Kinetic instability of spin waves in thin ferrite films

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For normally and tangentially magnetized iron-yttrium garnet films 16–30 μm thick, we studied experimentally the kinetic instability (KI) of spin waves parametrically excited by parallel pumping. The regions of constant magnetic fields where KI is allowed were thus determined, as were the KI formation thresholds in these regions. It was found that in comparison with solid single-crystal samples, the kinetic instability in films has a number of characteristics related to those of the spin-wave spectra of the films. In particular, there are two regions of constant magnetic fields—the low-field and high-field regions, within the confines of which KI sets in at a threshold. In the value of the effective magnetic field, the low-field region practically coincides with the KI region in the solid samples, while there is no analogue of the high-field region in such samples. The frequencies of the secondary spin waves excited as a result of KI are independent of the pumping frequency and located near the bottom of the spin-wave spectrum in both KI regions.

INTRODUCTION

The kinetic instability (KI) of spin waves, involving excitation of secondary spin waves (SSW) by parametrically excited spin waves, which was first predicted theoretically and detected experimentally in Ref. 1, has thus far been studied fairly closely in solid ferrite samples (see Refs. 2 and 3). For such samples, the KI formation thresholds and regions of constant magnetic fields in which first-order KI processes (one parametric wave forms two secondary waves) and second-order KI processes (two parametric waves form two secondary waves) are allowed have been determined. KI has also been repeatedly observed in ferrite films,[4-6] which differ from solid samples in the structure of the spin-wave spectrum in the range of low values of the wave vector k. Here the source (pumping) of the parametric waves and hence, also the source of secondary spin waves, as well as KI, consisted of magnetostatic waves propagating through the film, i.e., a primary internal, backward internal, or surface wave.

In the present work, a second-order kinetic instability in films was excited by the method of parallel pumping, in which the ferrite was placed in a constant magnetic field H and variable magnetic field h, which were parallel. Using this method, one can produce packets of parametric spin waves of arbitrary magnitude k (actually, $k \leqslant 10^6$ cm^{-1}), determined by the value of the external field H, whereas during pumping by a magnetostatic wave, the value of this field cannot be arbitrary, i.e., it should correspond to the resonance conditions for excitation of a particular magnetostatic wave. As a result, it was possible to determine the existence regions from the magnetic field and the KI excitation thresholds in normally and tangentially magnetized films of yttrium-iron garnet (YIG). It was found that by virtue of the characteristics of the spin-wave spectrum of the films, there are at least two different regions in which KI exists, not one, as in solid samples.

EXPERIMENT

Films 16–30 μm thick, grown on a gallium-gadolinium garnet substrate of (111) orientation, were studied. A microwave pumping field in the three-centimeter wavelength range was produced on a film by means of an open dielectric cavity glued to it, in either the $TM_{1\delta 1}$ (tangential external field **H**) or the $TE_{11\delta}$ (in the case of a normally magnetized film) oscillation mode. On the film, the variable magnetic pumping field **h** was always parallel to the constant magnetic field. The dielectric cavity was excited by the microwave field of a standard three-centimeter waveguide, in which a ferrite film with a dielectric cavity was placed. The waveguide with the film was connected through a bidirectional coupler, a precision attenuator, and a rectifier to a pump oscillator in pulsed operation. The pumping frequency was $f_p = \omega_p/(2\pi) = 9.5$ GHz, the pulse width was 40 μsec, and the repetition rate was 50 Hz.

