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## Abstract

## Full Text

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**PHYSICS**

Academician L. V. KIRENSKII, N. M. SALANSKII, V. I. LITVINCHUK

# MAGNETOSTRICTIONAL INSTABILITY OF A PARAMETRON ON A THIN MAGNETIC FILM

The study of thin magnetic films (TMF) in a parametric excitation system makes it possible to obtain information both about the magnetic film itself—the structure and dynamics of the magnetization in it—and about the system consisting of film + substrate. The first results of a study of the mechanical stability of a parametric system using a TMF deposited on a nonmagnetic substrate as a nonlinear element are presented in ([1]). It was found there that, under certain energy operating regimes of the parametron, magnetostrictive instability appears in the film + substrate system, causing unstable jumps in the amplitude of the parametric oscillations. When the energy thresholds were exceeded, these jumps turned into low-frequency amplitude modulation of the parametric oscillations, with a frequency of the order of $10^4$ Hz, which increased as the diameter of the substrate decreased. The observed effect was associated with the magnetoelastic interaction of the film with the substrate, which led to flexural vibrations of the substrate.

**Fig. 1.** Regions of existence of magnetoelastic interaction for films C27 (1) and C24 (2)

Further experiments on the study of nonlinear processes in the film + substrate system under parametric excitation of the film are presented below.

A film with uniaxial anisotropy, deposited on a glass substrate, was placed inside an electromagnetic excitation system—a resonator. The easy magnetization axis (e.m.a.) of the film could be rotated with respect to the direction of the biasing field $H_0$ and the high-frequency pumping field $H_p$. The frequency of the pumping field was $f = 11$ MHz; the removable resonant circuit was tuned to $f/2$. The values of the fields $H_0$ and $H_p$ corresponded to the excitation in

Fig. 2. Oscillograms of parametric oscillations

Figure 2: Fig. 2. Oscillograms of parametric oscillations

the removable circuit of parametric oscillations and magnetization oscillations in the film. With orthogonal orientation (e.m.a. $\perp (H_p + H_0)$), the rigid regime of excitation of parametric oscillations predominates. It is precisely under this rigid excitation regime and at a pumping-power level above a certain critical value that magnetoelastic instability appears in the film–substrate system, wh –

which, with a further increase in the field, manifests itself as a low-frequency amplitude modulation of the parametric oscillations.

Figure 1 shows the regions of existence of magnetoelastic interaction under parametric excitation for typical films (C27, C24); with respect to the constant field, the regions of existence are narrow—no more than 0.5 Oe; with respect to the high-frequency field, 1-2 Oe; they are elongated, with a slope opposite to that of the regions of existence of parametric oscillations. The regions of existence of magnetoelastic interaction, obtained for films with different values of $H_k$ and $H_c$, differ in their location within the field intervals: for a film with smaller values of $H_k$ and $H_c$ they are shifted toward lower fields.

Fig. 2. Oscillograms of parametric oscillations (film C27). $a$–$U_p = 40$ V, $H_0 = 6.9$ Oe; $b$–$U_p = 46$ V, $H_0 = 7.1$ Oe; $v$–$U_p = 40$ V, $H_0 = 7$ Oe; $g$–$U_p = 46$ V, $H_0 = 7.2$ Oe.

The orientation of the film within the excitation–pickup system is very critical for the existence of magnetoelastic interaction in the system. Displacement of the easy axis of the film from the orthogonal position with respect to the applied magnetic fields by $\pm(1 \div 2)^\circ$ disrupts the low-frequency modulation, and it is not restored when the excitation regime is changed. This situation can be used to control the modulation process by creating small additional fields along the easy axis in those cases where it is necessary to study the transient processes of excitation and breakdown of oscillations. At field values $H_0$ and $H_p$ corresponding to the beginning of the region of existence of magnetoelastic

interaction, elastic modes with $f = 10^5$ Hz are excited in the system; with a further increase in the high-frequency (h.f.) power or in the field $H_0$, modes of lower frequencies are excited, and at the center of the region the frequency of the excited mode is $10^4$ Hz.

