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THE NONDESTRUCTIVE DIAGNOSTICS OF THE FERRITE FILMS AT HIGH FREQUENCIES

V. Stalmahov, A. Ignatiev and A. Lepestkin

Saratov University, 83, Astrakhanskaya street, 410601, Saratov, U.S.S.R.

Abstract. This paper deals with the study of the simple experimental method of the determination of the fundamental magnetic parameters of the magnetic film. This method is based on the investigation of the high frequency signal passing through the below cut-off waveguide with the analysed material (the magnetic film).

Introduction

The reliable diagnostics of the magnetic film parameters at the high frequency – the ferromagnetic resonance (FMR) linewidth, the value of the losses, the magnetization saturation (Mo), the internal magnetic fields, etc. – are necessary for the investigation of the magnetostatic waves in the films and the correct interpretation of the experimental results at the frequency above 30 GHz. The knowledge of the local values of these parameters, that is, the distribution of these parameters on the surface (the volume) of the investigated magnetic film (the crystal) is necessary in certain cases.

This paper discusses the simple experimental method of the determination of the fundamental magnetic parameters of the magnetic film. This method is based on the investigation of the high frequency signal passing through the below cut-off waveguide with total or partial filling of the analysed material (the magnetic film). This waveguide system permits to follow the strict electrodynamic analysis and to have a high experimental accuracy of the measured values (the frequency). It in turn permits to evaluate the magnetic parameters of the analysed films reliable in the working ranges of frequencies.

Theoretical and experimental results

The experimentally discovered window of the transparency in the below cut-off waveguide section (see Fig. 1) with total or partial filling of the ferrite film not far from the ferromagnetic resonance lies in the basis of this simple method [1]. The geometry of the structure is determined by the working frequency ranges and is selected so as to have the difference between the input and output more than 40-50 dB in the absence of the magnetic field. The below cut-off waveguide is "opened" at the frequency near the FMR frequency in the presence of the magnetic field and the difference between the input and output decreases to 5-10 dB. The geometry and frequency characteristics in the below cut-off section and the loss parameter $\alpha$ of the ferrite film determine the width of the transparency window. The typical experimental amplitude vs. frequency characteristics of the cut-off section with the YIG film at 30 GHz is shown in figure 2. Such characteristics are measured reliably and easily interpreted.

![Fig. 1. – The section of the below cut-off waveguide with the magnetic film.](image)

![Fig. 2. – The experimental amplitude vs. frequency characteristics of the cut-off section with the YIG film.](image)

The theoretical analysis of the band characteristics of the below cut-off section of a rectangular waveguide with an in-plane magnetized ferrite film is based on the work of Gurevitch [2] and leads to the following results. The theoretical frequency dependencies of the output signal in this system for the identical geometry and different values of the loss parameter $\alpha$ in the ferrite: $\alpha = 10^{-4}$, $5 \times 10^{-4}$, $10^{-3}$, $5 \times 10^{-3}$ and $4\pi M_0 =$
1 760 Gs; \( H_0 = 10^4 \) Oe; \( f = \omega / 2\pi = 30.362 \) GHz are shown in figure 3. They follow bell-shaped curves centred at the reduced frequency \( \omega / \omega_H = 1.0844 \). The width of this curve is only connected with the parameter \( \alpha \).

The theoretical dependence of the relative bandwidth \( \Delta f / f \) in the below cut-off section on the loss parameter \( \alpha \) is shown in figure 4 for different thicknesses \( d \) of the ferrite films in the waveguide: \( d / h = 0.01; 0.05 \) for \( 4\pi M_0 / H_0 = 0.15 \).

The width of the transparency depends considerably on the value of the losses, especially for the small ones. It is possible to determine the loss parameter \( \alpha \) in the ferrite film by comparing those curves with the experimental dependences for different geometries and frequency ranges. This method allows to determine FMR linewidth \( \Delta H / H_0 \) easily, so far as the value \( \Delta H / H_0 \) is simply proportional to the parameter \( \alpha \) at the small losses [3].

The losses in the substrate and the guide walls enlarge the experimental bands \( \Delta f \). The role of the losses in the walls of the waveguide may be reduced to minimum by the moving the analysed ferrite film away from the walls. It is necessary to consider the losses in the substrate only for small parameter \( \alpha \). In a tangent magnetized ferrite film magnetostatic waves move forward on one side and back on the other. It permits to investigate the loss parameter on the inside and outside surfaces of the film by the change of the direction of the external magnetic field. The area of the analysis will depend on the width and length of the below cut-off waveguide section. The measuring cell may moved on the surface of the film and may measure the local structure of \( \Delta H \) on the film. There is a series of responses for the multilayered structure with different \( M_0 \).

The experimental investigation in a wide frequency range shows that the width \( \Delta H \) is increased with the frequency (approximately \( 10^{-1}-10^{-2} \) Oe/GHz). The comparison of the experimental curves \( \Delta H (\omega) \) for the ferrite films with [4] shows their good agreement.

The utilization of the YIG films at the high frequency requires large magnetic fields \( H_0 \gg 4\pi M_0 \). The accurate measurement of these fields by the usual methods is difficult. The proposed method permits to control the space configuration of the magnetic field in the film by measuring the central frequency of the response of the below cut-off waveguide section. The knowledge of the value \( M_0 \) is necessary for that. Reciprocally the \( M_0 \) value can be obtained exactly if the \( H_0 \) value is known. One can observe the profile of the magnetization \( M_0 \) across the film by the different magnetostatic waves.

**Conclusion**

The proposed method is reproduced easily, the experimental results are interpreted reliably and permit to determine the magnetic parameters of the ferrite films at high frequencies with a sufficient accuracy.