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Optical Microwave Devices Based on Waveguide-Light Interaction with Magnetostatic Waves in Ferrite Films

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The experimental results of investigations of waveguide-light (WL) scattering on magnetostatic spin waves (MSW) in yttrium-iron garnet (YIG) films for collinear as well as orthogonal geometries of interaction are presented. Some possibilities of implementation of WL-MSW interaction for microwave signal processing and optical communication are considered. Experimentally obtained parameters of light modulator, consequent and parallel optical microwave spectrum analyzers are given.

1. INTRODUCTION

The phenomenon of WL interaction with MSW in ferrite films, caused by dynamic Faraday effect, is promising for utilization in the optical microwave planar devices in the 1-20 GHz frequency band [1-4]. The specific sensitivity of MSW parameters to magnetic field variations extends the functional opportunities of WL-MSW devices in comparison with traditional acoustooptical ones. In present paper we consider the main characteristics of WL-MSW interaction in YIG film for different types of diffraction in homogeneous and inhomogeneous steady current and time varying magnetic fields. The principles, schemes and some experimentally obtained parameters of WL-MSW devices will be discussed.

2. WL-MSW INTERACTION IN YIG FILMS.

Experimental set-up for investigation of WL-MSW interaction is shown in Fig.1. The YIG film ($Y_3Fe_5O_{12}$) prepared by LPE technique on GGG substrate of [111] orientation was used in experiments. Parameters of the film were the following: thickness d = 3.8 mkm, saturation magnetization $-4\pi M$=1750 Gs, ferromagnetic resonance linewidth

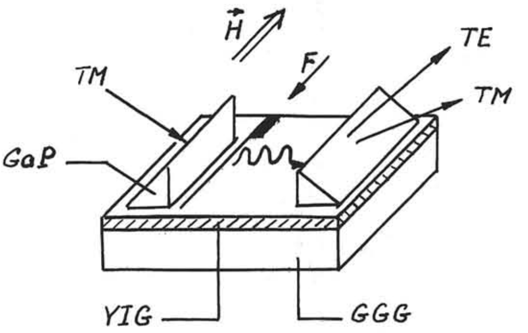

Fig.1 Set-up of collinear WL-MSW scattering experiment.

ΔH≈0.5 Oe, refractive index n=2.22, optical propagation losses -1.2 cm^{-1} and Faraday rotation F=280 deg/cm.

Microstrip transducer of 50 mkm width placed on the film surface was used to excite MSW in the 3-12 GHz frequency band. Two GaP prisms with cylindrical contacting surfaces placed at the distance L=12 mm one from another were used to couple TM modes into and couple TM and TE modes out of the film. The He-Ne laser (λ=1.15 mkm) or semiconductor GaAs laser (λ=1.3 mkm) served as light sources. To realize collinear or orthogonal geometry of WL-MSW interaction microstrip transducer was placed perpendicular or parallel to the light propagation direction. External tangential DC magnetizing field of strength H was applied parallel to the microstrip for excitation of surface MSW (MSSW) and perpendicular to that one for excitation of backward volume MSW (MSBVW).

Optical modes conversion caused by dynamic Faraday effect was observed at frequency F when phase-matching conditions were satisfied

$$\vec{\beta}_{TE_n} = \vec{\beta}_{TM_n} + \vec{K}\ , \quad f_{TE_n} = f_{TM_n} + F$$

where β_{TM}, β_{TE}, K-are the wave numbers of TM, TE waveguide modes, respectively, and MSW wave number, n - number of the optical mode.

The dependencies of conversion efficiency $\eta = (I_{TE\,out} / I_{TM\,in}) \cdot 100\%$ on microwave frequency F and mode number n for collinear WL scattering on MSSW[5a] are shown in Fig.2.

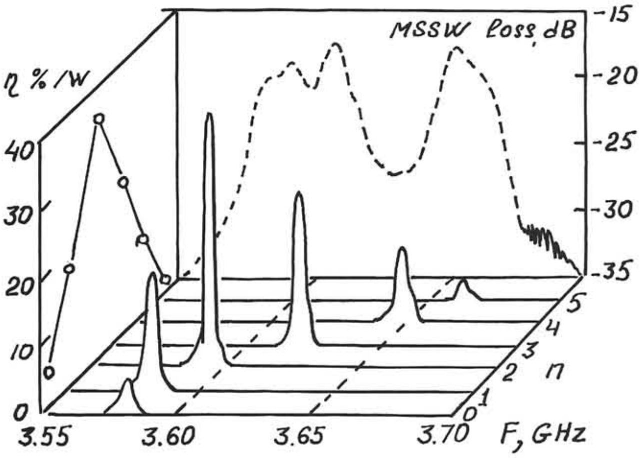

Fig.2 Efficiency of collinear TM-TE mode convertion.

By means of MSSW beam focusing in transvers-longitudinal inhomogeneous magnetic field, created by small magnets placed near the film we have obtained the conversion bandwidth δf=4 MHz at -3 dB level and maximal conversion efficiency η=0,28% for input microwave power P=8 mW. Linear extrapolation gives η=35% for P=1 W, that is compatible with the results for Bi-substituted YIG films[2]. The central frequency was linearly tuned in the frequency band 3.0-12.0 GHz by changing the applied field strength over 3 kOe.

