Ferrite-ferroelectric nonlinear microwave phase shifter

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Abstract

A nonlinear microwave phase shifter based on ferrite-ferroelectric composite material has been studied for the first time. The ferrite-ferroelectric composite is fabricated in the form of bilayer consisted of yttrium iron garnet and barium strontium titanate. A principle of operation of the device is based on the linear and nonlinear control of the phase shift of the hybrid spin-electromagnetic waves propagating in the bilayer. The device demonstrated a dual-function performance with a nonlinear phase shift up to 140 degree and electric field induced linear phase shift up to 330 degree.

1. Introduction

Recent years an increased research interest for fabrication and investigation of new composite, structured and artificial materials is observed (see e.g. [1]). In particular, the linear properties of hybrid spin-electromagnetic waves (HSEWs) propagating in ferrite-ferroelectric layered structures have been studied and a number of linear ferrite-ferroelectric devices have been designed and studied [2-4]. At the same time, the nonlinear properties of the HSEWs and their possible application have never been experimentally studied. This work reports for the first time on the experimental investigation of the ferrite-ferroelectric nonlinear microwave phase shifter.

2. Device structure and principle of operation

The device structure had a form of planar composite ferrite-ferroelectric waveguiding bilayer. The bilayer was fabricated from a 5.7 μm thick single-crystal yttrium iron garnet (YIG) film epitaxially grown on a 500 μm-thick gadolinium gallium garnet substrate and a 500 μm-thick ceramic barium strontium titanate (BST) slab of the composition $Ba_{0.6}Sr_{0.4}TiO_3$. In order to apply electric voltage U, 50 nm thick Cr electrodes were deposited on the both surfaces of the BST slab by vacuum evaporation. The thickness of Cr electrodes was much smaller than the skin depth at the operating frequencies and, therefore, the electrodes were transparent to the microwave electromagnetic field.

The nonlinear phase shifter used a conventional excitation/reception structure with two 50-μm-wide 2-mm-long short circuited microstrip antennae evaporated onto a grounded alumina substrate of thickness 500 μm (see Fig. 1). The distance between the two antennae was of 8 mm. They were fed by the microstrip transmission lines of 50-Ω characteristic impedance. The YIG film waveguide was positioned over the antennae and fixed, the YIG film side contacted with the antennae. The BST slab was pressed from below to the surface of the YIG film so that the chromium covered side was in contact with the film. A length of the composite YIG/BST region was of 5 mm. A bias voltage in the range of U = 0-1000 V was applied across the BST slab. The prototype device was placed between the poles of electromagnet. The bias magnetic field in the range of H = 1100-1400 Oe was applied in-plane of the YIG film parallel to the antennae.

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Consider briefly a principle of the device operation. Surface spin wave (SSW) is excited in the YIG film by the input microstrip antenna. During propagation, the wave enters the region where the YIG film is in contact with the BST slab. At the border of this region the SSW transforms into a surface HSEW which then propagates in the YIG/BST layered structure. The HSEW passed through the layered structure reaches the YIG film where it transforms back into the MSSW. After that, the MSSW is received by the output microstrip antenna.

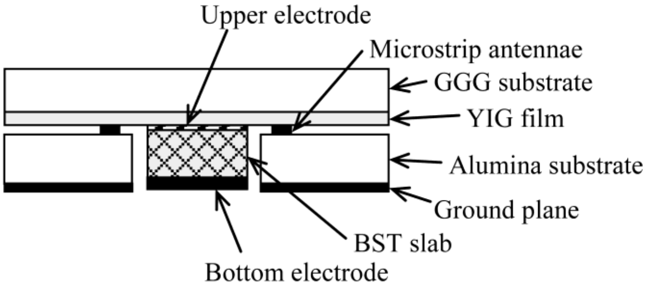

Fig. 1: Schematic diagram of the ferrite-ferroelectric nonlinear phase shifter.

