We studied the growth, structural and magnetic properties of the hexagonal ferrite ($\text{BaAl}_x\text{Fe}_{12-x}\text{O}_{19}$) films on a surface of Pt template/Si wafer. We determine that our hexagonal ferrite films are highly textured, with the $c$ axis perpendicular to the Si wafer surface and that Al substitution substantially increases uniaxial magnetic anisotropy from 17 to 25 kOe for $x=0$ and $x=2$ respectively. This increase in anisotropy field is governed by preferential substitution of Al ions into the 12$k$, 2$a$ and 2$b$ Fe sites as determined by our Mossbauer spectroscopy studies, consequently reducing magnetization. As a result, the ferromagnetic resonance frequency increases from 35 to 70.
We studied the growth, structural and magnetic properties of the hexagonal ferrite (BaAlxFe12-xO19) films on a surface of Pt template/Si wafer. We determine that our hexagonal ferrite films are highly textured, with the c axis perpendicular to the Si wafer surface and that Al substitution substantially increases uniaxial magnetic anisotropy from 17 to 25 kOe for x=0 and x=2 respectively. This increases in anisotropy field is governed by preferential substitution of Al ions into the 12k, 2a and 2b Fe sites as determined by our Mossbauer spectroscopy studies, consequently reducing magnetization. As a result, the ferromagnetic resonance frequency increases from 35 to 70 GHz in zero applied field. We built a prototype of a fully integrated on-wafer, magnetically tunable band-stop filter on a Si substrate. The filter uses a barium hexagonal ferrite film incorporated into the dielectric layer of a microstrip transmission line. The zero-field operational frequency is about 34 GHz, increasing linearly with the strength of an applied magnetic field at a rate of about 2.7 GHz/kOe. Experimentally, high signal attenuation (33–67 dB/cm) at the resonance frequency and insertion losses as low as 4.5 dB were simultaneously observed, while the 3 dB device bandwidths were below 1 GHz.
Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received  Paper


01/11/2013  11.00 Ian Harward, Yan Nie, Daming Chen, Josh Baptist, Justin M. Shaw, Eva Jakubisová Lišková, Štefan Višovský, Petr Široký, Michal Lesnák, Jaromír Pištora, Zbigniew Celinski. Physical properties of Al doped Ba hexagonal ferrite thin films., Journal of Applied Physics (accepted for publication), (03 2013): 0. doi:

01/21/2013  12.00 Ian Harward, Yan Nie, Daming Chen, Josh Baptist, Justin M. Shaw, Eva Liskova, Stefan Visnovsky, Petr Siroky, Michal Lesnak, Jaromir Pistora, Zbigniew Celinski. Physical properties of Al doped Ba hexagonal ferrite thin films., Journal of Applied Physics (accepted for publication), (02 2013): 0. doi:


Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

01/10/2013 7.00 I. Harward, Yan Nie, A. Gardner, L. Reisman, Z. Celinski. Al doped Ba hexaferrite (BaAlxFe12-xO19) thin films on Pt using metalloorganic decomposition, Journal of Applied Physics, (02 2012): 7514. doi:

01/10/2013 5.00 I. Harward, T. O’Keevan, A. Hutchison, V. Zagorodnii, Z. Celinski. A broadband ferromagnetic resonance spectrometer to measure thin films up to 70 GHz, Review of Scientific Instruments, (09 2011): 0. doi:


04/03/2014 18.00 Yan Nie, R. E. Camley, Ying Wang. High-frequency nonreciprocal reflection from magnetic films with overlayers, JOURNAL Od Applied Physics, (11 2013): 183908. doi:

TOTAL: 4
Number of Papers published in non peer-reviewed journals:

(c) Presentations
Zbigniew Celinski, New Semiconductors and Devices Workshop, Northrop-Grumman, Los Angeles, December 11-12th 2014
Number of Presentations: 1.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

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(d) Manuscripts

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Number of Manuscripts:

**Books**

Received  
Book

TOTAL:

Received  
Book Chapter

TOTAL:

**Patents Submitted**


Metallic surfaces as alignment layers for non-display applications of liquid crystals

**Patents Awarded**

Metallic surfaces as alignment layers for nondisplay applications of liquid crystals - US 20130208194 A1 Application number US 13/766,615 Publication date Aug 15, 2013 Filing date Feb 13, 2013

**Awards**

**Graduate Students**

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## Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period.

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields: 1.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense: 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 1.00

## Names of Personnel receiving masters degrees

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## Names of personnel receiving PHDs

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During the last year of this project our work concentrated in two areas:

1) Mossbauer studies of the Al doped BaAlxFe12-xO19 films and XRD studies of the bulk hexagonal ferrites to understand the nature of the Al substitution into the Fe sites

2) Development of fully integrated on-wafer band-stop filter using hexagonal ferrites films grown on Si wafer

3) In addition we prepared a paper on a nonlinear phase shifter and another paper on magneto-optical properties of the hexagonal ferrite films.

Our work on materials for on-wafer microwave devices concentrated on barium hexagonal ferrite (BaM) films grown on Si because these material is a good candidate material for new generations of on-wafer microwave devices operating at frequencies above 40 GHz. Doping BaM with Al increases the value of anisotropy field significantly, and in combination with a large value of remanence, could allow one to create a self-biasing material/structure that would eliminate the need for permanent bias magnets in millimeter wave devices. To examine the occupation of Fe sub-lattices by Al ions, we carried out Conversion Electron Mossbauer Spectroscopy (CEMS) measurements at room temperature and zero magnetic field (after magnetizing the samples in a strong magnetic field). The spectra can be reasonably fitted with three components (sub-spectra) corresponding to different Fe sublattices. There are significant changes in the spectra with the addition of Al: The magnetic hyperfine field decreases for all three components, and their relative contributions also change remarkably. These observations are in agreement with the fact that the Al substitutes Fe, thus lowering the component contributions and the value of the hyperfine field. Specifically, the Fe sites 12k, 2a and 2b are preferentially occupied by the Al ions. As a result the saturation magnetization decreases significantly with Al doping and this decreases of the saturation magnetization is responsible for the significant increase of uniaxial anisotropy field. In addition, our previous XRD analysis indicates increasing grain misalignment with Al content, further supporting the CEMS data.

We have devoted a significant effort to built a prototype of a fully integrated on-wafer, magnetically tunable band-stop filter operating at millimeter wave frequencies on a Si substrate. In contrast to earlier studies, our filter uses a very thin barium hexagonal ferrite film incorporated into the dielectric layer of a microstrip transmission line to filter the signal. We have used barium hexagonal ferrite film without Al doping, however the procedure to built would be identical using BaAlxFe12-xO19 films. The device operates by absorbing signals at the FMR frequency of BaM, while signals at off-resonance frequencies propagate through the structure with far less damping. The zero-field operational frequency is about 34GHz, increasing linearly with the strength of a static, perpendicularly applied magnetic field at a rate of about2.7GHz/kOe. Experimentally, high signal attenuation (33–67 dB/cm) at the resonance frequency and insertion losses as low as 4.5 dB were simultaneously observed, while the 3 dB device band-widths were generally below 1GHz. Our calculations are in quantitative agreement with the experimental results. We also find an important result that the thickness and conductivity of the Pt ground plane plays a key role in insertion losses, indicating directions for further improvements.

Technology Transfer