MAGNETOSTATIC WAVES-BASED INTEGRATED OPTIC DEVICE MODULES AND APPLICATIONS TO COMMUNICATIONS AND SIGNAL PROCESSSINGS

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ABSTRACT

In this paper an up-to-date progress report on wideband magnetooptic interactions between guided-optical waves and magnetostatic waves, the resulting device modules, and applications to communications and signal processing is given. First, the technique for realization of GHz bandwidth magnetooptic Bragg cells with electronically tunable center frequency and their applications to wideband light beam scanning and switching, and RF spectral analysis are described. The design, fabrication, and performance characteristics of ion-milled waveguide lenses and the resulting magnetostatic waves-based integrated optic device modules are then presented.

SUMMARY

Magnetooptic (MO) interactions between guided-optical waves and magnetostatic waves (MSW) [1] in Yttrium Iron Garnet-Gadolinium Gallium Garnet (YIG-GGG) waveguides [2] has become a subject of increasing interest in recent years. Similar to the guided-wave acoustooptic (AO) interaction in which the surface acoustic wave (SAW) induces a moving optical grating [3], the guided-wave MO interaction results from the moving optical grating induced by the MSW [4]. Specifically, in a noncollinear coplanar geometry, as shown in Fig.1, a portion of an incident guided-light wave is Bragg diffracted and mode-converted (TE- to TM-mode and vice versa). As in the AO Bragg diffraction in which the resulting modulator is called the AO Bragg cell, the resulting MO modulator may be called the MO Bragg cell.

We have recently obtained a very large bandwidth in such interaction geometry with magnetostatic forward volume waves (MSFVW) using a single microstrip line transducer together with a fixed homogeneous DC magnetic field [5]. For example, a -3dB bandwidth of 1.03GHz with tunable center carrier frequency was obtained at the optical wavelength of 1.317 μm. In a continuing effort we have used the wideband MO Bragg cell to perform, for the first time, wideband light beam deflection and RF spectral analysis, and have obtained large numbers of deflected light spots and frequency channels [6]. In addition, we have most recently succeeded in the first fabrication of waveguide lenses in the YIG-GGG substrate by using ion-milling technique [7]. The excellent performance characteristics that have been measured with such waveguide lenses ensure immediate construction of MSW-based integrated optic device modules such as high-speed multiport optical switches and wideband RF spectrum analyzers.

In this paper an up-to-date progress report on realization of MSW-based integrated optic device modules and their applications to communications and signal processings at microwave carrier frequencies is given. First, the technique that facilitates realization of GHz bandwidth MO Bragg cells with electronically tunable center frequency (from 2.0 to over 11.0 GHz) is briefly reviewed. The detailed results and related analyses for the experiments on wideband light beam scanning and switching, and RF spectral analysis are then described. Finally, the design, fabrication, and performance characteristics of the ion-milled waveguide lenses and the resulting integrated MO device modules are presented.

The geometry and the dimensions of the MO Bragg cell as well as the experimental configuration are shown in Fig.1. An incident light wave is edge-coupled into the waveguide to excite either a TM_0- or a TE_0-mode guided-light propagating along the X- axis. A fixed homogeneous DC magnetic field $\vec{H}_0$ is applied along the Z-axis to excite a Y-propagating MSFVW. We have previously shown that efficient excitation of the MSFVW with a GHz bandwidth may be readily facilitated by means of a single microstrip line transducer of proper width and a homogeneous DC magnetic field [5]. The rf magnetization of the MSFVW produces a moving optical grating (through the dynamic Faraday and Cotton-Mouton effects) which in turn results in coupling between the incident light in the TM_0-mode and the diffracted light in the TE_0-mode, and vice-versa [5]. A detailed analysis has been carried out to determine the appropriate conditions for the three wave vectors and the three frequencies involved that must be satisfied in order to accomplish efficient and wideband interaction. Fig.2 shows a typical frequency response that was measured with the resulting MO Bragg cells at a fixed homogeneous DC magnetic field of 3500 Oe and an optical wavelength of 1.317 μm.

