Basic Characteristics of Transmission Line Employing Periodic Ground Structure on MMIC for an EMC Solution

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***Abstract*— In this work, using the PGS, microstrip line structure with a high isolation characteristic was developed for an EMC solution on MMIC, and the origin of the high isolation characteristic was theoretically investigated. We also explored the basic characteristics of microstrip line employing PGS by using theoretical and experimental analysis. According to the results, the bandwidth of the PGS structure was more than 266 GHz, which indicates that the PGS structure can be employed as a transmission line for application to commercial microwave/millimeter wave device. In addition, the PGS structure showed a much shorter wavelength than conventional microstrip line due to its slow wave structure, which indicates that the PGS structure is a promising candidate for application to a development of miniaturized on-chip passive components.**

Key words: transmission line, periodic ground structure (PGS), monolithic microwave integrated circuit (MMIC), electromagnetic compatibility (EMC)

I. INTRODUCTION

With a rapid development of information and communication industry, the interests in the EMI (electromagnetic interference) and EMS (electromagnetic susceptibility) are gradually increasing for an improvement of electromagnetic environment [1-5]. Especially, a reduction of electromagnetic coupling has become an hot topic in EMC (electromagnetic compatibility) problem, because it causes a serious trouble in communication system.

Recently, using periodic ground structure (PGS), microstrip line structure with a high isolation characteristic was developed for application to compact signal lines of highly integrated MMIC (Monolithic Microwave Integrated Circuits). In this work, the basic characteristics of microstrip line employing PGS were investigated for application to compact signal lines of highly integrated MMIC.

II. BASIC RF CHARACTERISTICS OF MICROSTIP LINE STRUCTURE EMPLOYING PGS

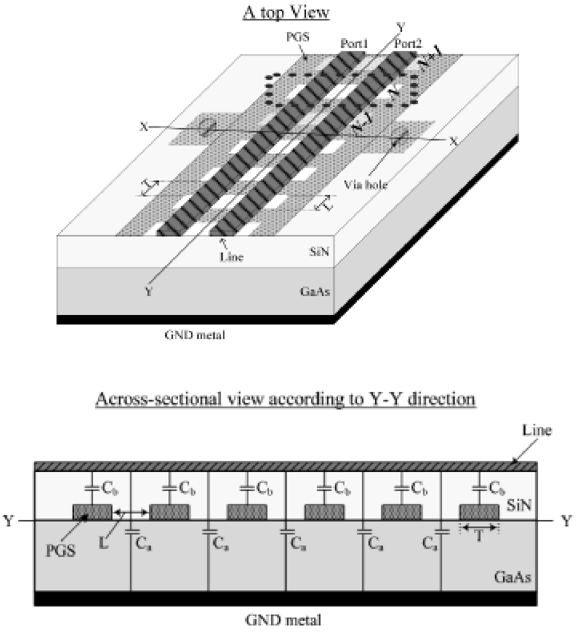


Fig. 1 Coupled microstrip line structure employing PGS.

Figure 1 shows the top view of coupled microstrip line employing PGS. The PGS was inserted at the interface between SiN film and GaAs substrate, and the PPGM serves as ground plane because it was electrically connected to backside ground metal through the via-holes. We fabricated coupled microstrip lines employing PGS. Figure 2 shows the photograph of the coupled microstrip line employing PGS. In this structure, W, S and L are all 20 μm, and SiN and GaAs substrate thickness are 0.1 and 100 μm, respectively. The measured isolation characteristic S_{12} between port 1 and 2 are shown in Fig. 3, where the isolation characteristic between conventional microstrip lines without PGS was also included for comparison, and W and S for the conventional microstrip lines are all 20 μm, respectively. The PGS structure shows much better isolation characteristics than conventional microstrip line. Especially, highly improved isolation characteristics are observed in the vicinity of resonance frequency. Concretely, with only a spacing of 20 μm, the coupled microstrip line employing PGS shows an isolation value of -47 dB at 60 GHz. On the other hand, the conventional coupled microstrip line without PGS shows an isolation value of -8 dB at 60 GHz.

