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Waveguide Light-Magnetostatic Waves Interaction in a Ferrite Film in Inhomogeneous Magnetic Fields

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Light scattering on magnetostatic waves (MSW) in ferrite films found by Fisher at all [1] and Tsai at all [2] may be applied sucsessfully in microwave optical devices, such as light modulators, deflectors and spectrum analyzers in the 1-20 GHz frequency band. The most attention in experimental investigation have been paid to light- MSW interaction in homogeneously magnetized films.

This paper represents new possibilities of MSW-waveguide optical modes interactions control by means of inhomogeneous magnetic field. Improving of interaction characteristics and some new functional opportunities of magnetooptic devices caused by inhomogeneous magnetization are demonstrated.

We found the increasing of collinear light scattering efficiency and narrowing of bandwidth in special type of inhomogeneous magnetic field. The experimental geometry is shown in Fig.1 The YIG film used in experiments has been prepared by LPE technique on GGG substrate. It's parameters are the following: thickness d = 3.8 mkm, saturation magnetization $4\pi M$= 1750 Gs, FMR linewidth ΔH = 0.5 Oe, refractive index n =2.22, optical propagation losses $\varkappa$ = 1.2 cm^{-1} and Faraday rotation F =280 deg/cm at λ =1.15 mkm. Microstrip transducer of 50 mkm width was used to excite magnetostatic surface waves (MSSW) in f =3...5 GHz band. Two GaP prisms with cylindrical contacting surfaces placed at the distance L=12 mm one from another were used to couple TM optical modes into and couple TE modes out of the film. External tangential magnetic field $\vec{H}$ was orientated parallelly to the transducer and orthogonally to the light direction. Modes conversion caused by dynamic Faraday effect was observed at frequency f_0 when phase-matching condition was satisfied

$$\vec{\beta}_{TM_n} + \vec{k} = \vec{\beta}_{TE_n}, \quad \text{where } \beta_{TM_n}, \beta_{TE_n}, k_0$$

- are wavenumbers of TM and TE waveguide modes, respectively, and MSSW wavenumber, n - number of optical waveguide mode.

The results obtained for six optical modes are shown in Fig.2 (R is the MSW delay line transmission loss). In homogeneous magnetic field (dotted line)for input microwave power P =15 mW the conversion bandwidth was equal Δf = 30 MHz and conversion efficiency

$$\eta = (I_{TE\,out} / I_{TM\,in})*100\ \%$$

did not exceeded 0.09 %.

In transverse-longitudinal inhomogeneous field (see Fig.1) created by small permanent magnets placed near the film surface the increase of efficiency up to η = 0.36 % and narrowing of bandwidth up to Δf = 8 MHz have been obtained at the same P for the third waveguide mode. Linear extrapolation gives modes conversion efficiency η = 28 % for P =1 W, that is much larger then result obtained by Fisher at all (1). The central frequency was linearly tuned in 3.8...4.6GHz band by changing the applied field over 300 Oe.

The proposal reason of efficiency increase is the MSW focusing in optical aperture with conservation of the wave vector value along the light beam (see Fig.1, solid lines - are calculated traectories of MSW rays).

MSW propagation in inhomogeneous magnetic field may be accompanied by controlled transformation of the wave vector. Noncollinear light scattering on magnetostatic backward volume waves(MSBVW) have been investigated under such conditions. We observed the transformation of Bragg diffraction regime to Raman-Nath one in accordance with the increase of the wave vector value.

External magnetic field was orthogonal to the light beam and was inhomogeneous along MSBVW propagation direction,field gradient was dH/dy = 200 Oe/cm. Wide optical contact of prism allowed to shift the light beam of 1 mm aperture over the film plane (see insertion in Fig.3). For small distances from the transducer y < 2 mm and high MSBVW frequences Raman-Nath difraction regime was observed.For distances y>2 mm and lower MSBVW frequencies only one diffraction maximum deflected at the angle θ have been observed [3]. Fig.3 shows angle distributions of zero order (damped in 30 times) and diffracted light intensities for two MSBVW frequences(f_1 = 4600 MHz and f_2 = 4650 MHz) and y = 3.5 mm. Diffraction efficiency was linearly increased with increasing of P and was equal η=0.5 % for P = 8 mW. In Fig.4 the measured dependences of angle θ on distance y (circles), measured dependence H(y) (dotted curve) and calculated dependences (solid lines) are shown. So, for the large distances from transducer the diffraction angle θ was equal to 2 deg and MSBVW wavenumbers were estimated to be k = 2 10 cm. Diffraction parameter Q = (k^2 * L) /(2 *π*β) was equal to ~4 that confirmed the realization of Bragg regime. The results obtained show the possibilities of application of MSW induced waveguide light diffraction in microwave light deflectors and spectrum analyzers.

