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Optical properties of nanostructured nickel thin films obtained by oblique angle deposition

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Abstract. The article presents a study of the optical properties of nickel nanospirals obtained by glancing angle deposition in order to identify and analyze circular dichroism (CD), a phenomenon in which a material exhibits different light absorption with left- and right- circular polarization. It has been experimentally established that the chiral geometry of nanospirals, formed due to the effect of shading and the speed of rotation of the substrate during deposition, is the cause of a pronounced optical response. The use of scanning electron microscopy (SEM) confirmed the formation of a series of spiral samples with varying pitch and diameter, which connects these morphological parameters with their spectral characteristics. Spectroscopic measurements in the visible range revealed circular dichroism. It is shown that the specific chiral geometry of nanostructures, formed due to sputtering conditions, leads to differential absorption of left- and right-circularly polarized light in the visible range. The results demonstrate the dependence of the optical response on the morphology of nanospirals, which opens up opportunities for designing metamaterials with specified parameters. The discovered circular dichroism makes such structures promising for use in nanophotonics, the creation of polarization filters, etc. The application of a magnetic field has little effect on the optical properties of the studied samples.

Keywords: chiral metasurfaces, circular dichroism, nanospirals, oblique angle deposition

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Оптические свойства наноструктурированных пленок никеля, полученных методом наклонного напыления

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Аннотация. Представлены результаты экспериментальных исследований киральных пленочных структур на основе массивов наноспиралей никеля, полученных методом наклонного осаждения. Показано, что в условиях испарения электронным пучком на вращающейся наклонной подложке формируется массив наноспиралей, закрученных в одном направлении. Полученные таким образом киральные тонкопленочные метаматериалы обладают выраженным круговым дихроизмом, который может быть использован для создания поляризаторов и оптических фильтров.

Ключевые слова: киральные метаповерхности, циркулярный дихроизм, наноспирали, наклонное напыление

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Introduction

The possibility of creating artificial chiral materials with unique optical characteristics allows to study the fundamental mechanisms of the interaction of light with matter and opens up broad prospects for their practical application [1]. Chirality is manifested in optical phenomena in the form of different types of interaction of such a material with right- and left- circularly polarized light [2]. These phenomena can be used for practical applications in the creation of optical filters, polarizers and sensors of various types.

Materials and Methods

In this work, the method of glancing angle deposition (GLAD) was used for nanostructuring the film. Within the framework of this method, nanospiral arrays are formed under conditions of electron beam evaporation onto an inclined substrate due to the shading effect. This effect consists in the fact that crystallites, which have received a random advantage in grow that the initial stages of deposition, further shade their neighbors, suppressing their growth. As a result, pores form in the growing film and an array of individual nanofibers is formed. Turning on the rotation of the substrate around the normal to its surface during growth leads to a gradual displacement of the shadow region and the formation of nanospirals from nanofibers [1, 2]. Spirals are twisted fibers in the same direction, which is determined by the direction of rotation of the sample.

Experiments on glancing angle deposition of thin films were carried out at the Oratoriya-9 electron beam evaporation facility. During spraying, the angle of inclination of the sample to the source was 85°.Base vacuum is equal to $4 \cdot 10^{-6}$ Torr. The morphology and structure of the resulting films were studied by scanning electron microscopy (SUPRA-40). Optical characteristics were measured on a Jasco J-1500 circular dichroism spectrometer in the transmission mode. To study the effect of the magnetic field on optical properties, measurements were repeated with the induction of an external magnetic field of 2100 Oe along the optical axis.

Results and discussion

Fig. 1 shows the results of studies for samples obtained at different speeds of rotation of the substrate from 0.1 to 0.3 rpm: SEM images of the side view of films are shown on the left panel, and the corresponding top view are shown on the right panel. Table 1 shows the average geometric parameters of the resulting nanostructures. The pitch of a spiral is the height of one complete spiral turn, measured parallel to the axis of the spiral. The external diameter of the spiral is the maximum diameter of the spiral coil, measured from the outermost point of the coil to its center. The fiber diameter is the diameter of the circle, which is the cross-section of the fiber from which the spiral is twisted.

a)
b)
c)