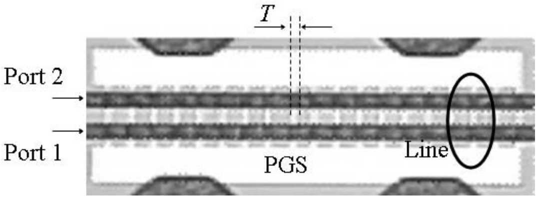


Fig. 2 The photograph of Coupled microstrip line employing PGS.

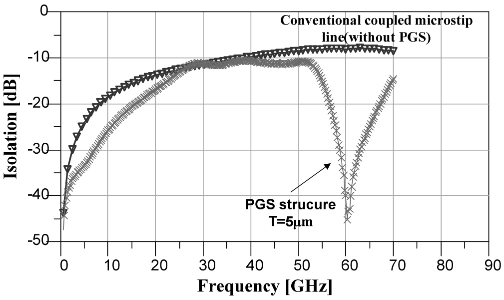


Fig. 3. Measured isolation characteristic S_{12} of coupled microstrip line employing PGS and conventional coupled microstrip line.

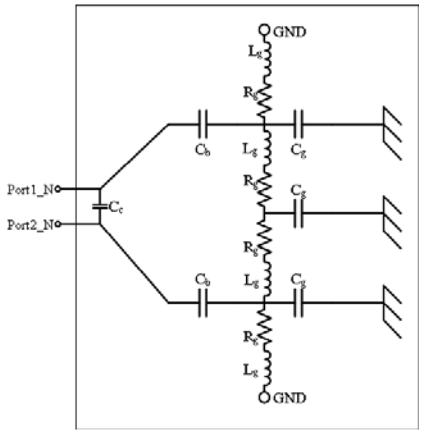


Fig. 4. An equivalent circuit for a unit section of the adjacent two lines of coupled microstrip employing PGS.

According to the theoretical analysis, a good isolation characteristic originated from the resonance of the PGS structure. In other words, the innate resonance characteristic originating from the parasitic elements of PGS structure enabled a high isolation characteristic. Figure 4 shows the equivalent circuit of adjacent two lines, which corresponds to the equivalent circuit of the N^{th} unit section of the periodic structure surrounded by rectangular box in Fig.1. As shown in this figure, this circuit has a resonance structure, and the resonance occurs in the following frequency.

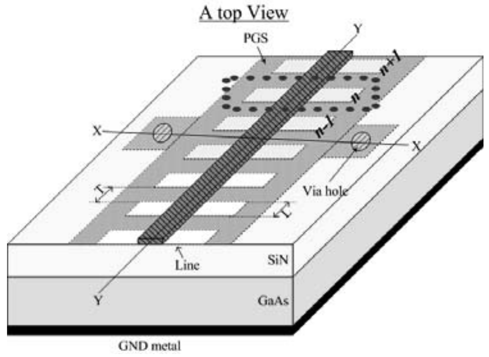
$$f_c = \frac{1}{2\pi}\sqrt{\left(\frac{1}{L_g}+\frac{1}{L_g+L_p}\right)\cdot\frac{1}{(C_g+2C_{bc})}} \qquad (1)$$

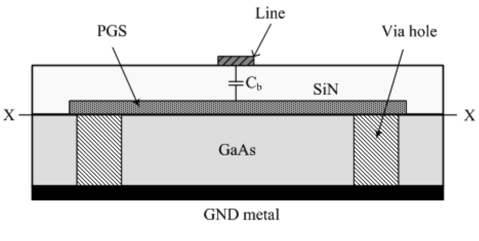
$$\approx \frac{1}{2\pi}\sqrt{\frac{1}{2}\left(\frac{1}{L_g}+\frac{1}{L_g+L_p}\right)\left(\frac{1}{C_c}+\frac{2}{C_b}\right)},\ \left(\frac{1}{C_{bc}}=\frac{1}{C_b}+\frac{1}{C_c}\right)$$

Therefore, a good isolation characteristic of PGS structure shown in Fig. 3 originated from the resonance characteristic of the PGS structure, which shows a resonance at the above frequency. In this case, the resonance occurred at 60 GHz as shown in Fig. 3.

