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EXCITATION AND PROPAGATION OF MAGNETOSTATIC MICROWAVES IN FERRIMAGNETIC LAYERED STRUCTURES

by

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ABSTRACT

This thesis investigates the excitation and propagation of magnetostatic microwaves in ferrimagnetic layered planar structures. The propagation characteristics of magnetostatic bulk waves in dielectric layered structure have been studied. In general, when the direction of the biasing field is arbitrary, the bulk wave spectrum contains forward as well as backward wave branches. The associated phenomenon of magnetic steering, which occurs when the biasing field is rotated in the plane of the film, has also been investigated. The effect of magnetocrystalline anisotropy on the delay characteristics of magnetostatic bulk waves in a dielectric layered structure has been analysed. In the case of cubic ferrimagnetics, like YIG, the effect of magnetocrystalline anisotropy is relatively small. However, for a hexagonal planar magnetoplumbite, like Zn_2Y, the anisotropy significantly influences the magnitude of delay as well bandwidth of the guided waves. The effect of finite width on the propagation characteristics of magnetostatic bulk waves in YIG layered structure has also been investigated. In the region close to the cutoff, the delay characteristics are appreciably influenced by finite width. However, far from the cutoff, the effect of finite width can be neglected.

The excitation of magnetostatic surface and bulk waves in a multilayered structure containing a YIG film has been studied. In the case of surface waves, the present analysis explains the finite radiation resistance close to the lower cut off frequency. Over the useful frequency region, the radiation resistance of higher order modes may be about ten percent of that of the (dominant) first order mode. The analysis of bulk wave excitation has been carried out for different transducers, viz., single microstrip, grating and meander line. The excitation efficiency in the case of grating can be larger than for microstrip, though at the cost of reduced bandwidth of the dominant lobe. It is concluded that, over the significant frequency range, the effect of higher order modes can be neglected compared to the first order mode; this contradicts the earlier conclusion, by Parekh, which was based on erroneous numerical calculations.

PREFACE

In recent years, there has been a renewed interest[1-5] in the study of the excitation and propagation of microwaves in ferrimagnetic layered planar structures. Such investigations are warranted by the potential applications in microwave signal processing using narrow linewidth ferrimagnetics. The biased ferrimagnetics are known[6] to exhibit anomalous dispersion in the region of ferromagnetic resonance. For biasing fields of normal strengths, the resonance frequency lies in the microwave region of the electromagnetic spectrum. Hence, at microwave frequencies, biased ferrimagnetics exhibit strong dispersion which is, in turn, utilized in the various microwave devices[6-13].

A detailed study of the microscopic structure of ferrimagnetics leads to the conclusion that, ferrimagnetics consist of permanent magnetic dipoles (spins), which are coupled by means of interactions such as direct or indirect exchange interaction, dipolar interaction, spin-orbit interaction, etc. It is this coupling which is responsible for the propagation of a magnetic disturbance (spin wave) in the system. The spin waves are highly dispersive and have phase velocities ranging from the speed of light to the speed of sound. In the dispersion diagram of these waves, there exists a region wherein the energy of the waves is largely magnetic and the exchange effects are also negligible[6,14]. In this region, the dipolar forces are significant and the waves are called magnetostatic. The phase velocity of magnetostatic waves is about two to three orders of magnitude smaller than that of light. Hence, these waves are potentially useful[14] in microwave devices for producing non-dispersive or variable delay, frequency translation, mode conversion, gating, time scaling, time inversion, pulse compression, amplification etc. Beyond about 3 GHz, the magnetostatic waves are considered to be superior[5] to surface acoustic waves for signal processing applications.

The earliest fabricated magnetostatic wave devices[15-23] used ferrimagnetic rods, discs and plates. However, such devices could not attain the desired figures of merit. The main reason for this was the fact that the geometries (rods, discs, plates) used in these devices were non-ellipsoidal, for which, the internal dc magnetic field is nonuniform even if the applied field is uniform. The transverse dependence of the internal dc field causes a focusing lens effect[1] in the aforementioned geometries. This effect enhances the undesirable non-linear signal limiting, sideband generation etc.

In recent years, these difficulties have been overcome with the advent of the growth of high quality epitaxial ferrimagnetic films on nonmagnetic substrates[24-26] While in the beginning, the films were grown by vapour phase epitaxy[24], superior quality films were grown later by liquid phase epitaxy (LPE)[26,27]. The aspect ratio of such films being large, the internal dc magnetic field is more or less uniform and the lens effects are eliminated. Thus the latest magnetostatic wave devices[5,28-30], viz., delay lines, filters, resonators, etc., employ layered planar structures consisting of LPE ferrimagnetic films and films/layers of other materials.

The excitation and propagation characteristics of magnetostatic waves in ferrimagnetic layered planar structures are known to depend critically on a large number of parameters such as the magnitude and orientation of the dc field, magnetocrystalline anisotropy field, saturation magnetization, thicknesses of the ferrimagnetic and dielectric layers, etc. Hence, an empirical approach to the fabrication of the associated devices cannot yield the desired characteristics. Detailed analyses[31-61] are required to appreciate the dependence of coupling and propagation characteristics on the various parameters.