At the threshold value of the microwave pump power $P = P_0$, directed along the waveguide toward the dielectric cavity, parametric excitation of spin waves of frequency $\omega_p/2$ started in the film. The instant of the threshold was determined from the spike on the pumping pulse reflected from the dielectric cavity. As the pumping power P (or supercriticality $\zeta = P/P_0 > 1$) increased, the amplitude of the parametric waves increased, and finally, at some power $P = P_c$, or at $\zeta = \zeta_c = P_c/P_0$ below the threshold, SSW of frequency $\omega = 2\pi f \neq \omega_p/2$ were also excited in the film in a threshold manner, i.e., a KI was formed. The secondary waves, and hence, the KI excitation threshold, were recorded with the aid of an ungrounded wire antenna 25 μm in diameter glued to the film. The secondary waves induced in the antenna an electromagnetic signal which was fed through a low-noise transistor microwave amplifier to a recording circuit consisting of a selective measuring microwave receiver and oscillograph. The sensitivity of the circuit in the 1.1–5.0 GHz frequency range was $\sim 10^{-14}$ W, and the accuracy of measurement of the frequency of the signal emitted from the film was ± 3 MHz.

Figures 1 and 2 show typical results of the study of KI in an YIG film 20 μm thick; Fig. 1 corresponds to a normally magnetized film, and Fig. 2, to a tangentially magnetized film. These figures depict the threshold supercriticality ζ_c at which a KI is formed and the frequencies of the electromagnetic radiation from the film at the threshold value of the

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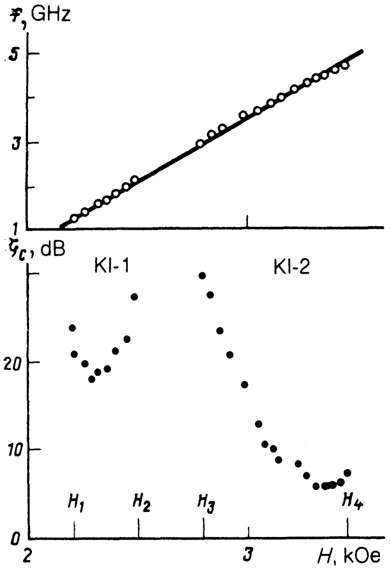

FIG. 1. Threshold supercriticality of KI ζ_c (●) and frequency f of the emission arising at the threshold (○) as a function of constant magnetic field H for a perpendicularly magnetized YIG film 20 μm thick. Straight line—frequency of the bottom of the SW spectrum; H_1 and H_2, H_3 and H_4—boundaries of experimental regions within the confines of which KI is observed.

supercriticality as a function of the value of the constant magnetic field H.

For the normally magnetized film (Fig. 1), the KI exists in two regions of values of the constant magnetic field (KI-1 and KI-2), bounded by fields H_1, H_2 and H_3, H_4. In

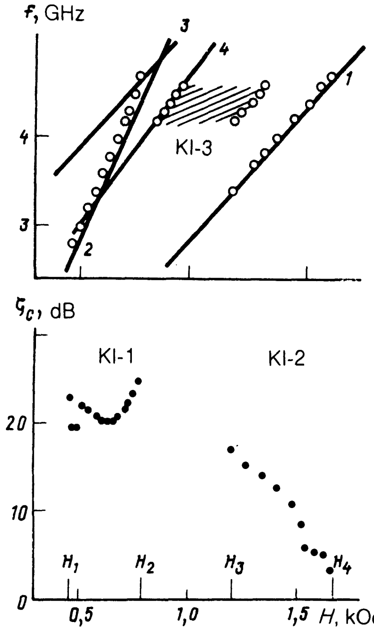

FIG. 2. Threshold supercriticality of KI ζ_c (●) and frequency f of the emission (○) arising at the threshold as functions of constant magnetic field H for a tangentially magnetized YIG film 20 μm thick. Continuous lines correspond to: 1—$f=\gamma H_{\rm eff}/(2\pi)$, 2—$f=2\gamma H_{\rm eff}/(2\pi)$, 3—$f=(\gamma H_{\rm eff}+\gamma 2\pi M_0)/(2\pi)$, 4—$f=\gamma[H_{\rm eff}(H_{\rm eff}+4\pi M_0)]^{1/2}/(2\pi)$; H 1 and H 2, H 3 and H 4—boundaries of the KI-1 and KI-2 regions; region shaded at the top—emission for $P=5$ W (KI-3 region).

