Lublin University of Technology
Faculty of Electrical Engineering and Computer Science

Production, research and application of metal-dielectric nanocomposites on the example of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites

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Visegrad Fund

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Lublin University of Technology
Faculty of Electrical Engineering and Computer Science

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Scientific investigations:

Metal-dielectric nanocomposites

Structure: ferromagnetic alloy (FeCoZr) or metal (Cu) – dielectric matrix (Al_2O_3, CaF_2, SiO_2 and PZT – $(Pb_{81}Sr_4(Na_{50}Bi_{50})_{15}(Zr_{57,5}Ti_{42,5}))O_3$

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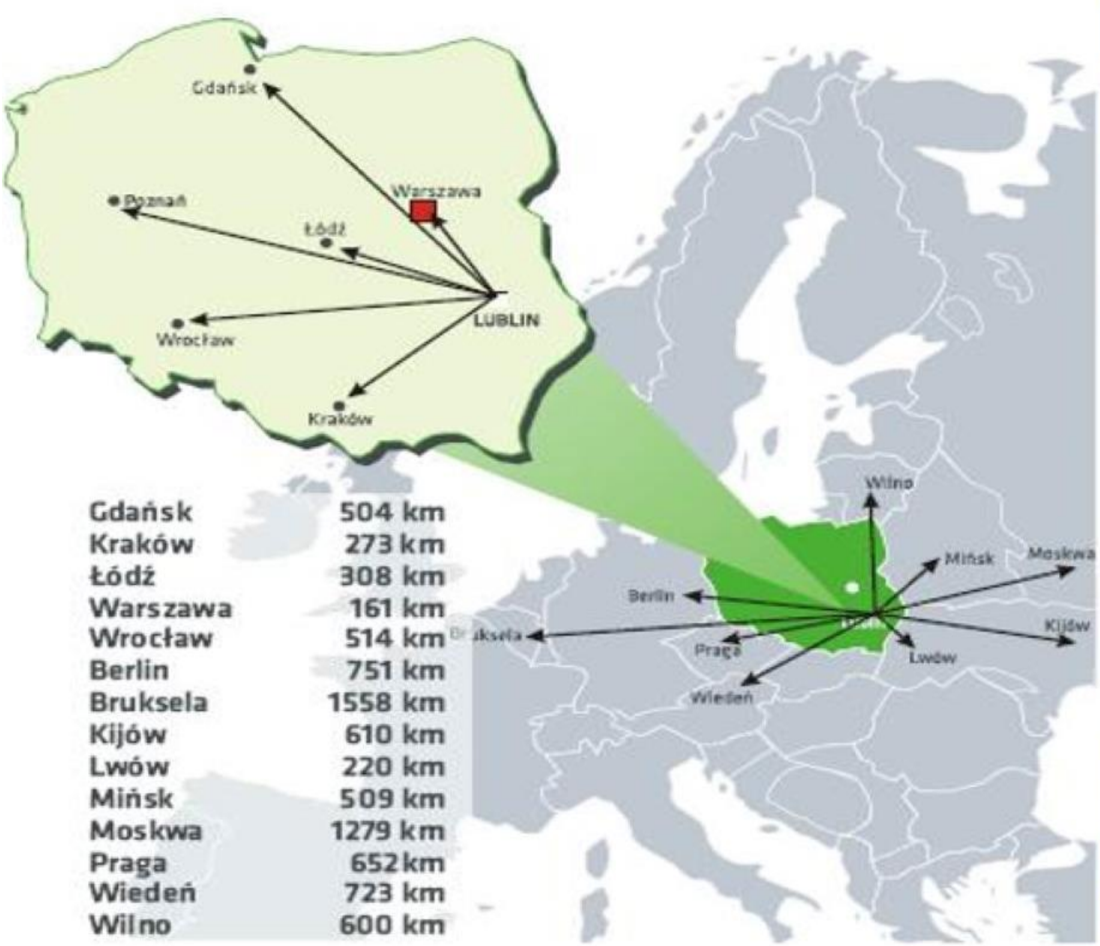
Plan of the presentation

1. Information about Lublin and Lublin University of Technology
2. Introduction
3. The aims of the research
4. Production and studies of chemical composition and structure of nanocomposites
5. Test stand for the study of alternating current properties of nanocomposites
6. Investigation of alternating current properties of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites
7. The phenomenon of non-coil like inductance in $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites
8. Summary and conclusions

Lublin



Gdańsk	504 km
Kraków	273 km
Łódź	308 km
Warszawa	161 km
Wrocław	514 km
Berlin	751 km
Bruksela	1558 km
Kijów	610 km
Lwów	220 km
Mińsk	509 km
Moskwa	1279 km
Praga	652 km
Wiedeń	723 km
Wilno	600 km

Lublin University of Technology

6 Faculties of the Lublin University of Technology:

- Mechanical Engineering
- Electrical Engineering and Computer Science
- Civil Engineering and Architecture
- Environmental Engineering
- Management
- Fundamentals of Technology

1. Introduction

Nanocomposites, like conventional composites, are composed of at least two components, except that at least one of them is in nanosize scale.

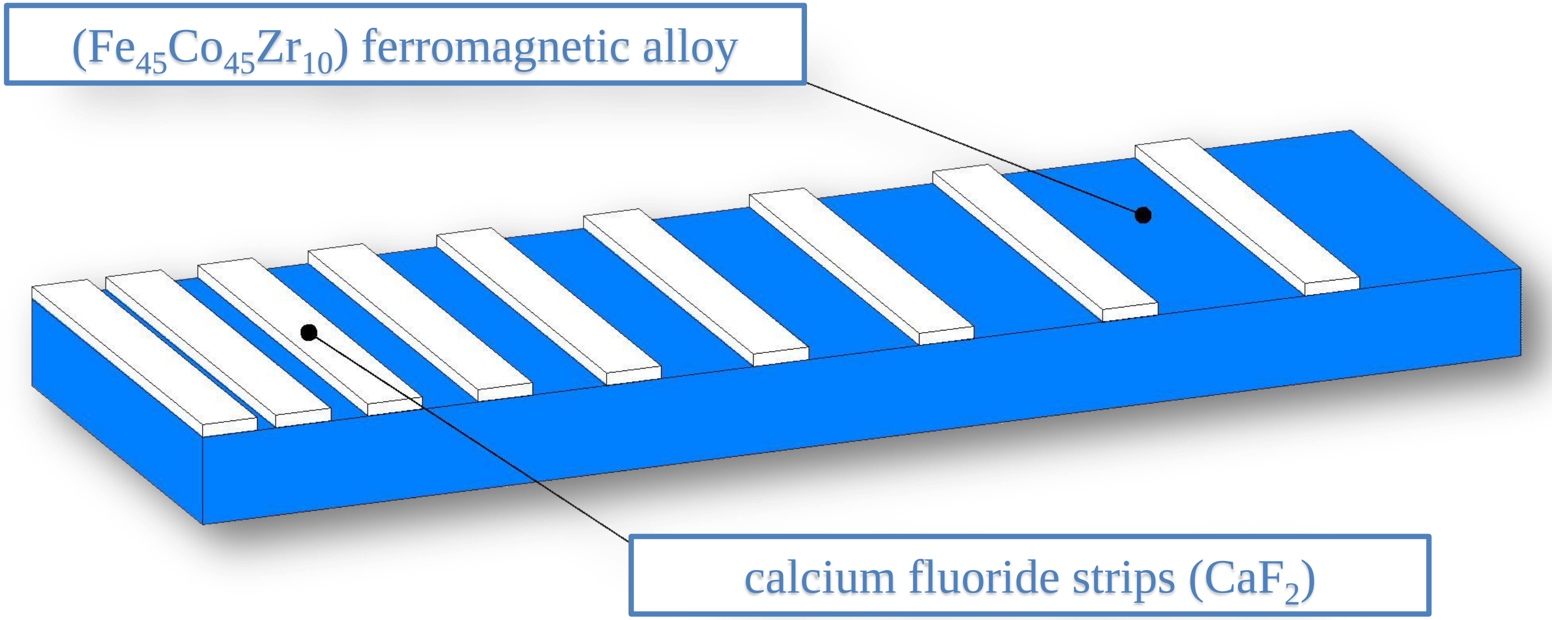
Nanocomposites often exhibit unique properties that are fundamentally different from those of their bulk counterparts. Owing to the possession of unique properties, nanocomposites are actively used in many fields such as electronics, electrical engineering, mechanical engineering, aerospace, medicine, etc.

