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Thin films of magnetic monocrystals as light signal converters*

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This paper presents the results of study on thin garnet films and yttrium orthoferrite plates as magnetic gratings that can be used in optoelectronic light-signal converters for the deflection and modulation of the laser beam. The magnetic domain structures of the investigated monocrystals can be sufficiently regular, depending on the adequate choice and configuration of the external magnetic fields. One-side epitaxial films with a minimal number of defects proved to be the most suitable magnetic gratings. Methods and testing equipment can be used for diagnostic and parameter measurement of thin magnetic films.

1. Introduction

Magnetic monocrystals in the form of thin films with adequate magnetooptical parameters (high figure of merit, high Faraday rotation, low coefficient of absorption) and material parameters as well as domain structure controlled by the external magnetic field can be applied as light signal converters on optoelectronic devices.

Magnetooptical diffraction of the laser light on the regular domain structure controlled by a magnetic field is the base for this application. Magnetic diffraction gratings (MDG) can be the essential element of modulators, switches or laser beam deflectors.

The necessity of further investigations in the field of magnetooptical use of epitaxial films arises from the evaluation of the scientific and patent papers published so far, especially concerning experimental results and from the technological possibilities of the country [1].

As investigated samples in most cases uniaxial ferromagnetics in a form of a thin film have been used, non-magnetized with easy magnetization axis perpendicular to the sample surface. In the film there occur domains with the same magnetization direction but with a reverse sense in the adjacent domains. The resultant magnetization equals zero.

Thin magnetic films (TMF), transparent in the visible range of the electromagnetic spectrum, can be studied with the help of Faraday's magnetooptical

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laser-light method. This method has been chosen from those applied so far because of its simplicity in laboratory work. It makes it possible to get domain structure pictures of good quality and together with the optical diffractometry method it may be used for magnetic gratings investigations.

TMF with uniaxial anisotropy create a binary transmitting grating for the laser beam. The change of the structure period d (of two adjacent antiparallel magnetized domains) causes a change of deflection angle a_n. This is the principle of the laser beam deflection. Change of the domain structure orientation is used for this purpose. Change of symmetry (increase of width of the applied field magnetized domains and decrease of width of the domains of an antiparallel direction of magnetization with an unchanged period structure) brings about the modulation of the light beam power in all deflected orders. Even diffraction orders that do not exist in symmetric gratings (with the same width of adjacent domains) may appear and there is a power change in the zero maximum. This is the principle of switch or optical filter functioning. It can also be applied in high sensitive instruments for magnetic field measurements.

Other magnetooptical applications investigated in world laboratories are: page composer being a dynamically controlled slide necessary in optical coherent processors, logical facilities and operational holographic memories, and reversible recording material for magnetooptical and holographic memories. Films of domain structure with low coercive force can serve for reproduction of magnetic field leakage configuration in complex magnetic systems. Bubble domains are repeatedly tested information carriers in digital processors. All given suggestions for the application of magnetic gratings can be solved in integrated technology [1–3].

Depending on the properties of TMF (technology, domain structure, crystallographic orientation, magnetooptical parameters, defects) the results of various magnetic diffraction grating configurations and the results of deflection and modulation being a base of their application may appear in various forms.

2. Aim of research

The aim of research is to investigate thin monocrystal yttrium orthoferrite plates and garnet films: $Y_3Fe_5O_{12}$, $EuEr_2Ga_{0.8}Fe_{4.2}O_{12}$, $Y_3Ga_{1.2}Fe_{3.8}O_{12}$, $Y_{2.1}Bi_{0.1}Fe_{3.9}Ga_{1.1}O_{12}$ of various thicknesses in laboratory magnetooptical systems as controlled diffraction gratings for optical signal processing. The investigated films have been produced in the Magnetic Materials Plant POLFER and in the Institute of Physics in the Polish Academy of Science in Warsaw.

3. Experimental arrangements

The experimental program based on Faraday's and optical diffractometry methods included following works:

– Setting up of laboratory systems adapted to the properties of magnetic films and to the purpose of the experiment, including the design and construction of approximate coils of the homogeneous magnetic field.

— Domain visualization in Faraday's laser arrangements.

— Studying the formation of various two-dimensional magnetic gratings in a magnetic field with an adequate configuration.

