Magnetic Oxides for Optical Isolators and Magnetoelectronic Devices

C. A. Ross, G. J. Dionne, A. Taussig, L. Bi, V. Sivakumar, H. S. Kim

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We have established a thin-film laboratory that includes a pulsed-laser deposition (PLD) system and an ultra-high vacuum sputter/analysis system. In PLD, a high-energy excimer laser is used to ablate a target, releasing a plume of material that deposits on a substrate to form a thin film. The PLD is particularly useful for making complex materials such as oxides because it can preserve the stoichiometry of the target material.

We have been using PLD to deposit a variety of oxide films for magneto-optical devices such as isolators. These materials include iron oxide, which can adopt one of four different ferrimagnetic or antiferromagnetic structures depending on deposition conditions, and bismuth iron garnet (BIG, $Bi_3Fe_5O_{12}$), which is useful for magneto-optical isolators in conventional photonic devices. The ideal material for an isolator combines high Faraday rotation with high optical transparency. Garnets have excellent properties but do not grow well on silicon substrates, making it difficult to integrate these materials. In contrast, iron oxide (maghemite) grows very well on MgO or Si, with high Faraday rotation but its optical absorption is high. One way to solve this problem is to develop new magneto-optical active materials, which can grow epitaxially on Si by using buffer layers. doping with transitional metal ions, these materials can exhibit strong Faraday rotation as well as low optical loss. Recently, we have examined Fe and Co-doped $SrTiO_3$ thin film (Figure 1) [1], which shows strong magneto-optical properties and lower optical absorption compared with iron oxide. The best figure of merits of 1.1 deg/dB and 0.57 deg/dB, which are defined as Faraday rotation divided by optical absorption loss at 1550nm wavelength, have been achieved in $Sr(Ti_{0.6}Fe_{0.4})O_3$ and $Sr(Ti_{0.7}Co_{0.3})O_3$ respectively. These films could be useful for waveguide isolators and other magnetoelectronic devices in which optical absorption losses are critical. $As_2S_3/Sr(Ti_{0.6}Fe_{0.4})O_3$ strip-loaded waveguides were fabricated on epitaxial $Sr(Ti_{0.6}Fe_{0.4})O_3$ on LSAT (001) substrates (Figure 2) [2]. Optical transmission measurements at 1550nm wavelength confirmed the relatively high transparency of the magneto-optical film. A second project involves the use of electrochemical methods to control the magnetization of iron oxide spinel structure films (magnetite or maghemite) grown on conducting substrates, making a chemically-switchable material. The insertion of Li ions by electrochemical discharge changes the oxidation state of the Fe(III) to Fe(II) and can reduce the magnetization of the film by about 30%, in a reversible process. Recent experiments on nanoparticles of iron oxide show much greater changes in magnetization, up to ~80%, indicating that the process is kinetically limited. Lithiation of CrO_2 also successfully changed the magnetization with an intial change of $10\mu_B$ per Li^+ ion insertion.

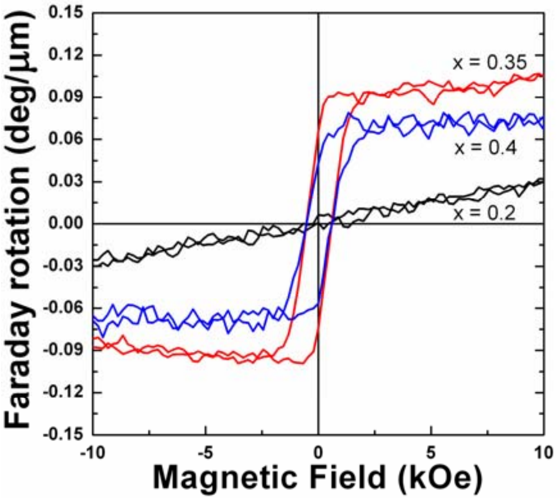

Figure 1: Faraday rotation at 1550nm wavelength vs. applied field for $Sr(Ti_{1-x}Fe_x)O_3$ films grown on $LaAlO_3$ (001) substrates.

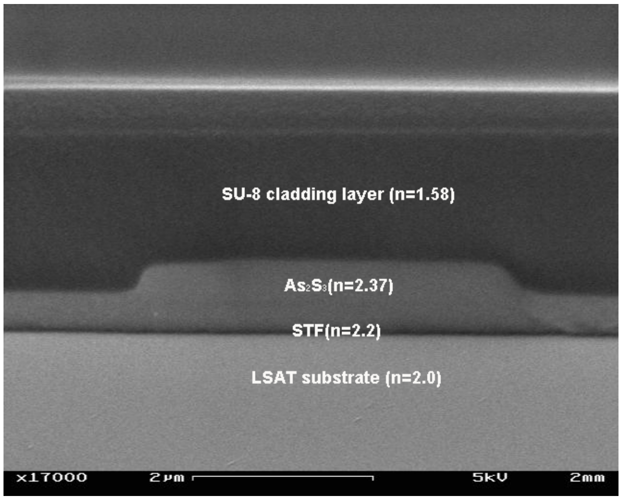

Figure 2: Cross-sectional SEM image of an $As_2S_3/Sr(Ti_{0.6}Fe_{0.4})O_3$ strip-loaded waveguide with an SU-8 top-cladding layer fabricated on an LSAT(001) substrate.

REFERENCES

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[2] Lei Bi, Hyun-Suk Kim, Juejun Hu, Lionel C. Kimerling and C. A. Ross, “$As_2S_3/Sr(Ti_{0.7}Co_{0.3})O_3$ and $As_2S_3/Sr(Ti_{0.6}Fe_{0.4})O_3$ strip-loaded waveguides for integrated magneto-optical isolator applications”, Proc. SPIE 7218, 721803 (2009).