Nanocomposites containing magnetic phase nanoparticles in their composition can be described as functional materials. The most significant changes in the properties of nanostructures occur at nanoparticle size lower then 10 nm, when the contribution of surface atoms to the atoms in the volume is between 20 % and 90 %.

2. Research objectives

- Production of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites by argon and oxygen-doped argon ion beam sputtering.
- Chemical composition and structure studies.
- Studies of the electrical properties of nanocomposites (AC measurements).
- Investigations of changes of electrical properties of nanocomposites under the influence of high temperature annealing.
- Analysis of the possibilities of using nanocomposites to produce components with resonant circuit properties.

3. Production and studies of chemical composition and structure



($Fe_{45}Co_{45}Zr_{10}$) ferromagnetic alloy

calcium fluoride strips (CaF_2)

Fig. 1. View of the sprayed target

3. Production and studies of chemical composition and structure

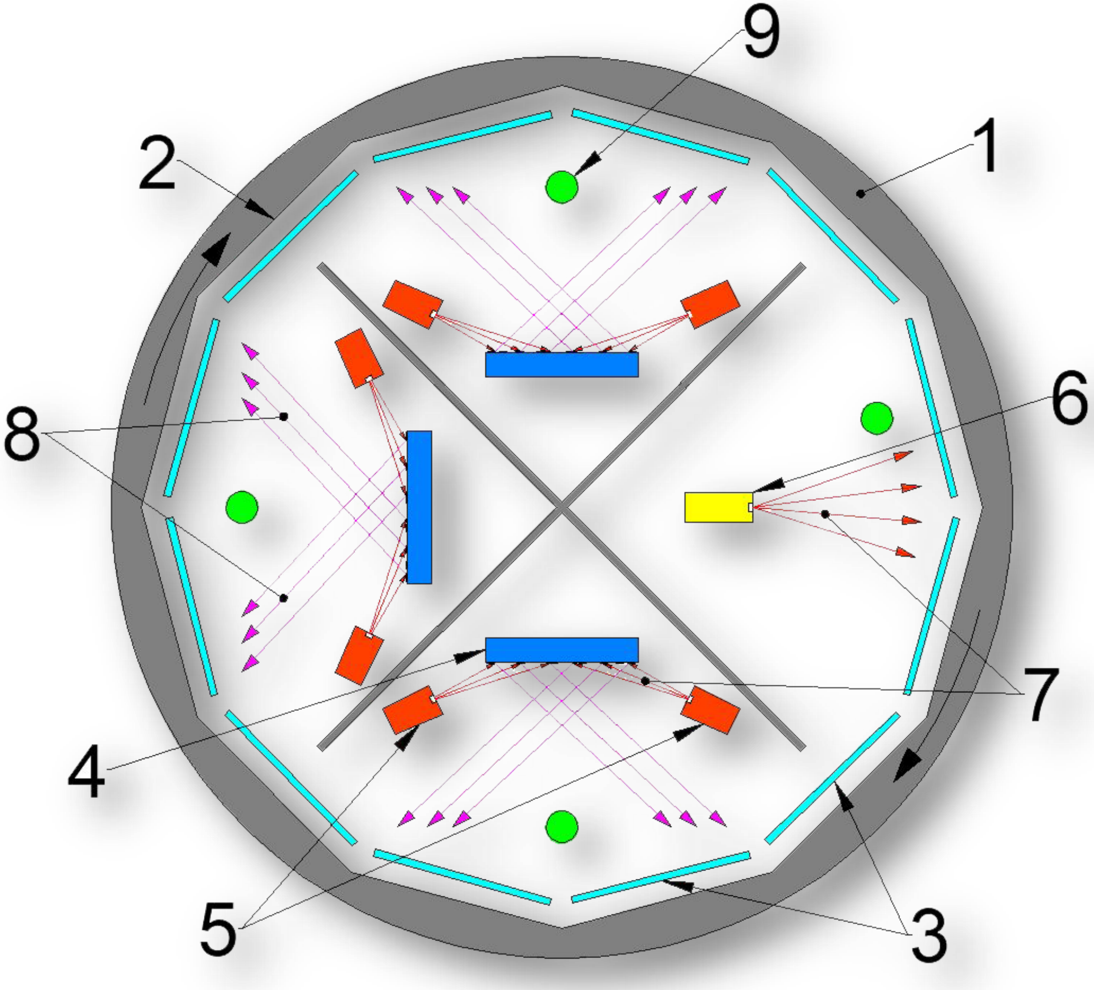


Fig. 2. Scheme of the sputtering station

1 – vacuum chamber
2 – rotating drum for attaching substrates
3 – ceramic dielectric substrates
4 – atomized disks cooled by water
5 – ion beam sputtering source
6 – ion beam source for ion cleaning of substrates
7 – streams of ions with Ar
8 – streams of atomized atoms
9 – compensator – electron sources

3. Production and studies of chemical composition and structure

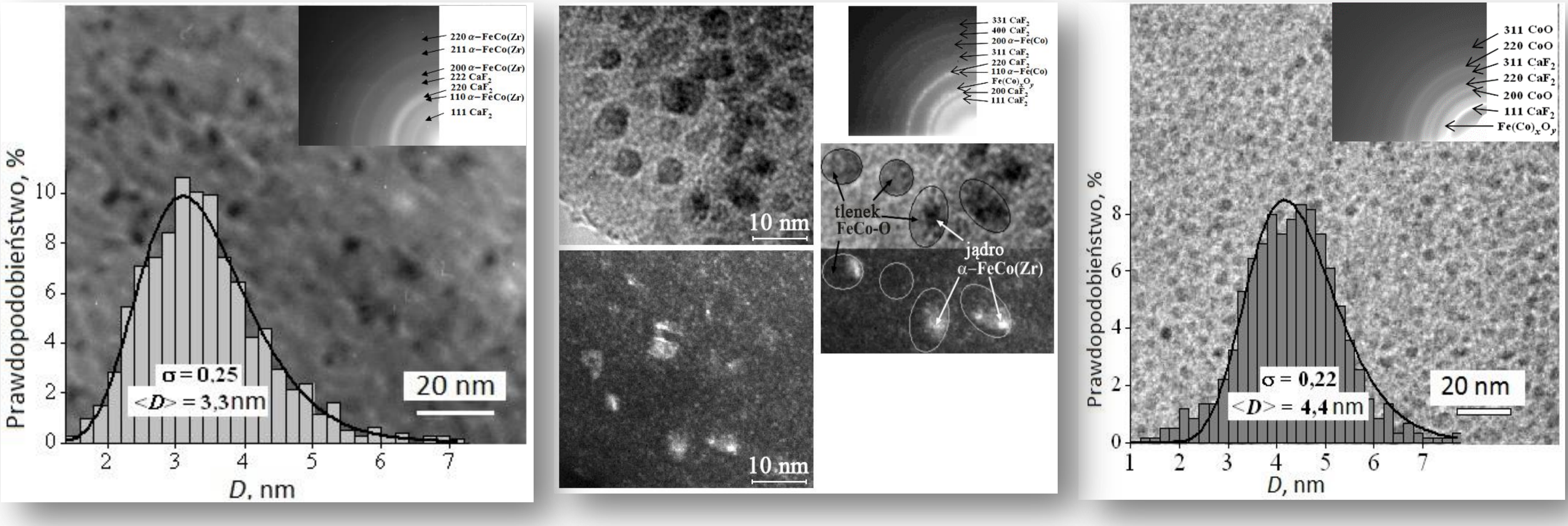


Fig. 3. TEM images of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite produced by Ar beam sputtering (P_O=0 mPa), combined Ar ion beam with low O_2 content (P_O=4.3 mPa), and Ar beam with high O_2 content (P_O=9.8 mPa)

