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ELECTRON-BEAM DEPOSITION OF MAGNETO-DIELECTRIC COATINGS IN MEDIUM VACUUM

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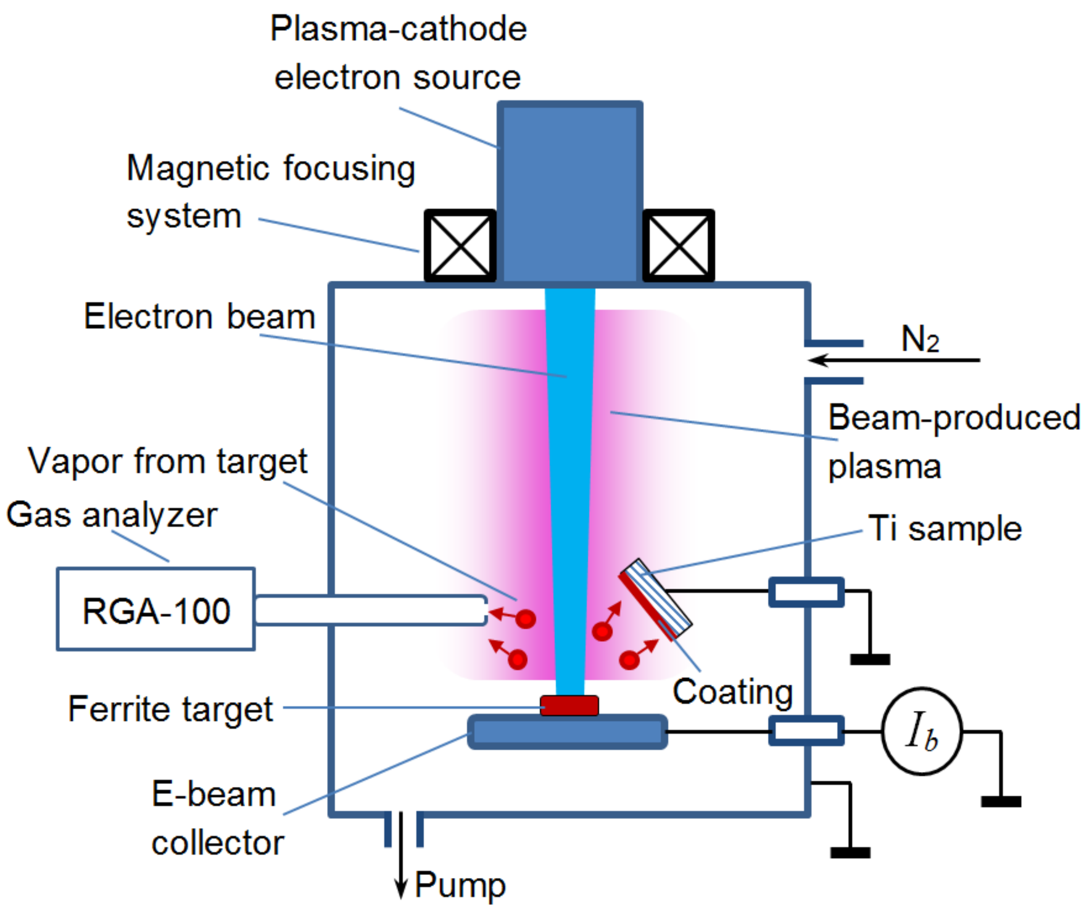
Relevance and Outline