regard to the characteristic fields H_c and H_i corresponding to the coincidence of the frequency of the parametric waves $\omega_p/2$ with the upper boundary of the spectrum of volume magnetostatic waves $\omega_\perp$ and with its bottom, i.e., the lower boundary of the spin-wave $\omega_{\rm min}$ spectrum, they are arranged as follows: H_1, $H_2<H_c-H_1\approx0.6$ kOe, $H_c-H_2\approx0.3$ kOe, $H_3\approx H_c=2.8$ kOe, $H_4\approx H_i=2.45$ kOe. Here

$$\omega_\perp=2\pi f_\perp=\gamma[H_{eff}(H_{eff}+4\pi M_0)]^{1/2},\quad \omega_{min}=2\pi f_{min}\approx\gamma H_{eff},$$

γ is the gyromagnetic ratio for the electron spin, $H_{\rm eff}=H-NM_0+H_a$, N is the demagnetizing factor of the film in the direction of magnetization, H_a is the effective field of crystallographic anisotropy, and M_0 is the saturation magnetization of the film.

The minimum value of the threshold supercriticality in the first region of the fields is ~ 18 dB, and in the second region, 6 dB; at the boundaries of the region, the KI excitation threshold increases.

The frequency of the signal (see Fig. 1) emitted from the film as a result of KI at $\zeta=\zeta_c$ increases linearly with H, and in both instability regions KI-1 and KI-2 it is close to the frequency of the bottom of the spin-wave spectrum, i.e., to the minimum frequency of the spin waves $\omega_{\rm min}$ present in the film at a given value of the constant magnetic field. This is indicated by the dependence, shown in Fig. 1, of the frequency of the bottom of the spin-wave spectrum $f_{\rm min}=(\gamma/2\pi)H_{\rm eff}$ on the magnetic field.

An increase in pumping power leads to an appreciable broadening of the band of the generated frequencies. Thus, if the magnetic field is fixed at $H=3300$ Oe and the supercriticality is raised from the threshold $\zeta_c=7$ dB, where the emission frequency was 4360 ± 3 MHz, to $\zeta=10$ dB, emission is observed even at frequencies ranging from 4350 to 4600 MHz. At the same time, the power of the electromagnetic signal induced in the antenna is of the order of 10^{-11} W.

For the tangentially magnetized film (Fig. 2), there also exist two regions KI-1 and KI-2 of values of the constant magnetic field where the kinetic instability exhibits a threshold. The minimum threshold supercriticalities in these regions were ~ 20 dB and ~ 3 dB, respectively. Almost analogously to the preceding case, $H_c-H_1\approx0.57$ kOe ($H_c=1.03$ kOe), $H_4\approx H_i$ ($H_i=1.66$ kOe), $H_c-H_2\approx0.24$ kOe, the boundary of H_3 in this case is fairly arbitrary: as the field H decreases from H_4 to H_3, the signal induced by the SSW in the antenna decreases continuously, and near H_3 it drops below the sensitivity of the equipment. Usually $H_3\approx H_c+(200$–$300)$ Oe.

The frequencies of the electromagnetic signals emitted from the film now differ appreciably from the preceding case of a normally magnetized film. This is clear from Fig. 2, which for clarity, in addition to the experimental results, shows how certain characteristic frequencies of the spin-wave spectrum depend on H: lower boundary of the spin-wave spectrum $f_{\rm min}$ (trace 1), $2f_{\rm min}$ (trace 2), upper boundary of magnetostatic oscillations and waves in the free tangentially magnetized film (trace 3)

$$f_{max}=(\gamma/2\pi)(H_{eff}+2\pi M_0),$$

and upper boundary of backward volume magnetostatic waves $f_\perp$ (4). According to Fig. 2, during the KI in the first region KI-1, the oscillation frequencies in the tangentially magnetized film are close to the doubled frequency $2f_{\min}$ of the bottom of the spin-wave spectrum. In the region KI-2, as in the case of the normally magnetized film, the emission frequencies are close to the frequency $f_{\min}$ of the bottom of the spectrum. Here the threshold value ζ_c decreases continuously as the value of the field H approaches H_4.