3. Production and studies of chemical composition and structure

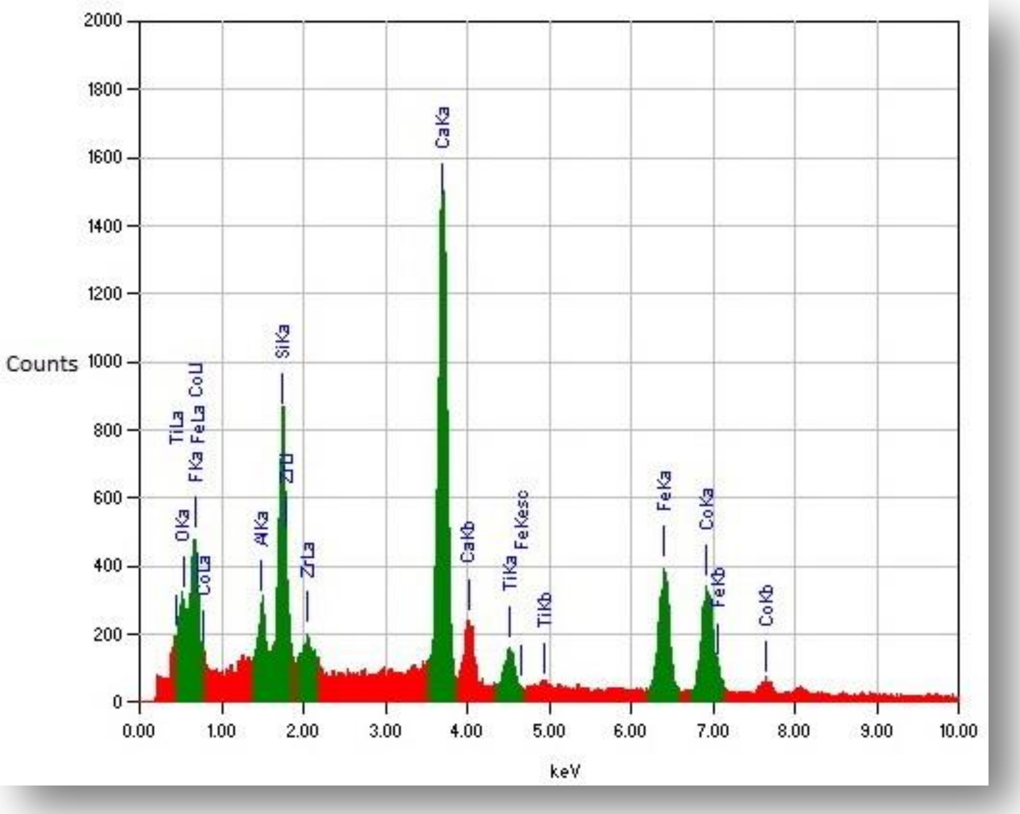


Fig. 4. X-ray spectrum for $(FeCoZr)_{50.3}(CaF_2)_{49.7}$ nanocomposite layer produced by Ar ion beam sputtering

Table 1. Elemental content of $(FeCoZr)_{50.3}(CaF_2)_{49.7}$ nanocomposite layer produced by Ar ion beam sputtering determined by EDX

Element	E, (keV)	Mass %	At. %
O	0,525	11,85	23,76
F	0,677	12,76	21,56
Al	1,486	2,75	3,28
Si	1,739	8,94	10,21
Ca	3,690	24,47	19,59
Ti	4,508	2,71	1,82
Fe	6,398	16,14	9,27
Co	6,924	17,32	9,43
Zr	2,042	3,05	1,07
Total		100	100

4. Test stand for the study of alternating current properties of nanocomposites

Measurement temperature range T_p : **15-373 K**

1, 2, 3, 4 – impedance meters
6 – helium cryostat head
7 – vacuum pump
8 – helium cryostat compressor
9 – vacuum gauge
10 – LakeShore temperature controller
11 – temperature sensor connected to the regulator (10)
12 – measuring contacts
13 – sample under test
14 – computer

