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Features of magneto-optical response on multilayer nanostructures $\{(Co_{45}Fe_{45}Zr_{10})_Z\ (Al_2O_3)_{100-Z}/\alpha\text{-}Si\text{:}H\}_n$

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Abstract. Spectral and field dependencies of Transversal Kerr Effect (TKE) for [(Co45Fe45Zr10)Z (Al2O3)100-Z(X)/α-Si:H(Y)]n multilayers have been studied in the energy range 0.5 - 4.0 eV. It was found that TKE field dependencies in the nearest IR energy range exhibit anomalous behavior for structures only with thin Si layers and this behavior vanishes with increasing of the Si layer thickness. TKE spectra measured in small and large magnetic fields were essentially different. It was shown that magneto-optical response of multilayered structure composite-silicon is the sum of contributions from two composites: (Co45Fe45Zr10) - Al2O3 + Si + silicides and (Co45Fe45Zr10) - Si + silicides, which have a different sign of TKE in the nearest IR spectrum and their magnetic states depend both on composite and semiconducting layer thicknesses.

Introduction

Exploitation of nanogranular composites as functional systems for microelectronics creates lots of questions about interaction mechanisms of heterogenic systems with semiconductors. Active phase interaction makes difficulties for interpretation of obtained results and limits to possibilities of application these materials.

Previous studies of multilayer structures (ML) nanocomposites-silicon (CoFeZr)-Al_2O_3/Si [1-3] have shown that silicon introduction leads to anomalous behavior of electrical, magnetic and magneto-optical properties of ML with small thicknesses of Si (< 2nm). Authors in [1] suggested that changes of ML magnetic properties relate with bifurcation temperature of composite layer due to Si conduction electrons. In [2,3] peculiarities of magnetic and magneto-optical properties were related with grown features of Si layer on the interface ferromagnetic (FM) granule – semiconductor. For further studies of FM – semiconductor interface influence on magnetic and magneto-optical properties of MS additional measurements of spectral and field transversal Kerr effect (TKE) dependencies in the nearest infrared (IR) energy range have been performed for nano-multilayered structures $[(Co_{45}Fe_{45}Zr_{10})_Z(Al_2O_3)_{100-Z}(X)/\alpha\text{-}Si\text{:}H(Y)]_n$ As a magnetic layer in this structure a granular composite based on the $Co_{45}Fe_{45}Zr_{10}$ alloy with concentrations before the percolation threshold was used.

Additional experimental evidences that anomalous behavior of magnetic and magneto-optical properties for nanocomposite – silicon ML with small silicon thicknesses relates with peculiarities of FM granule – semiconductor interface formation are presented below.

Experimental details and results

Multilayered nanostructures were prepared by ion-beam sputtering. Nominal thicknesses of studied samples are presented in the Table 1.

Concentrations of metal in the composite layers were below the percolation threshold in the bulk samples with the same metal concentration. The characteristic granule size in bulk composites at given concentrations was 2-3 nm [4].

Magneto-optical properties of samples have been measured in the TKE geometry. TKE measurements have been performed in the energy range 0.5 ÷ 4.0 eV at the light incidence angle of 68° and in magnetic fields up to 3.0 kOe. The sensitivity of the experimental set-up was 10^{-5}.

Measurements of TKE field dependences δ(H) in the near IR range have shown their abnormal behavior that was considerably differ from δ(H) curves obtained in the visible range of spectra [3]. The maximum of TKE was achieved at small fields (H < 100 Oe), and with following increasing of magnetic field H the sign of the effect has changed with further saturation at fields ~2.5kOe (Fig. 1 A,B). In some cases the TKE value at the maximum was 3 times greater in comparison with the saturation value (Fig. 1 B). The change of TKE sign is absent on the field dependencies measured at E = 2 eV for the same samples [3]. Moreover, anomalous behavior of δ(H) disappeared with increasing of Si layers thicknesses. The TKE spectra measured in small and large applied magnetic fields were essentially different (Fig. 2 A,C and B,D).