A phase shift of the carrier HSEW was controlled by both the electric field applied to BST and the power level of input microwave signal. The electric field induced phase shift originated from the dependence of the HSEWs dispersion on the applied electric field [5]. The nonlinear phase shift appeared with an increase in microwave power due to the four-wave interaction processes of the HSEWs [6]. Thus, the device performed a dual-function operation.

3. Results and discussion

In the experiment S-parameters as a function of frequency f and as a function of input microwave power P_{in} were measured for different H and U. Here we present the data obtained for a particular $H = 1190$ Oe. Fig. 2 shows the insertion loss (S_{21}) vs. frequency characteristic measured for $P_{in} = -10$ dBm. It is clear that the pass band of the device was in the range of 5.42-5.7 GHz. Figs. 3(a) and 3(b) show the nonlinear phase shift vs. input power P_{in} and the differential phase shift vs. applied voltage U measured at the particular carrier HSEW frequencies within the device pass band, as indicated in the figures. The results demonstrate that the nonlinear phase shift increases with frequency whereas the differential phase shift decreases with frequency. Therefore, the nonlinear and differential phase shifts are competing characteristics for the surface HSEW nonlinear phase shifters. The experimental results also show that the nonlinear phase shift of the HSEW has the values comparable with that of spin waves reported in [7]. Thus, one may conclude that the nonlinear properties of the HSEWs in the ferrite-ferroelectric structures are mainly due to nonlinearity of the ferrite material.

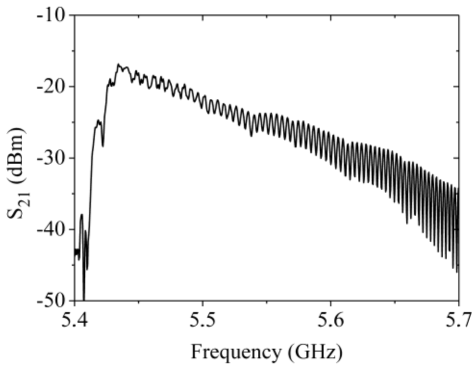

Fig. 2: Insertion loss vs. frequency characteristic of the experimental device.

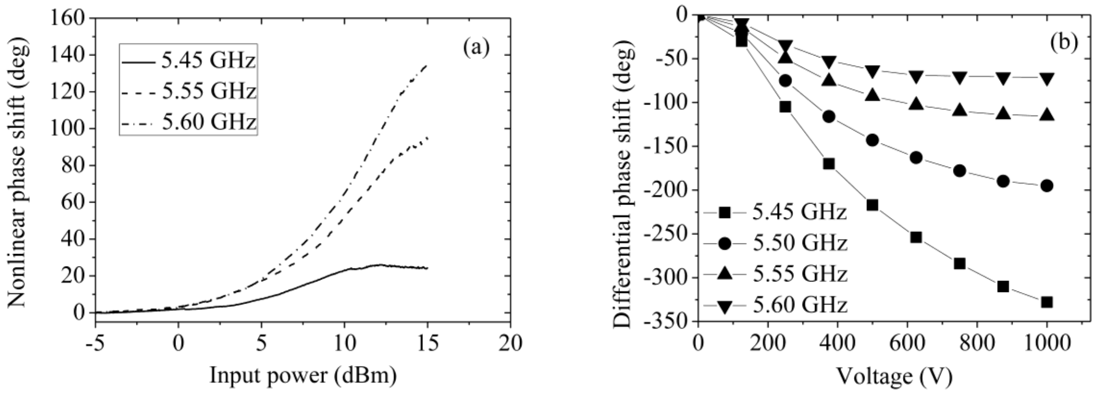

Fig. 3: (a) Nonlinear phase shift vs. input power. (b) Differential phase shift vs. electric voltage.

4. Conclusion

The ferrite-ferroelectric nonlinear phase shifter has been investigated. The dual control of the phase shift of the hybrid spin-electromagnetic waves propagating in the ferrite-ferroelectric layered structure has been demonstrated. The investigated device could find different applications. In particular, it could be used for development of the microwave logic gates, nonlinear interferometers and nonlinear directional couplers.

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