Modification Of Normal Microscope To Magneto-Optical Microscope

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Abstract: The present work reports on the modification of polarizing microscope to a magnetic domain imaging microscope based on Faraday Effect. Sample used in this research is a ferromagnetic garnet; $(Bi,Tm,Na)_3(Fe,Ga)_5O_{12}$. The halogen lamp in the microscope is replaced by helium-neon (HeNe) laser as a light source. To reduce the laser spatial coherent effect, thin transparent plastics placed in the laser path. The plastics are rotated at certain velocity. Other factors to be considered are the plastic rotation velocity, the laser intensity and the laser alignment. Typical magnetic domain pattern is obtained with the new system.

Index Terms: Magnetic domain, ferromagnetic garnet, HeNe laser.

1 Introduction

Magneto-Optical Faraday Effect Microscope is one of the important tools for observing the structure of magnetic domains of magnetic samples. According to Lee et al. [1], magneto-optical microscope provides shorter observing time and easier experimental methodology compared to other techniques. Other techniques can be performed on magnetic materials to study and measure the magnetic domain structure such as magneto-optical imaging, Bitter pattern imaging, transmission electron microscopy (TEM), electron reflection and scattering methods, mechanical microscanning techniques, etc. [2]. Tremendous studies about synthetic rare-earth iron garnets have been reported as they are widely used in microwaves and magneto-optical devices. One common based magnetic materials used in most research for magneto-optical imaging is Yttrium Iron Garnet (YIG). A survey of the characteristic of the optical and magneto-optical properties of the representative ferrite materials YIG and iron borate ($FeBO_3$) have been presented [3] and showed that these compounds are good electrical insulators, optical transparency in the visible spectral range and large variety of magneto-optical phenomena due to the interaction of light with the spontaneous magnetization. According to Aichele et al. [4], YIG can only provide a small amount of Faraday rotation (about 0.08 °/cm) which is not sufficient for the development of integrated magneto-optical devices. Thus, the additions of rare-earth elements such as bismuth into iron garnet thin films could increase the Faraday rotation in the visible to infrared range [5, 6].

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Sample used in this research is a transparent ferromagnetic garnet; $(Bi,Tm,Na)_3(Fe,Ga)_5O_{12}$. Previous report [7] has mentioned that the material has an area called ferromagnetic domains that is areas where the magnetic moments aligned. Magnetic domain structure of the ferromagnetic garnet (FMG) can be observed by Faraday or Kerr Effect using magneto-optical effect. Sherwood et al. [8] reports that several magnetic oxides (Li, Mg, Cd and Zn) with a thickness of about 0.002 inch were transparent in the red end of visible light when viewed under a microscope with transmitted light. Magnetic domain of transparent rare-earth iron garnets, YIG have been observed through polarized light microscope [9]. Magneto-optical observation in transmission; using the Faraday effect is applied in this research as ferromagnetic sample is transparent. Faraday Effect depends on the rotation axis of polarized light. This technique requires the polarizing microscope, equipped with image processing equipment. The basis of the magneto-optical imaging refers to the rotation plane of polarization of linearly polarized light from the reflection or transmission through the magnetic material. Normally, the transmission is based on the Faraday Effect while the reflection is based on the Kerr effect. In both cases, the contrast domain is dependent on the magnitude and direction of magnetization of the sample. Polarization microscope used in this study is limited to magnetic samples as it cannot observe magnetic domain. Therefore, the aim of this study is to modify the set-up of polarizing microscope to a magnetic domain imaging system.

2 Experimental

The polarizing microscope apparatus used in this study is "Research Metallurgical Microscope", DMLM model. This polarization microscope is equipped with a charge-coupled device (CCD) camera and is supported by a software known as Vision Builder AI 2.0. The image of the magnetic domains can be viewed via computer and stored in a file using the software with the help of the CCD camera. However, this microscope is limited to magnetic materials because of their inability to observe the magnetic domain structure. Therefore, some changes on the source of light of polarization microscope need to be done. First, the light source is replaced to a more appropriate light source. Next, some plastic sheets are aligned to the new light sources and a new black box to store light source is designed and finally aligned in the polarization microscope. Fig. 1 shows the schematic diagrams of polarizing microscope before and after modification. The illustrations of the optical system give an overview of the laboratory works to obtain the magnetic domain structure of a ferromagnetic sample.