For noncollinear light scattering on MSBVW in a longitudinally inhomogeneous magnetic field with a gradient dH/dy=200 Oe/cm the Bragg diffraction regime was obtained[5b]. Fig.3 shows the angle distribution of zero-order (damped in 30 times) and diffracted light intensities for two MSBVW frequencies. Owing to wavenumber transformation in

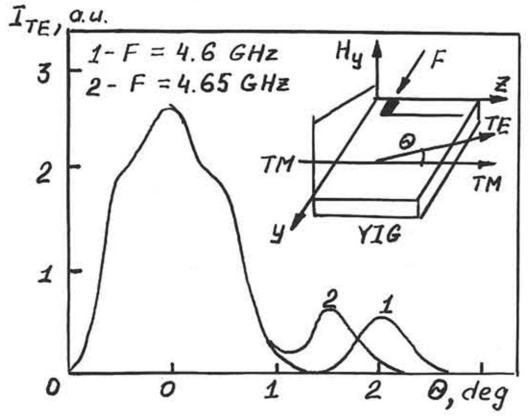

Fig.3 Bragg-diffraction efficiency vs diffraction angle.

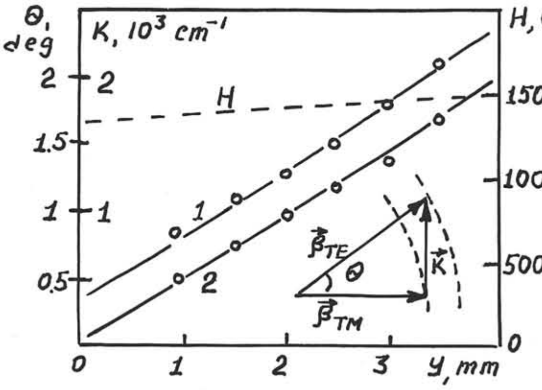

Fig.4 Magnetic field, Bragg-angle and MSBVW wave number vs longitudinal coordinate.

nonuniform field the MSBVW wavenumber up to $k=2*10^3\ cm^{-1}$ and the light diffraction angles up to Θ=2 deg have been obtained (Fig.4). Diffraction efficiency was equal η=0,5% for P=8 mW.

Fig.5 demonstrates the geometry of collinear WL-MSW interaction in YIG film placed in a two-dimentional inhomogeneous magnetizing field[5c]. In this case the weak transverse linear field variation H(0,z)=H(0,0)+(dH/dz)*z results in the space separation of the film region where waveguide modes conversion is caused by MSW of different frequencies F_1 and F_2 while the longitudinal quadratic field gradient provide the high conversion efficiency.

In experiment a due field inhomogeneity with gradient dH/dz=100 Oe/cm was formed by means of a small permanent magnet. In this way the frequency resolution approximately $\delta f \approx 50$ MHz over total bandwidth of interaction $\Delta f = 200$ MHz and diffraction efficiency $\eta = 0.1\%$ have been obtained.

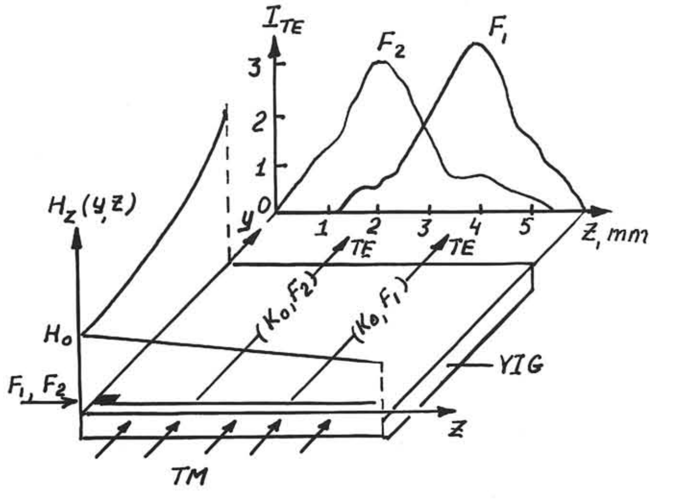

Fig.5 Space separation of WL-MSSW interaction regions in inhomogeneous field.

3. APPLICATIONS IN MAGNETOOPTICAL MICROWAVE DEVICES

The results obtained show the possibilities of application of WL-MSW interaction in ferrite films for spectrum analysis of microwave signals. Fig.6 demonstrates the frequency resolution in operational band for magnetic field tuned analyzer based on collinear WL-MSSW interaction (see Fig.2). Experimental device operated in the frequency range 4-12 GHz, had frequency resolution $\delta f = 4$ MHz, observation rate was equal~10 GHz/s.

Parallel spectrum analysis of microwave signals may be realized in traditional Bragg diffraction way using noncollinear WL-MSBVW scattering (see Fig.3) or on the basis of collinear WL-MSSW interaction in inhomogeneous field (see Fig.5).

Bragg WL-MSW diffraction may be used for design of planar microwave magnetooptical deflectors controlled by signal frequency as well as by external magnetic field. The estimated steepness of these deflectors is about 30 deg/kOe. Such WL-MSW device are of great interest for application as combined electrically controlled modulator - deflector in complex radio systems.

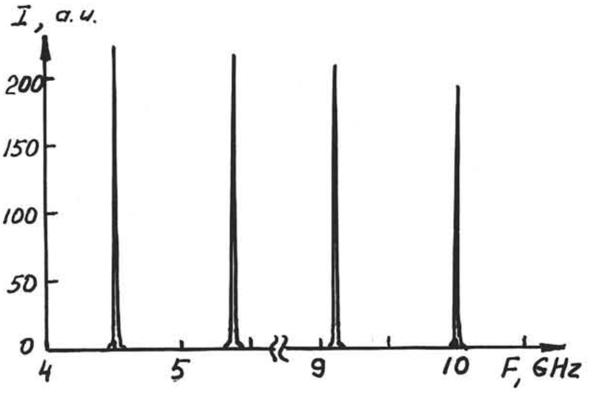

Fig.6 Frequency response of sequential microwave optical analyzer.

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