Application of CPW Based Spiral-Shaped Defected Ground Structure to The Reduction of Phase Noise in V-Band MMIC Oscillator

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Abstract — **The CPW based spiral-shaped defected ground structure (DGS) is used in MMIC for the first time to reduce the phase noise in V-band MMIC oscillator. The parallel equivalent L-C components resulted from the defects on the both ground planes in CPW produce a band rejection property. Hence the spiral-shaped DGS can be employed at the gate circuit of the series feedback oscillator to improve quality factor of the oscillator. A V-band CPW MMIC oscillator incorporated with this DGS resonator was designed, fabricated and measured. To demonstrate the effect of the spiral-shaped DGS on phase noise, another oscillator with only conventional open stub CPW line was also tested. The phase noise performance of the oscillator with spiral-shaped DGS is improved by 8 dB compared to that of the oscillator without DGS.**

I. Introduction

In recent years, there have been increasing interests in the applications of defected ground structure (DGS) in the field of microwave passive and active circuits. The published application examples of the DGS have been focused on the microstrip line with DGS mainly [1]-[4]. The DGS in the microstrip line needs backside fabrication process because the ground plane of the microstrip line is located on the backside of the substrate. On the other hand, the signal plane and ground plane of CPW are located on the same plane, which allows fully planar integrated circuits without any additional fabrication process. We have recently reported the CPW based spiral-shaped DGS including its equivalent circuit, and also suggested the potential possibilities of applications to microwave circuits [5].

The phase noise in microwave oscillators has been the most important parameter for oscillator designers. There have been several techniques to reduce the phase noise such as employing high quality factor (Q) resonator in oscillators. In particular, dielectric resonator (DR) has been the most promising element for low phase noise oscillator, however it cannot be used in an MMIC oscillator on chip unfortunately due to its three-dimensional (3D) structure. To solve this problem, various planar type resonators have been developed for microstrip line [6]-[8], but few resonators have been reported for CPW line [9].

In this paper, a method to reduce the phase noise in CPW MMIC oscillators using the spiral-shaped DGS is proposed. Improvement of the quality factor of the oscillator with DGS can be achieved, which indicate that the phase noise performance of the oscillator can be also improved.

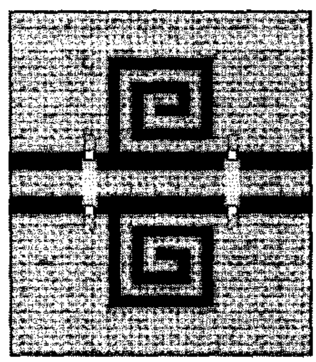


Fig. 1. The layout of the CPW based spiral-shaped Defected Ground Structure.

II. Spiral-Shaped DGS and Its Application To Oscillator

Fig. 1 shows the layout of the spiral-shaped DGS in CPW transmission line. Unlike the conventional CPW line, the spiral-shaped defects or slots on the both ground planes give rise to the equivalent L-C components in parallel connection. It means that larger slow wave effect is generated due to increased inductance below the resonant frequency, which is applicable to the size reduction of matching circuits and the unequal power divider due to its higher characteristic impedance than conventional transmission line.

At the resonant frequency, the equivalent parallel L-C components form a band rejection property, which is similar to the dielectric resonator or hairpin resonator coupled to the microstrip line. The length and number of turns of the defected slots determine the equivalent value of inductance, which eventually determines the resonant frequency of the structure. Therefore by inserting this spiral-shaped DGS with 50 Ω termination in the gate embedding circuit of the active device, a series feedback oscillator with small circuit size and high Q property can be designed without any additional high Q resonator coupled to CPW.

The width of the signal strip of CPW and the gap between the ground planes and signal line are fixed as conventional 50 Ω line. The GaAs substrate with 650μm thickness and a dielectric constant of 12.9 was used. The slot width on the both ground planes is 15μm for convenience' sake, as a result the only remaining parameter to determine the resonant frequency, in this work-60GHz, is the length of the slot in the spiral structure. The whole size of the DGS resonator is within 135μm, 1/14 wavelength (1959μm for one wavelength at 60GHz). Furthermore its area occupies only the ground planes of the CPW.