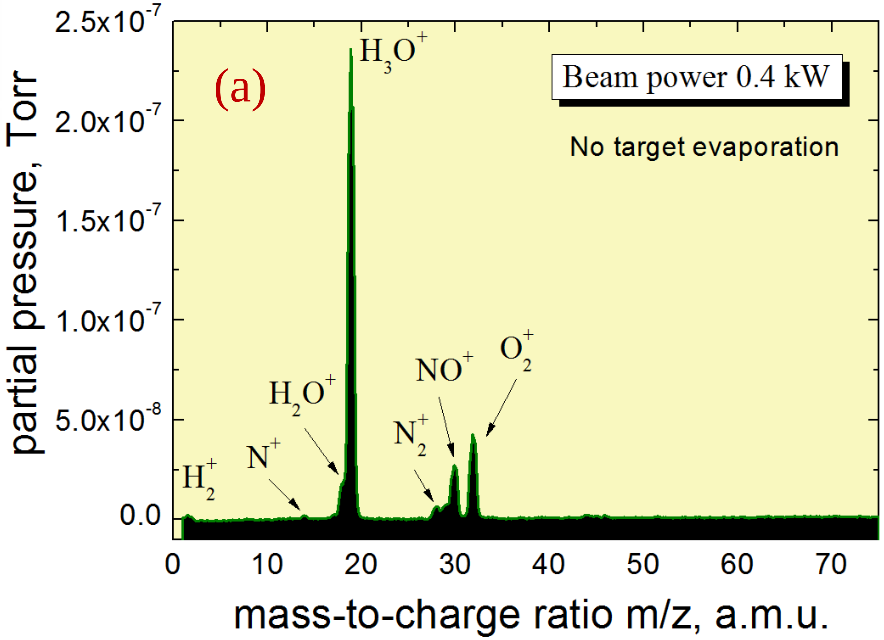
- Materials combining dielectric and magnetic coatings are very attractive to use in such fields of industry as RF electronics, and aerospace industry for the manufacturing of radio-absorbing coatings. The emerging trend towards miniaturization of the various devices, such as unmanned aerial vehicles, requires deposition of thin and light-weight magnetic films that combine magnetic and dielectric properties.
- We propose an advanced approach to formation of such thin magneto-dielectric coatings – by the use of a fore-vacuum plasma-cathode electron source. Using the electron-beam evaporation of both dielectric (alumina ceramics) and magnetic targets in medium vacuum (several Pa), we create dense multi-component plasma, which provides the flux of the particles of target materials, allowing to deposit a magneto-dielectric coatings on a metallic substrate with very high deposition rate (approximately microns per minute) and high degree of coating uniformity.
- We report the most updated results on the regimes of the electron-beam evaporation of ceramic and magnetic targets, discuss the mass-to-charge composition of the beam plasma at the different stages of the target evaporation, and demonstrate the preliminary results of the mageto-dielectric coatings deposition onto metallic substrate.