The present thesis is devoted to a theoretical investigation of the effect of some specific parameters on the excitation and propagation characteristics of magnetostatic surface and bulk (volume) waves in ferrimagnetic layered planar structures. The problems investigated in the thesis include (i) the effect of arbitrary orientation of dc magnetic field on dispersion and delay of magnetic waves and the associated steering phenomenon (ii) the effect of cubic and hexagonal magneto-crystalline anisotropy[6] on delay characteristics of magnetostatic waves (iii) the effect of finite width on bulk wave characteristics (iv) the radiation resistance of magnetostatic surface waves in multilayered structure and (v) the radiation resistance of magnetostatic bulk waves. Thus, the thesis has been divided into five chapters; the summaries of the chapters are given below:

Chapter-I: Magnetostatic Bulk Waves in an Arbitrarily Magnetized YIG Dielectric Layered Structure

This chapter presents a general analysis of the propagation of magnetostatic bulk waves in an arbitrarily magnetized YIG (Yttrium-iron-garnet) film separated from a perfect conductor by a dielectric layer. Using the transformed permeability tensor, the magnetostatic equations have been solved subject to appropriate boundary conditions in order to obtain the dispersion relation and the expression for group delay time. Numerical calculations indicate that, in general, the propagation characteristics are non-reciprocal. The delay curves contain forward as well as backward wave branches. While the forward waves are non-dispersive over a small bandwidth, no such region of nondispersive delay is obtained for backward waves. The associated phenomenon of the magnetic steering of magnetostatic bulk waves has also been studied. It is seen that the steering angle can be controlled by changing the biasing field and the angle between the direction of phase propagation and biasing field.

Chapter-II: Magnetostatic Volume Waves in Dielectric Layered Structure: Effect of Magnetocrystalline Anisotropy

In this chapter, a theoretical investigation of the effect of magnetocrystalline anisotropy on the group delay of magnetostatic volume waves has been presented. The analysis has been carried out under the magnetostatic approximation for the layered structure consisting of a normally magnetized ferrimagnetic film separated from a perfect conductor by means of a dielectric layer. The cases of cubic, as well as hexagonal planar anisotropy have been considered. Numerical calculations for YIG (cubic) and Zn_2Y (planar magnetoplumbite)[6] show that, in general, the magnetocrystalline anisotropy leads to anisotropic propagation in the plane of the film. It also affects the range of frequency of nondispersive delay as well as the overall magnitude of the group delay time. In the case of cubic ferrimagnetics, the specific crystallographic orientations have been obtained for which the effect of magnetocrystalline anisotropy on propagation characteristics is negligible. In the case of the Zn_2Y planar ferrimagnetic, the frequency range of allowed modes is found to be extremely large; it extends from about 3 to 12GHz, with an effective bias field as low as 200 Oe.

Chapter-III: Magnetostatic Bulk Wave Propagation in Multilayered Structure: Effect of Finite Width

This chapter discusses the effect of finite sample width on the dispersion and delay characteristics of magnetostatic bulk waves in a multilayered structure consisting of a YIG sandwiched between grounded dielectric layers. It is seen that, unlike for surface waves, the cutoff frequency of bulk waves is different for different modes. In the case when one of the dielectric layers is ungrounded, the effect of finite width is significant near the cutoff, but decreases rapidly with increasing wave frequency. When both the dielectric layers are grounded, the effect of finite width can be neglected for a wide range of parameters.

Chapter-IV: Theory of Microstrip Excitation of Magnetostatic Surface Waves

In this chapter the author has investigated the excitation of magnetostatic surface waves in a multilayered structure consisting of a ferrimagnetic film sandwiched between two metal backed dielectrics. The analysis takes into account the effect of finite sample width. This leads to hybridization of TE and TM modes

As such the generalization of Ganguly-Webb/Sethares[39,52] analysis to the present case becomes extremely difficult. The author has therefore resorted to quasistatic approximation in order to express wave field and finally obtain the radiation resistance. Numerical results have been presented for a wide range of practical parameters. For the dielectric layered structure, the present numerical results are in reasonable agreement with the experimental results of Ganguly and Webb[39]. Specifically our analysis and calculations explain the finite radiation resistance at the lower cutoff frequency, which was not explained by the previous analyses.

Chapter-V: Excitation of Magnetostatic Bulk Waves in Multilayered Structure

This chapter presents an analysis of the excitation of magnetostatic bulk waves in a layered structure consisting of a YIG film sandwiched between metal backed dielectrics. The effect of finite sample width has been neglected. The radiation resistance has been obtained under the magnetostatic approximation. The radiation resistance for different design of couplers has been numerically investigated.

In the end, the main conclusions reported in the thesis have been summarized and the scope for further work has also been outlined.

The aforementioned work has resulted in the following publications/communications:-

1. Magnetostatic bulk waves in an arbitrarily magnetized YIG-dielectric layered structure, Phys.Status Solidi (a) ~~(In Press 1980).~~ 57, (307) 1980.

2. Steering of magnetostatic bulk waves in a dielectric layered structure, J.Appl.Phys. 50, 6564 (1979).

3. Magnetostatic volume waves in dielectric layered structure: Effect of magneto-crystalline anisotropy, J.Appl.Phys. 50,2887 (1979).

4. Magnetostatic bulk wave propagation in Multilayered structure: Effect of finite sample width, ~~Communicated (1979)~~. Electron Lett. 16, 269 (1980,

5. Theory of microstrip excitation of magneto-static surface waves, Communicated (1979).

6. Excitation of magnetostatic bulk waves in a multilayered structure, Communicated (1979).

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