— Investigating magnetooptical diffraction through a study of diffraction patterns, measurement and calculation of diffraction parameters: grating period, deflection angles and optical frequency in the given range of magnetic field characteristics of the film, diffraction efficiency as well as through comparing those results.

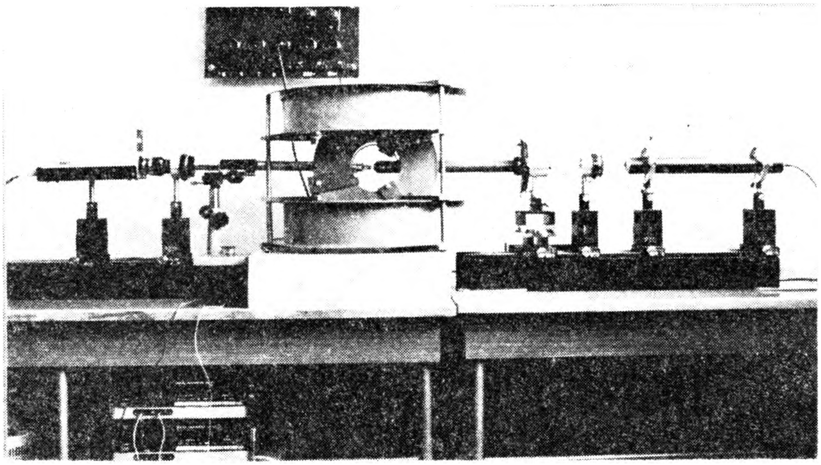


Fig. 1. Magnetooptical arrangement for domains visualization including: He-Ne laser with 6 mW-output power of continuous wave ($\lambda = 632.8$ nm, TEM_{00} mode, polarizer and analyser, sample of TMF, two pairs of Helmholtz coils, microscope, cine-camera or set of cameras, television camera coupled with monitor, single-line scanner and oscilloscope

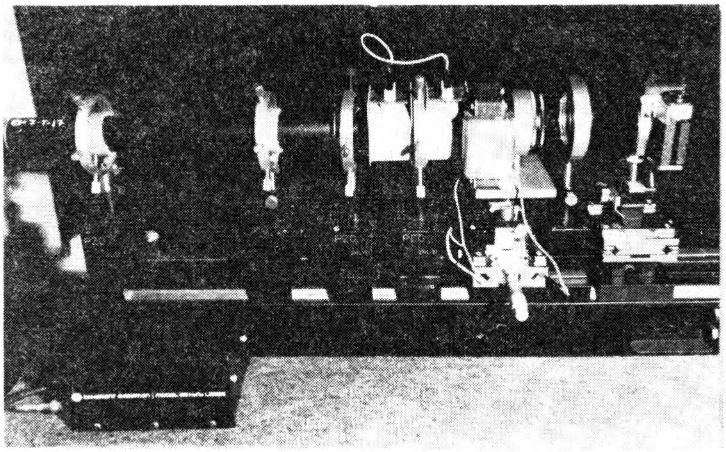


Fig. 2. Laser set-up of lens diffractometer with generator of homogeneous in-plane and perpendicular magnetic field

Figures 1 and 2 present exemplary laboratory arrangements for visualization of domain structure control and for the study and analysis of domain structure diffraction patterns in the magnetic field. All the arrangements have been scaled in order to determine diffraction parameters.

4. Characteristics of thin magnetic films as light signal converters

Characteristics of investigated magnetic monocrystals as laser beam converters is shown in the Table. This table summarizes the results of the experiments. The magnetic-field and diffraction-parameters change ranges and are repeatable ones. Diffraction efficiency has been measured and compared with the result of calculations according to the formula given in paper [4], where the film parameters are known.

On the ground of obtained results the following inferences have been drawn.

The sample 1 may be used as two-dimensional controllable grating for both laser light deflection (change of d without a change of symmetry, change of orientation with small hysteresis) and modulation in zero maximum. The fourteen distinguishable positions of diffraction beam are visible. The thickness of plate should be smaller than 60 μm.

The sample 2 can serve for multi-channel one-dimensional diffraction (change of d without a change of symmetry). The defect is superimposing of domain structures from films deposited on both sides of the substrate.

The sample 3 makes the dynamic magnetic grating of various domain structures: labyrinth, zigzag, honeycomb, stripe and bubble (dynamic slide) for modulation and two-dimensional deflection (change of d, orientation and a type of structure).