Table 1

	X, nm	Y, nm
series 1 n=36	2,00	0,52
	2,27	0,77
	2,43	0.95
	2,54	1,09
	2,64	1,18
	2,74	1,26
	2,86	1,32
	3,75	1,82
series 2 n=69	1,39	0,18
	1,58	0,27
	1,68	0,34
	1,76	0,38
	1,83	0,41
	1,89	0,44
	1,98	0,45
	2,17	0,50
	2,50	0,59
	2,66	0,67
	2,55	0,98

TKE spectra for samples in the 1st series measured at magnetic field of 2.5 kOe were similar to each other and have a positive sign for whole energy range. The TKE magnitude increases for Y = 0.52 ÷ 0.95 nm. Further increasing of the Si layer thickness leads to the decrease of the TKE maximum value. All TKE spectra are similar to the spectra of $Co_{45}Fe_{45}Zr_{10}$/Si ML [5], but drastically differ (both in sign and shape) from the spectra of the $(Co_{45}Fe_{45}Zr_{10})_x(Al_2O_3)_{1-x}$ granulated composite with metal concentration below the percolation threshold [4,6] (Fig. 2 F). For ML with Y≤0.95 nm the spectra measured in small magnetic fields (H < 10 Oe) TKE has a negative sign for energies E < 1.75 eV and a spectra character is similar to spectra of $Co_{45}Fe_{45}Zr_{10}$ composites in a dielectric matrix [6].

Further increasing of Si layer thicknesses (0.95 < Y ≤ 1.26 nm) leads to sharp change of spectra shapes in small fields and to the disappearance of anomalous form of δ(H) curves.

It have been found that field dependences of TKE for ML with Y = 0.95÷1.26 nm had a ferromagnetic character and for ML with Y = 1.32÷1.83 nm they had a superparamagnetic one.

For samples from the 2nd series there was analogous dependency of TKE on layer thicknesses but the anomalous behavior of MO properties have been observed at smaller Y.

Results obtained allow to conclude that MO response in the studied ML are formed both by magnetic composite layer and new magnetic phase formed on the magnetic granule – semiconductor interface. Two composites that give contributions in the total response could be described as follows:

1. $Co_{45}Fe_{45}Zr_{10}$ in Al_2O_3 matrix with a sputtered Si layer. Si layer is bringing together adjacent grains, leading to an increase in the magnetic interactions through the silicon granules and / or silicides, and thus increases the concentration of magnetic phase in complex composite $Co_{45}Fe_{45}Zr_{10}$ in Al_2O_3 matrix + Si (and/or silicides). The sign of TKE in the IR range is negative. The contribution of this composite can explain the shape of TKE spectra in small fields for the 1st series at Y ≤ 0.95 nm.

2. ML composite $Co_{45}Fe_{45}Zr_{10}$ – Si + silicides for which TKE spectra are similar to spectra of $Co_{45}Fe_{45}Zr_{10}$/Si ML [5]. The sign of TKE for this ML is positive in the near IR range.

The magneto-optical results correlate with data on studying of the transport and magnetic properties of ML. The specific electric resistance value of ML depends very strongly on the Si thickness. The ρ value sharp decrease on two orders is observed at thickness Si in the range from 0.75 up to 1.25 nm (1ser) and 0.36 – 0.47 nm (2ser). The further semiconductor layer thickness increase does not lead to significant ρ changes**.** [3] So, changes of ML transport properties in the small thickness range of silicon could be related with formation and growth of intergranular Si layer on FM CoFeZr granules. It means that at the FM granule-semiconductor interface there is a formation of new composite (CoFeZr)-Si or (CoFeZr)-silicides + Si, where a concentration of magnetic phase depends on either shapes or sizes of granules in the magnetic layer, X/Y thickness ratio and rate of silicide formation. Increasing of Si thicknesses up to the percolation threshold range will lead to merging of neighboring granules through Si islands within the layer as well as between of adjacent layers, and hence to increasing of the magnetic phase in the (CoFeZr)- silicides + Si composite.