When the model of uniform rotation of the magnetization vector is used, the thin-film—substrate system can be represented as two independent oscillators: the film—magnetic oscillator and the substrate—acoustic oscillator. The frequencies of these oscillators are determined by the properties of their own systems: when magnetostrictional instability arises, the establishment of magnetization oscillations in the film is determined by the quality factor of the magnetic mode; the

Figure 3

Figure 3: Figure 3

establishment of oscillations of the acoustic system is determined by the quality factor of the elastic mode. Low-frequency amplitude modulation of the parametric oscillations arises as a result of the nonlinear interaction of the magnetic and acoustic systems; therefore, the modulation frequency for a given excited elastic mode must be determined mainly by the mechanical characteristics and linear dimensions of the substrate.

**Fig. 3.** Dependence of the amplitude of parametric oscillations on the magnitude of the pump field $H_p$ at a fixed biasing field $H_0$ during the existence of magnetoelastic interaction in film C27 for a biasing field $H_0 = 7.0$ Oe (1) and $H_0 = 7.3$ Oe (2).

The presence of several thresholds corresponding to different frequencies of elastic modes is apparently connected with features of the remagnetization of the films as a function of the field amplitude.

There is reason to suppose that, in some regimes of excitation of magnetoelastic interaction, the film is not in a single-domain state. The inhomogeneity of the structure of the films studied causes not only dispersion of the anisotropy (angular and amplitude), but also inhomogeneity of the magnetostriction coefficient (2), and consequently inhomogeneity of the magnetoelastic parameter over the film surface.

Then, during the existence of magnetoelastic interaction in the system, there may be moments when individual regions do not operate at magnetic-field values below the threshold, which leads to different degrees of interaction of the magnetic and elastic systems over the region of existence. In general, the establishment of one stable mode in the system proceeds by switching the oscillations of several modes. The type of substrate oscillation is established for which the given energy state of the system corresponds to a stable one. Measurement of the excitation thresholds in the high-frequency field of individual elastic modes in the system gives a difference of these thresholds of the order of 0.1 Oe. This latter circumstance can

associated with the presence in the film of amplitude dispersion of anisotropy over the surface.

Figure 2 shows oscillograms of the natural modulated parametric oscillations, taken with the same oscilloscope sweep duration and the same vertical gain. From Fig. 2a, b, c it is seen how, with increasing field $H_p$, the frequencies of the excited elastic modes change. Figure 2d presents an oscillogram of parametric oscillations modulated by two modes with different frequencies. The values of $H_p$ and $H_0$ in this case corresponded to one of the threshold values, and the level of high-frequency energy in the system was still insufficient for excitation of the lower-frequency elastic mode; therefore, small parasitic changes of the field $H_p$ led to periodic existence of this mode in the system and, on the oscilloscope screen, to superposition of the two modes.

The threshold characteristics (the dependence of the amplitude of parametric oscillations on the rf pump field), recorded in different parts of the region of existence of magnetoelastic interaction, have the same character of dependence on the field $H_p$ at fixed field $H_0$ (Fig. 3). Before modulation arises, the amplitude of the parametric oscillations increases with growth of the rf field; then a point is reached at which the slope of the amplitude increase grows, and at the same time a sharp decrease of the voltage on the tank-circuit parameter is observed. In the section $a$–$b$ there is a jump in the amplitude of the parametric oscillations with the appearance of low-frequency modulation. Subsequently the amplitude increases almost linearly with growth of the rf field; before the modulation breaks down, a horizontal section $b$–$c$ is seen on the characteristic: the resistance of the mechanical system increases and energy is absorbed by the acoustic system, but the oscillations break down; at the instant of breakdown of the oscillations a small jump in the amplitude of the parametric oscillations is observed, and its subsequent course is analogous to the amplitude characteristic under perpendicular excitation ([1]).

For each excited elastic mode the depth of low-frequency modulation changes linearly when $H_0$ is changed (the rf power level is fixed), or when $H_p$ is changed within a certain interval (the value of $H_0$ is fixed).

**Conclusions.** 1. It has been found that, under certain severe regimes of excitation of parametric oscillations, a magnetoelastic instability simultaneously arises in the substrate-film system.

2. The regions of existence of magnetoelastic interaction of the film with the substrate under parametric excitation of the film have been investigated. Several thresholds within each region have been found; these correspond to the occurrence of elastic modes of different frequencies.
3. The dependence of the degree of interaction of the magnetic and elastic systems on the magnitude of the bias field and of the high-frequency pump field has been investigated.

Institute of Physics
Siberian Branch of the Academy of Sciences of the USSR

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## CITED LITERATURE

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