The sample 4 is useful as deflecting and modulating element (change of d, orientation and symmetry). It is the one-side film with the best contrast of domain structure (admixture of Bi), the best figure of merit, Faraday rotation and spatial frequency.

The sample 5 works as regulated slit for deflection (change of domain width and orientation).

The following Figs. 3–6 show the selected results of the experiments.

5. Conclusions

The presented investigations of the home-made thin monocrystal magnetic films, especially epitaxial films with various chemical compositions, have been carried out for the first time in our country on such a large scale.

It has been experimentally stated that the domain structure of the investigated home-made thin magnetic films creates magnetic diffraction gratings which can be applied as laser-beam converters in optoelectronic devices (particularly one-side epitaxial films). To this end, however, their technology should be

Characteristics of investigated thin magnetic films as light signal converters

Chemical composition and main parameters of sample	Range of magnetic field changes $H_{\parallel}$ [kA/m]	$H_{\perp}$ [kA/m]	Range of structure period changes, d [mm]	Range of spatial frequency changes, f [mm^{-1}]	Range of diffraction angle changes, α [deg]	Diffraction efficiency, η [%]
1. $Y_3Fe_5O_{12}$, plate (100), $t = 100$ μm, $d_0 = 0.070$ mm, $F = 4 \times 10^2$ deg/cm, $M_s = 139{,}3$ kA/m	1.43–4.7		0.033–0.014	30–70	1.1–2.6	0.05
2. $EuEr_2Ga_{0.8}Fe_{4.2}O_{12}$, LPE film on (111) GGG substrate,		0–20	0.020–0.66	50–15	1.73–0.55	
$t = 3.9$ μm, $d_0 = 0.020$ mm, $F = 5 \times 10^3$ deg/cm, $M_s = 17.5$ kA/m		0.8–20	0.030–0.120	33–8	1.2–0.3	1.5
3. $Y_3Ga_{1.2}Fe_{3.8}O_{12}$, LPE film on (111) GGG substrate,	9.2–20.7	0–3.6 bubble structure	0.011–0.013	91–77	$(3.3–2.7\ )\alpha_1$	0.05
$t = 3.3$ μm, $d_0 = 0.008$ mm, $F = 6 \times 10^2$ deg/cm, $M_s = 19.1$ kA/m	32.6–0	0–3.7 stripe structure	0.008–0.014	125–71	$(3.93–2.42)\alpha_1$	
4. $Y_{2.1}Bi_{0.9}Fe_{2.9}Ga_{1.1}O_{12}$, one-side LPE film on		12.7–25.5	0.0065–0.009	154–111	7.24–4.24	
(111) GGG substrate,	0–79.6		0.0075–0.0051	137–196	8.92–11.7	2
$t = 4.8$ μm, $d_0 = 0.006$ mm, $F = 2 \times 10^4$ deg/cm, $M_s = 31.8$ kA/m	for 111.4		0.0042	238		
5. $YFeO_3$, plate, $t = 60$ μm, $d_0 = 0.260$ mm, $F = 4 \times 10^3$ deg/cm, $M_s = 8{,}3$ kA/m	0–40.6		0.130–0.063 (width of stripe domain)	3.42–3.86	$(0.28–0.56)\alpha_1$ $(0.56–0.94)\alpha_2$ $(0.94–1.58)\alpha_3$	4