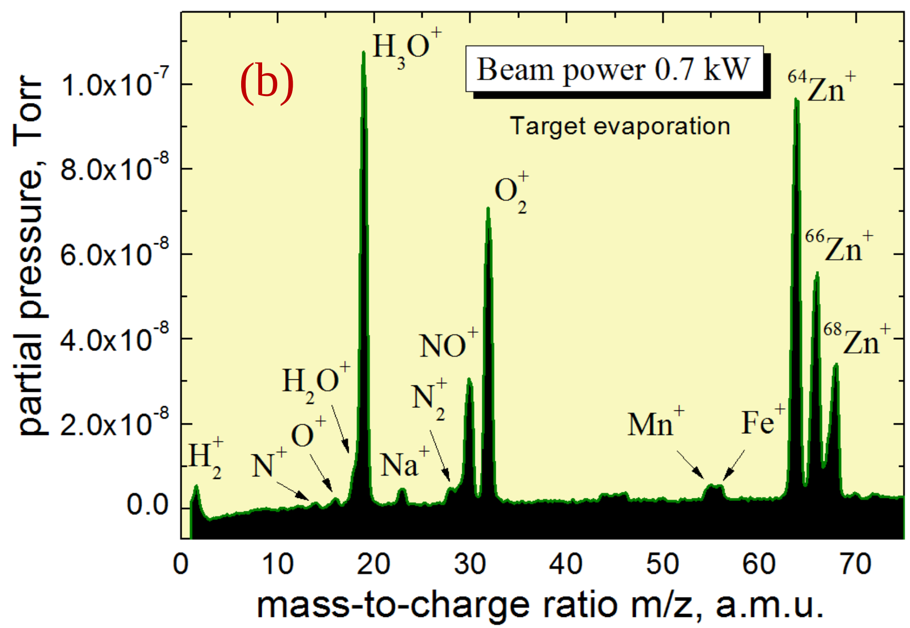
Experimental setup



- A continuous electron beam of circular cross section with a diameter of 5 mm, a current of I_b = 100 mA and an energy of 4-7 keV was generated by a fore-vacuum plasma electron source based on a glow discharge with a hollow cathode. The base pressure in the vacuum chamber pumped out only by a mechanical fore-vacuum pump, was p_0 = 0.5 Pa. The working pressure was set by introducing nitrogen into the chamber up to p = 10 Pa.
- The ceramic target was a thin plate of alumina ceramic with a size of 10 × 10 mm^2.
- The ferrite target was Mn–Zn ferrite from the HM2000 brand with the chemical composition $Mn_{0.6}Zn_{0.4}Fe_3O_4$, made in the form of a cylindrical tablet with a diameter of 20 mm and a thickness of 5 mm. The composition of this ferrite is (50–75 at. %) $MnFe_3O_4$ + (25–50 %) $ZnFe_3O_4$. To avoid cracking of targets during their heating by an electron beam, the beam power gradually increased from 0.2-0.4 kW to 0.7 kW, over a period of the order of several tens of minutes.
- The substrate was a polished Ti disk with a diameter of 2 cm, set at a small angle to the target at a distance of 5 cm from it.