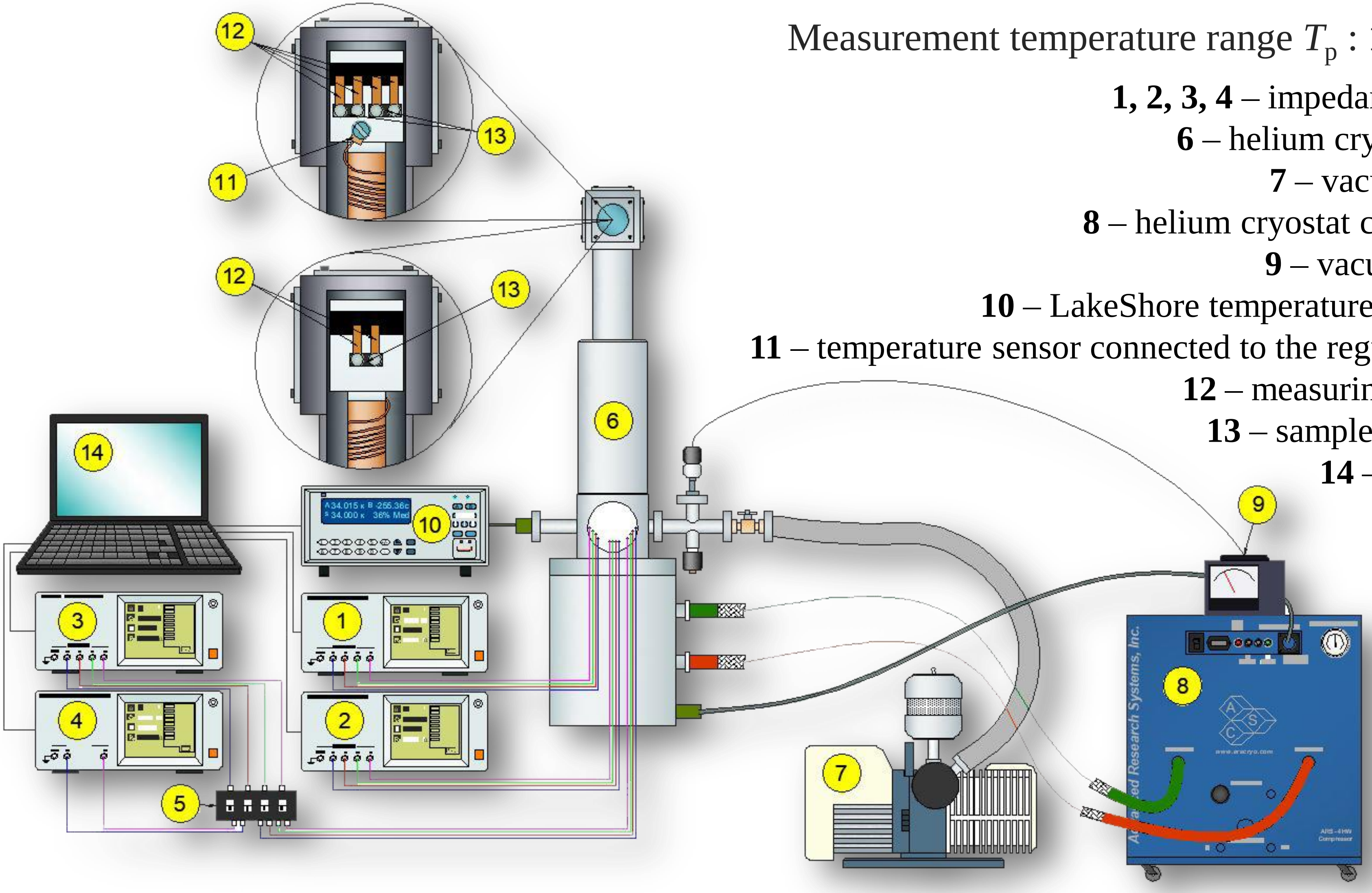
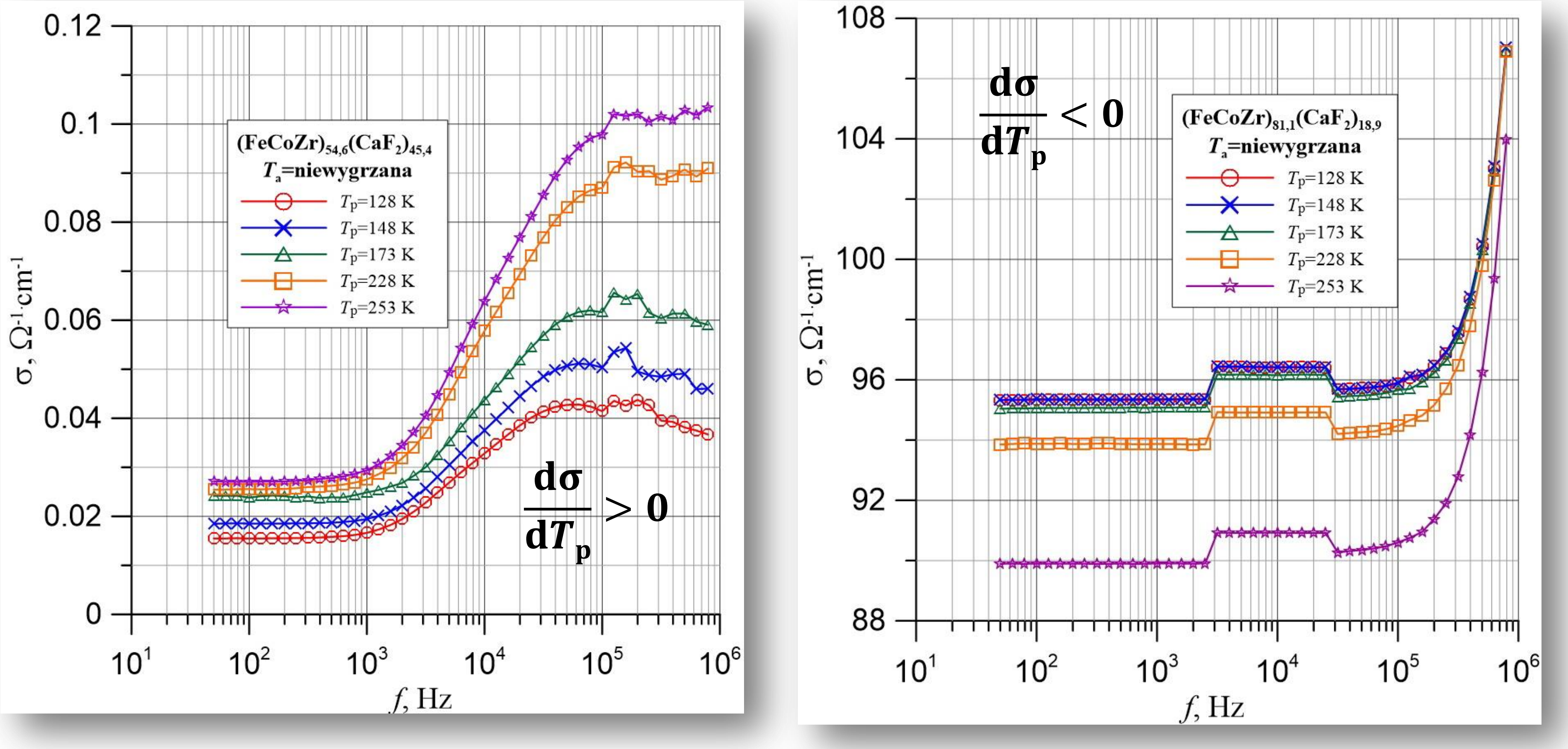


Fig. 5. Test stand for determination of electrical properties of nanocomposites

5. Investigation of electrical properties of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites



$$\frac{\mathrm{d}\sigma}{\mathrm{d}T_{\mathrm{p}}} > 0$$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}T_{\mathrm{p}}} < 0$$

Fig. 6. Frequency dependence of conductivity σ of nanocomposite $(FeCoZr)_x(CaF_2)_{(100-x)}$ with metal phase content $x = 54.6$ at.% and $x = 81.1$ at.% immediately after production by Ar ion beam sputtering