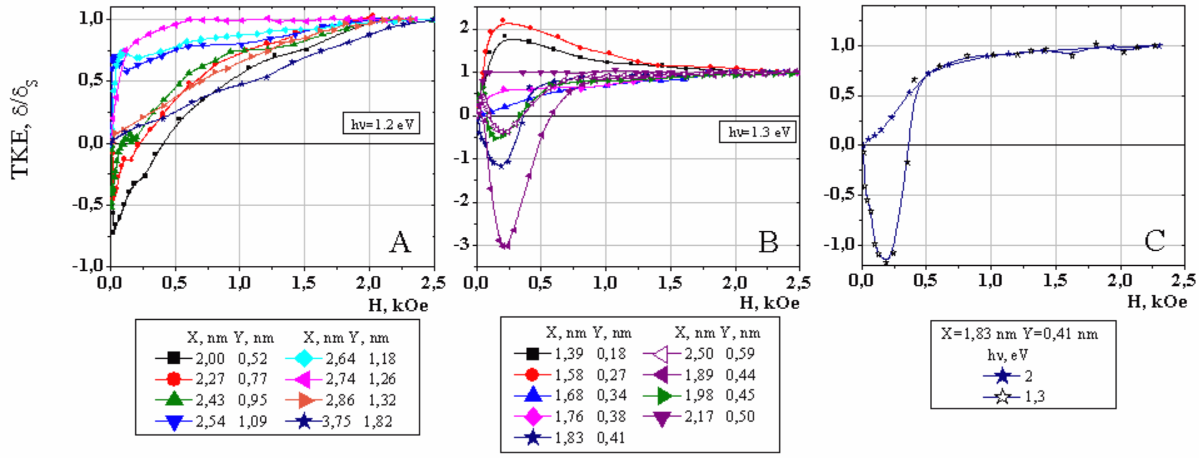

Fig. 1. The field dependences of TKE for 1st (A), 2d (B) series and for different wavelength for the sample from 2d series (C).

