MAGNETOOPTICAL MEASUREMENTS OF GEOMETRICAL QUANTITIES

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Abstract: Many optical methods of geometrical quantities' measurements need continuous, precise, and high speed determination of positions of light beams interacting with the measured surface. Existing photodetectors, namely charge-coupled devices (CCDs) and position sensitive detectors (PSDs) in many cases do not comply with these demands. We are developing a new device with superior characteristics. It is based on the domain wall motion in a transparent ferromagnet, a so-called orthoferrite. The velocity limit of the domain wall motion in orthoferrite crystals is extremely high: 20 km/s. The device consists of an orthoferrite plate, an analyzer and a single point photodetector. It can measure positions of the light spots continuously with submicrometric accuracy. The sampling rate of the measurements can reach1 MHz. The application of the device to the angular measurements is briefly described.

Keywords: light spots positions measurements, magnetooptics, orthoferrite

1   INTRODUCTION

The progress of many optical methods of measurements of geometrical quantities is restricted because of a lack of appropriate light detection techniques. In many cases it is necessary to measure the position of a light beam interacting with the surface to be measured (reflection, deflection, etc.). These measurements have to be done with a high spatial accuracy combined with high sampling rates. Existing photodetectors (CCDs, PSDs) however do not comply with these demands. Sampling rates of CCDs are typically as large as 1 ms and the pixel size is about 5 μm [1]. PSDs provide higher spatial resolution, but the reproducibility of the measurements is rather poor: e.g. for a 18 mm long receiving area the reproducibility equals 26 μm in the center of the photodetector and is 4 times worse in the peripheral areas [2]. Moreover the PSDs cannot measure positions of several light spots simultaneously.

We are developing a new magnetooptical device for precise, high speed measurements of light beams, namely of positions of the light spots in a given plane [3]. The principle of operation is based on magnetooptical spatial light modulation performed [4] by domain wall motion in orthoferrite crystals.

2   SAMPLES AND MEASUREMENT METHOD

Orthoferrites are canted ferromagnets transparent in the visible and in the near infrared regions of spectrum. T. They possess the highest velocity of the domain wall (DW) motion among all magnetic materials. Orthoferrites are optically biaxial crystals with a large birefringence. For a vast majority of their potential applications a high Faraday rotation and low ellipticity of the output light beam is necessary. This is only the case when the light propagates strictly along the optical axis [5]. Then the ellipticity can be as small as $1 \cdot 10^3$ and angles of rotation of the polarization plane are as large as several tens degrees.

Figure1 shows a domain structure in a plate of yttrium orthoferrite cut perpendicularly to the optical axis. An analyzer placed behind the plate and completely extinguishing a light beam which is passing through one (lower) domain, transmits a light beam passing through the upper domain. At a wavelength of $\lambda = 630$ nm the light intensity transmitted by the upper domain (and the analyzer) equals 10% of the intensity of the initial light beam. At the wavelength of 1500 nm this figure can be increased up to 99%.

A two-domain structure with a single domain wall is formed by means of an external nonuniform magnetic field in an orthoferrite plate (the width of the domain wall is about 30 nm). When an additional magnetic field is applied to the plate, the domain wall moves to a new equilibrium position and the