5. Investigation of electrical properties of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites

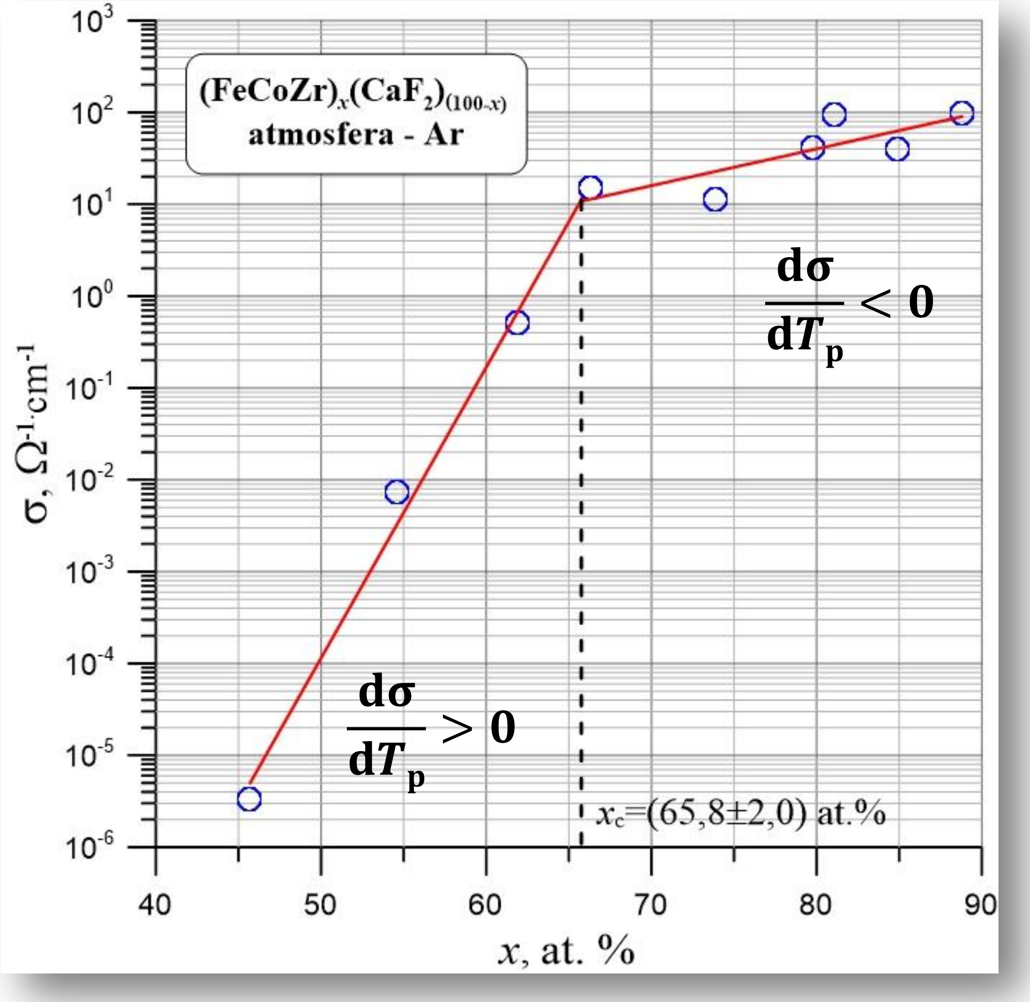


Fig. 7. Dependence of conductivity σ of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite produced by sputtering with Ar ion beam with metallic phase content *x* measured for LNT temperature and frequency 100 Hz

5. Investigation of electrical properties of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites

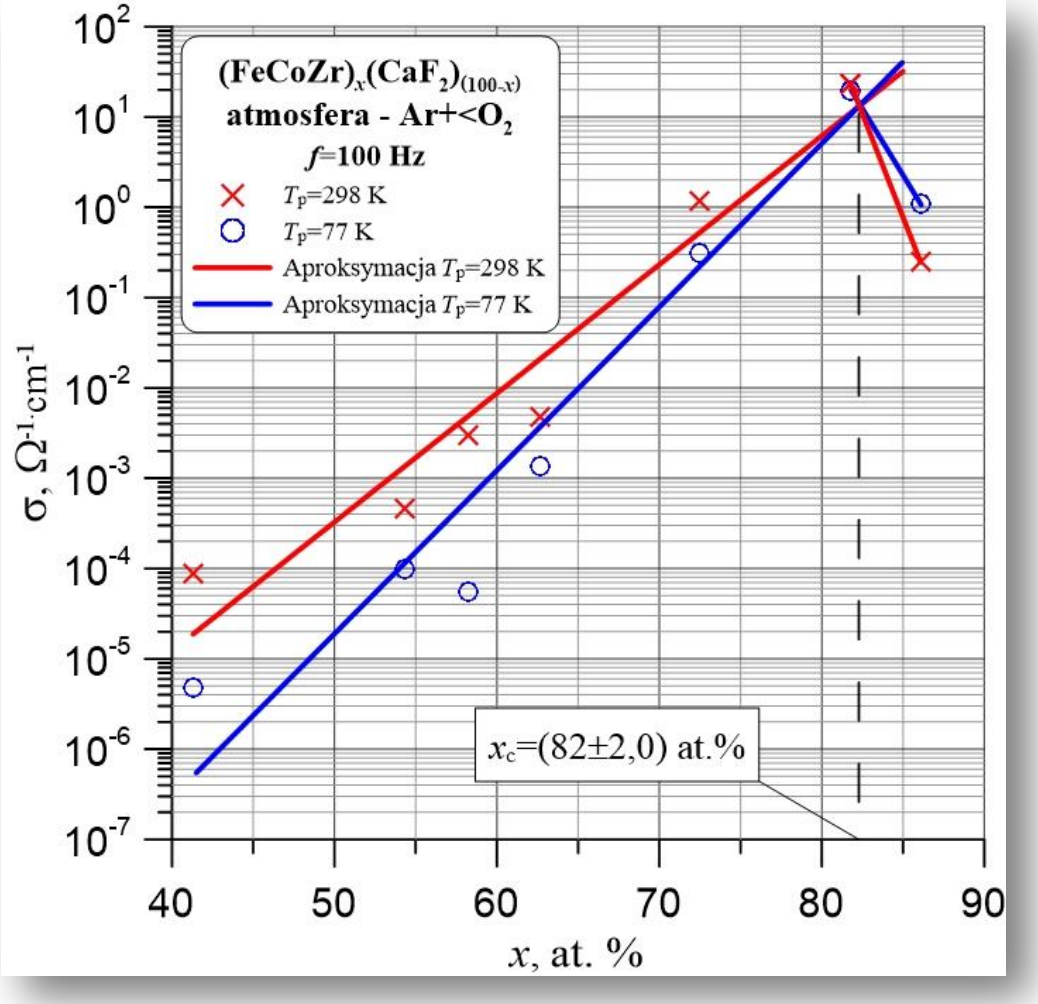
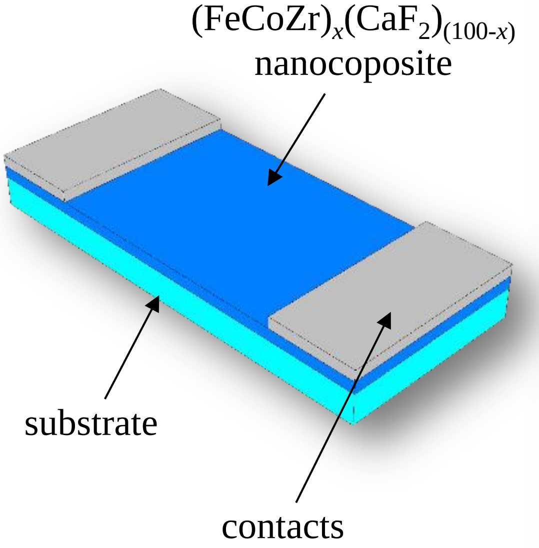
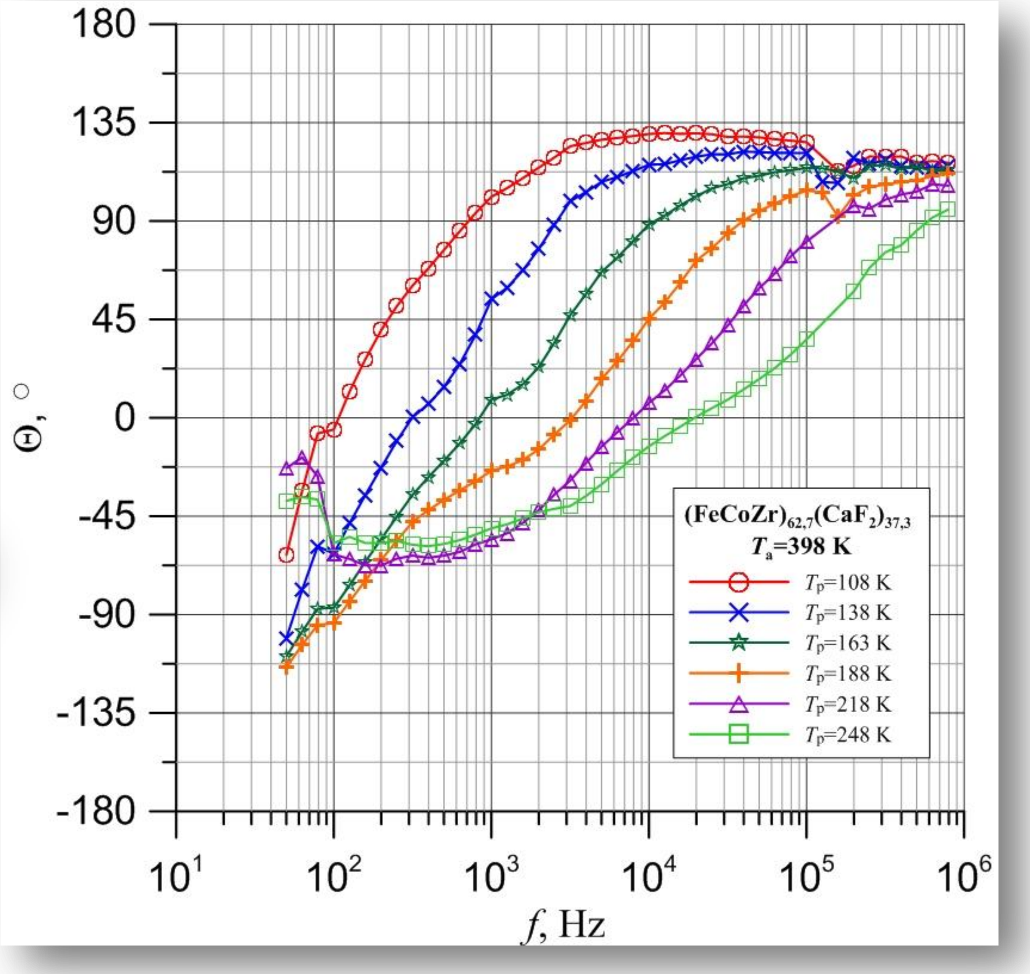