The simulated and measured characteristics of the DGS resonator are depicted in Fig. 2. The measured results are in good agreement with the simulated ones. The EM simulator, IE3D was used for this simulation. The calculated value of the loaded Q is 6.59.

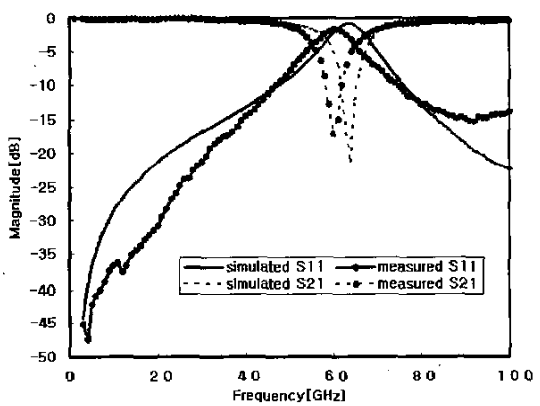


Fig. 2. The simulated and measured S parameters of spiral-shaped DGS.

III. Fabrication Of The Active Device

The schematic cross section of the HEMT is shown in Fig. 3. From Hall measurements on the MBE-grown epitaxial wafer, the sheet resistance and sheet carrier density are 175Ω/□ and 3.44×10^{12}cm^{-2}, respectively with room temperature mobility of 5580cm^2/V-s. Ni/Ge/Au/Ni/Ag/Au was used as ohmic metal with ~0.1Ωmm contact resistance. After the wide recess, SiO_2/Si_3N_4 bilayer dielectric film was deposited subsequently. The bottom of the T-shaped gate (0.15μm) was patterned by electron beam lithography, and transferred on the bilayer dielectric film by RIE using CF_4/O_2 gas. Then, SF_6/Ar RIE was carried out to etch the Si_3N_4 film selectively. Finally, the gate recess was performed with selective wet etching and Ti/Pt/Au was deposited as the gate metal. A very thin 600Å Si_3N_4 was deposited by a remote PECVD to be used as MIM dielectric layer and NiCr resistors are 20Ω/□. The threshold voltage of fabricated devices is -1V and maximum transconductance is 560mS/mm. Breakdown voltage (BVGD) is -8.5V. The peak f_T and f_{max} is 90GHz and 270GHz, respectively.

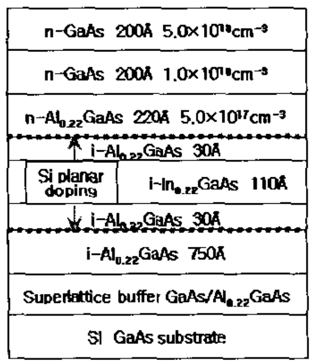


Fig. 3. The cross section of AlGaAs/InGaAs pHEMT.

IV. V-Band Oscillators Design

A V-band CPW MMIC oscillator incorporated with the spiral-shaped DGS resonator was designed using the nonlinear design technique [10]. As described earlier, this DGS resonator was employed at the gate embedding circuit of the active device with 50 Ω termination. The short stub CPW line was placed at the source embedding circuit to generate negative resistance characteristic at the gate terminal. In order to confirm the validity of the proposed technique, another oscillator with only open stub CPW line at the gate circuit, in other words without DGS resonator, was also designed. The source and drain embedding circuits of these two oscillators were identical respectively, and the embedding impedance of the gate circuit of these two oscillators was made to be equal by adjusting the length of the CPW line connected to the gate terminal.

Fig. 4 shows the layout of the oscillator with spiral-shaped DGS resonator at the gate circuit. The layout of the oscillator without DGS is same except the gate circuit.

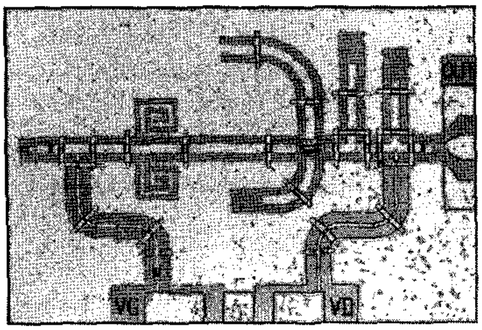


Fig. 4. The layout of the oscillator with spiral-shaped DGS at the gate circuit. The chip size is 1500μm x 1000μm.