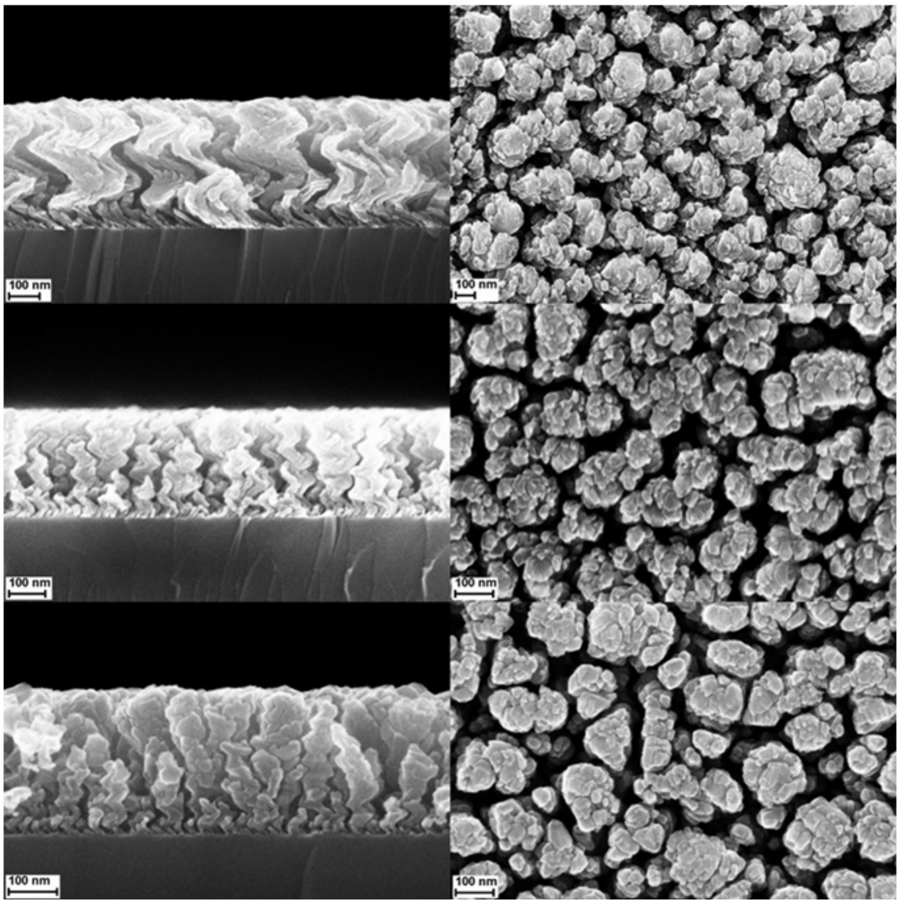

Fig. 1. Microscopic images of nanostructured Ni films (left panel on the side, right panel on the top) obtained at a growth rate of 0.3nm/s and at a rotation speed: 0.1 rpm (*a*), 0.2 rpm (*b*), 0.3 rpm (*c*)

Table 1

Geometric parameters of nanospirals

Rotation speed, rpm	Height, nm	Pitch, nm	External diameter of spiral, nm	Fiber diameter, nm
0.1	403±16	203±8	162±36	27±3
0.2	287±69	75±5	70±31	25±2
0.3	277±75	53±8	40±17	23±2

The results of measurements of the circular dichroism effect are shown in Fig. 2. The circular dichroism spectra for samples obtained at different speeds of rotation of the substrate are shown: from 0.1 to 0.3 rpm. An analysis of the above data shows that the films obtained demonstrate a pronounced effect of circular dichroism of up to several degrees. At the same time, the obtained spectra significantly depend on the geometric dimensions of the nanospirals (pitch of the spirals) [3, 4]. As the rotation speed of the substrate increases, the pitch of the spiral decreases and, accordingly, the minimum and maximum on the spectrum shift to the region of shorter wavelengths [4, 5]. The inclusion of an external magnetic field slightly changes the optical characteristics. The intensity of CD is related to the quality of the resulting nanostructures. When the nanospiral shape approaches the geometric perfection of the spiral, that is, their proximity to the model of a regular spiral with constant pitch, diameter and smooth curvature, the intensity of maximum and minimum, that is, the difference in absorption of left- and right-circularly polarized light increases in amplitude.

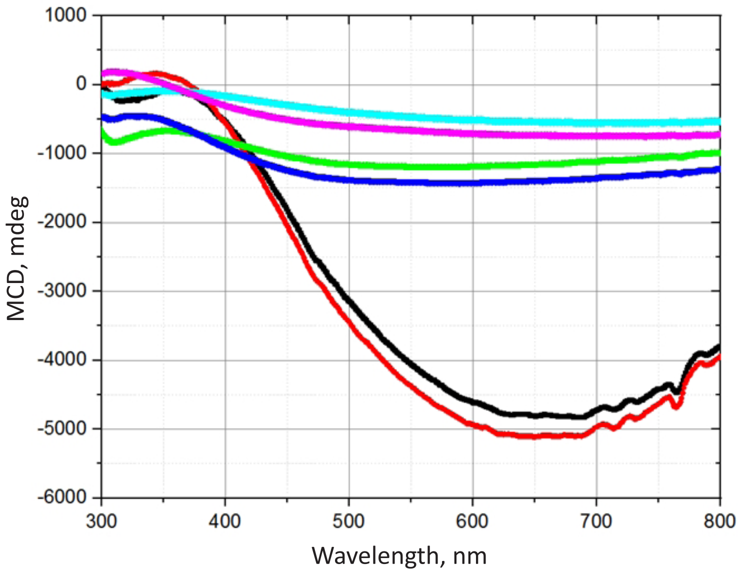

Fig. 2. Magnetic circular dichroism spectra for a series of samples with different rotational speeds: 0.1 rpm at $H = 0$ Oe (black line) and at $H = 2100$ Oe (red line), 0.2 rpm at $H = 0$ Oe (green line) and at $H = 2100$ Oe (blue line), 0.3 rpm at $H = 0$ Oe (light blue line) and at $H = 2100$ Oe (pink line)

Conclusion

To sum up, the experimental studies have shown that thin nanostructured nickel films obtained by the method of GLAD with the rotation of the substrate are arrays of nanospirals twisted in the same direction. By changing the speed of rotation of the substrate during deposition, it is possible to directionally change the geometric dimensions of the nanospirals, thereby changing the optical characteristics of the resulting films. The addition of an external magnetic field slightly increases the value of circular dichroism, that is the difference in absorption of left- and right- circularly polarized light.

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