Finally, as is evident from Fig. 2, for the tangentially magnetized film, there exists one more emission region, KI-3. Here the emission arises in a nonthreshold manner at very large supercriticalities ($\zeta > 25$–30 dB); it resembles noise, and induces in the antenna a weak electromagnetic signal with power comparable to the sensitivity limit of the equipment. As is evident from Fig. 2, this region adjoins the upper boundary of the backward internal magnetostatic waves (line 4), where their wave vector is $k \to 0$.

As in Fig. 1 (except for the KI-3 region), the experimental data of Fig. 2 correspond to $\zeta = \zeta_c$. As the pumping power changes, just as in the case of the normally magnetized film, the emission spectrum expands. For example, for $H = 1560$ Oe at $P = P_0 = 5$ mW ($\zeta = 1$), spin waves are excited parametrically at frequency $f_p/2$; at $\zeta = \zeta_c = 6$ dB (i.e., at $P = Pc = 20$ mW) SSW with frequency $f = 4430$ MHz ($f_{\min} = 4367$ MHz) are excited, and when the margin above threshold is 12 dB ($P = 80$ mW), emission is observed in the frequency band from 4250 to >5000 MHz with a maximum near $f_{\min}$. Particular attention should be paid to the fact that the minimum emission frequency (4250 MHz) was appreciably below the minimum frequency of all possible frequencies of the spin waves at the given field (4367 MHz).

DISCUSSION OF RESULTS

We shall first analyze the KI in a normally magnetized film (Fig. 1). We note that for films as well as solid samples,[1] we have $H_c = H_1 \approx 550$–650 Oe, $H_c = H_2 \approx 250$–300 Oe. Therefore, KI-1 may be assumed to be an analogue of the KI in solid samples. This is possible when the parametric waves in the KI-1 region in the film do not, for all practical purposes, sense the boundaries of the film, i.e., parametric excitation of plane spin waves propagating perpendicularly to the constant magnetic field takes place in the film, as well as in the solid sample. Physically, this condition signifies that the path length of a parametric wave in a direction perpendicular to the surface of the film

$$l_\perp = (\partial \omega_k / \partial k_\perp)/(\gamma \Delta H_k), \tag{1}$$

is less than the film thickness d: $l_\perp < d$. In Eq. (1), ω_k, $k_\perp$ are, respectively, the frequency and the component normal to the surface of the film of the wave vector of the spin wave, and ΔH_k is its attenuation ($\Delta H_k \approx 0.3$ Oe). To find $l_\perp$, it is necessary first of all to determine precisely which waves are excited during the parametric instability. This problem can be solved by finding the minimum of the parallel-pumping threshold. When finding the threshold, it is necessary to allow for the fact that in the case of parametric excitation of spin waves the pumping is local, and the localization region L is equal to the size of the dielectric cavity. In our case, $L = 3.5$ mm. Then, according to Ref. 7, the minimum excitation threshold for the given pumping frequency f_p will be exhibited by waves at frequency $f_p/2$ with values of k and v such that the function

$$g(k,v) = \left[1 + \left(\frac{\pi v}{\gamma \Delta H_k L}\right)^2\right]^{1/2} \frac{1}{\sin^2\theta_k} \tag{2}$$

is minimal. Here v is the group velocity of the wave along the film plane, and θ_k is the polar angle of the spin wave.