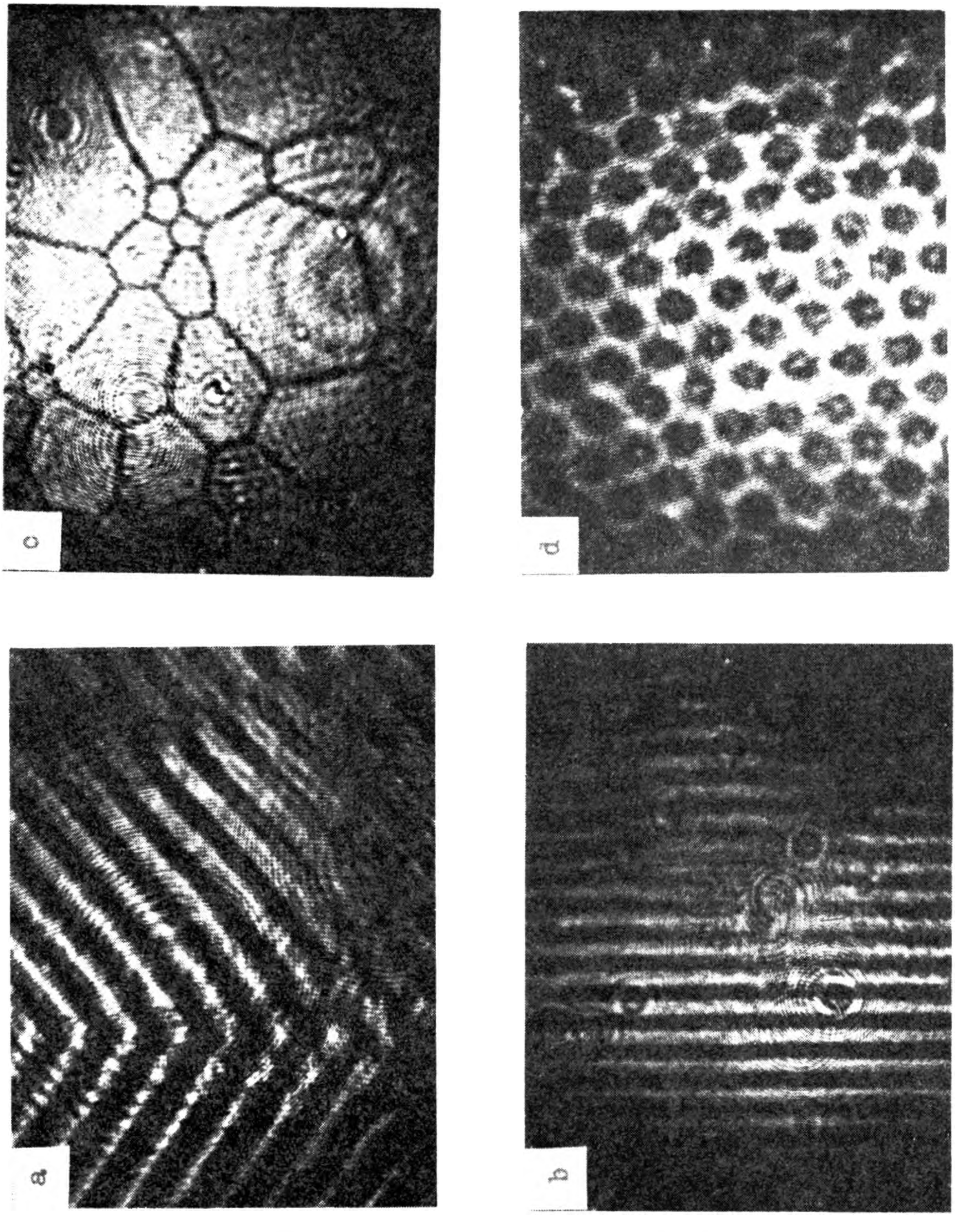


Fig. 3. Various magnetic gratings in sample 3: zigzag (a), stripe (b), bubble (c) and honeycomb (d) domain structures

developed so as to minimize the number of defects and to improve the diffraction parameters.

Laser arrangements, based on the magnetooptical Faraday's method for the laser-light deflection, proved to be laboratory arrangements having also the functions of non-destructive diagnostic systems of thin magnetic films.