Experimental Results & Discussion: plasma ions composition

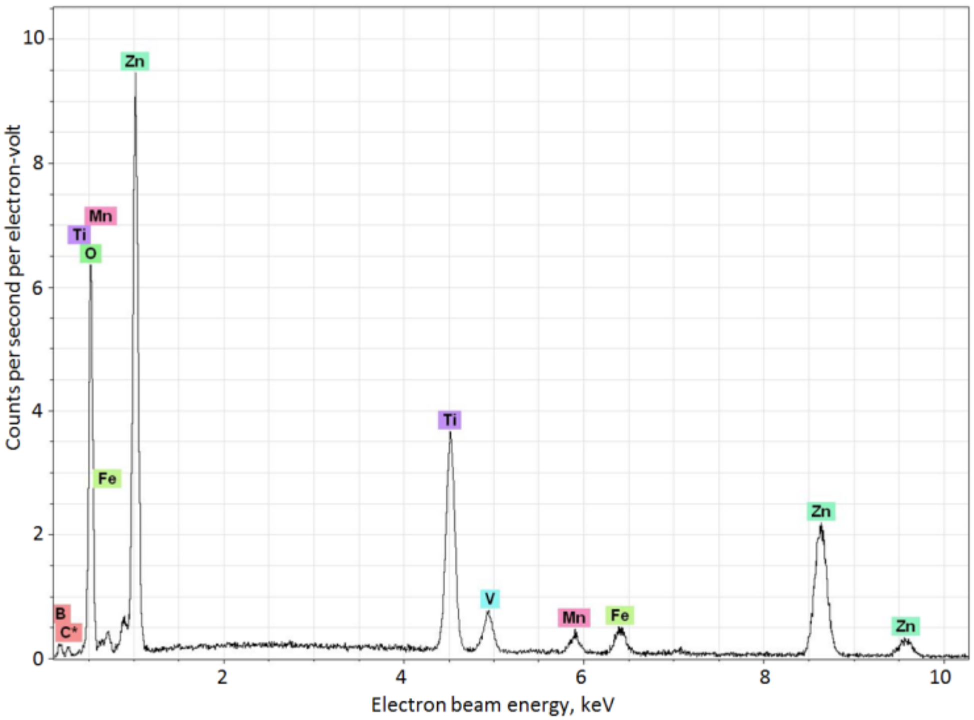


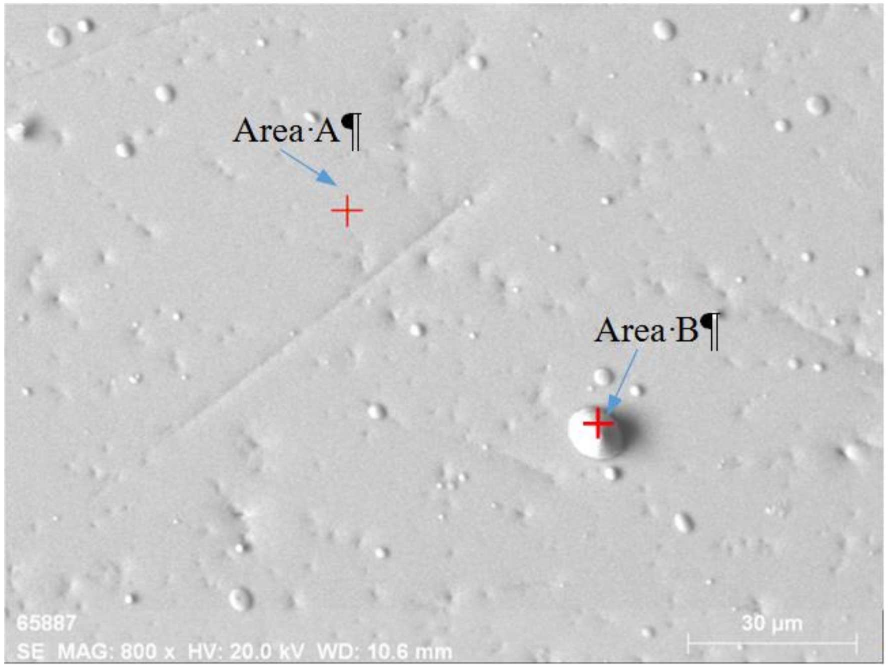


- The spectrum of the mass-charge composition of plasma ions, at the lowest level of the electron beam power density of 2 kW/cm^2 (a), does not contain ions of the target materials, even such easily evaporating as zinc. Only the ions of water and its components (H_2O^+, H_3O^+, H_2^+, O_2^+), ions of the injected working gas (N^+, N_2^+), as well as ions of gaseous products of chemical reactions (NO^+) of these components, are clearly visible in the spectrum.

- With an increase in the beam power up to 0.7 kW, and, accordingly, the power density up to 3.6 kW/cm^2, the ions of the working gas and the residual atmosphere are supplemented with ions of the elements that compose the target: Na^+, Mn^+, Fe^+, and zinc isotopes $^{64}Zn^+$, $^{66}Zn^+$, $^{68}Zn^+$. It should be noted that with the increasing beam power, the fraction of oxygen ions O_2^+ also increases. This, apparently, is also associated with the active evaporation of this substance from a heated target.

Experimental Results & Discussion: deposited coating composition





Elemental composition of the coating deposited on Ti substrate after evaporation of a ferrite target in nitrogen atmosphere. Beam power 700 W (current 100 mA, energy 7 keV), pressure 10 Pa, deposition time 20 min.

Microphotograph of the coating deposited as a result of electron-beam evaporation of ferrite target in nitrogen. Red cross marks the areas where the elemental analysis has been studied

Experimental Results and Discussion: deposited coating analysis

TABLE I. ELEMENTAL COMPOSITION OF COATING (AREA A)

Element	AN	Net	Norm wt.%	Norm at. %	Err in wt.% (1σ)
Boron	5	475	13.3	29.6	4.1
Carbon	6	343	0	0	0
Oxygen	8	14618	32.1	48.2	4.7
Titanium	22	21045	14.3	7.2	0.5
Vanadium	23	933	0.6	0.3	0.1
Manganese	25	1768	1.5	0.6	0.1
Iron	26	2638	2.5	1.1	0.1
Zinc	30	17622	35.7	13.1	1.1
		Sum:	100	100	

TABLE II. ELEMENTAL COMPOSITION OF DROPLET (AREA B)

Element	AN	Net	Norm wt.%	Norm at. %	Err in wt.% (1σ)
Boron	5	410	15.8	31.1	5.6
Carbon	6	460	0	0	0.0
Oxygen	8	17248	38.6	51.4	6.0
Titanium	22	3027	2.9	1.3	0.1
Vanadium	23	193	0.17	0.07	0.0
Manganese	25	6921	9.1	3.5	0.3
Iron	26	18484	29.2	11.1	1.0
Zinc	30	1440	4.3	1.4	0.2
		Sum:	100	100	

- Boron presents in the coating composition from both areas A and B, which follows from Tables 1 and 2. Most likely, its presence is explained by the presence of a boron-containing impurity in the material of the ferrite target.
- Droplets deposited on the coating mainly consist of iron and manganese, since the content of specifically these elements in area B is noticeably higher than in area A.
- The mere presence of droplets on the coating surface indicates an over-optimal high beam power density, which leads to excessively intense boiling of the material of the ferrite target and the formation of droplets.
- Therefore, efforts should be made to reduce this parameter in further experiments.

Conclusion

The feasibility of synthesizing magneto-dielectric coatings as a result of electron beam evaporation of a ferrite target in nitrogen with an average vacuum pressure of 10 Pa using a fore-vacuum plasma electron source is shown. The elemental composition of the deposited coating showed the presence of a noticeable number of atoms of elements with magnetic properties (iron, manganese). This indicates the promise of the proposed method, and stimulates the further study of the magnetic and dielectric properties of the obtained films.

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Thank you for attention!