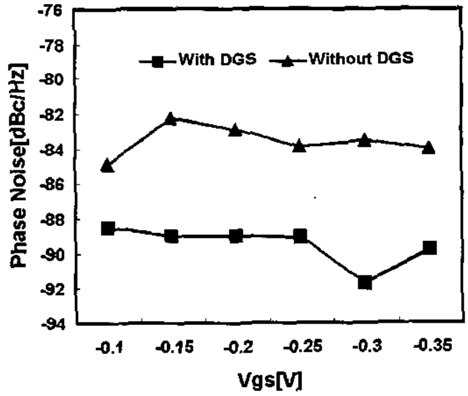
V. Measurements

The fabricated two oscillators were measured on wafer using harmonic mixer.

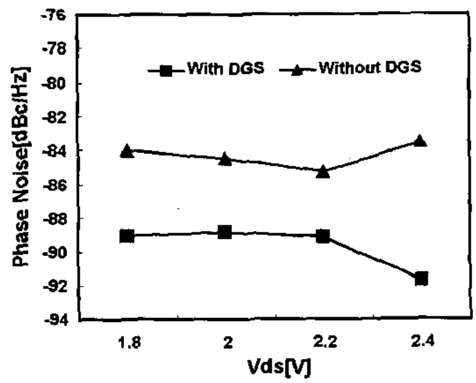
The measured phase noise performances of these two oscillators depending on the bias voltages are depicted in Fig. 5. The phase noise characteristics of the oscillator with DGS are lower than that of the oscillator without DGS by 6-8dB. In general, the quality factor of an oscillator is estimated as the slope of the total reactance versus frequency at the output port [11]. It is calculated that this reactance slope of the oscillator with DGS is 2.47 times that of the oscillator without DGS. This implies 7.8 dB phase noise improvement of the oscillator with DGS, which agrees well with the measured results.

The output powers of the oscillators with and without DGS are 1.4 dBm and 2.9 dBm respectively at Vds=2.4V and Vgs=-0.3V considering the conversion loss of the harmonic mixer and cable loss. It is believed that this is because the return loss of the DGS resonator is slightly larger than that of the conventional open stub line.

Fig. 6 shows the output spectrum of the oscillator with DGS resonator at Vds=2.4V and Vgs=-0.3V. It exhibits reduced phase noise performance of -91.7dBc/Hz at 1MHz offset.



(a)



(b)

Fig. 5. The phase noise characteristics of the oscillators with and without DGS at 1 MHz offset. (a) Vds=2.4V (b) Vgs=-0.3V

VI. Conclusion

The new application of the CPW-based spiral-shaped DGS to MMIC for the reduction of phase noise in V-band oscillator has been presented. The spiral-shaped defects or slots on the both ground planes in CPW cause the equivalent parallel inductor and capacitor circuit, and it is acted as a band rejection resonator for series feedback oscillator topology. Two kinds of V-band CPW MMIC oscillators with and without DGS were designed, fabricated and measured. Measurements show that the phase noise of the oscillator with DGS resonator is reduced by 8 dB compared to that of the oscillator without DGS resonator. It is expected that further optimization of the structure of the defects would lead to the improvement of the quality factor and resulting phase noise in CPW MMIC oscillators.

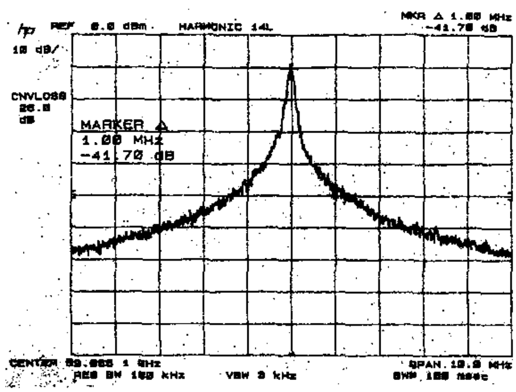


Fig. 6. The output spectrum of the oscillator with spiral-shaped DGS (Vds=2.4V, Vgs=-0.3V).

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