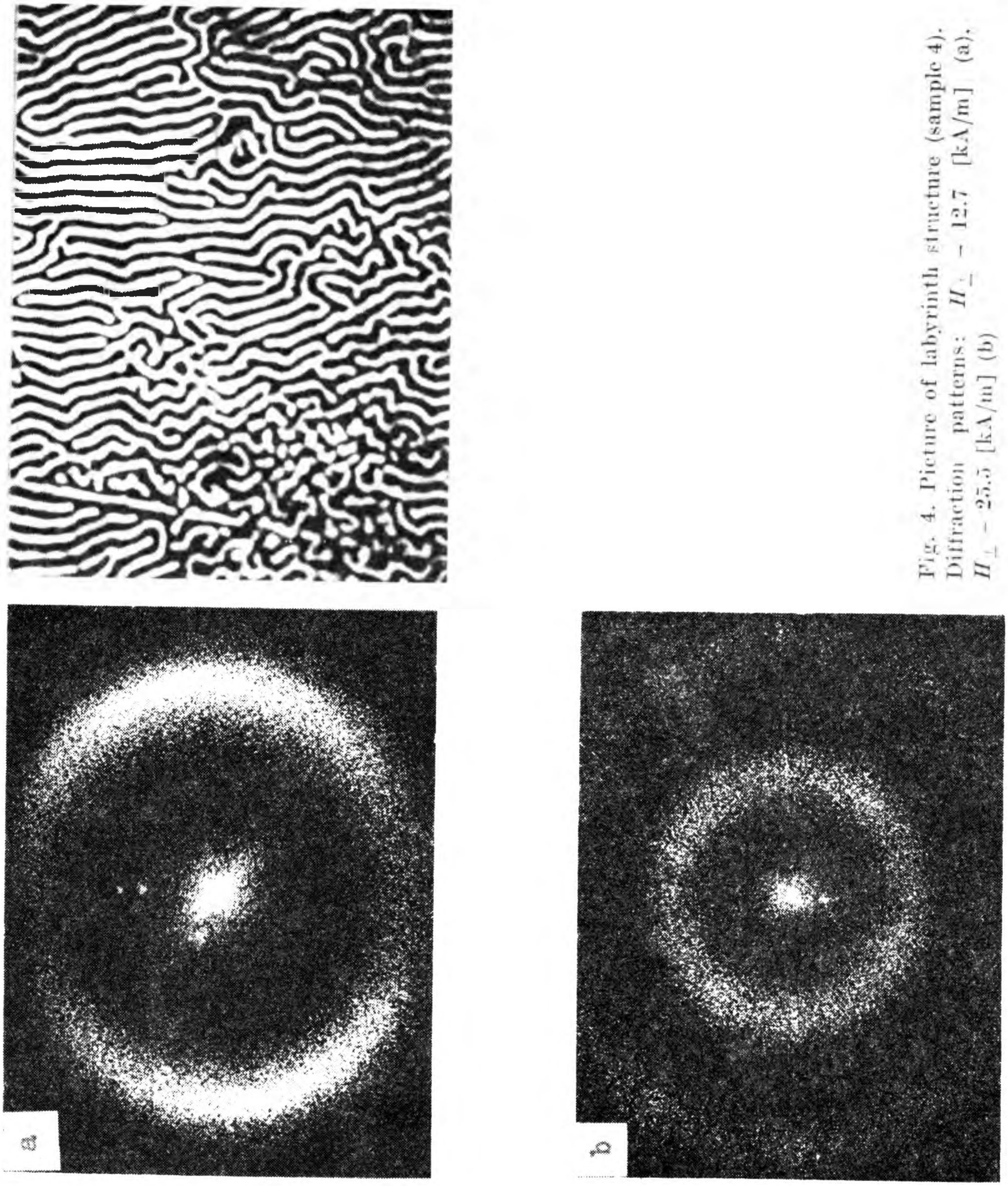


Fig. 4. Picture of labyrinth structure (sample 4). Diffraction patterns: $H_\perp = 12.7$ [kA/m] (a), $H_\perp = 25.5$ [kA/m] (b)

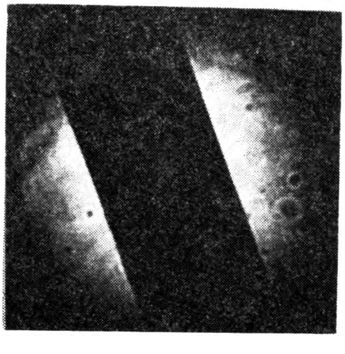


Fig. 5. Picture of stripe domain (for its diffraction patterns and oscillograms see Fig. 6)