III. BASIC RF CHARACTERISTICS OF MICROSTIP LINE STRUCTURE EMPLOYING PGS

For application to the communication system, the basic characteristics of the transmission line employing PGS should be investigated thoroughly. Therefore, we investigated the basic RF characteristics of the transmission line employing PGS. Figure 5 shows single microstrip line structure employing PGS.




Across-sectional view according to X-X direction

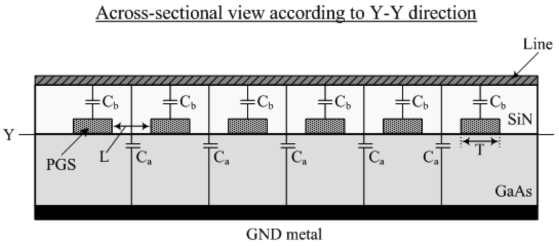


Fig. 5. Single microstrip line structure employing PGS.

As shown in Fig. 5, PGS was inserted at the interface between SiN film and GaAs substrate, and it was electrically connected to backside GND metal through the via-holes. As is well known, the conventional microstrip line without PGS has only a periodical capacitance C_a (C_a is shown in Fig. 5) per a unit length, while the microstrip line with PGS shown in Fig. 5 has additional capacitance C_b as well as C_a. Therefore, according to the theoretical and experimental results, it was found that the microstrip line with PGS exhibited much lower characteristic impedance Z_0 and shorter guided-wavelength λ_g than conventional one, because Z_0 and λ_g are inversely proportional to the periodical capacitance as shown from the following equations [6].

$$Z_O = \sqrt{\frac{L}{C}} \tag{2a}$$

$$\lambda_g = \frac{1}{f\sqrt{LC}} \tag{2b}$$

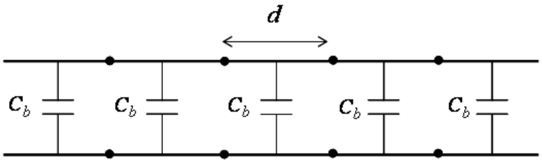


Fig. 6. An equivalent circuit of the PGS structure with periodically loaded capacitor C_b.

The PGS structure can be expressed as the periodically loaded line shown in Fig. 6, and C_b is the periodical capacitance for the SiN film between the line and PGS as shown in Fig. 5. The theoretical calculation was performed using the well-known *kd-βd* equation for periodic structures [6], which can be expressed as follows:

$$\cos\beta d = \cos\theta - \frac{b}{2}\sin\theta \tag{3a}$$

$$\theta = kd = \omega\sqrt{\mu_0\varepsilon_e\varepsilon_0}\,d \tag{3b}$$

$$b = \omega C_b Z_0 = 2\pi f C_b Z_0 \tag{3c}$$

$$d = \frac{L}{2} + T + \frac{L}{2} = L + T \tag{3d}$$

, where β, ε_e and Z_0 are propagation constant for the microstrip line with PGS, effective dielectric constant and characteristic impedance for the microstrip line without PGS, respectively. The guided wavelength λ_g was obtained from the relation of $\lambda_g = 2\pi/\beta$. Figure 7 shows *kd-βd* graph obtained from Eq. 3.

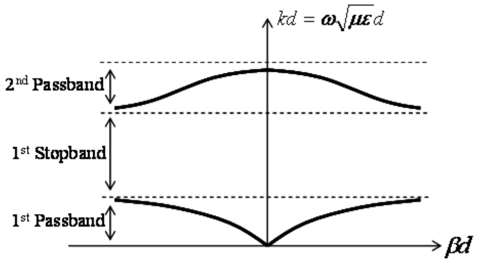


Fig. 7. *k-β* graph obtained from Eqs. (3).

The bandwidths of pass- and stopband for the microstrip line with PGS were also calculated from Eq. 3 and Fig. 7, and the results are summarized in Table I. From the practical bandwidth (first passband) summarized in the table, we can see that the microstrip line with PGS is also suitable for applications to a higher frequency band as well as to a K/Ka band.