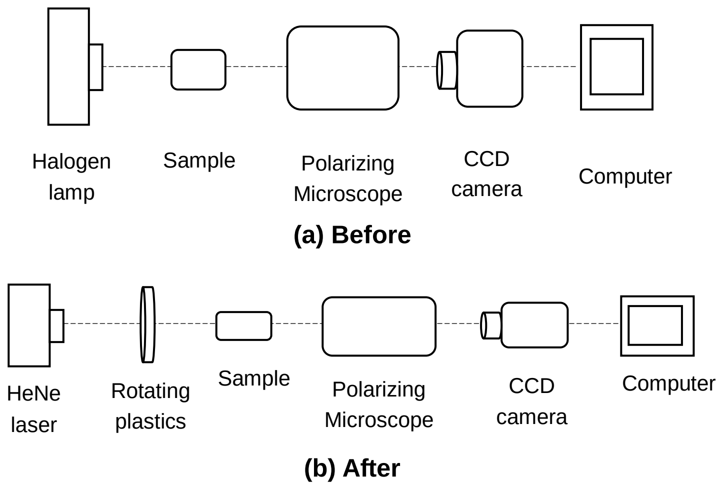


Fig. 1 *Schematic illustration of the visibility of domains*

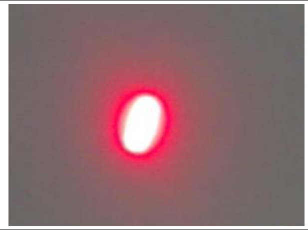
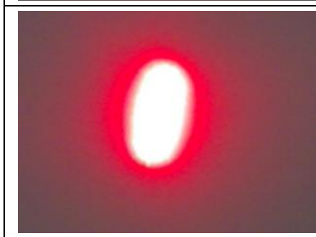
2.1 Light Source Replacement

The original light source of this microscope is halogen lamp (12 V, 100 W). To overcome this problem; the light source of polarizing microscope is replaced by halogen lamp to helium-neon (HeNe) laser [10, 11]. Kishore [12] used red laser with wavelength 650 nm to verify the Faraday rotation. Bi-substituted yttrium iron garnet thin film prepared by Lee et al [1] used 530 nm green LED as a light source to measure magnetic domain. HeNe laser with a wavelength of 633 nm is in the range of visible light corresponding to the sample observations that are transparent with the help of magneto-optics systems Faraday Effect. Furthermore, HeNe laser has a greater intensity, coherent and monochromatic. The observation of magnetic domains using a HeNe laser is done with the help of CCD camera and as an eye protection from laser beam; the microscope lens is covered with an aluminium foil to prevent the laser beam from passing through the lens.

2.2 Laser Intensity Increase

If any transparent solid or liquid is placed in a uniform magnetic field, and a beam of plane polarized light is passed through it in the direction parallel to the magnetic lines of force, it is found that the plane of polarization of transmitted light is rotated by an angle proportional to the field intensity. This "optical rotation" is called the Faraday rotation (or Faraday Effect) [13]. The idea of rotating plastic sheets which act as a polarizer, at a high speed using a small electric motor, is obtained by referring to the previous report of magneto-optical Kerr Effect microscope [14]. In this study, only three thin transparent rotating plastic sheets are used. These plastics are aimed at breaking the spatial coherence of laser so that the domain area observed is increased and therefore the image can be seen more clearly. The use of lens in this study to break the spatial coherence is not suitable because it is quite heavy and requires power more than 0.06 V for small electric motor to rotate the lens. Moreover, the laser intensity will decrease and it will be difficult to observe the magnetic domain. The 1 mW HeNe laser intensity is observed on the white screen before deciding whether to use the three pieces of plastic to break the spatial coherent laser. The distance between laser and white screen is 7 cm. The length of 7 cm is considered due to the alignment of the laser light from the laser to the back of the polarizing microscope which takes a distance of 7 cm. Table 1 shows the intensity of the light for a few pieces of rotating and non-rotating plastic.

TABLE 1
THE INTENSITY OF THE LIGHT FOR A FEW PIECES OF ROTATING AND NON-ROTATING PLASTICS.

Rotating	Plastics Sheets
	1
	2
	3

Non-rotating	Plastics Sheets
	1
	2
	3

2.3 Lamp house Design

Basically, the box of halogen lamp is constructed to avoid the divergence of the light beam in all directions. The black box for the laser known as lamp house is designed as a security feature for protection of the eyes and to store the light source systematically. Furthermore, it is also designed to place the HeNe laser and motor holder; in which motor is utilized to rotate the plastics. Fig. 2 shows the laser and motor holder that has been designed to develop magneto-optical system using laser light. The materials used to build the holders are metal and perspex. Ring-shaped perspex is used to prevent the plastic from folding or creasing during rotation due to plastic thickness. The lamp house was then built to house the laser, plastic sheets and motor as shown in Fig. 3.