Optical mode conversion induced by codirectional MSSW takes place when MSSW wavenumber is equal to k_o. At the same time the value of MSSW wavenumber is conditioned by the wave frequency and the local magnetic field H. Hence, it is possible, by means of a transversely inhomogeneous magnetic field, to obtain the space separation of MSSW-light interaction regions where conversion is caused by MSSW with different frequencies (Fig.5).Our calculations showed that such separation requiers both transverse and longitudinal field gradients to maintaine high conversion efficiency. For example, weak transversal linear field variation

$$H(0,z) = H(0,0) + (dH/dz)*z$$

requiers quadratical field change along MSSW propagation direction

$$H(y,z)=H(0,0)+ [H(0,z)+(2*\pi*M)]/[16*\pi^2*M^2*k_0*d]*(dH/dz)^2*y^2$$

A due field inhomogenity in ferrite film was formed in experiment owing to small permanent magnets. Light beam of 6 mm width was passed through cylindrical lens. Fig.5 shows measured transverse distributions of output TE mode intencity for MSSW frequencies f_1 =3.4 GHz and f_2 =3.45 GHz in transversely inhomogeneous magnetic field with gradient dH/dz = 100 Oe/cm. In this way the frequency resolution approximately δf=50 MHz over bandwidth of interaction Δf = 200 MHz has been obtained.

Thus, our investigations have demonstrated the capabilities of inhomogeneous magnetic field utilization in magnetooptic devices based on waveguide-light interaction with MSW in ferrite films. Field inhomogenity results in the increase of mode conversion efficiency and narrowing of conversion bandwidth for collinear interaction and the increase of diffraction angles for orthogonal interaction. Transverse field inhomogenity leads to the space separation of MSW-light interaction regions that may be used for parallel analysis of microwave signals spectra.

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3. Galkin O.L., Klimov A.A.,Preobrazhensky V.L., Fetisov Y.K. 1989, Sov. J.Techn.Phys. Lett, 15, 79-82.

