AD-A129 035 MILLIMETER WAVE NONRECIPROCAL DEVICES(U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE F R MORGENTHALER 03 JAN 83 1/1

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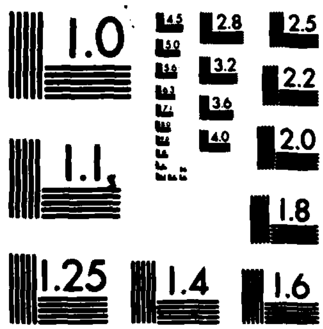

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Microwave and Quantum Magnetics Group within the MIT Department of Electrical Engineering and Computer Science and the Research Laboratory of Electronics proposed a three year research program aimed at developing coherent magnetic wave signal-processing techniques for microwave energy which may form either the primary signal or else the intermediate frequency (IF) modulation of millimeter wavelength signals-especially at frequencies in the 50-94 GHz. range. Emphasis has been placed upon developing advanced types of signal processors that make use of quasi-optical

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20. ABSTRACT CONTINUED

propagation of electromagnetic and magnetostatic waves propagating in high quality single crystal ferrite thin films. A strong theoretical effort is required in order to establish valid models useful for predicting device performance. We emphasized new filter and circulator designs that employ combinations of the Faraday effect, field displacement nonreciprocity and magnetostatic resonance and periodic structures.

FINAL REPORT

MILLIMETER WAVE NONRECIPROCAL DEVICES

Massachusetts Institute of Technology
Department of Electrical Engineering and Computer Science
Research Laboratory of Electronics
Cambridge, Massachusetts 02139

July 17, 1981 - January 3, 1983

ARO Project No. P-17873-EL

Contract No. DAAG29-81-K-0126

Professor Frederic R. Morgenthaler

Research Objectives

The Microwave and Quantum Magnetics Group within the MIT Department of Electrical Engineering and Computer Science and the Research Laboratory of Electronics proposed a three year research program aimed at developing coherent magnetic wave signal-processing techniques for microwave energy which may form either the primary signal or else the intermediate frequency (IF) modulation of millimeter wavelength signals——especially at frequencies in the 50-94 GHz. range.

Emphasis has been placed upon developing advanced types of signal processors that make use of quasi-optical propagation of electromagnetic and magnetostatic waves propagating in high quality single crystal ferrite thin films.

A strong theoretical effort is required in order to establish valid models useful for predicting device performance. We emphasized new filter and circulator designs that employ combinations of the Faraday effect, field displacement nonreciprocity and magnetostatic resonance and periodic structures.

Results

In July 1981 shortly before this contract was initiated, MIT was requested to submit the second and third year budgets of the original proposal to the Army Advanced Concepts Technology Committee chaired by Dr. Charles Church; the resubmission was made in August 1981, followed by a verbal presentation to the ACT Committee on April 1, 1982. Although the reaction appeared (and still appears) to be favorable, a funding hiatus seemed likely and MIT sought and obtained an extension of the first year effort without additional funds. Accordingly, capital equipment items originally planned for in the first year were deferred so as to provide monies for salaries, materials and services. Nevertheless, despite the gap in funding that did occur, we believe that we were able to accomplish a number of our preliminary goals.

Because we have proposed to use an analogous approach in the development of nonreciprocal millimeter wave components, an extensive literature search on the topic of nonreciprocal optical wave guides employing both the Faraday effect and birefringence was carried out. The basic idea is to use quasi-optical dielectric wave guides supporting nearly degenerate TE and TM modes (one of which is guiding, the other leaky). The Faraday (nonreciprocal) and birefringence (reciprocal) effects add for one direction of propagation and cancel for the other. The principal advantage is that only very low magnetic dc bias fields are required.

Spatial gradients of the dc bias field saturation magnetization, or magnetic anisotrophy can control mode properties of magnetostatic waves (MSW) propagating in thin ferrite films. Properties include the frequency dispersion, energy distribution and the threshold for nonlinear effects. Particular attention has been given to the case of forward-volume-waves when the bias is normal to the film plane but has a gradient solely along the lateral dimension of the film. For rectangular strips, the lateral dimension is the width.

For forward volume waves near the bottom of the frequency band, the equation governing the MS potential reduces to the Schrödinger Equation for particles in a potential well that is shaped by the applied field, $4\pi M$, and the magnetic anisotropy. The distribution of particles is naturally sensitive to the effective field gradients; however edge effects mix in surface wave character that is different for opposite edges. Thus, even when the potential well is symmetric, the particle density is not. This effect can induce strong field-displacement nonreciprocity in a mode that is normally reciprocal. The synthesis of such modes should serve to allow the construction of novel forms of thin film isolators and circulators.

The above-mentioned analysis is pertinent to the case of forward-volume wave modes that have strong magnetostatic character. For millimeter wave frequencies, that generally requires ferrite materials with high magnetostatic anisotropy, but we have investigated the nonresonant low bias field limit in which the dominant frequency dependence of the Polder permeability tensor arises from the off-diagonal component. As expected, when the modes have strong electromagnetic- and weak magnetostatic-characters, it is more difficult for bias gradients to induce the desired field displacement nonreciprocity. Nevertheless, the analysis indicates which factors tend to maximize the effect.

