Fabricating Faraday Rotators Using Mesoporous Films

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ABSTRACT

A Faraday rotator is a device that, in combination with two polarizers, allows light to pass in only one direction. This is useful to prevent light from reentering the laser cavity of a laser. In this work, we fabricated Faraday Rotators using novel structures composed of periodic mesoporous films (PMFs). Using a combination of silica and titania-based PMFs, we grew dielectric stacks, producing an enhanced reflectivity in a specific band of optical frequencies. In addition, we incorporated a magneto-optical material into the PMFs to elicit the desired rotation of light.

INTRODUCTION

An optical isolator is a component that only allows light to pass in one direction. This can be used, for example, to allow light to exit a laser cavity while at the same time preventing it from reentering the cavity. Optical isolators consist of three main parts: an input polarizer, a Faraday rotator, and an analyzer, which is polarized at 45 degrees with respect to the input polarizer. A Faraday rotator is made from a magneto-optical material, where its optical properties can be changed by an external magnetic field.

When light enters the input polarizer, it is polarized in a specific direction. As the light passes through the Faraday rotator, a magnetic field causes the polarization of the light to rotate as a result of the Faraday effect. The angle of rotation (β) will be given by the equation β=νBd, where ν is the Verdet constant for the material, *B* is the strength of the magnetic field, and d is the length of the Faraday rotator. The angle β is set to be 45 degrees so that the transmitted light can pass through the analyzer. However, light traveling in the opposite direction will end up polarized perpendicularly to the input polarizer, and as a result, will not be transmitted.

While there are Faraday rotators available presently, these have several deficiencies. Specifically, one has to use a very thick film of the material to achieve a sufficient rotation in the polarization. As a result, these devices tend to be very expensive. By incorporating a relatively thin magneto-optical film between two dielectric mirrors, one can increase the effective thickness because the light will travel back and forth in the structure.

Periodic mesoporous films (PMFs) are composed of either silicon dioxide or titanium dioxide. When these molecules are combined with a surfactant, micelle ordering takes place, with the hydrophobic tails of the surfactant pointing inward and the hydrophilic heads facing outward. When the resulting film is calcinated at high temperature, a structure with tiny pores is produced. By varying the size of these pores, the optical properties of the material can be altered.

CALIBRATION FOR FILM THICKNESSES

The films were fabricated using a spin coater. The thickness of the film can be controlled by the spin rate; higher spin rates form thinner film. Several samples of both SiO_2 and TiO_2 mesoporous films were spun to produce calibration curves relating thickness and spin speed. For each curve, a polynomial fit was obtained, which allows us to design combinational-structures with varying thickness.

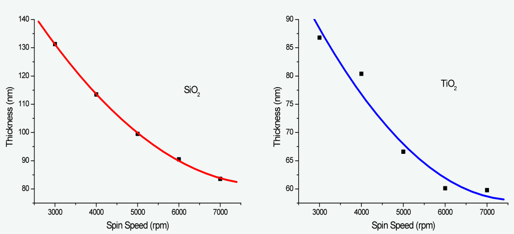

Figure 1. The calibration curves for SiO_2 (left panel) and TiO_2 (right panel) mesoporous films.

DIELECTRIC MIRRORS

A dielectric mirror can be fabricated by forming a superlattice of two different materials, each of which has a thickness of a quarter wavelength, causing the mirror to have a reflectivity peak at this wavelength. As shown in Fig. 2, it is essential to use two materials which have a large index contrast. By combining two materials, one with a higher index of refraction (n_H) and one with a lower index of refraction (n_L), and by fabricating several periods (N) of them, one could obtain a reflectivity given by:

$$R = \left[\frac{n_0 - n_s(n_L/n_H)^{2N}}{n_0 + n_s(n_L/n_H)^{2N}}\right]^2$$

Where n_s and n_0 are the indices of refraction of the substrate and surrounding environment respectively[1].

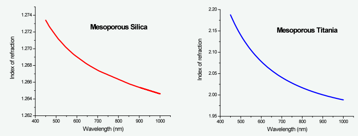

Figure 2. The indices of refraction versus wavelength of light for mesoporous silica (left panel) and titania (right panel).

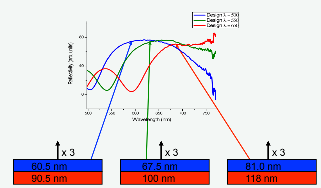

Figure 3. The reflectivity peaks for different period thicknesses. By changing the thicknesses of the individual layers, the reflectivity spectrum can be tuned. The samples had not been calcinated at the time these measurements were taken so λ_{max} is not equal to the design λ's.

In addition, the reflectivity of the mirrors is increased by adding more periods onto the mirrors.

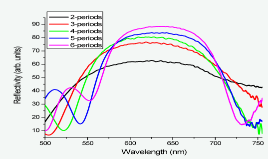

Figure 4. The reflectivity of a sample mirror at different number of periods.

The films were analyzed using ellipsometry. The mirrors were scanned as each layer was added.

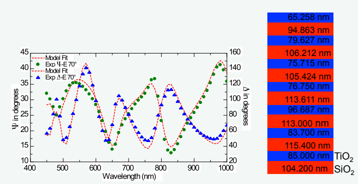

Figure 5. The ellipsometric data and the layer thicknesses for a sample mirror.

Magneto-Optical Layers

After fabricating the dielectric mirrors, our next goal was to deposit a magneto-optical layer in between two dielectric mirrors in order to construct the Faraday rotator. For this purpose, we used bismuth and aluminum substituted Yttrium Iron Garnet (YIG) films of molecular formula $Y_xBi_{3-x}Fe_yAl_{5-y}O_{12}$. We prepared these films through sol-gel techniques and spun them onto samples using a spin coater. The solutions were made from nitrates of yttrium, bismuth, iron, and aluminum as described in literature[2]. The samples were then analyzed using x-ray diffraction. The results compared fairly well with what was observed in literature[2].

$$Y(NO_3)_3 + Bi(NO_3)_3 + Fe(NO_3)_3 + Al(NO_3)_3 \longrightarrow Y_xBi_{3-x}Fe_yAl_{5-y}O_{12}$$

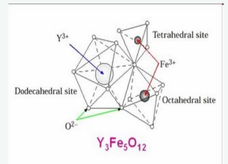

Figure 6. The crystal structure of Yttrium Iron Garnet. In our structures, Bismuth has been partially substituted for Yttrium, and Aluminum has partially been substituted for Iron[3].

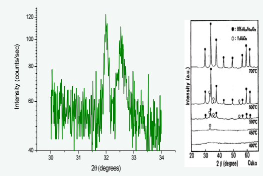

Figure 7. The x-ray diffraction spectrum for a Bi,Al:YIG film. The insert is found in literature[2].

DIELECTRIC MIRRORS WITH YTTRIUM IRON GARNET LAYER

It was originally planned to build the YIG layer on top of a layer of TiO_2. However, The YIG did not adhere to TiO_2, so the YIG was built on a layer of SiO_2 instead. It appears that the reflectivity of the samples maxed out when one and a half periods had been grown over the YIG layer.

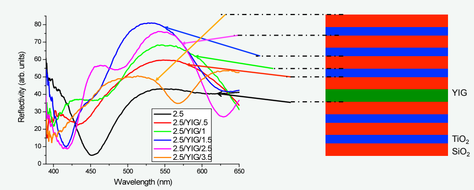

Figure 8. The structure of the mirrors with YIG. Arrows point to the corresponding reflectivity spectrum.

ACKNOWLEDGMENTS

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