Fig. 8. Dependence of conductivity σ of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite produced by sputtering with combined ion beam (Ar and high O_2 content) with metallic phase content *x* measured for LNT temperature and frequency 100 Hz

6. Phenomenon of non-coil like inductance in $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites





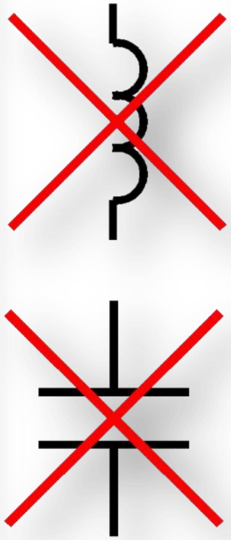


Fig. 9. Frequency dependence of the phase shift angle θ of the nanocomposite $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ produced by sputtering with combined ion beam (Ar and high O_2 content) and annealed at 398 K

6. Phenomenon of non-coil like inductance in $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites

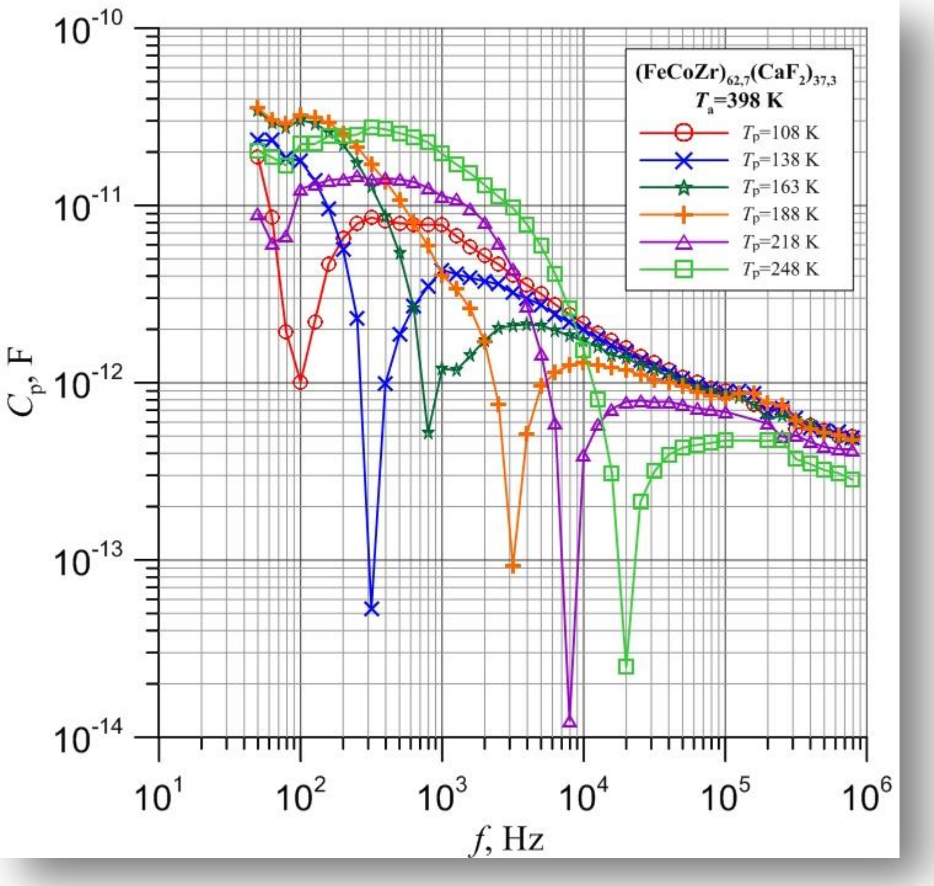


Fig. 10. Frequency dependence of capacitance C_p of $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ nanocomposite produced by sputtering with combined ion beam (Ar and high O_2 content) and annealed at 398 K

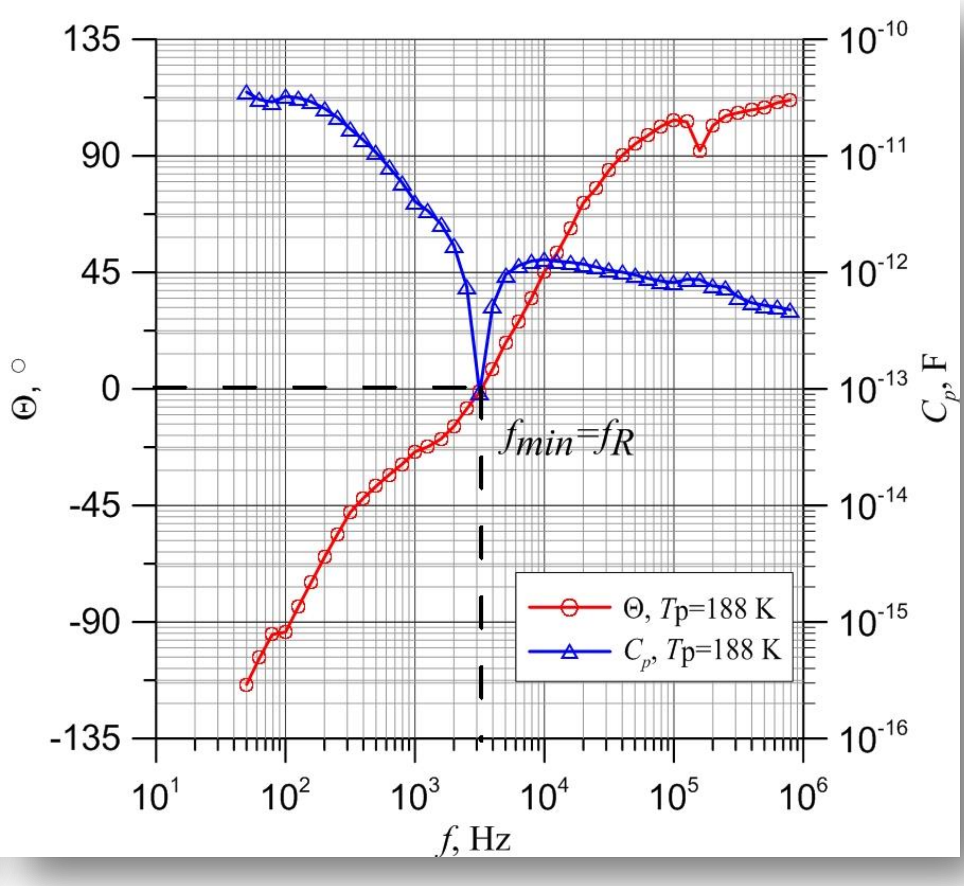


Fig. 11. Comparison of frequency dependence of capacitance C_p and frequency dependence of phase shift angle θ of $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ nanocomposite