Most recently, the wideband MO Bragg cells referred to above have been utilized to perform wideband light beam scanning and switching as well as RF spectral analysis. By means of appropriate beam-shaping optics at both the input and the output ends of the device, the diffracted light was spatially separated from the incident (undiffracted) light. The diffracted light was imaged onto an IR camera. Two types of beam deflection experiments were carried out: one with the frequency of the MSFVW tuned continuously from the center frequency while keeping the DC magnetic field fixed, and another with the DC magnetic field tuned continuously while keeping the frequency of the MSFVW fixed. Figs.3(A) and 3(B) show, respectively, the photographs of the deflected light spots obtained in the first experiment at the center frequency of 2.5GHz, and in the second experiment with the frequency fixed at 2.2GHz. The photographs were taken from a video display through an IR camera. It is important to note that while the first experiment is analogous to the conventional AO light beam deflection, the second experiment does not have any counterpart in acoustooptics.

As in the case of guided-wave AO beam deflection, one of the potential applications of such wideband MO beam deflection concerns real-time spectral analysis of wideband RF signals [3]. This application was clearly demonstrated by simultaneously applying two RF signals of varying frequency separation (centered at 3.2 GHz) and power to the transducer. Again, this experiment represents the first successful demonstration of RF spectral analysis using guided-wave MO interaction. Similar results were obtained with the experiment performed at the center frequency of 6.0 GHz.

It should be noted that a number of studies on bulk-wave MO interactions involving an unguided light wave and spin and/or magnetoelastic waves were reported in the late 60's and early 70's. To the best of our knowledge, however, neither work on light beam deflection nor on RF spectral analysis using such bulk-wave MO interactions has been reported.

In comparison to its AO counterparts, the unique advantages associated with the wideband MO Bragg cells or deflectors are: 1. A much larger range of tunable carrier frequency (2 to 20 GHz, for example) may be readily obtained by varying a DC magnetic field. Such high and tunable carrier frequency with the MO devices enable direct processing at the carrier frequency of wideband RF signals rather than indirect processing via frequency down-conversion as is required with the AO devices. 2. A large MO bandwidth may be realized by means of a simpler transducer geometry, and 3. Much higher and electronically tunable modulation/switching and scanning speeds are achievable as the velocity of propagation for the MSW is higher than that of the SAW by one- to three-order of magnitude, depending upon the DC magnetic field and the carrier frequency.

Fig.4 shows one of the integrated MO device modules that are being constructed. This module consists of a wideband MO Bragg cell as described above and a collimation -- Fourier transformation waveguide lens pair in a YIG-GGG waveguide substrate 0.2 x 1.5 x 2.0 cm^3 in size. The waveguide lens pair was formed by using the ion-milling technique [7] that had been developed by us most recently. This new lens fabrication technique has proved to be very simple and versatile, and applicable to practically all substrate materials. For example, this technique has recently facilitated the first successful fabrication of waveguide lenses in GaAs [8]. Clearly, like it's AO counterpart [9] this integrated MO device module can perform various functions including modulation, deflection, multiport switching of light beams and spectral analysis, correlation and convolution of wideband RF signals. Measured performance characteristics of some of these applications will also be presented.

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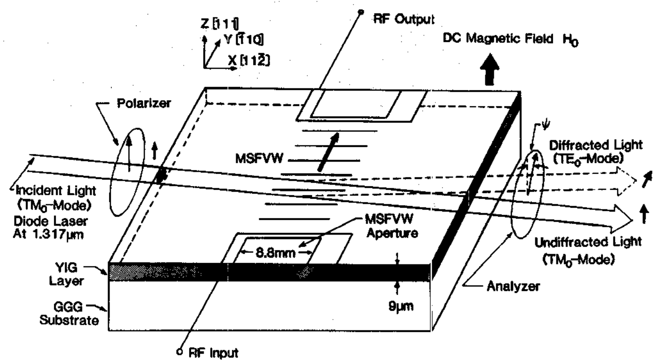

Fig.1 Noncollinear Coplanar Guided-Wave Magnetooptic Interaction Using Magnetostatic Forward Volume Wave

