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PHASE-MATCHED WAVEGUIDE USING THE ARTIFICIAL ANISOTROPIC STRUCTURE AND ITS APPLICATION TO MODE CONVERTER

Tetsuya Mizumoto, Hirohiko Yamazaki, and Yoshiyuki Naito

Dept. of Electrical and Electronic Engineering,
Tokyo Institute of Technology
Meguro-ku, Tokyo, Japan

ABSTRACT

Phase-matching technique by the artificial anisotropic structure and its application to mode converter are proposed for the millimeter-wave dielectric circuitry. Phase-matched dielectric planar waveguide is designed and mode conversion characteristics are studied. Mode conversion experiment is successfully performed.

INTRODUCTION

As a transmission medium for low-cost integrated circuitry, dielectric waveguides have been studied in the millimeter-wave frequency range. Couplers and filters were designed in dielectric waveguide forms and realized with good performances.[1],[2] Nonreciprocal devices, such as isolators and circulators, were also studied.[3] As the waveguiding property of dielectric waveguides in millimeter-wave frequencies is very similar to that in optical frequency, some devices in dielectric waveguide forms are interesting for optical integrated circuits.

In this paper, we propose an artificial anisotropic structure which provides phase-matching between two cross-polarized modes in a dielectric slab waveguide. A similar waveguide has been proposed and designed for optical applications.[4] This technique can be applied with no difficulty to waveguide-type mode converters and/or isolators, in which phase-matching is essential to device performances. The optical artificial anisotropic waveguide consists of dielectric thin film loaded by dielectric strips. In the proposed waveguide for millimeter-wave, dielectric strips are replaced by thin conductor strips, for a conductor can be regarded as a dielectric of infinite permittivity in this frequency range.

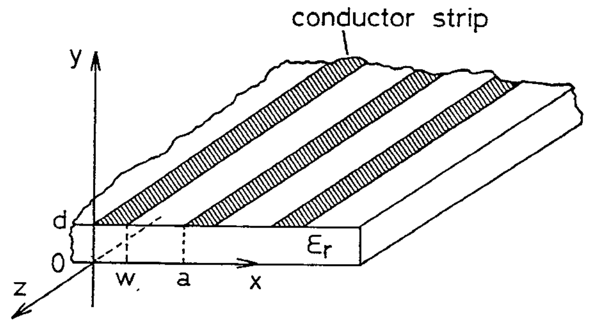

Fig.1 The artificial anisotropic waveguide.

PHASE-MATCHING CONDITION AND MODE CONVERSION CHARACTERISTICS

Fig.1 shows the proposed waveguide structure. A dielectric slab of thickness d is loaded by conductor strips of width w. The dielectric is assumed to be lossless and its relative dielectric constant is ε_r. To simplify the analysis, we set the conductor strips periodic in the x direction with periodicity a. Let the wave propagate in the z direction. The eigenmodes can be classified into two groups, TE-like and TM-like modes, from the consideration of boundary conditions. Propagation constants are calculated by using a rigorous analysis described in the reference [5].

Fig.2 shows the calculated propagation constants of the lowest TE-like and TM-like modes as a function of the slab thickness. Other waveguide parameters are indicated in the inset of the figure. You can see clearly that the two modes are phase-matched when d=0.72mm.

Moreover, when the waveguide is composed of magnetic anisotropic material like a ferrite, nonreciprocal mode converter can be constructed. We estimate the mode conversion between TE-like and TM-like modes by using a perturbation method.[6] Fig.3 shows the maximum mode conversion and the conversion length as a parameter

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of the applied magnetic field, i.e., the magnitude of magnetic anisotropy. The assumed waveguide consists of a ferrite slab loaded by the conductor strips of the same dimension as in Fig.2. The relative dielectric constant of ferrite is 15.5 and its permeability is given by the Polder's tensor with $4\pi M_s$=1800(gauss). A 100% conversion occurs at 49 GH_z where the two modes are phase-matched.

EXPERIMENTAL EXAMINATION

In order to confirm experimentally our idea, we fabricated an artificial anisotropic waveguide and performed experiments on mode conversion. The fabricated waveguide consists of YIG polycrystalline slab of 0.72mm thickness loaded by copper strips, which are formed by etching the evaporated copper thin film. The width and periodicity of strips are 1.2mm and 2.0mm, respectively. The artificial anisotropic waveguide is 5.0cm long.

The guiding wave was launched from a metalic waveguide by way of teflon waveguide and detected through the analyzer (Fig.4). When the DC magnetic field H_m was applied parallel to the propagation direction, nonreciprocal mode conversion occured by virtue of magnetic anisotropy. This phenomenon was observed as the rotation of polarized direction (Fig.5). In Fig.5, the abscissa and ordinate indicate the angle of analyzer ϕ and the detected power, respectively. The polarized direction makes a right angle ϕ at which the detected power is minimum in the figure. It is observed that the polarized direction rotates about 40° when H_m=300(Oe). On the other hand, it rotates in the reverse direction when the applied field is reversed. This means that nonreciprocal mode conversion occured in the fabricated waveguide. Though the waveguide was designed to be phase-matched at 49 GH_z, the maximum mode conversion was obtained at 52 GH_z. We attribute this to the fabrication errors. No mode conversion occurred in the same YIG slab without copper strips.