6. Phenomenon of non-coil like inductance in $(FeCoZr)_x(CaF_2)_{(100\text{-}x)}$ nanocomposites

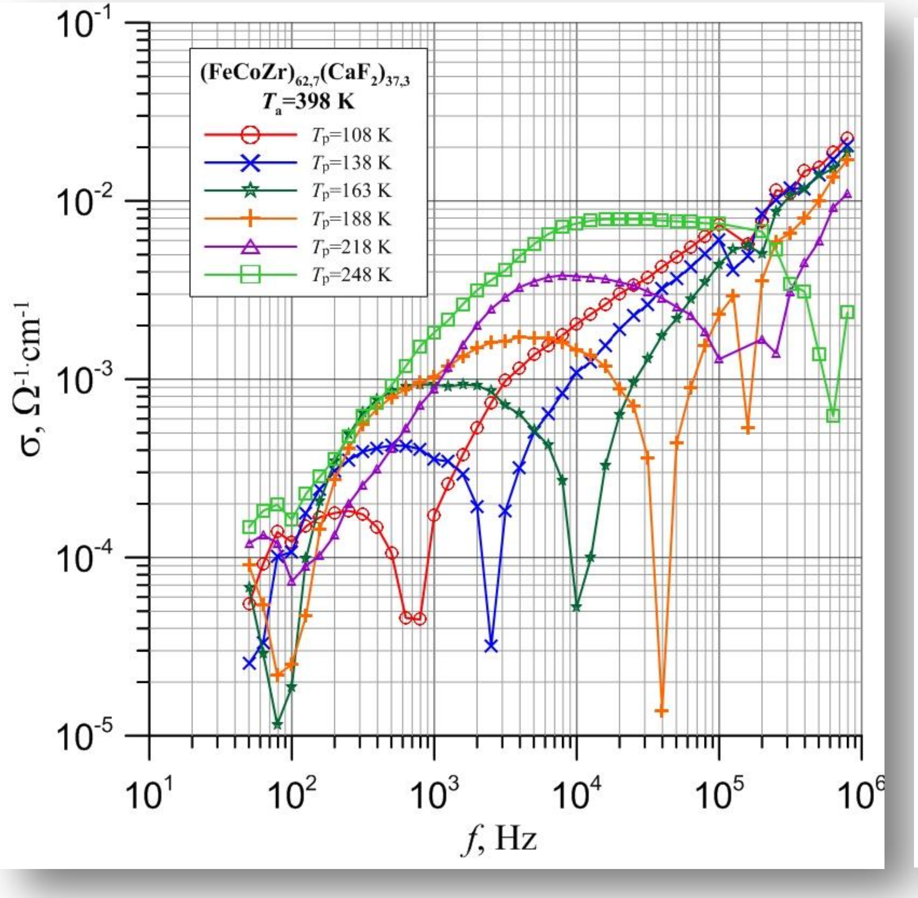


Fig. 12. Frequency dependence of conductivity σ of $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ nanocomposite produced by sputtering with combined ion beam (Ar and high O_2 content) and annealed at 398 K

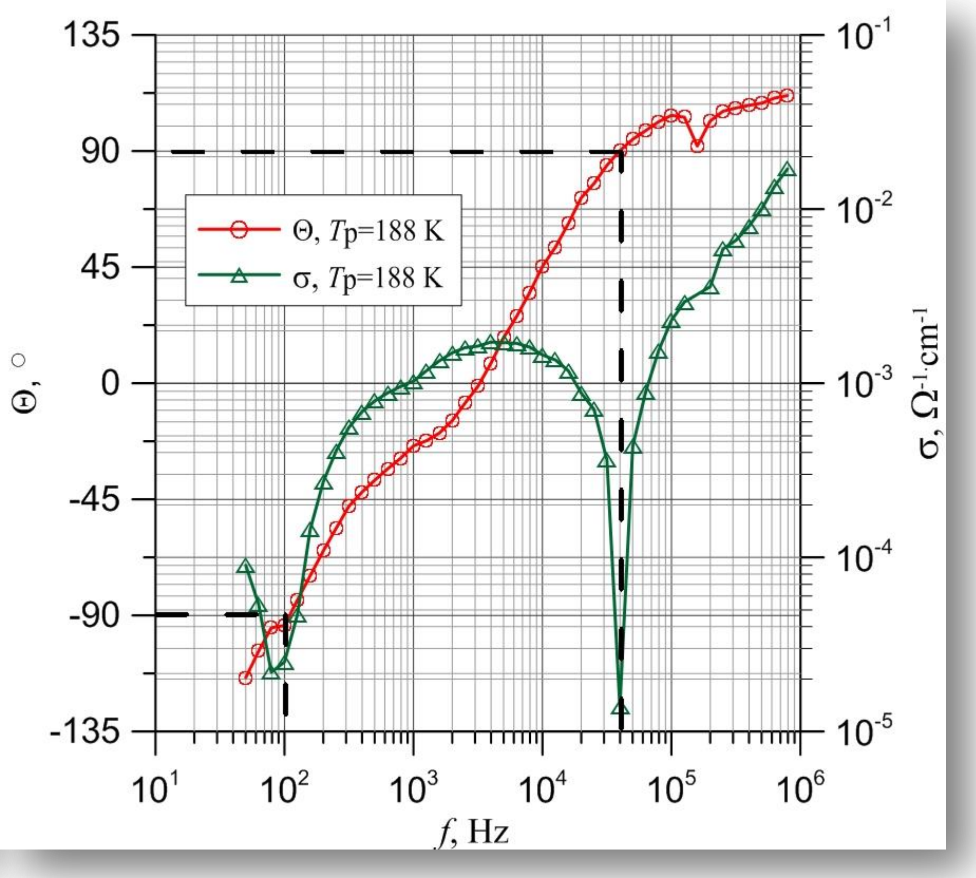


Fig. 13. Comparison of frequency dependence of conductivity σ and phase shift angle θ of $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ nanocomposite

