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► To cite this version:

A. Chervonenkis, V. Randoshkin, A. Tanielian. High Speed High Sensitive Magneto optic Materials for Promising Civilian Applications. Journal de Physique IV Proceedings, 1997, 07 (C1), pp.C1-715-C1-716. 10.1051/jp4:19971291 . jpa-00255008

HAL Id: jpa-00255008

<https://hal.science/jpa-00255008>

Submitted on 1 Jan 1997

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High Speed High Sensitive Magneto-optic Materials for Promising Civilian Applications

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Abstract. Using new epitaxial growth technology we produced (R, Bi)₃(Fe,Ga)₅₀₁₂ wafers possessing unique combination of static magnetic, magneto-optic (MO) and domain wall dynamic properties. New concept of numerous and promising applications of the developed materials is presented. These applications include: 1) High resolution localizer of magnetic axis for multipole magnets in nuclear accelerators with space accuracy better than 10 μm in the field gradient $>0.5 \text{ T/m}$. 2) MO flaw detectors providing real time image of defects both in magnetic and nonmagnetic metal articles; 3) Set of devices for latent marking of arbitrary articles; 4) Highly reliable MO bank-note tester for operative definition of bills and securities; 5) High speed MO spatial light modulators; 6) MO nonmechanical system for light beam scanning.

1. MATERIAL PREPARATION

Among various MO materials known up to date the most promising are epitaxial films of Bi-substituted iron garnets grown on nonmagnetic substrates with large lattice parameters [1]. Using new epi growth regimes and flux compositions we succeeded in producing (R,Bi)₃(Fe,Ga)₅₀₁₂ structures with (111), (110) and (210) orientations, where R = Y, Lu, Pr, Gd, Tm, Yb, Er, Ho, Dy, Tb, Eu, possessing unique combination of electrophysical properties: saturation magnetisation $\mu\text{Mo} = 0 \dots 1000 \text{ G}$, specific Faraday rotation $\Theta_F = 2.3 \text{ grad}/\mu\text{m}$, absorption coefficient $\alpha = 0.35 \dots 0.40 \text{ dB}/\mu\text{m}$, maximum domain wall velocity $V = 200 \dots 2800 \text{ m/s}$, coercivity $< 0.1 \text{ Oe}$.

The idea of μMo reduction (thus increasing of sensitivity) is well known: substitution of Fe^{3+} by Ga^{3+} ions in tetrahedral sublattice of garnet structure. However in this case one can't reach good spatial resolution, since low magnetisation leads to increase of the domain size. To overcome this obstacle we introduce Pr^{3+} ions in order to reduce uniaxial magnetic anisotropy constant and thus to compensate the influence of low magnetisation on the domain size.

High MO figure of merit $\Psi = 2\Theta_F/\alpha > 10 \text{ grad/dB}$ was achieved by high Bi^{3+} ions substitution (due to large lattice parameter: 1.2495 nm) and small amount of Pb contamination from flux. Moreover, we found out that even in case Pb contamination is high the absorption coefficient α may be significantly reduced by special heat treatment of the wafer at $770 \dots 800 \text{ K}$ by which pairs $\text{Pb}^{2+} - \text{Pb}^{4+}$ (responsible for absorption in visible) are destroyed.

High domain wall velocity ($> 1000 \text{ m/s}$) was obtained in: 1) the high anisotropic (I I I)-oriented films with R = Y and Lu (in the presence of in-plane magnetic field only); 2) the (III)-oriented films with R = Gd and Tm (around angular momentum compensation (AMC) point only); 3) the (210)-oriented films with R = Y, Lu and Pr (with orthorhombical magnetic anisotropy (ORMA)); 4) the (110)-oriented films with R = Gd and Eu (with both AMC and ORMA).

Low coercivity (and thus high sensitivity) was achieved using slow epi growth rate (low flux supersaturation) producing homogeneous composition through the film thickness. Application of small additional alternative magnetic field allowed to decrease H_c down to $10 \mu\text{Oe}$.

