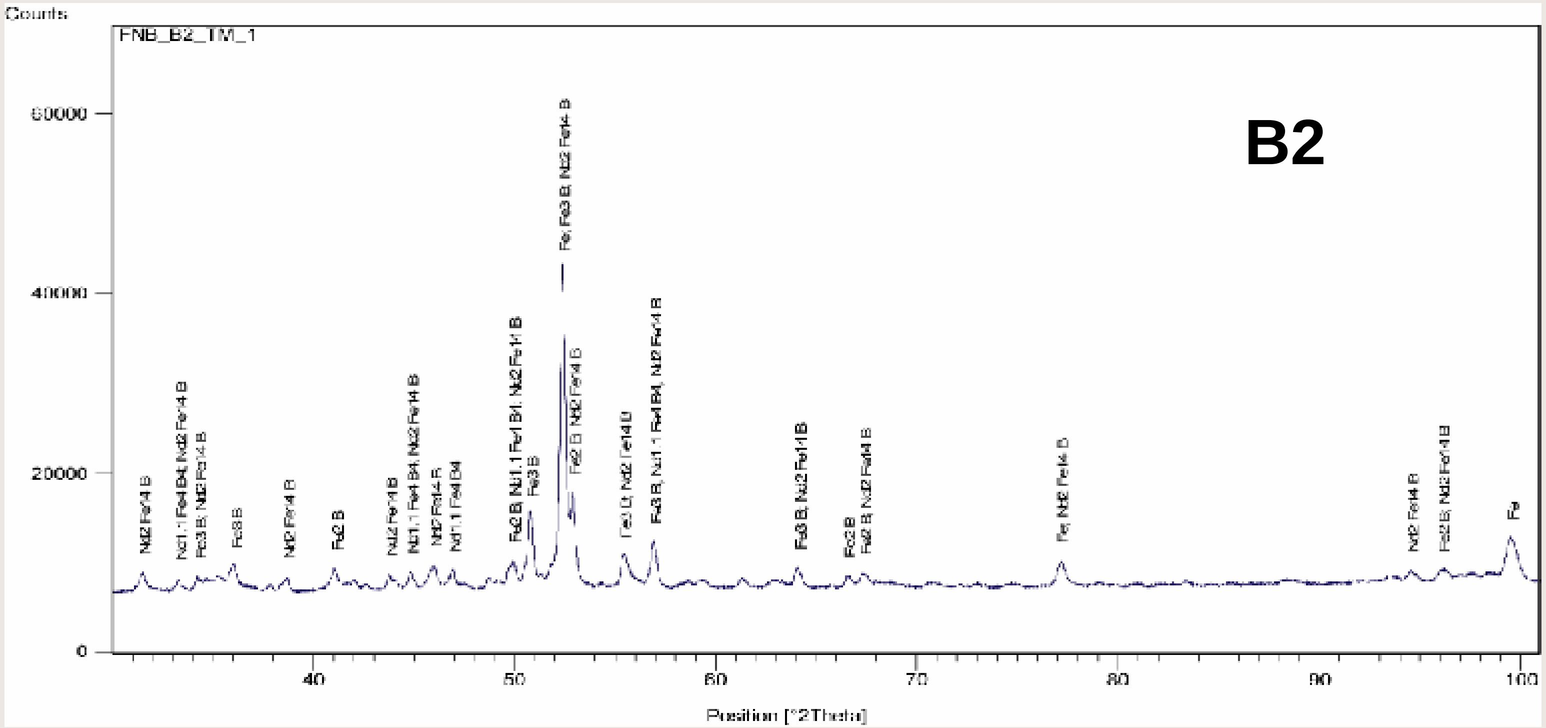




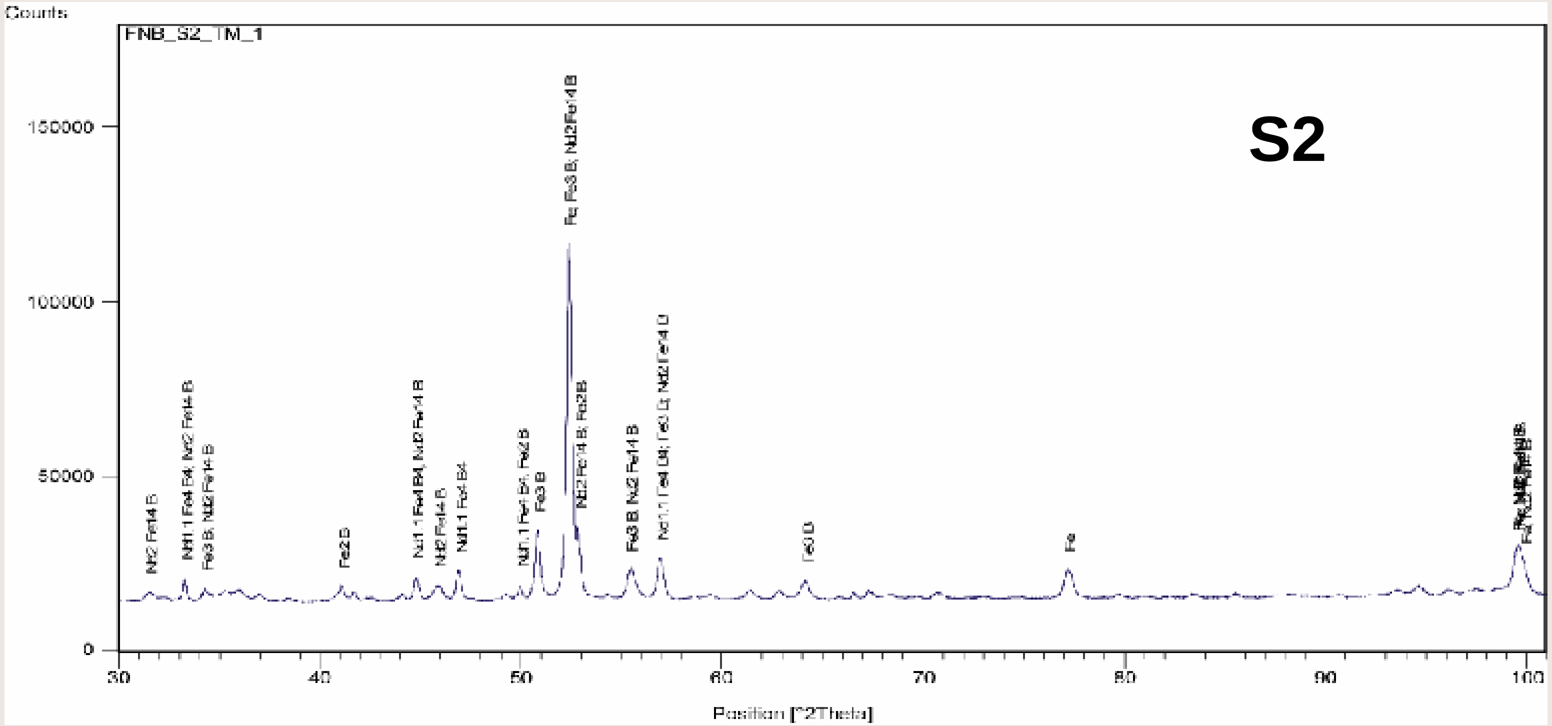
X-ray diffraction after TM measurement

- On the contrary to other methods, spectrum analysis suggests existence of $Nd_2Fe_{14}B$ phase, but no FeB phase
- There is no wonder in the case of FeB as its amount is definitely very low
- XRD detection of weak $Nd_2Fe_{14}B$ phase can be vague because of large number of peaks
- Mössbauer detection of $Nd_2Fe_{14}B$ phase is more reliable due to typical configuration of peaks
- The cooling branch of the thermomagnetic curve exhibits no kink at the $Nd_2Fe_{14}B$ Curie temperature

X-ray diffraction after TM measurement



X-ray diffraction after TM measurement



Phase analysis

Tentative phases	Before TM		After TM	
	B2	**S2**	**B2**	**S2**
$Nd_2Fe_{14}B$	0.02	0.06	—	—
Fe(B,Nd)/Fe(B)	0.24	0.08	—	—
Fe_3B	0.67	0.66	0.42	0.36
Fe_2B	—	0.09	0.20	0.12
FeB	0.01	0.02	0.02	0.02
α-Fe	0.02	0.04	0.27	0.37
Fe(Nd)	—	—	0.05	0.04
$Nd_{1.1}Fe_4B_4$	0.04	0.04	0.04	0.09

- Table shows the most representative iron containing phases as an eclectic result of all method used
- Quantitative results taken from Mössbauer phase analysis
- Amount of iron containing phases is supposed to be equal to intensities of corresponding spectral components

Conclusions

- Obtained values of magnetic properties can be explained by the different phase composition after the heat treatment and by the presence of the intergranular interactive mechanisms
- Melt spun material with better magnetic qualities seems to have more “clean” phase constitution without spurious phases and interfaces
- Thermal decomposition will be the main reason for quality loss of this hard magnetic material

Thank

you

for

your

attention!