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Suppression of Insertion Loss by Slit-Patterning of a Magnetic Film in a CoFeB/Polyimide Hybrid Thin-Film Coplanar-Line for a RF Impedance Matching Device

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A hybrid thin-film coplanar-line with a slit-patterned CoFeB magnetic film for a RF impedance matching was fabricated, and an effect of the loss reduction by introducing a slit-patterned magnetic film was investigated. The fabricated hybrid thin-film coplanar-line device consisted of the top and bottom 5 μm thick copper conductors, an inner (0.5 μm thick polyimide)/(0.15 μm thick CoFeB)/(0.5 μm thick polyimide) trilayer. A signal line width was 6 μm. Total width of the slit-patterned magnetic film was about 200 μm. The devices with some kinds of the width of the magnetic film stripe were fabricated. As a result, insertion loss per unit line length decreased greatly above 1.5 GHz with decreasing width of the magnetic film. The loss suppression was due to an effect of reducing the in-plane eddy current of the magnetic film. On the other hand, the propagation signal-wavelength of the device increased with decreasing width of the magnetic film, which was due to a decrease of distributed inductance. When applying the device to a quarter-wavelength impedance matching device, the slit-patterned magnetic film was effective for decreasing the insertion loss at high frequencies beyond 1.8 GHz.

I. INTRODUCTION

Recently, wireless communication equipments such as cellular phones and wireless-LAN have increased rapidly. For example, RF front-end circuit in the cellular phones consists of various devices such as power amplifier, LNA, LC impedance matching circuit, filter, duplexer, antenna, and so on. Although the low temperature co-fired ceramics (LTCC) chip LC devices consisting of the plural passives are currently used for the RF impedance matching circuit, it is difficult to integrate it into RF IC. On the other hand, the monolithic microwave integrated circuit (MMIC) including thin film passives such as integrated spiral air core inductors and capacitors has been developed.[1] However, it is not so easy to reduce the chip size of MMIC, because of a difficulty of the miniaturization for the spiral inductor. Yamaguchi et al.[2] developed an RF integrated magnetic thin film inductor and demonstrated that the inductor can be miniaturized by introducing a magnetic thin film to the air core spiral.

As well known, a quarter-wavelength transmission-line functions as an impedance conversion transformer. The authors reported a (CoFeB magnetic film[3])/(polyimide dielectric film) hybrid transmission-line with a large effect of the wavelength shortening.[4,5] If the device has the acceptable size and insertion loss for practical use, the hybrid transmission-line would be used for an integrated RF impedance matching device.

In a previous paper,[5] insertion loss of the fabricated hybrid thin-film coplanar-line with a CoFeB magnetic film for a RF impedance matching device was about 0.8 dB, which was larger than the target specification of below 0.5 dB at frequency of 1.8 GHz range used in the GSM cellular phone. One cause of the large loss was owing to an in-plane eddy current due to the perpendicular magnetic flux component to the magnetic film plane. On the other hand, it has been reported that a slit-patterned magnetic film is effective to the loss suppression of the high frequency band except ferromagnetic resonance (FRM) frequency.[6]

The purpose of this study is to develop the impedance matching device for GHz frequency band using hybrid thin-film transmission-line. In this study, to reduce an in-plane eddy current loss, an effect of insertion loss decrease by using a slit-patterned magnetic film for a hybrid thin-film coplanar-line for a RF impedance matching device was investigated.

II. FABRICATION OF THE HYBRID THIN-FILM COPLANAR-LINE

The magnetic/dielectric hybrid thin film transmission-line operates as a distributed constant circuit with a large effect of wavelength shortening, because of an enhancement of inductance due to the magnetic film. When a quarter wavelength λ/4 is equal to a line length l at a specific frequency $f_{\lambda/4}$, the device functions as an impedance conversion transformer, that is an impedance matching device. When a signal source impedance is Z_s and a load impedance is Z_L, the impedance matching can be done by inserting the quarter wavelength device between Z_s and Z_L, where the quarter wavelength device should have a characteristic impedance Z_c, and as follows.

$$Z_c = \sqrt{Z_L Z_s} \qquad (1)$$

For example, in the power amplifier circuit of the cellular phones, Z_s of the amplifier is a few ohms, and Z_L of the antenna is from fifty to a few hundred ohms. Therefore, the characteristic impedance Z_c of the device should have a few ten ohms.

Fig. 1 shows the structure of the fabricated hybrid thin film coplanar-line device. The fabricated device consisted of the top and bottom 5 μm thick copper conductor layers, and an inner (0.5 μm thick polyimide)/(0.15 μm thick CoFeB)/(0.5 μm thick polyimide) trilayer. The device was 1mm in width and 5 mm in length. The signal line and ground plane width were 6 μm and 397 μm, respectively. The Total width of a continuous film or slit-patterned magnetic film was about 200 μm. As shown in Fig. 2, the slit-patterned magnetic film consisting of some magnetic film bars (stripe width w_m) and spaces (10 μm wide). The longitudinal direction of the magnetic film bar was same as the signal line direction.