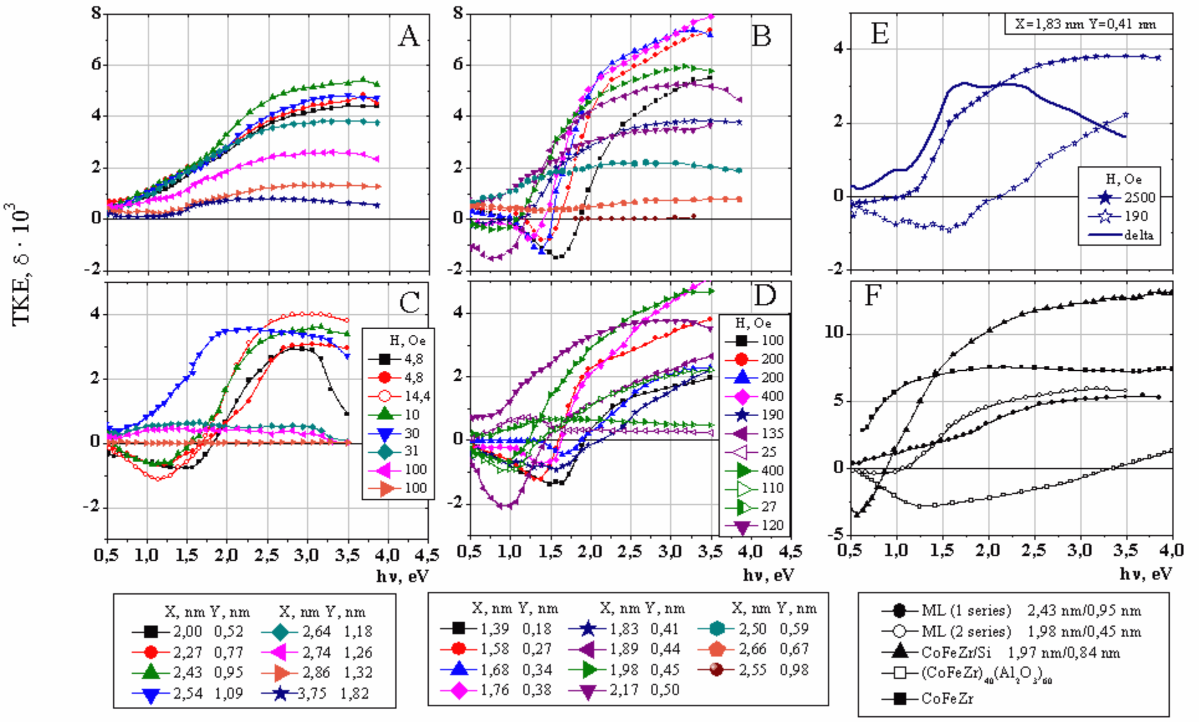

Fig. 2. The TKE spectra measured in field of 2.5 kOe for 1st (A) and 2d (B) series and TKE spectra measured in weak magnetic field 1st (C) and 2d (D).
(E) – TKE spectra measured in fields of 2.5 kOe and 0.19 kOe and difference of these spectra for the sample of the second series.
(F) – Comparison spectral dependences of TKE for 1st and 2nd series and spectra for bulk composites $(Co_{45}Fe_{45}Zr_{10})_{40}(Al_2O_3)_{60}$, bulk $Co_{45}Fe_{45}Zr_{10}$ and ML $Co_{45}Fe_{45}Zr_{10}/Si$.

This could be an explanation of the magnetization and TKE growth with institution of silicon. The maximum of magnetization values and TKE for both systems have been observed near the percolation threshold for the (CoFeZr) - Silicides + Si composite.Similar conclusions can be made from the coincidence of TKE spectra shapes and magnitudes of ML nanocomposite-silicon and ferromagnetic-silicon with X and Y from the range of percolation. (fig.2F)

Further growth of Y ($Y > Y_{per}$) expands the amount of non-magnetic phase from silicides at the interfaces, and at the same time the connection between of FM granules through Si and silicides becomes extinct. Formed interface blocks subsequent diffusion of FM in Si and a silicon streak appears, that isolates silicides and breaks of magnetic interaction between of adjacent layers.

Anomalous behavior δ(H) in the nearest IR range most probably relates with a competition between of two contributions from different (CoFeZr)- Al_2O_3 silicides + Si + and (CoFeZr)- silicides + Si composites that have opposite sign of TKE in this spectral range.

Conclusion

Detailed studies of TKE field dependencies at different wavelengths and MO spectra at weak fields for $[(Co_{45}Fe_{45}Zr_{10})_z(Al_2O_3)_{100-z}(X)/Si:H(Y)]_n$ nanostructures showed that magneto-optical response of composite-silicon multilayer films is determined by sum of partial responses of two composites: $(Co_{45}Fe_{45}Zr_{10})$–Al_2O_3+Si+silicides and $(Co_{45}Fe_{45}Zr_{10})$–Si+silicides. The contribution of each composite was identified because TKE signs for these nanocomposites differ in the nearest IR spectrum. The magnetic states of both $(Co_{45}Fe_{45}Zr_{10})$–Al_2O_3+Si+silicides and $(Co_{45}Fe_{45}Zr_{10})$–Si+silicides nanocomposites depend on the thickness of either semiconductor or composite layers. The thicknesses X and Y at which the anomalous changes in magnetic and MO properties take place are well correlated with sharp changes in the electric properties both series, and this is related to the intrinsic features of the process by which the composite $(Co_{45}Fe_{45}Zr_{10})$ is formed on the interface in the (Si+silicides) matrix. As result magnetooptical methods allow to exhibit the formation of two composites in magneto-semiconductor structures.

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