velocity of this motion may reach 20 km/s. In the velocity range up to 4 km/s the dependence of velocity on magnetic field is very close to linear.
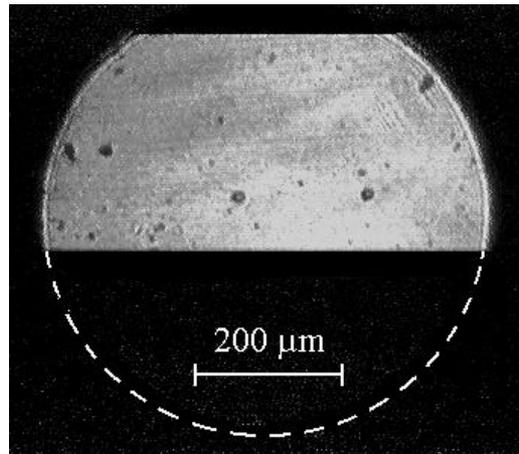
Figure 1. A two-domain structure in an yttrium orthoferrite plate cut perpendicularly to the optical axis.
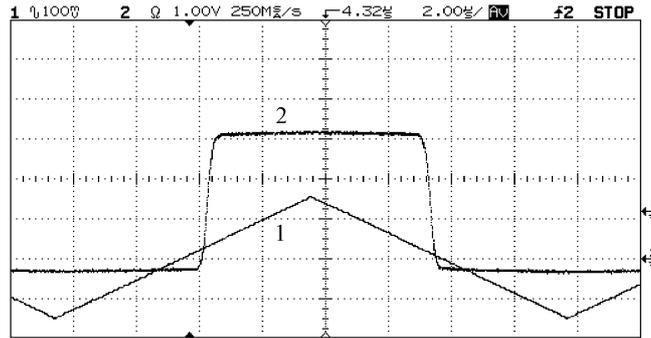
Under action of an oscillating magnetic field of a given frequency the domain wall oscillates with the same frequency. The range of the domain wall oscillations is proportional to the amplitude of the magnetic field and its width typically equals several hundreds micrometers. In figure 2 the zone of the domain wall motion is seen as a zone of the intermediary brightness. This zone is alternatively occupied by the upper (bright) and the lower (dark) domains. The zone of the DW motion has very clear margins witnessing the high reproducibility of the DW motion [6]. The current flowing in the coils has a meander form, its frequency is equal to 300 kHz. Up to 10^6 A/m the contrast of the images of the two domains, related to Faraday rotations in the domains, do not depend on the field.
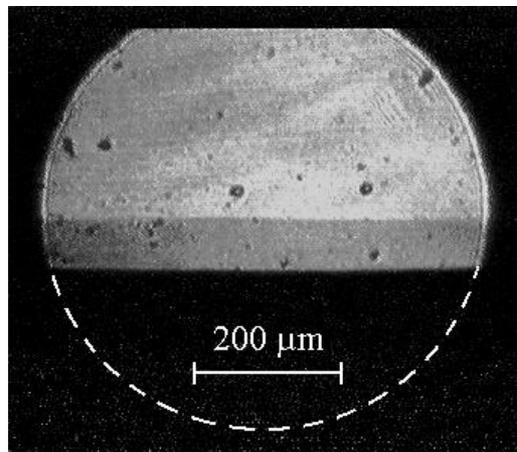
Figure 2. Zone of intermediate brightness caused by domain wall oscillations.

3   MEASUREMENT RESULTS

To perform the position measurements the laser light was focused on the orthoferrite plate in a spot with a diameter of 10 μm. By means of a micrometric screw the orthoferrite plate was moved in the vertical direction, causing corresponding displacements of the light spot on the surface of the orthoferrite plate. Results of these measurements are presented in figure 3 and 4. Figure 3 shows the modulation of light by the moving DW. Curve 1 represents the current in the coils. The frequency of the current is equal to 60 kHz. Curve 2 shows the photoreceiver's signal for a given position of the light spot on the orthoferrite plate. The lower parts of curve 2 correspond to the moments when the "opaque" domain covers the light spot. After crossing the light spot by a DW the transmitted light intensity remains constant and thus the photoreceiver's signal does not change, until the next crossing of the light spot occurs.

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Figure 3. Crossing of a 10 µm wide light spot by the domain wall at 60 kHz.

Figure 4 compares 3 curves of the photoreceiver's signal corresponding to the 3 different positions of the orthoferrite plate y_1, y_2 and y_3. The differences of the coordinates $y_1 - y_2$ and $y_2 - y_3$ were equal to 20 µm. One can see that transient parts of the curves are shifted along the horizontal axis. The two shifts are equal to 640 ns, each, and the sensitivity of the measurements can be established as 32 ns/µm.
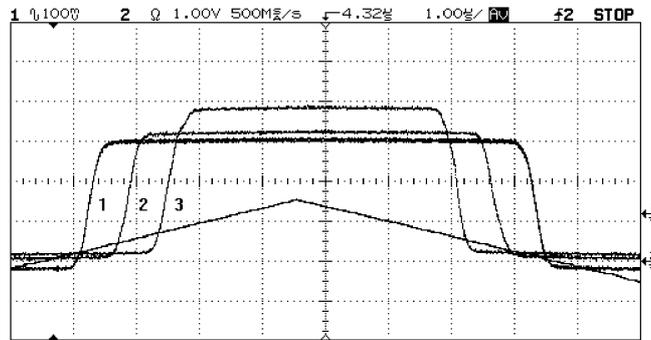

Figure 4. Crossings of the light spots for different positions of the orthoferrite plate; frequency 60 kHz.

The reproducibility of the measurements is 25 ns, or 0.8 µm. By increasing frequency of the current in the coils, the sampling time may be reduced to below 1 µm. One should note, that contrary to the PSDs, this method allows one to measure simultaneously positions of several light spots. An essential feature of the measurements is the uniformity of the response due to the good spatial uniformity of the orthoferrite plate.

