Integration of RF passive components into semiconducting device through 3D capacitive coupling for application to fully-integrated MMIC

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Abstract— In this work, a 3D capacitive coupling structure employing periodic pattern was used for application to miniaturized on-chip passive components on MMIC (Monolithic Microwave Integrated Circuit). Unlike conventional periodic structure, the characteristic impedance of the 3D capacitive coupling structure was hardly dependent on frequency. Using the 3D capacitive coupling structure, RF passive component was highly miniaturized in comparison with conventional one.

1. Introduction

Recently, demands for broadband and fully integrated MMICs (monolithic microwave integrated circuits) have increased in the broadband wireless communication systems market [1]-[6]. However, RF passive components (such as coupler and filter) can't be integrated on MMIC due to their large size, which has been an obstacle to a realization of fully-integrated MMIC. For a size reduction of RF components, we proposed a 3D capacitivecoupling structure employing periodic structure [7]-[11].

In this work, we introduce highly miniaturized RF passive components employing the 3D capacitive coupling structure.

2. Periodic structure with 3D capacitive coupling

Figure 1 shows a structure of conventional 2D capacitive line [13]. Using this structure, miniaturized couplers were fabricated on teflon substrate. As shown in Fig. 1, periodic open stubs were connected to transmission line employing coplanar waveguide structure. Basically, however, 2D capacitive line structure shown in Fig. 1 has a limitation in circuit size reduction, because open stub occupies a large area in RF circuit. Therefore, for a further size reduction, 3D capacitive line structure should be developed.

Figure 2 shows periodic structure with 3D capacitive coupling[10]. As shown in this figure, periodically patterned plane was inserted at the interface between insulator and semiconducting substrate, and it was electrically connected to backside GND metal through the via-holes. As is well known, the conventional microstrip line without 3D capacitive coupling structure has only a periodical capacitance C_a (C_a is shown in Fig. 1) per a unit length, while the microstrip line employing 3D capacitive coupling structure 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 employing 3D capacitive coupling structure exhibited much shorter wavelength than conventional one, because λ_g is inversely proportional to the periodical capacitance as shown from the following equations[14].

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

In addition, unlike conventional periodic structure[13], [15]-[19], the characteristic impedance of the 3D coupling structure is hardly dependent on frequency, because the additional capacitance C_b is a parallel plate capacitance between line and periodically patterned plane, which is not dependent on frequency. In other words, the characteristic impedance of transmission line and the additional capacitance C_b are expressed by Eq. (2) and (3), respectively.

$$Z_0 = \sqrt{\frac{L}{C}} \tag{2}$$

$$C_b = \varepsilon_i \cdot \frac{W \cdot T}{d_i} \tag{3}$$

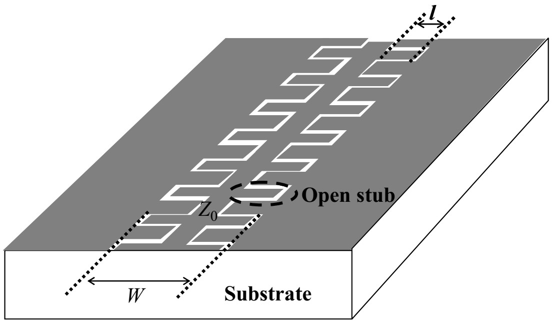

Fig. 1 A structure of conventional 2D capacitive line [13]

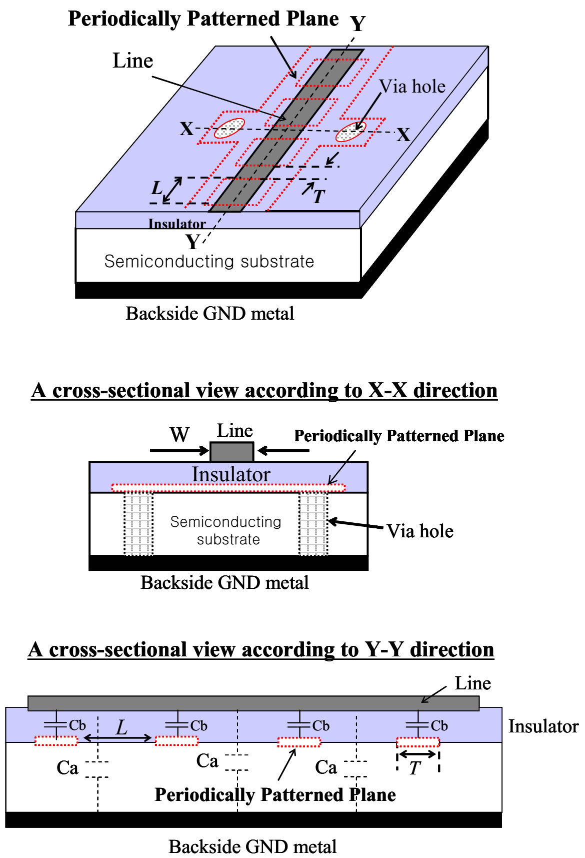

Fig. 2. Microstrip line employing periodic structure with 3D capacitive coupling

, where ε_i and d_i are permittivity and thickness of insulator, and W and T are line width and width of periodic ground strip shown Fig. 2. On the other hand, the characteristic impedance of conventional periodic structure is highly dependent on frequency, which originate from a frequency-dependent periodic capacitance. For example, the open stub capacitance