A plain CoFeB amorphous magnetic film had a FMR frequency of about 4 GHz and a static relative permeability of 180. A polyimide dielectric film had a relative permittivity of 3.5.

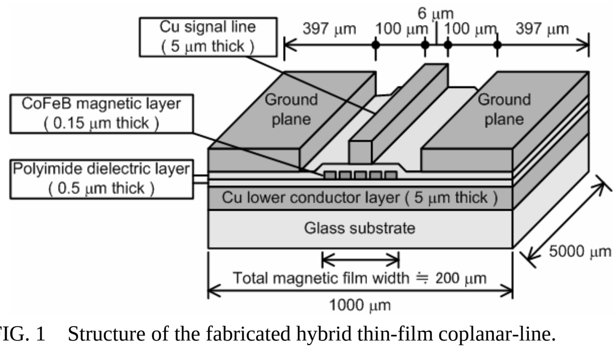

FIG. 1 Structure of the fabricated hybrid thin-film coplanar-line.

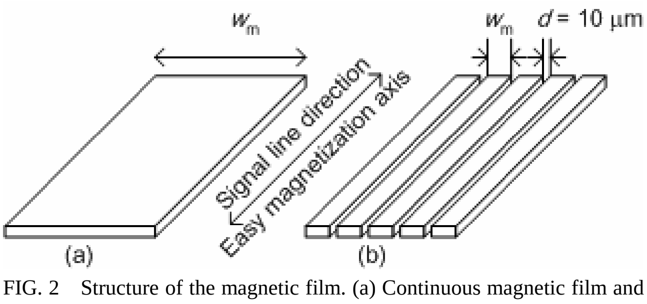

FIG. 2 Structure of the magnetic film. (a) Continuous magnetic film and (b) slit-patterned magnetic film.

The specifications of the fabricated devices such as each film thickness and dimensions are shown in Fig. 1. The hybrid thin-film coplanar transmission-lines were fabricated through the following methods: (1) the top and bottom copper conductor films were deposited by electroplating, (2) the polyimide dielectric film was deposited by spin- coating and baking, (3) the CoFeB magnetic film was deposited by RF magnetron sputtering with rotating a cylindrical electrode[3] and was patterned by lift-off process. The devices with magnetic film stripe width w_m of 10, 20, 40, and 200 μm were fabricated.

Fig. 3 shows the photograph of the fabricated device with 10 μm wide magnetic film stripes.

III. EXPERIMENTAL RESULTS AND DISCUSSION

The transmission characteristics of the fabricated devices were evaluated by using a network analyzer (HP 8720D) and GSG RF probe. The propagation signal wavelength λ, characteristic impedance Z_c and insertion loss L were estimated by measured S parameters.[5]

The fabricated devices with each magnetic film structure had the characteristic impedance of 30 to 40 Ω.

Fig. 4 shows the frequency dependences of insertion loss per unit line length L_{mm} of the fabricated devices. In this figure, the insertion loss L_{mm} was almost constant 0.1dB/mm below 1.2 GHz in any case. It was considered that the constant loss below 1.2 GHz was due to a dc resistance of a signal line. The loss L_{mm} of the device with a continuous magnetic film increased rapidly beyond 1.5 GHz. The increase of loss beyond 1.5 GHz was suppressed by slit-patterning of the magnetic film. Although not shown in detail here, it was found that the magnetic flux perpendicular to the magnetic film plane gives rise to the in-plane eddy current,[5] hence it was considered that the rapid increase of loss of above 1.5 GHz is mainly due to the in-plane eddy current of the magnetic film, and the in-plane eddy current was suppressed by introducing the slit-patterned structure for the magnetic film.

On the other hand, the peak of the loss per unit line length of each fabricated device occurred at around 6 GHz. The peak frequency related to FMR was shifted to high frequency side, which was due to the increase of shape anisotropy field with decreasing width of a magnetic film bar in Ref. 6. However, the peak fre-

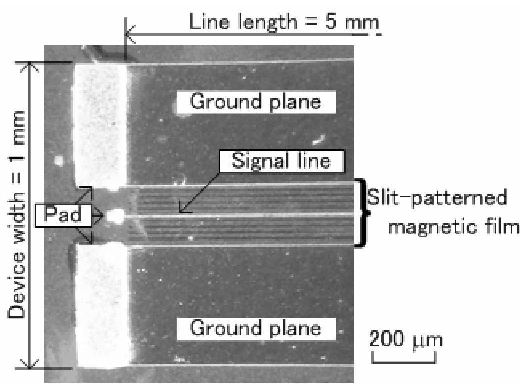

FIG. 3 Photograph of the fabricated hybrid thin-film coplanar-line with 10 μm wide magnetic film stripes.