An example of determination of waves excited during parallel pumping in a normally magnetized film is given in Fig. 3a. This figure shows the dispersion curves of primary internal magnetostatic waves for index values $n = 1$, 100, 190, 240 (the index n is equal to the number of half-waves of a wave traveling along the film which fit into the film thickness). The thick line was plotted for n and kd values corresponding to the minimum of the function (2) for different frequencies of the parametric waves—the waves excited as a result of a parametric instability. Dashes indicate the lower boundary of the existence region of forward volume magnetostatic waves. We note that in Fig. 3a the dispersion curves are represented in the usual manner in terms of frequency f vs wavenumber k with $H = \text{const}$, although in the experiment, we change the constant magnetic field at constant frequencies ω_p and $\omega_p/2$. Therefore, instead of the characteristic fields H_c and H_i, the characteristic frequencies $f_\perp$ and $f_{\min}$ corresponding to them arise in these new coordinates (see Fig. 3a).

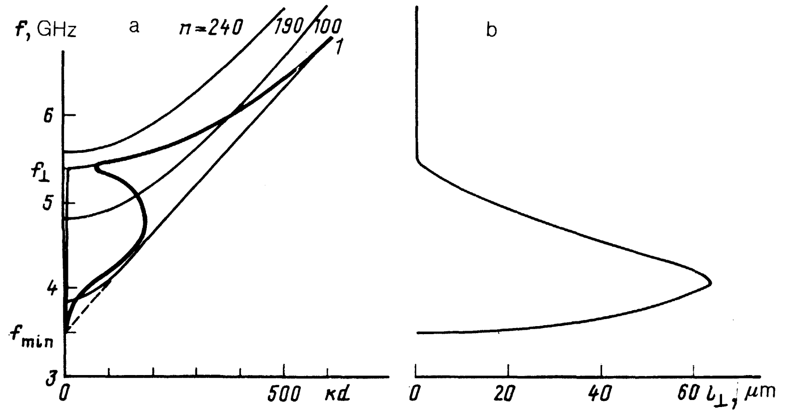

FIG. 3. a—Spectrum of primary internal magnetostatic waves for an YIG film 20 μm thick for $n = 1$, 100, 190, 240. Constant field $H = 3000$ Oe. Double-valued trace corresponds to waves having a minimum threshold of local parallel pumping. b—Path length of spin waves along the normal to the surface of the film for waves denoted by the double-valued trace in Fig. 3a.

It is apparent from Fig. 3a that for $f_p/2 > f_\perp$ (which would correspond to the condition $H < H_c$ for $f_p = \text{const}$), a parallel-pumping electromagnetic wave is unstable against decay to short spin waves with a large value of k ($k > 10^5$ cm^{-1}) and $n = 1$. When $f_{\min} < f < f_\perp$ ($H_c < H < H_i$) for the wave with $n = 1$, the group velocity v increases sharply, and therefore, the minimum value of the function (2) is reached at greater n, where the group velocity v is smaller. For example, according to Fig. 3a when $f_p/2 = 4.75$ GHz $< f_\perp$, the waves with $kd = 190$, $n = 70$ are the ones that become unstable first with respect to parallel pumping.

The path length $l_\perp$ of parametrically excited waves at different pumping frequencies is shown in Fig. 3b. It is evident that for $f > f_\perp$ ($H < H_c$), the parametric waves being excited have $l_\perp < 1$ μm, i.e., such waves do not perceive the boundaries of the film, and for the given region of frequencies (or constant magnetic fields $H < H_c$), the parametric spin waves actually are homogeneous plane waves, as in an unbounded medium. Thus, the KI-1 region (Fig. 1) is a field analogue of second-order KI in solid samples, and this region is bounded by the fields H_1 and H_2; according to Ref. 1, for $H > H_2$, the laws of conservation of energy and momentum cease to be obeyed for SSW; for $H < H_1$, three-magnon combination and decay processes, which compete with the KI, come into play.