Guided wave length λ_g and effective permittivity ε_{eff} can also be calculated from the above equations and *βd-kd* graph of Fig. 7. Firstly, propagation constant β of the PGS structure can be calculated from the Eqs. (3) and *βd-kd* graph shown in Fig. 7, and then, λ_g and ε_{eff} can be obtained from the following relations,

$$\lambda_g = \frac{2\pi}{\beta} \tag{4a}$$

$$\beta = \omega\sqrt{\mu\varepsilon} = \omega\sqrt{\mu_0\varepsilon_0\varepsilon_{eff}} \tag{4b}$$

$$\varepsilon_{eff} = \left(\frac{\beta}{\omega\sqrt{\mu_0\varepsilon_0}}\right)^2 \tag{4c}$$

Figure 8 and 9 shows the measured and calculated λ_g and ε_{eff} respectively. As shown in this figure, the λ_g can be highly reduced by using the PGS structure. As shown in Fig. 8, the PGS structure shows much higher value of ε_{eff} than the dielectric constant of GaAs (=12.9) due to its slow wave structure. The above results indicate that highly miniaturized and low impedance passive components on MMIC can be realized by using the microstrip line employing PGS.

TABLE I

Bandwidth for pass- and stopbands (W = 20 μm, L = 20 μm)

T (μm)	C_b (pF)	First passband	First stopband
5	0.00885	•f = 639 GHz •BW = 639 GHz	• 639 ~ 1650 GHz •BW = 1011 GHz
10	0.0177	•f = 443 GHz •BW = 443 GHz	•443 ~ 1373 GHz •BW = 930 GHz
20	0.0354	•f = 266 GHz •BW = 266 GHz	•266 ~ 1031 GHz •BW = 765 GHz

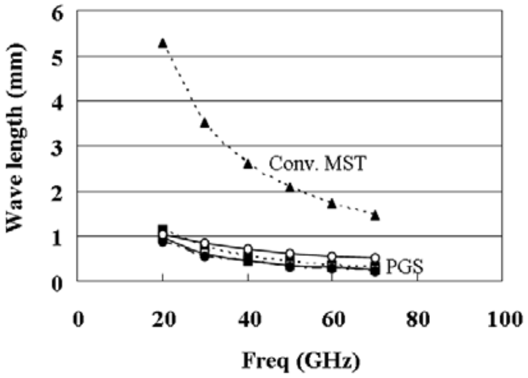


Fig. 8. Measured wavelength of microstrip line employing PGS and conventional one.

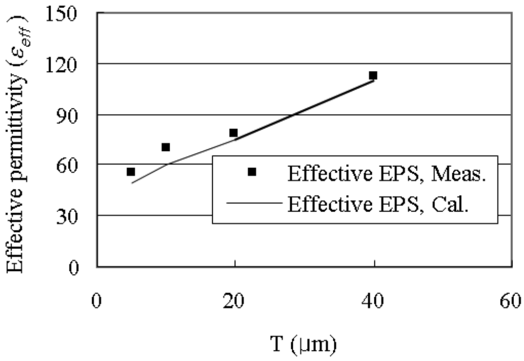


Fig. 9. Measured and calculated effective permittivity ε_{eff}.

IV. CONCLUSION

Using the PGS, we developed microstrip line structure with a high isolation characteristic for an EMC solution on MMIC, and also theoretically investigated the origin of the high isolation characteristic. With only a spacing of 20 μm, the coupled microstrip line employing PGS showed an isolation value of -47 dB at 60 GHz. On the other hand, the conventional coupled microstrip line without PGS showed an isolation value of -8 dB at 60 GHz. According to the theoretical analysis, it was found that the innate resonance characteristic originating from the parasitic elements of PGS structure enabled a high isolation characteristic. We also explored the basic characteristics of microstrip line employing PGS by using theoretical and experimental analysis. According to the results, the bandwidth of the PGS structure was more than 266 GHz as long as T is less than 20 μm, which indicates that the PGS structure can be employed as a transmission line for application to commercial microwave/millimeter wave device. In addition, the PGS structure showed a much shorter wavelength than conventional microstrip line due to its slow wave structure, which indicates that the PGS structure is a promising candidate for application to a development of miniaturized on-chip passive components.

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