6. Phenomenon of non-coil like inductance in $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites

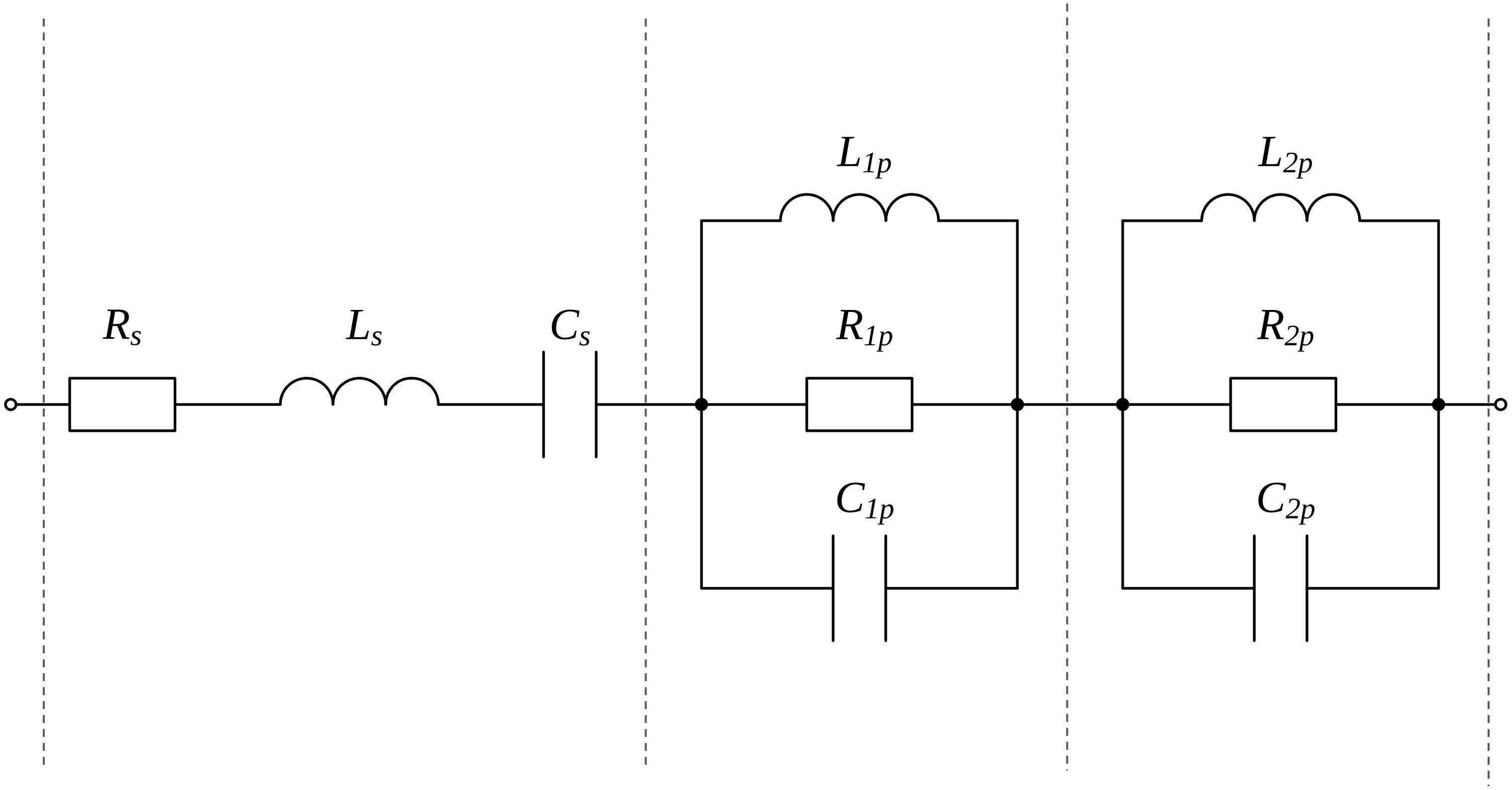


Fig. 14. Schematic representation of $(FeCoZr)_{62.7}(CaF_2)_{37.3}$ nanocomposite produced by sputtering with combined ion beam (Ar and high O_2 content)

7. Production of non-coil like inductance circiut and capacitance-inductance circuit

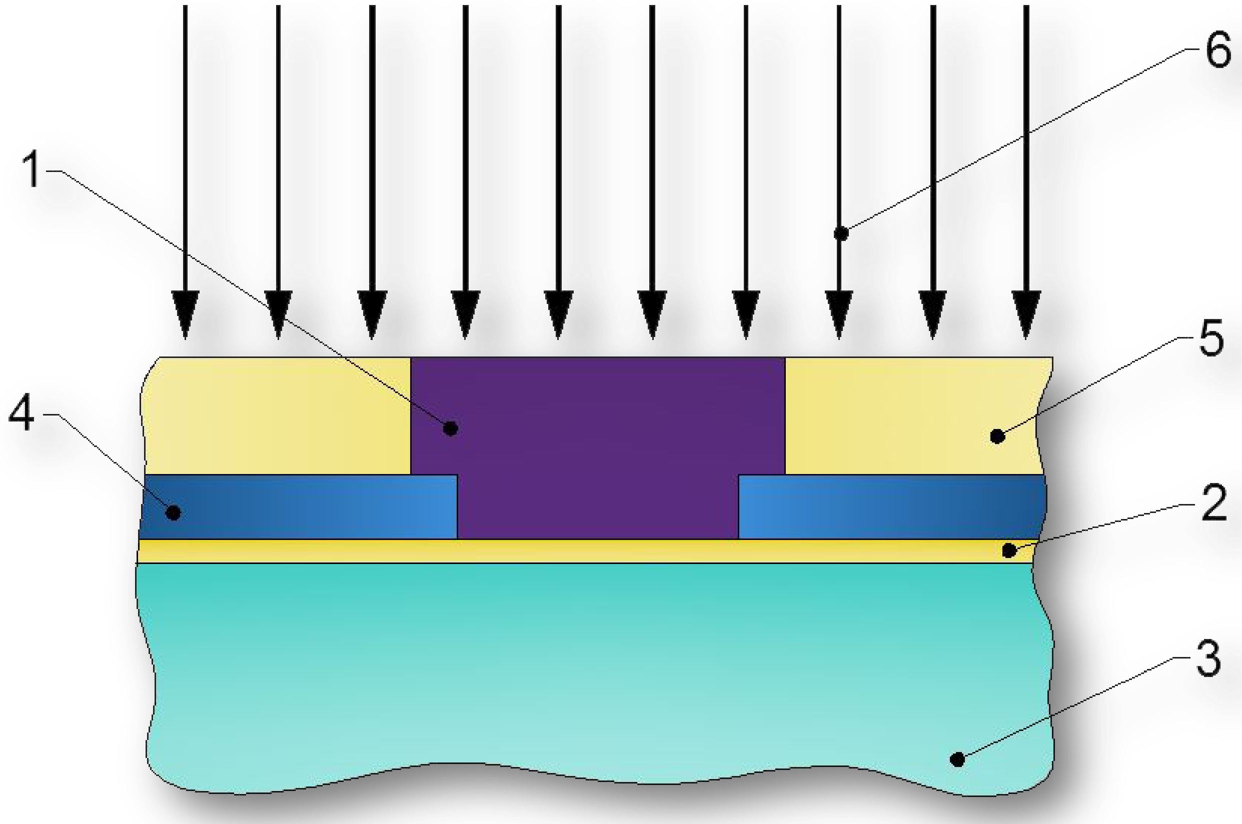


Fig. 15. Method of producing non-coil like inductance and capacitance-inductance circuit: 1 – vaporized layer of $(FeCoZr)_x(CaF_2)_{(100\text{-}x)}$ nanocomposite, 2 – insulation layer, 3 – silicon substrate plate, 4 – metallization layer, 5 – mask for photolithography, 6 – atomic sputtering stream

8. Conclusions

- Three series of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite samples were produced. The first series by pure argon ion beam sputtering, the second by argon with low oxygen content and the third one by argon with high oxygen content.
- From the EDX X-ray spectra of the $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites, the actual atomic composition of the metallic and dielectric phase elements was determined.
- The formation of the granular structure of the $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites was determined from the images obtained by TEM.
- Using the thermo-gravimetric method, it was determined that high-temperature treatment in air of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites produced with an argon ion beam causes first oxidation of the surface of the metallic phase grains and then complete oxidation of these grains.

8. Conclusions

- The alternating-current properties of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposites were investigated, based on which the percolation threshold values of x_C=(65.8±2.0) at.% for the nanocomposite produced with pure argon ion beam and x_C=(82±2.0) at.% for the nanocomposite produced with argon ion beam with high oxygen content were determined.
- Current and voltage resonance phenomena characteristic of conventional RLC circuits were observed in $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite layers without windings after thermal treatment.
- On the basis of the results of the research on the phenomenon of the non-coil like inductance occurring in the layers of $(FeCoZr)_x(CaF_2)_{(100-x)}$ nanocomposite, two patents were obtained, in which the methods of producing the non-coil like inductance and the capacitance-inductance system were described.

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