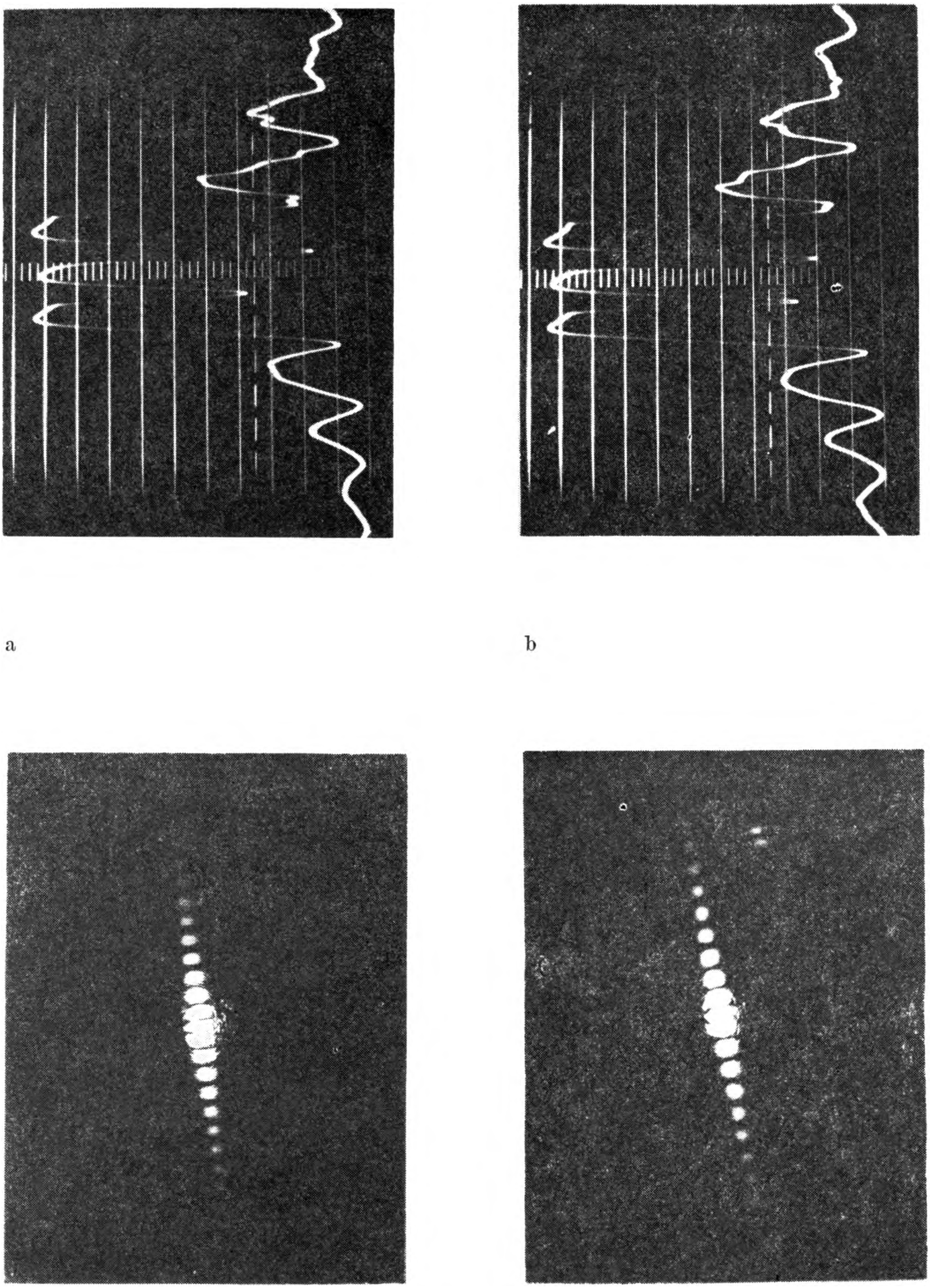
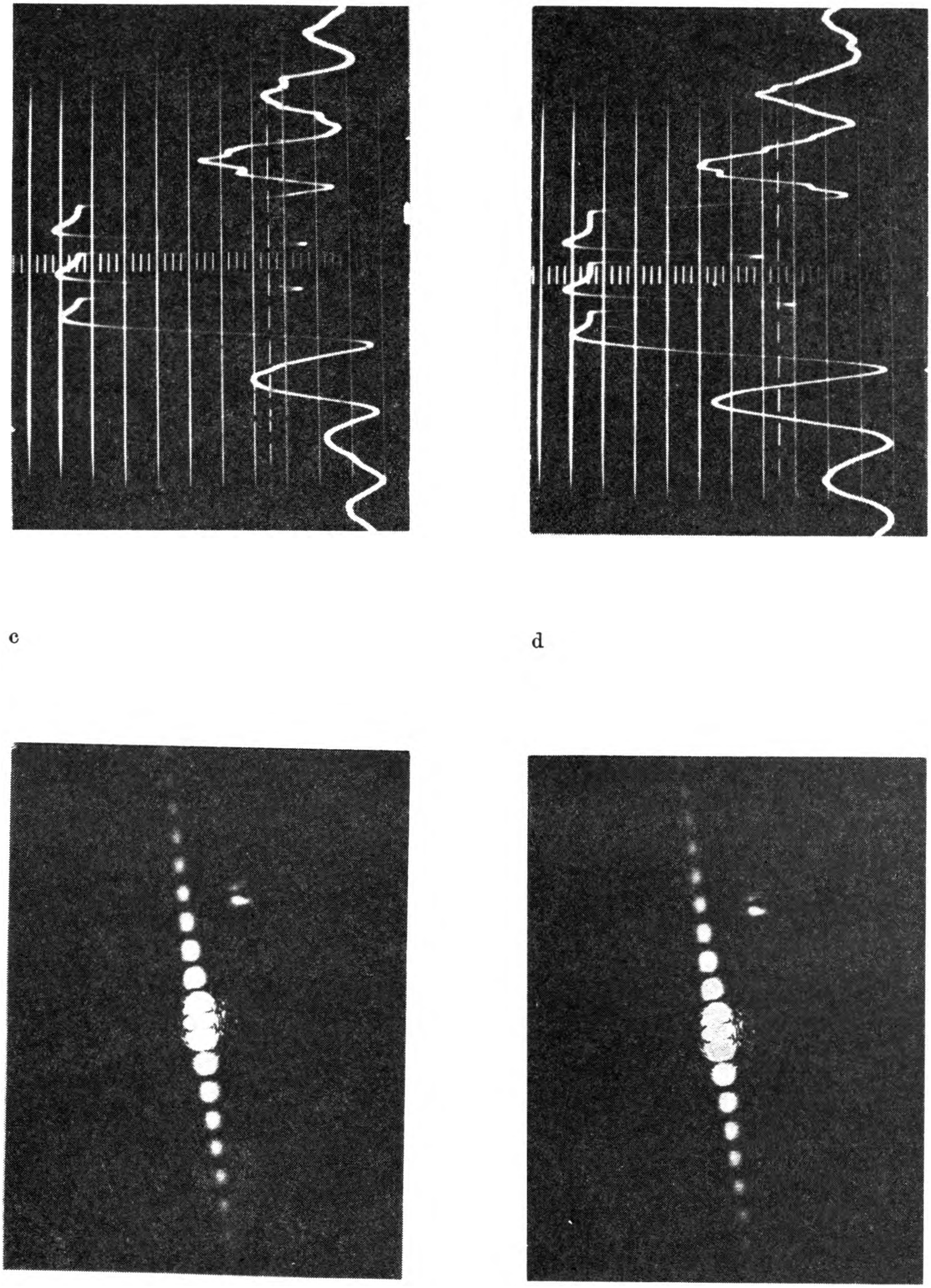