CONCLUSIONS

Phase-matching technique by the artificial anisotropic structure and its application to mode converter are proposed for

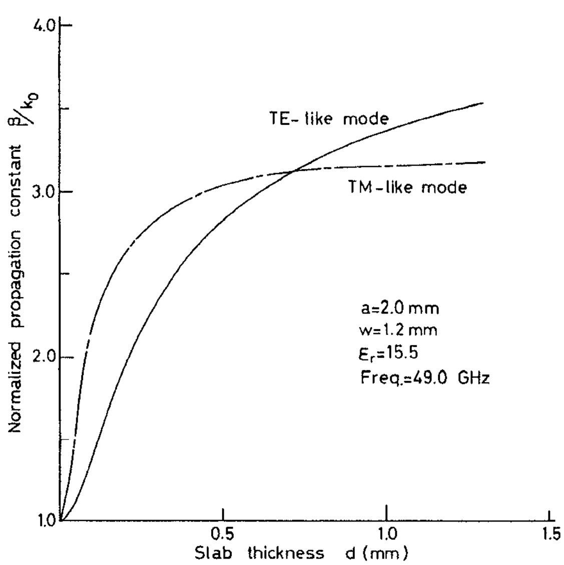

Fig.2 Propagation constants of TE-like and TM-like modes normalized by free space wavenumber k_0.

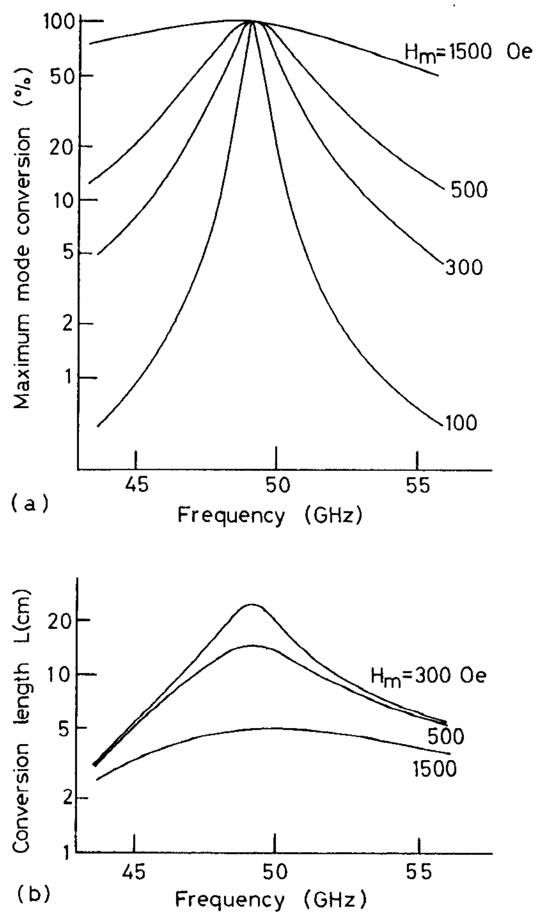

Fig.3 (a)Maximum mode conversion efficiency vs. frequency. H_m denotes the magnitude of the applied magnetic field. (b)Conversion length vs. frequency.

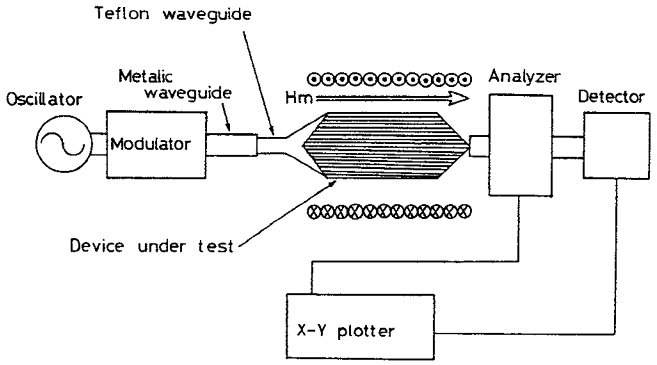

Fig.4 Set-up of mode conversion experiment

the millimeter-wave dielectric circuitry. Phase-matched dielectric planar waveguide is designed by using a rigorous analysis. Mode conversion characteristics are also studied in the artificial anisotropic waveguide composed of a magnetic anisotropic material. Nonreciprocal mode conversion is observed in the YIG artificial anisotropic waveguide. The polarized direction rotates about 40° when the magnetic field of 300 (Oe) is applied to the waveguide of 5.0cm length. Therefore, it is concluded that the planar mode converter and/or isolator can be constructed in the artificial anisotropic waveguide by virtue of the magnetic anisotropy.

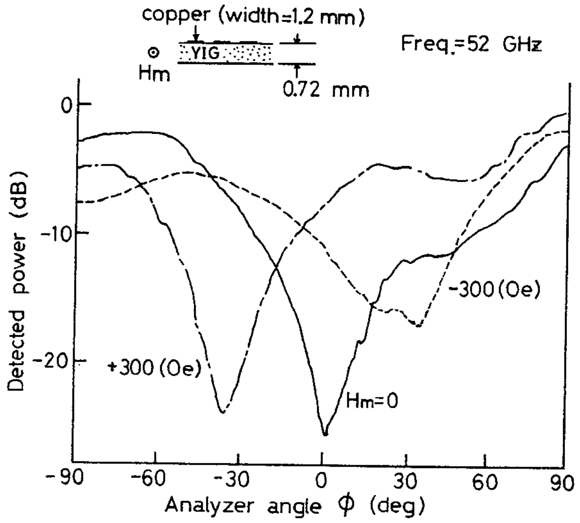

Fig.5 Observed rotation of polarized direction

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