D. D. Stancil and F. R. Morgenthaler reported the propagation characteristics of magnetostatic surface waves in a rectangular yttrium iron garnet film placed between strips of mumetal and in the plane of the strips. The microstrip excitation structure was designed so as to permit the strips to extend along the entire path of propagation, thereby minimizing field nonuniformities in the longitudinal direction. These experiments suggest that nonuniform in-plane fields can be used to alter the dispersion characteristics of the waves. A theoretical argument is also presented describing a possible energy localization mechanism in nonuniform in-plane fields. In addition, experiments are described in which nonuniform fields caused by a slot in a mumetal covering layer are used to guide magnetostatic surface waves through a turn of 160°.

Nickolas Vlannes developed a new induction probe that measures microwave magnetic field patterns of magnetostatic waves in LPE-YIG thin films has been developed. The probe's sensing element is either a strand of 25.4 μm diameter gold wire wrapped around a plastic support, or an aluminum rectangular loop photolithographically fabricated on glass. The gold wire method yielded a smallest resolution of 120 μm and the aluminum loops achieved a smallest size of 45 μm. Each sensing element is attached to rotation and tilt stages for proper alignment of the sensing element. This assembly is mounted on a balance arm which is counterbalanced to minimize pressure on the crystal and sensing element. The balance arm is supported by a vertical translation stage mounted on horizontal X-Y translation stages with 2.5 μm accuracy and total travel of one inch in X and Y.

The probe is designed for studies of amplitude profiles, dispersion relations and phase propagation direction. Investigations of magnetostatic surface waves (MSSW) under uniform and nonuniform in-plane magnetic bias field conditions have been done.

F. R. Morgenthaler and T. Bhattacharjee analyzed magnetostatic surface wave (MSSW) propagation on one or more co-planar rectangular films of finite width and gave numerical solutions using an integral equation formulation. In the case of uniform in-plane bias, the eigenfrequencies and the associated eigenvectors are obtained by solving the coupled equations which determines the frequency dispersion and spatial form of MSSW potentials. In addition to modes having the expected localization of energy on the film surfaces, the results confirm the existence of certain modes having primary energy concentration at the film edges.

The formulation is also specialized to the case of two uniformly magnetized rectangular parallel strips separated by an air gap and coupled via the fringing fields of magnetostatic waves. The results should prove useful in modelling directional couplers for MSSW.

D. A. Fishman and F. R. Morgenthaler studied velocity of energy circulation associated with the uniform precession mode in a ferrite sphere. Specifically, the effect of the boundary conditions imposed by a concentric conducting spherical cavity was considered for the uniform precession magnetic resonance mode of a YIG sphere. Theoretical analyses show that there is a critical ratio between the radius of the ferrite sphere and the conducting cavity where the energy velocity of the uniform precession mode approaches zero. Spin wave instabilities, as a result of the nonlinear coupling of the uniform precession mode to spin wave excitations, are brought on if the rf-energy density inside the ferrite exceeds the specific threshold value. Thus a decrease in the energy velocity is expected to decrease the amount of incident power required for the onset of spin wave instabilities. They reported that decreases in threshold power for the Suhl first order spin wave instability have been observed as a function of the cavity radius. The experimental cavity consists of two conducting partial hemispheres, one on each side of the YIG sphere

Personnel Supported in Part during the Contract Period

Professor Frederic R. Morgenthaler	Professor of Electrical Engineering
Professor Robert L. Kyhl	Professor of Electrical Engineering
Dale A. Zeskind	Senior Researcher
Nickolas P. Vlannes	Graduate Student (Research Assistant)
Daniel D. Stancil	Graduate Student (now Asst. Professor of Electrical Engineering at North Carolina State University)
Alan Wadsworth	Graduate Student
Larry Hegi	Graduate Student (Research Assistant)
Maurice Borgeaud	Graduate Student (Research Assistant)

Degrees Granted

D. D. Stancil, Doctor of Philosophy Degree in the Field of Electrical Engineering from the Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science, September 1981.

Leslie Itano, Degree of Master of Science in the Field of Electrical Engineering and the Degree of Electrical Engineer from the Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science, Sept. 1981.

Alan Wadsworth, Degree of Master of Science in the Field of Electrical Engineering from the Massachusetts Institute of Technology Department of Electrical Engineering and Computer Science, January 1982.

Theses

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Leslie Itano, "Microwave Delay Line with Thin Film Antennae," M.I.T. Department of Electrical Engineering anc Computer Science S.M. Thesis dated September 1981; available as M.I.T. Microwave and Quantum Magnetics Laboratory Technical Report No. 43.

Alan Wadsworth, "Improvements in the Design of Microwave Magnetoelastic Delay Lines," S.M. Thesis dated January 1982; available as M.I.T. Microwave and Quantum Magnetics Laboratory Report No. 46.

N. P. Vlannes, "Optical and Induction Probing of Magnetostatic Waves in Nonuniform Bias Fields," M.I.T. Department of Electrical Engineering and Computer Science Ph.D. thesis (in progress——to be completed by September 1983); will be made available as an MIT Microwave and Quantum Magnetics Laboratory Report.

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F. R. Morgenthaler, "Field-Displacement Nonreciprocity Induced in MSW Modes by DC Magnetic Field (or other) Gradients," to be published in the forthcoming special issue on "Magnetostatic W[illegible]es and [illegible]lications for Signal Processing" of the journal, Circuits, Systems an[illegible] [illegible]ig[illegible] Processing.

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D. D. Stancil and F. R. Morgenthaler, "Guiding Magnetostatic Surface Waves with Nonuniform In-plane Fields," Proceedings of the 1981 RADC Microwave Magnetics Technology Workshop, published as RADC In-house Report No. RADC-TR-83-15, January 1983.

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