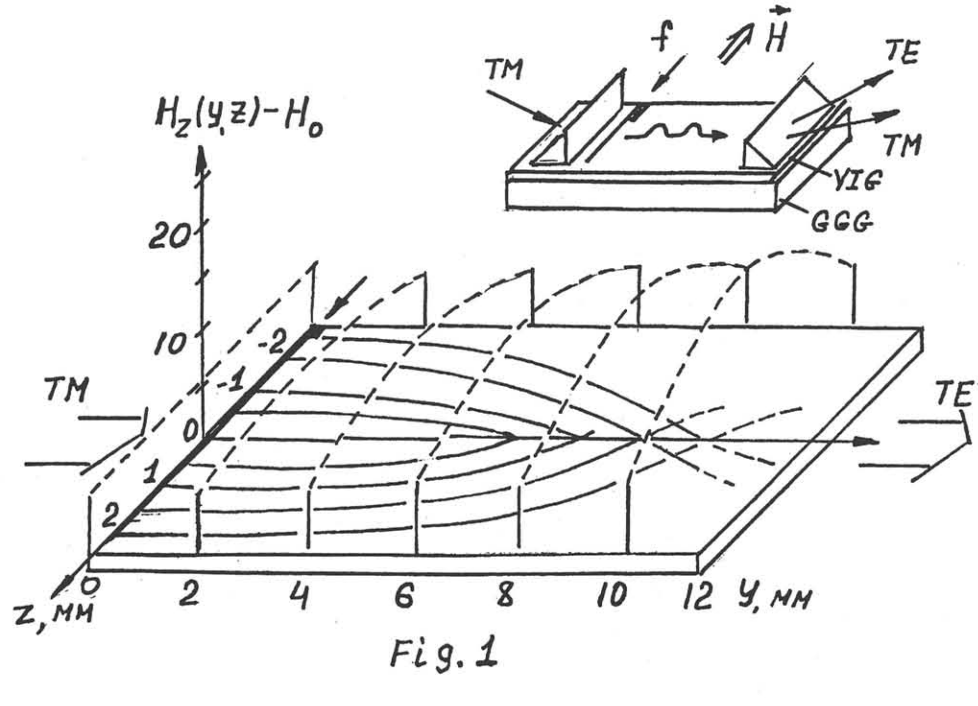

Fig.1

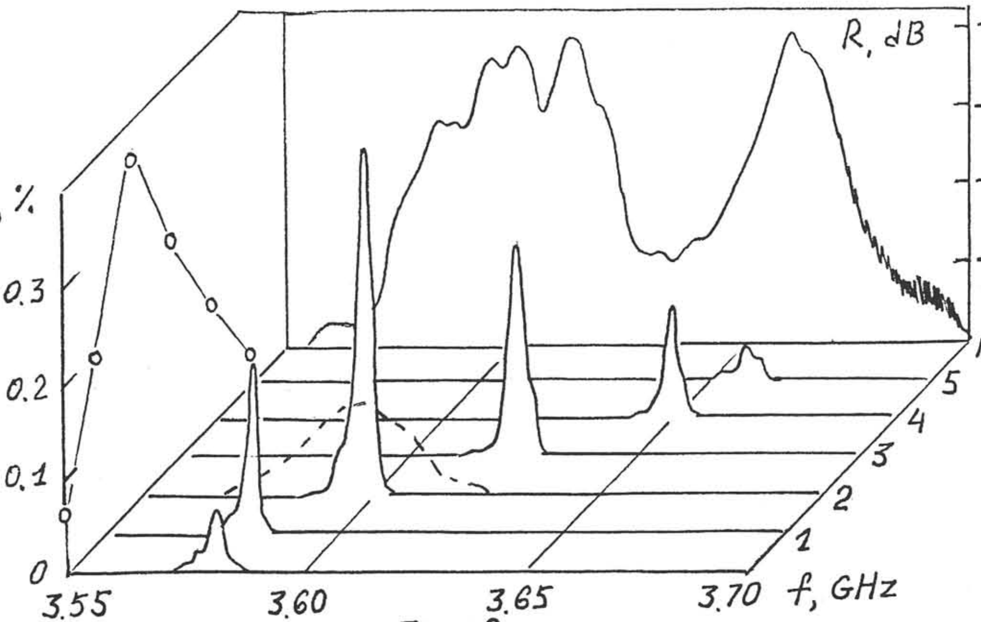

Fig. 2

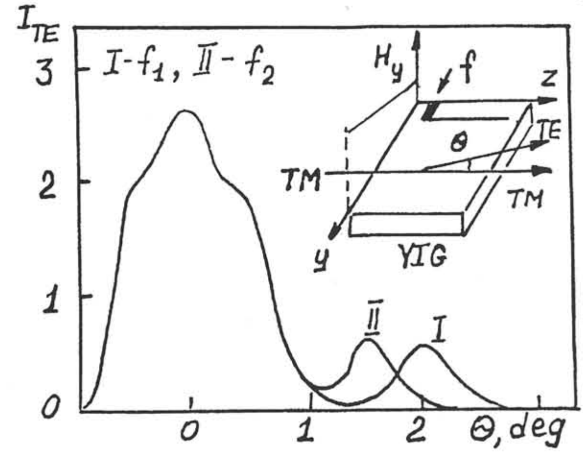

Fig. 3

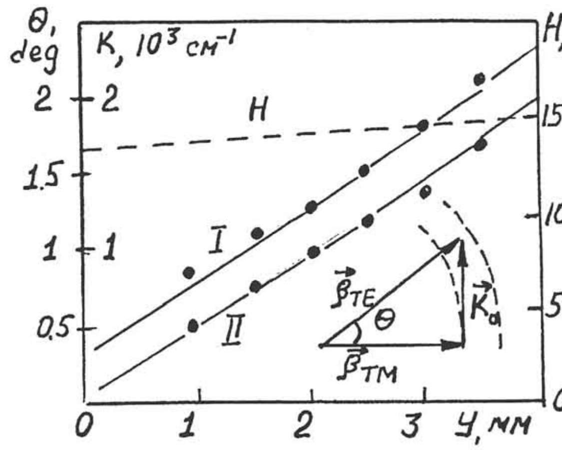

Fig. 4

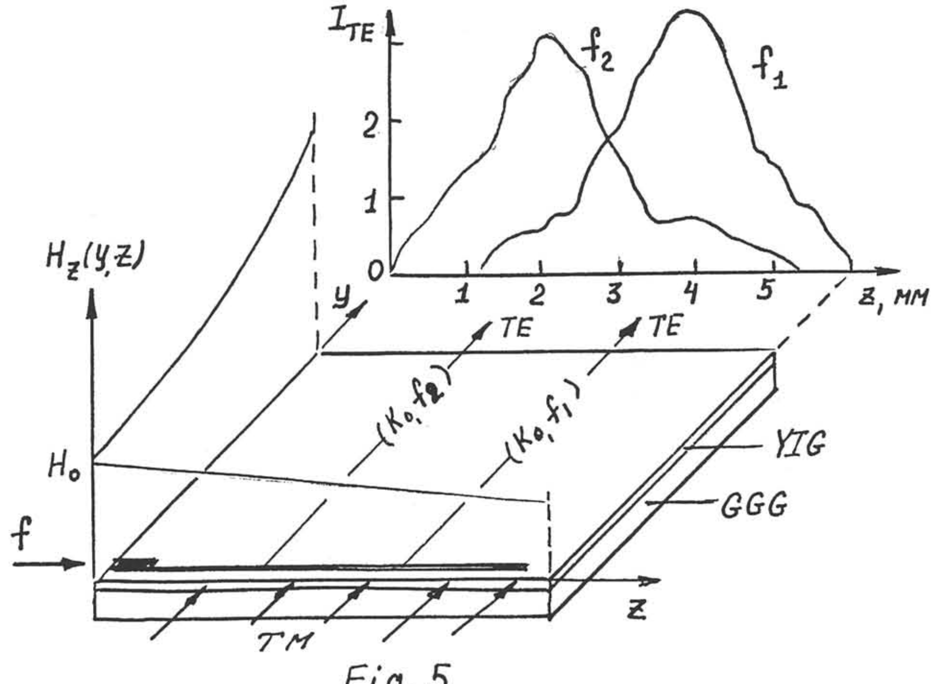

Fig. 5