Amplification of traveling magnetostatic waves by a parametric pump

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The parametric excitation of surface magnetostatic waves has been observed experimentally for the first time. The particular nature of the surface magnetostatic waves and the parametric excitation of different groups of spin waves give this excitation some distinctive features. These features have been studied.

Although the parametric excitation of resonant oscillations of a thin ferrite film has been studied both experimentally and theoretically (see Ref. 1, for example), there has been only a single theoretical study[2] of the parametric excitation of traveling surface magnetostatic waves. The reason is that it has appeared more promising to make use of the amplification of surface magnetostatic waves by carriers drifting in an electric field in a semiconductor film (see Ref. 3, for example), since it is possible in principle to arrange in this case the amplification of exclusively one specific surface magnetostatic wave. During parametric excitation, two surface magnetostatic waves are excited simultaneously and propagate along different surfaces of a ferrite film (along the air-film and film-substrate boundaries) in opposite directions,[2] and there can be a parametric excitation of spin waves with a frequency equal to the frequency of the

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surface magnetostatic waves. For several physical reasons,[3] however, there has been no previous study of amplification in ferrite-semiconductor structures. The use of surface magnetostatic waves in delay lines with prespecified dispersion law, in a variety of filters, and in nonreciprocal devices requires an amplification of these waves. There is thus a need for a study (especially an experimental study) of the parametric amplification of traveling surface magnetostatic waves. This letter reports such experiments.

In the experiments we use a prototype magnetostatic-wave apparatus. The apparatus consists of two parallel, uncoupled microstrip lines on a common polycore base and an yttrium iron garnet (YIG) film on a gallium-gadolinium garnet (GGG) substrate. The substrate overlaps the microstrip lines. At the center of the YIG film on the side of the GGG substrate there is an open dielectric pump cavity resonator. The saturation magnetization of the YIG film is $4\pi M_0 = 1750$ G, the width of the resonance line is $2\Delta H \approx 0.5$ Oe, and the thickness of the film is 9.6 μm. The particular magnetostatic wave mode which is excited is determined from the dependence of the delay time on the static magnetic field. The signal energy loss during propagation from the entrance microstrip to the exit line is 22 dB. We use "parallel pumping," which requires less power than "transverse pumping" [2]; i.e., the magnetic field of the pump resonator on the YIG film is parallel to the static magnetic field. The frequency of the surface magnetostatic waves is $\sim$4.7 GHz, and the pump frequency is $\sim$9.4 GHz. The static magnetic field is $H \sim 940$ Oe. The pump oscillator is operated in pulses to avoid heating the YIG film. The length of the signal and pump pulses is 20 μs, and the repetition frequency is 50 Hz.

We achieved the first amplification of a traveling surface magnetostatic wave: The signal at the exit microstrip line was 16 dB higher than that at the entrance line at a pump power $P_p = 2.2$ W. The passband was 8 MHz. The amplified pulse was delayed 3 μs with respect to the pump pulse. Figure 1 shows the gain K vs the pump power P_p ($P_s = -80$ dB/W).

In the amplification of the surface magnetostatic waves we see effects that have much in common with the amplification of microwave oscillations through the use of magnetostatic precession modes in single-crystal ferrite samples.[1,4,5] The most impor-

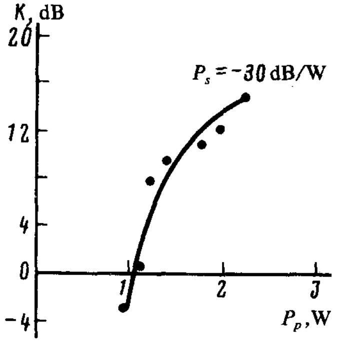

FIG. 1. The gain K vs the pump power P_p.

tant of these effects is that, as the pump power is raised, the amplification of the surface magnetostatic waves is followed immediately by the parametric excitation of various groups of spin waves and of collective oscillations of these waves.[4,5] As a result, the signal is amplified only for a few microseconds after the application of the pump pulse, and the amplified pulse is bell-shaped. The pulse length depends in a complicated way on the pump power, the magnetizing field, and the ratio of the signal and pump frequencies. The pulse length at half-maximum lies in the range 0.5–2 μs. The delay time, 3 μs at pump power levels $P_p \leqslant 1$ W, falls off smoothly above the threshold for the parametric excitation of spin waves, down to 1 μs at $P_p = 2.4$ W. The electronic (physical) gain, which reaches 40 dB, sets in at $P_p \sim 0.1$ W; taking into account the electrodynamic characteristics of this prototype apparatus, we conclude that this gain agrees with the theoretical prediction of Ref. 2. The 22-dB propagation loss of the surface magnetostatic waves is completely offset at $P_p \sim 1$ W.

Amplification of the surface magnetostatic waves is observed at a static magnetic field H_0 corresponding to the maximum transmission of the signal from the entrance microstrip line to the exit line. Exactly at $H = H_0$, however, at pump power levels $P_p \gtrsim 1$ W, an oscillation gives rise to a pulse at the exit with a shape reproducing that of the amplified pulse. The power level of the signal radiated from each of the microstrip lines is on the order of a few microwatts. To prevent this oscillation and to observe stable amplification, we adjust the static magnetic field to a point ~ 0.3 Oe below H_0.

Yet another oscillation region was observed at $H \sim H_0 + 4$ Oe. In this case the power level of the signal radiated from each of the microstrip lines was on the order of a hundred microwatts, and the duration of the radiation was the same as the length of the pump pulse. In this case, the radiation was apparently due to the parametric excitation of spin waves, followed by the reradiation of these waves through long-wave magnetostatic oscillations.[5] Indirect evidence for this assertion comes from the fact that the signal has absolutely no effect on the amplitude of the radiation in this oscillation region. The minimum threshold for the parametric excitation of spin waves was determined from the splitting of the pump pulse[4] to be 50 mW. In a field $H_0 + 4$ Oe, significant radiation appeared at $P_p \sim 1$ W.

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