2. NEW APPLICATIONS OF MO MATERIALS

2.1. Localizer of magnetic axis for multiple magnets

The idea is based on the use of highly anisotropic uniaxial films with material quality factor $Q \gg 1$. Some pieces of such films were placed inside the quadrupole in two orthogonal planes XZ and YZ while the location of zero magnetic field was determined by the position of boundary between two areas of the film having opposite direction of magnetisation. The

structure of magnetic field, visualised by means of MO Faraday effect was transferred away from the quadrupole by fiber-optic waveguide, TV camera and monitor.

2.2. MO flaw detector

This instrument produces real-time images of defects in both magnetic and nonmagnetic metal articles. It detects magnetic anomalies caused by these defects using MO sensor based on Bi-substituted iron garnet film. In ferromagnetic metals, such as steel, the instrument senses and displays an image of the flux leakage associated with the flaw in a previously magnetised test piece, while in nonferromagnetic metals, in particular titanium, the instrument excites the test piece with induced currents to provide a direct image of defects resulting from the magnetic fields associated with eddy currents.

2.3. Latent marking

Latent marker allows invisible identification of household and industrial property. It can be used on arbitrary surfaces such as METAL, ADHESIVES, PLASTIC, WOOD, LEATHER, etc as well as on PAPER. Ideal for easy invisible marking of valuables such as TV's and stereo equipment, car radios, cameras, paintings, or any item you choose. The invisible imprint can be read using special MO lens. In case of theft and later recovery, the LATENT MARKER identifies ownership when its otherwise invisible imprint is exposed to MO lens. Stolen goods, when invisibly marked with a code known only to user, constitute an additional risk for thieves.

2.4. Bank-note tester

MO bank-note tester permits you to reveal with your own eyes the authenticity of your security. Moreover the developed bank-note tester allows to identify magnetic credit card. Depending on user's demands we offer 4 variants of bank-note tester.

- 1) MO tester, which by the use of special MO lens and magnetisation system reveals the fine structure of magnetic pattern on the bank-note. This version is intended for individual users.
- 2) Combined MO and ultraviolet (UV) bank-note tester.
- 3) MO bank-note tester supplied with portative TV camera and monitor.
- 4) The complete of devices including MO lens, magnetisation system, UV illumination system, TV system, automatical bank-note slide-system and computer processing of visualised pattern.

2.5. High speed MO spatial light modulator

We have constructed high-speed MO SLMs with typical switching times 1 - 10 ns, optical contrast more than 1000:1 and optical efficiency of 15 % at $\lambda = 0.63 \mu\text{m}$. Our MO SLMs are based on epitaxial films of $(\text{R,Bi})_3(\text{Fe,Ga})_{5012}$ system grown on $(\text{Gd,Ca})_3(\text{Zr,Mg,Ga})_{5012}$ with lattice parameter 1,2495 nm.

The regime of epi process provided smooth change of saturation magnetization (- 10 %) through the film thickness. The information cells of MO SLMs were formed by local ion beam milling in such a way that the thickness of the film inside the cell became significantly lower (- 2 μm than the initial film thickness (- 5 μm). The combination of magnetization gradient with local film thickness decrease resulted in new magnetization switching mechanism: it takes place by vertical shift of so called "back-to-back" domain wall inside the initially single-domain cell and thus requires much less time (- 1 μm) in comparison with usual remagnetization process by horizontal Bloch or Neel domain wall moving (- 1 μm).

2.6 Light beam scanning

A nonmechanical MO system for light beam scanning was constructed. MO wafer with two identical MO layers from the opposite sides of the substrate is placed on the way of the widening light beam. Previously one of the MO layers is processed by special heat treatment in such a way that the sign of Faraday rotation becomes opposite to the sign of Faraday rotation of the other layer. A constant gradient magnetic field is applied to the wafer along with alternative spatially homogeneous magnetic field. In this case if polarizer and analyzer are strictly crossed one could see a narrow bright (transparent) slot on absolutely opaque background. This results is a simple and fast possibility for nonmechanical light beam reamer and scanning.

[1] Randoshkin V.V. and Chervonenkis A.Ya., "Applied Magneto-optics" (Energoatomizdat, Moscow, 1991) 320 p. (In Russian).