4   MAGNETOOPTICAL MEASUREMENTS OF ANGULAR DISPLACEMENTS.

A scheme shown in figure 5 illustrates the operation principle for angular measurements based on orthoferrite. A light beam of a laser (11) impinges on the measured object (12). After reflection by a surface of the object the light is focused by means of the lens (13) in a small spot on the plate of yttrium orthoferrite (6). The value of the angle ϑ is determined by measuring of the position of the light beam in the plane of the orthoferrite plate. This measurement is performed by means of the moving domain wall. Small magnets (8) produce a gradient magnetic field forming a two-domain structure with a single domain wall. Current pulses in the coil (7) generate a driving magnetic field and under action of this field the domain wall oscillates with a given frequency. As a result the area of the domain wall motion is sequentially occupied by domains with the opposite directions of magnetization. After passing through the analyzer the light is focused on the photoreceiver (5) by means of the lens (4). When the "opaque" domain occupies the area of the plate at which the reflected light beam is incident then the light cannot reach the photoreceiver. In the course of its motion the DW crosses the reflected light spot, the "opaque" domain is changing to a "transparent" domain and the reflected light reaches the photoreceiver. The intersection moment is thus registered by an oscilloscope (10) as a sharp change of the photoreceiver's signal. Since the dependence of the DW position on time is previously determined, the moment of the photocurrent pulse corresponds to the position (and, respectively, to the incidence angle) of the reflected beam.
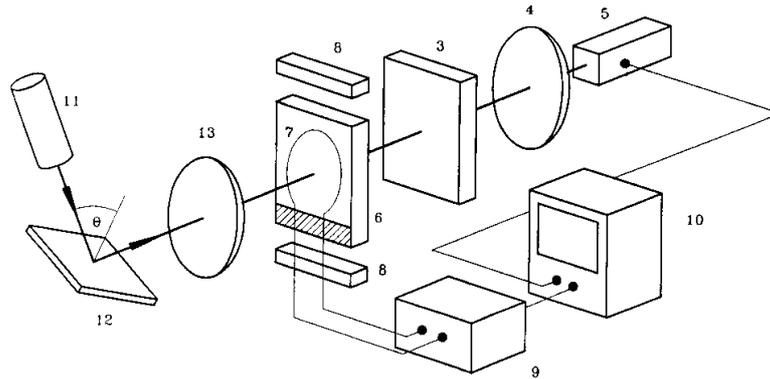
Figure 5. Scheme of angular measurements based on the magnetooptical spatial modulation.

5   CONCLUSION

Measurements of the light beam positions by means of the magnetooptical spatial light modulation in the plate of yttrium orthoferrite have been described. Amplitude and velocities of the DW motion in the orthoferrite plate substantially exceed those in other magnetooptical materials providing the opportunity for measurements of the light positions in wide limits and with high speed. The reproducibility of measurements of positions of the laser beam with diameter 10 µm is 0.8 µm. In our experiments amplitude of the driving magnetic field was 700 A/m providing a measuring range of 300 µm which can be increased several times by increasing the magnetic field. The sampling time can be chosen as short as 1 µs.

The resolution of the measurements and the sampling rate exceed those for CCDs by orders of magnitude. The accuracy exceeds also that of PSDs, providing in addition the opportunity to measure positions of several light beams simultaneously, in a single pass of the DW across the scanning range. The proposed method enables to perform high speed, precise angular measurements. It provides also the opportunity to determine the surface parameters by means of precise high speed measurements of positions of the light beams reflected by the given areas of the surface.

REFERENCES

[1] M. Baba, T. Konishi and Y. Furui, A new method for measuring plural light spot positions in a spatially continuous manner using a sensor array, *Meas. Sci. Technol.* **10** (1999) 531-537.
[2] P. Schaefer, R. Williams, G. K. Davis and R. A. Ross, Accuracy of position detection using a position-sensitive detector, *IEEE Trans. Instrum. & Meas.* **47** (1998) 914-919.
[3] Y. S. Didosyan, H. Hauser, and J. Nicolics, Application of orthoferrites for light spot positions measurements, *Journal of Applied Physics*, (in press).
[4] M. Gaugitsch, F. Haberl, J. Hochreiter and H. Hauser, Investigations of a position resolving light modulator for refraction studies". *J. Appl. Electromagnet. Mech.* **7** (1996) 11-20.
[5] Y. S. Didosyan and V. Y. Barash, Faraday Effect in yttrium orthoferrite in the range 1280 - 1600 nm, *Journ. Magn. & Magn. Mater.* **151** (1995) 207-210.
[6] Y. S. Didosyan, Measurement of domain wall velocity by the dark field method, *Journ. Magn. & Magn. Mater*, **133** (1994) 425-428.

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