Fig. 6. Diffraction patterns (below) and oscillograms (above) of radiant-power $H_{\|}$ – 0 [kA/m], $H_{\|}$ – 15.9 [kA/M] (b)



c

d

distribution in diffraction patterns of single stripe domain (sample 5), shown in Fig. 5. $H_{\|} = 33.4$ [kA/m] (c), and $H_{\|} = 40.6$ [kA/m] (d)

Determination of the magnetic-domains grating period by the method of diffraction-pattern measurement is very useful when investigating films with submicronic structure or when a direct measurement of the grating period under a microscope is impossible. The method of magnetooptical diffraction is more accurate than those used so far and may be applied in many fields of science.

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Тонкие слои магнитных монокристаллов как преобразователи оптической информации

В статье представлены результаты исследований тонких слоев гранатов и плиток иттриевого ортоферрита как магнитных дифракционных рещеток, которые могут найти применение в оптоэлектронных преобразователях оптической информации для отклонения пучка лазерного света и его модуляции. Структуры магнитных доменов обследованных монокристаллов могут быть достаточно регулярными при соответствующем подборе и сформулировании внещних магнитных полей. Как магнитные дифракционные рещетки самыми подходящими оказались эпитаксиальные односторонние слои с минимальным количеством дефектов. Методика и исследовательская аппаратура пригодны для диагностики и измерения параметров тонких магнитных слоев.