We now turn to the KI-2 region. In Fig. 3, this region corresponds to the frequencies $f_{\min} < f < f_\perp$, at which waves with $l_\perp > d$, are excited, i.e., waves traveling in the plane of the film and standing along its thickness. This means that the law of conservation of momentum, written for solid samples for all three components of the wave vectors in the form $\mathbf{k}_1 + \mathbf{k}_1 = \mathbf{k}_2 + \mathbf{k}_3$, should now be obeyed only for the projections of the wave vectors on the film plane or for the wavenumbers of backward internal magnetostatic waves:

$$k_1 + k_1 = k_2 + k_3. \tag{3}$$

Along with Eq. (3), the law of conservation of energy should also be obeyed:

$$\omega_1 + \omega_1 = \omega_2 + \omega_3. \tag{4}$$

Here $\omega_1 = \omega_p/2$, k_1 are the frequency and wavenumber of the parametric wave, ω_2 and k_2, ω_3, and k_3 are the frequencies and wavenumbers of the SSW, with k_2 corresponding to the spin wave lying near the bottom of the spectrum, and k_3 usually falls in the exchange part.

As a result of the conservation laws (3) and (4), a KI in films can also be observed at fields greater than H_2. Indeed, it can be seen from Fig. 3a that for $f_{\min} < f < f_\perp$ (or for $H_c < H < H_i$), for any parametrically excited parallel pumping pair of spin waves with wavenumber $|k_1|$, one can find two SSW with k_2, k_3 such that the SW with $k = k_2$ lies near the bottom of the spectrum of primary internal magnetostatic waves, and the spin wave with $k = k_3$ falls into the exchange part of the spectrum, and the laws of conservation of energy and momentum (3) and (4) will be obeyed. Thus, for $f = 4.75$ GHz and $kd = 190$, there exists a pair of SSW: $f_2 = f_{\min} = 3.5$ GHz, $k_2 d \approx 0$, $n_2 \approx 1$ and $f_3 = f_p - f_{\min} = 6.0$ GHz, $k_3 d = 2k_1 d - k_2 d = 380$, $n_3 \approx 190$. In contrast to solid samples, the inequality of the transverse wavenumbers before and after the interaction (for the example discussed $2n_1 \neq n_2 + n_3$) now affects only the magnitude of the threshold P_c, but does not prohibit the occurrence of the process.

Let us turn to the case of a tangentially magnetized film. Now our first priority is to answer the question, why in the KI-1 region (see Fig. 2) is emission absent near the frequency $f_{\min}$, but observed at frequencies $2f_{\min}$? For this purpose, we examine the spectrum of backward volume magnetostatic waves for a tangentially magnetized film, shown in Fig. 4 for waves with indices $n = 1$, 10, 61, 100, 150 (with a constant magnetic field $H = 1300$ Oe; of all the possible parametric and secondary spin waves, we confine ourselves to discussing waves whose wave vector lies in the xz plane, as shown in the inset of Fig. 4). The double-valued curve corresponds to waves $v = 0$ for different n. Analysis with the aid of Eq. (1) shows that local parallel pumping at $P = P_0$ for different f_p will be unstable precisely with respect to the decay into these waves.

It is evident from Fig. 4 that near the bottom of the spin-wave spectrum, the waves in the tangentially magnetized film have fairly large k: $k \sim 10^4$–10^5 cm^{-1} (for the film thicknesses discussed). Such waves are difficult to record experimentally, especially near the upper boundary with respect to k, and this apparently accounts for the absence of emission at frequencies near $f_{\min}$ in the KI-1 region. However, the presence of SSW in this range of magnetic fields and frequencies is confirmed by emission from the film of a signal with a frequency close to $2f_{\min}$. This emission can result from a process in which two counterpropagating secondary waves combine to form one magnetostatic wave (or oscillation) with a small k. Observation of this wave is possible when the doubled SSW frequency falls into the spectrum of magnetostatic waves, i.e., lies below the frequency $f_{\max}$ (trace 3 in Fig. 2 for a free film of YIG). The slight excess over $f_{\max}$ of the frequency of the experimentally observed emission near the field H_2 is apparently due to widening of the band of surface magnetostatic waves in the film under the antenna. For $H < H_1$, the KI, as in solid samples and normally magne-