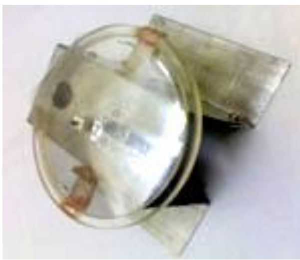


Fig. 2 *Laser and motor holder*

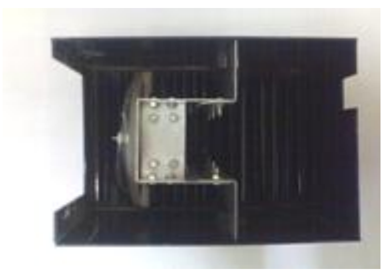


Fig. 3 *Laser and motor holder host placed inside lamp house*

3 Results and Discussion

The distribution of the laser light of rotating plastic is more evenly than non-rotating plastic as shown in Table 1. The light intensity for the three rotating plastic sheets shows the most even, bright, focus and increased in spot area when motor is supplied with 0.06 V. Thus, a total of three pieces of plastic is found to be applicable to the domain observations in this study. Therefore, 0.06 V of power supply is supplied to the motor to rotate the plastic sheets. The lamp house (contains laser and motor holder, and plastic sheets) is placed at the back of the microscope to replace halogen light source with Helium-Neon laser light source. Next, the alignment of the laser beam at a distance of 7 cm from laser to the back of polarizing microscope is done so that the laser light beam that goes through the microscope will penetrate the sample that is placed on a glass slide. Focus adjustment is made to obtain the image domain structure using the CCD camera and software Vision Builder AI 2.0. The image of magnetic domain structure of sample $(Bi,Tm,Na)_3(Fe,Ga)_5O_{12}$ with the rotation angle of 45º, 30° and less than 30° and with analyst using 100x magnification power were obtained.

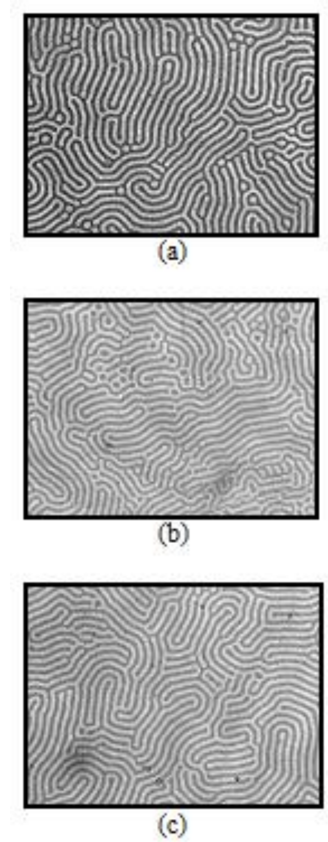


Fig. 4 *(a) Image of magnetic domain sample [$(Bi,Tm,Na)_3(Fe,Ga)_5O_{12}$] at 45º rotation angle of analyzer (b) Image at 30º (c) Image at less than 30º. Observed domains are not applied with magnetic field.*

Fig. 4 (a), (b) and (c) show the domain pattern of ferromagnetic films that are transparent and yellow in non-polarized light, but when viewed through a polaroid, domain patterns appear as bright and dark areas. Magnetic domain can be observed at various angle of analyst. The pattern of the sample domain $(Bi,Tm,Na)_3(Fe,Ga)_5O_{12}$ obtained in this study for zero magnetic field is typical of ferromagnetic materials that are transparent when not subjected to any magnetic field.

4 Conclusions

In conclusion, the magneto-optical system based on the Faraday Effect has been successfully developed. However there are some aspects which can be considered for further studies such as the application of magnetic field on the sample to observe the changes in the pattern of domain until it reaches saturation. Lens which can also be used to replace the plastic sheets need higher power motors that can withstand the heavy burden of the lens. Essentially, the effect of modified polarizing microscope on the magnetic structure facilitate greatly in the understanding of the fundamental studies of magnetism.

Acknowledgment

The authors appreciate the Universiti Kebangsaan Malaysia (UKM) for giving permission to use their laboratory facilities.

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