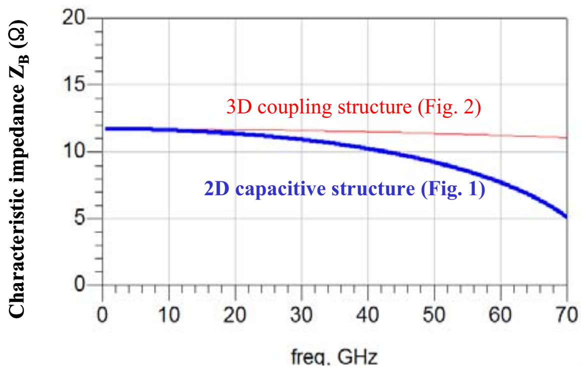

Fig. 3 The characteristic impedance of the 3D coupling structure and 2D capacitive line structure,

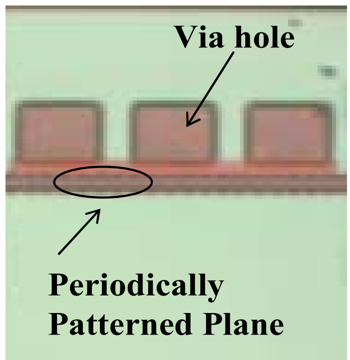

Fig. 4 An impedance transformer employing periodic structure with 3D capacitive coupling.

of the conventional 2D periodic structure shown in Fig. 2 can be expressed by the Eq. (4) [14], and the characteristic impedance expressed by Eq. (2) shows a fairly large dependence on frequency.

$$C_o = \frac{1}{2\pi f \cdot Z_0 \cot(\beta\ell)} \tag{4}$$

where Z_0 and β are characteristic impedance and propagation constant of the transmission line comprising the open stub, and l is length of the open stub. Figure 3 shows the characteristic impedance of the 3D coupling structure and 2D capacitive line structure, which were calculated using a theory of periodic structure [14]. As shown in this figure, the characteristic impedance of the 3D coupling structure is hardly dependent on frequency up to 70 GHz.

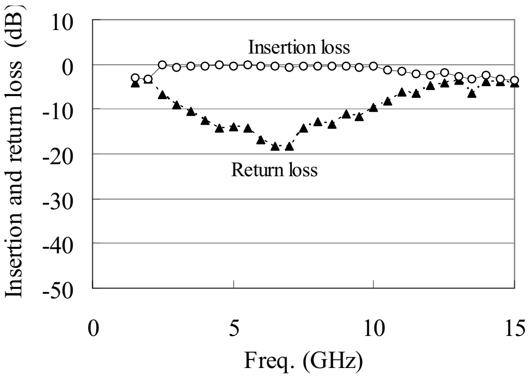

Fig. 5. Measured insertion and return loss of the single section λ/4 impedance transformer employing PPGM.

3. A highly miniaturized RF passive component employing periodic structure with 3D capacitive coupling

Using the periodic structure with 3D capacitive coupling, we fabricated a highly miniaturized a single section λ/4 impedance transformer for UWB band MMIC applications. Figure 4 shows a photograph of a single section λ/4 impedance transformer employing the periodic structure with 3D capacitive coupling on GaAs substrate. The size of the transformer including via holes is 0.0425 mm^2, which is 2.3% of the size of the transformer employing conventional microstrip line. Figure 5 shows measured return loss S_{11} and insertion loss S_{21}, respectively. We can observe return loss values lower than -9 dB from 3 GHz to 10.5 GHz, and insertion loss values lower than 1 dB in the above frequency range.

4. Conclusion

In this work, we proposed a 3D capacitive coupling structure employing periodic patterns for application to miniaturized on-chip passive components on MMIC. Unlike conventional periodic structure, the characteristic impedance of the 3D capacitive coupling structure was hardly dependent on frequency. Using the 3D capacitive coupling structure, we fabricated a single section λ/4 impedance transformer. The size of the transformer including via holes is 0.0425 mm^2, which is 2.3% of the size of the transformer employing conventional microstrip line.

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