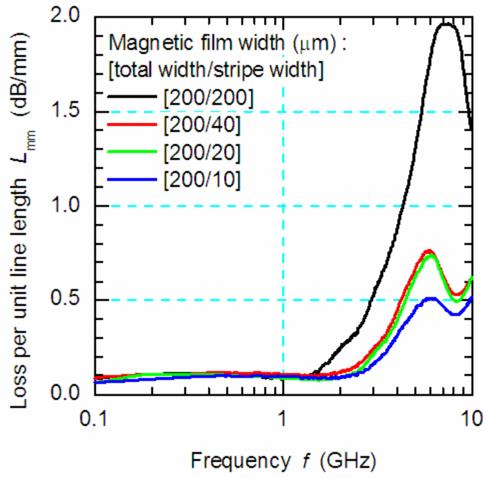

FIG. 4 The frequency dependences of loss per unit line length L_{mm} of the fabricated devices. The labels show total width and stripe width of magnetic film.

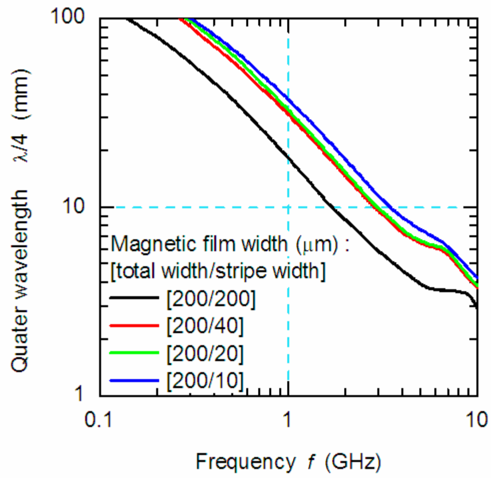

FIG. 5 The frequency dependence of quarter wavelength λ/4 of the fabricated device. The labels are similar to Fig. 4.

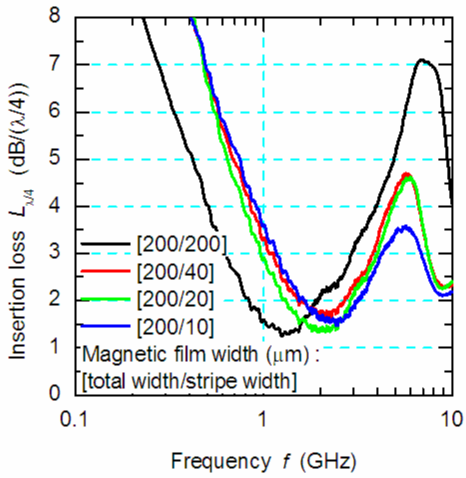

FIG. 6 The frequency dependence of insertion loss per a quarter wavelength $L_{\lambda/4}$ of the fabricated device. The labels are similar to Fig. 4.

quency of the fabricated device was hardly changed with magnetic film stripe width in Fig. 4. It might be a cause that the effect of a shape anisotropy magnetic field is relatively small, because of CoFeB film with large intrinsic anisotropy magnetic field of about 10 kA/m.

Fig. 5 shows the frequency dependences of the quarter wavelength λ/4 devices. The propagation signal-wavelength of the fabricated devices was almost in inverse proportion to the frequency. Signal-wavelength of the device increased with decreasing magnetic film stripe width of the slit-patterned magnetic film. It was considered that the increase of wavelength was influenced by increasing shape anisotropy magnetic field and decreasing magnetic film volume.

Fig. 6 shows the frequency dependences of insertion loss of the four kinds of the quarter-wavelength devices with a continuous film, w_m=40, 20 and 10 μm. In the frequency range that loss per unit line length was almost constant in Fig. 4, the insertion loss $L_{\lambda/4}$ decreased linearly with increasing frequency, which was due to a decrease of signal-wavelength. The insertion loss $L_{\lambda/4}$ exhibited a minimum value at around 1.2 to 2.5 GHz. When decreasing magnetic film stripe width in the slit-patterned magnetic film, the frequency for minimum insertion loss became higher, which was due to the suppression of the in-plane eddy current loss of magnetic film. In this case, the slit-patterned magnetic film was effective for decreasing the insertion loss at high frequencies beyond 1.8 GHz.

IV. CONCLUSIONS

The CoFeB/polyimide hybrid thin-film coplanar transmission-line for impedance matching was fabricated and investigated. (1) Loss per unit line length of the fabricated device decreased greatly above 1.5 GHz with decreasing the magnetic film stripe width of the patterned magnetic film, which was due to an effect of reducing the in-plane eddy current of the magnetic film. (2) The propagation signal-wavelength of the device increased with decreasing the magnetic film stripe width, which was due to an increase of a shape magnetic anisotropy and decrease of magnetic film volume. (3) When applying the device to a quarter-wavelength impedance matching, the slit-patterned magnetic film was effective for decreasing the insertion loss at high frequencies beyond 1.8 GHz.

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