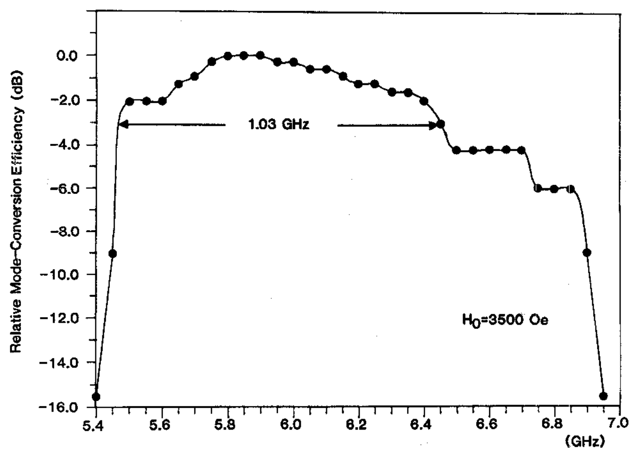

Fig.2 TM_0 To TE_0 Mode-Conversion Efficiency Versus The Carrier Frequency Of The Magnetostatic Forward Volume Wave

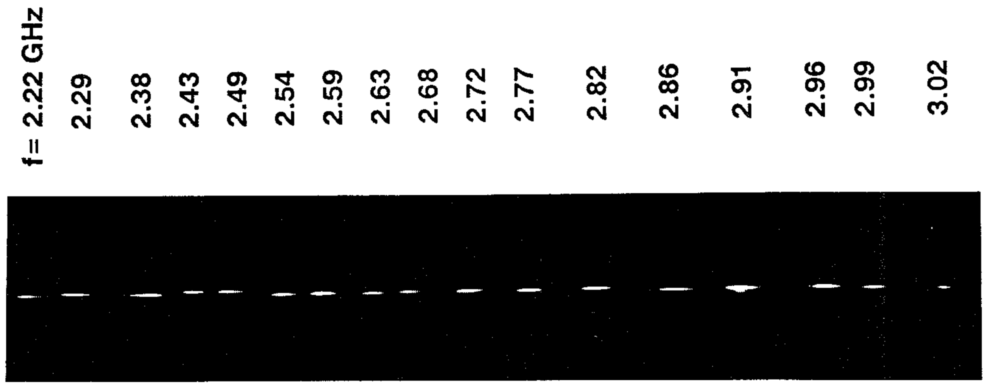

Fig. 3(A) Diffracted (Deflected) Light Beam Spots Versus The Frequency Of MSFVW At A Fixed Homogeneous DC Magnetic Field Of 2250 Oe

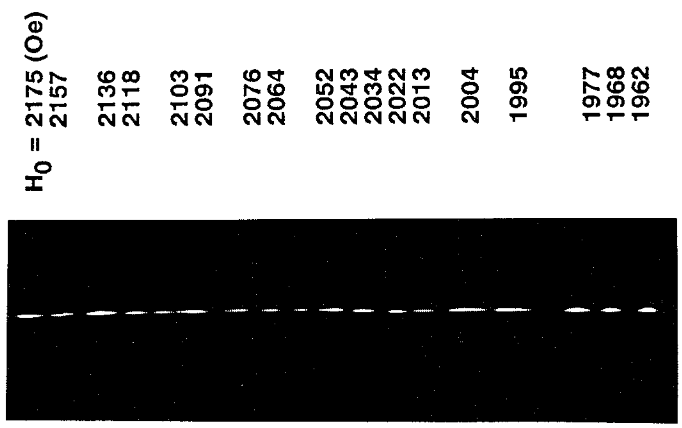

Fig. 3(B) Diffracted (Deflected) Light Beam Spots Versus The Homogeneous DC Magnetic Field At A Fixed Frequency Of 2.2GHz For The MSFVW

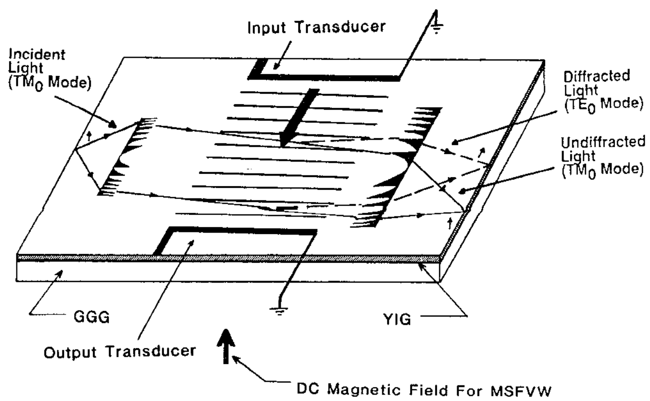

Fig.4 An Integrated Magnetooptic Deflector And RF Spectrum Analyzer