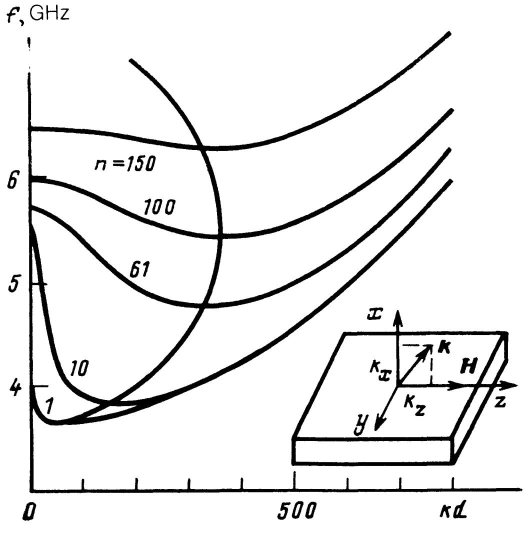

FIG. 4. Spectrum of backward internal magnetostatic waves for an YIG film 20 μm thick for $n = 1$, 10, 61, 100, 150. Magnetic field $H = 1300$ Oe. The double-valued trace corresponds to waves with group velocity $v = 0$ that have the minimum threshold of local parallel pumping. Inset—coordinate system and direction **H**, **k** for a tangentially magnetized film.

tized films, was limited by the processes, in competition with it, of three-magnon decay and combination of parametric waves, and therefore, for these fields, the emission at frequencies near $2f_{\min}$, due to SSW, was absent.

In the KI-2 field region, where parametric waves have a path length $l_\perp > d$, it suffices for the development of the KI process that the law of wavenumber conservation (3) be obeyed. It follows from Fig. 4 that for any value of the pumping frequency, there exists a pair of secondary waves for which the conditions (3) and (4) will be satisfied. Thus, for example, for $f_p/2 = 4.75$ GHz, according to Fig. 4, waves with $kd = 330$, $n = 61$ become unstable at the parametric instability threshold. Then for two such parametric waves, we can find the following pair of SSW satisfying the conditions (3) and (4): $f_2 = f_{\min} = 3.65$ GHz, $k_2 d = 50$, $n_2 \sim 1$ and $f_3 = f_p - f_{\min} = 5.85$ GHz, $k_3 d = 2k_1 d - k_2 d = 610$, $n_3 \approx 100$.

Emission with a frequency near the bottom of the spin-wave spectrum, observed in the KI-2 region, is apparently related to the decrease of the SSW wavenumber as the constant magnetic field increases (it was noted above that for tangentially magnetized films, the spin waves near the bottom of the spectrum have wavenumbers $k \sim 10^4$–10^5 cm^{-1}; if as a result of KI, secondary waves are excited near the lower boundary of the wavenumbers $k \sim 10^4$ cm^{-1}, they are fully capable of inducing a signal of power $\sim 10^{-14}$ W in an antenna 25 μm in diameter).

An increase of the constant magnetic field in the KI-2 region results in a decrease of the difference between the indices n of parametric waves and SSW. If for $H = 1300$ Oe we have $n_1 = 61$, $n_2 \approx 1$, $n_3 \approx 100$, then for $H = 1500$ Oe we have $n_1 = 30$, $n_2 \approx 1$, $n_3 \approx 49$. This is related to the lowering of the threshold value of supercriticality ζ_c in Fig. 2.

The widening, associated with the increase in supercriticality, of the spectral composition of the emission from the film is due to the growth of the region in ω-k space near the bottom of the spin-wave spectrum, a region for which the spin-wave losses are balanced by the energy of parametric waves.[1] In the presence of high supercriticalities, the difference of the spin-wave amplitude from thermodynamically equilibrium values can take place in the entire magnetostatic part of the spectrum. However, energy will be emitted only by those waves that have $k \to 0$ (since the wavenumber of the centimeter electromagnetic wave is $k_{\rm em} \approx 1$–10 cm^{-1}). This may be the cause, far above threshold, of the onset of weak emission in the KI-3 region, where, as was noted above, the wavenumbers of the spin waves are small. This is also supported by the nonthreshold character of the onset of emission in the KI-3 region. One must not, however, preclude the possibility of existence of a new type of KI in which secondary waves are also excited when $k \to 0$, but not in the lower, but upper, part of the spin-wave spectrum.

The onset of emission from a tangentially magnetized film at frequencies appreciably smaller than the minimum frequency of the spin waves may be due to excitation far above threshold of magnetoelastic waves whose frequencies may lie below the spin-wave spectrum.

CONCLUSION

The kinetic instability (KI) of spin waves which results from the action of parametric pumping of 9.5-GHz frequency was studied in films of iron-yttrium garnet 16–30 μm thick. The existence regions of KI were determined as the constant magnetic field was varied. In the first region, observed at low fields, the sources of secondary spin waves, as in solid samples, were short, parametrically excited plane spin waves whose path length along the normal to the surface of the film was small compared to its thickness. Consequently, the boundaries of the first region do not differ appreciably in the magnitude of the effective field from the case of KI in solid samples. These boundaries are determined by the laws of conservation of energy and by the wave vector of the waves interacting when KI occurs in an unbounded medium. In the second, high-field region, parametric spin waves are excited which are magnetostatic waves propagating in the plane of the film and whose spectrum differs appreciably from the spin-wave spectrum in an unbounded medium. For such waves, the laws of conservation in the presence of KI are considerably simpler to obey, since what is required is the conservation of wavenumbers, not vectors, as in the case of solid samples. Because of these circumstances, the analogue of the second KI region, which takes place in films, is absent from solid samples.

As a result of KI, in both regions of magnetic fields, SSW are excited which lie near the bottom of the spin-wave spectrum and whose frequency ω is independent of the pumping frequency ω_p and determined by the magnitude of the effective magnetic field $H_{\rm eff}$: $\omega = \gamma H_{\rm eff}$. By virtue of the characteristics of the spectral structure, for a normally magnetized film, the wave vector of SSW satisfies $k \to 0$, while for a tangentially magnetized film we have $k = 10^4$–10^5 cm^{-1}, the lower value being reached in the range of high values of the constant magnetic field, i.e., in the second KI region. Therefore, for a normally magnetized film, excitation of secondary waves gives rise to electromagnetic radiation at frequency $\gamma H_{\rm eff}$ in both the existence regions of KI. For a tangentially magnetized film, this radiation is observed only in the second existence region of KI at maximum values of the constant field, where the value of k is minimal; as the field decreases, the intensity of the emission at frequency $\gamma H_{\rm eff}$ decreases. However, for such magnetization, emission also takes place in the first existence region of KI, but at a frequency near $2\gamma H_{\rm eff}$—as a result of the merging two SSW traveling in opposite directions, the process of transformation of secondary waves into a longwave (with $k \to 0$) magnetostatic oscillation or a wave becomes possible, and this oscillation reradiates electromagnetic energy into the receiving antenna.

The excitation threshold of KI in the films as well as in the solid samples depended on the magnitude of the constant magnetic field and amounted to 3–20 dB above the parametric excitation threshold. Exactly at threshold, the width of the SSW emission spectrum was ~ 6 MHz, and further above threshold, this width increased to several hundred megahertz. Very far above threshold (25–30 dB) in tangentially magnetized films in the intermediate region of constant magnetic fields between the first and second existence regions of KI, additional emission was produced in a nonthreshold manner whose power was appreciably lower than in the two threshold regions. This emission corresponded to excitation of secondary waves lying near the upper boundary of the spectrum of exchange-free backward internal magnetostatic waves, where their vector satisfied $k \to 0$.

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