27 GHz Flip-Chip Assembled pHEMT Oscillator

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Abstract

In this paper, we present a microwave integrated circuit (MIC) with flip-chip assembled 0.15µm-gate pHEMT. Single transistor (pHEMT of 4×75 µm from WIN Semiconductor) with negative resistance combined with resonant network was designed for Ka-band oscillator. After characterizing the 0.15µm-gate pHEMT, the passive components and CPW connection were designed and fabricated on Al_2O_3 substrate with consideration of bump transition. The measured output signal was at 27.55 GHz while biasing at V_{DS} = 2 V and I_D = 50 mA (V_{GS} = -0.5 V), respectively. The measured signal output power is 1.87 dBm with consideration of cable loss. The corresponding phase noise is -84 dBc/Hz@1MHz offset. To our knowledge, this is the 1st flip-chip assembled pHEMT oscillator using feedback methodology at Ka-band.

INTRODUCTION

Flip-chip bonding technology applied to millimeter-wave circuits is attractive due to the shorter connection in reducing the parasitic elements while comparing to the bond-wire connection. MIC (microwave integrated circuit) with flip-chip assembled discrete transistors leads to the advantages including design flexibility, low cost and high yield. MICs with flip-chip assembled pHEMTs have been demonstrated excellent results including power and low-noise amplifiers in Ka-band [1] and amplifiers in Ka/V-band [2]. However, the electromagnetic interaction between chip and substrate limits the use of flip-chip assembly, especially in oscillators which require careful consideration in both magnitude and phase. This paper presents the 1st Ka-band flip-chip assembled pHEMT oscillator using feedback methodology.

FLIP-CHIP TECHNOLOGY AND CIRCUIT PERFORMANCE

The An/Sn materials is used and fabricated on carrier (Al_2O_3 substrate) for the bump in flip-chip technology. For high-frequency applications, both size and height of the flip-chip bump indeed affect the circuit performance significantly. How to reduce the parasitic capacitors and inductors due to the transit effect from flip-chip bump is an important issue. By using the 2.5D and 3D EM simulation, we simulated the bump characteristics with CPW connection to 50-Ω impedance [3]. Different bump heights and diameters were studied to optimize the return loss (S_{11}) for application at Ka-band. In Fig. 1, the simulation results show the Au/Sn bumps with height of 30-µm and diameter of 20-µm and 50-µm show better return loss than the bump with diameter of 80-µm. Fig. 2 shows the return loss is not a strong function of the bump diameters while bump diameter is 50-µm. With considering the fabrication and the circuit layout, the flip-chip Au/Sn bump with a diameter of 50-µm and a height of 30-µm was used for Ka-band applications.

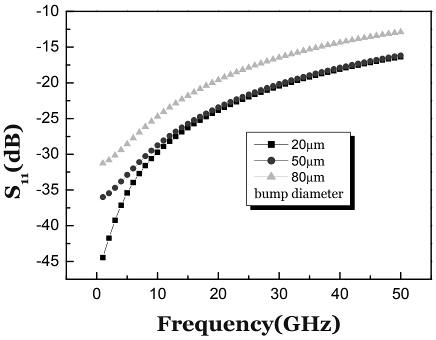


FIG. 1 THE SIMULATED RETURN LOSS OF FLIP-CHIP BUMP WITH DIFFERENT DIAMETERS (BUMP HEIGHT IS 30-µM)

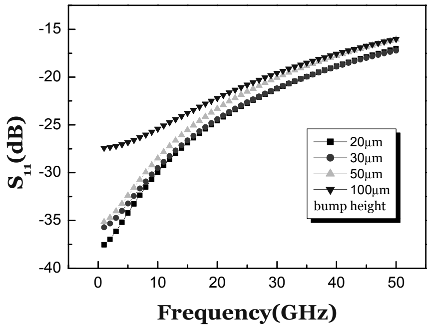


FIG. 2 THE SIMULATED RETURN LOSS OF FLIP CHIP BUMP WITH DIFFERENT HEIGHTS (BUMP DIAMETER IS 50-µM)

To implement the flip-chip bonding, carrier (Al_2O_3 substrate) and the chip (pHEMT) were heated to 300°C and 280°C, respectively, during bonding. The equivalent circuit of the pHEMT with flip-chip bump model is shown in Fig. 3 [4][5]. Fig. 4 shows the measured and calculated *S*-parameters of pHEMT flip-chip assembled on Al_2O_3 substrate. Good agreement has been achieved from 50 MHz to 40 GHz.

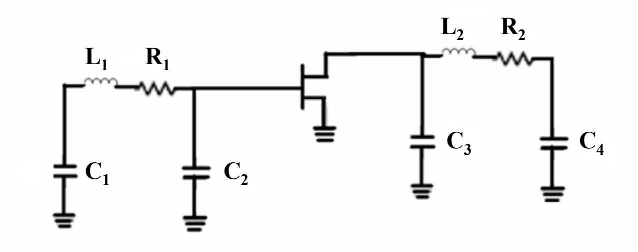
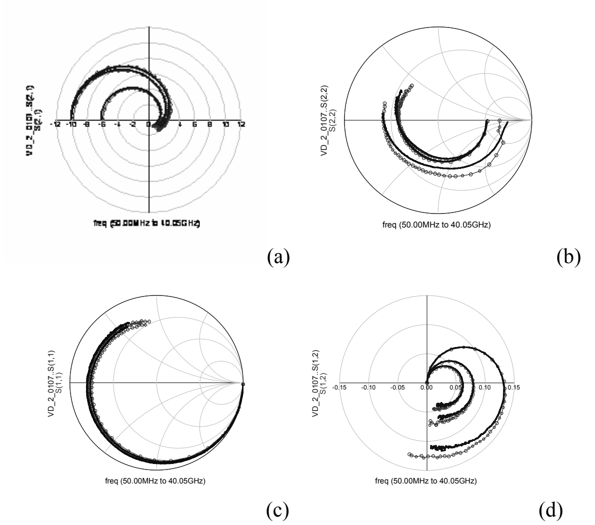


Fig. 3 The equivalent circuit of the pHEMT with flip-chip bump model.



(a) (b)

(c) (d)

Fig. 4 The measured and calculated S-parameters of pHEMT flip-chip assembled on Al_2O_3 substrate. (a) S_{21} (b) S_{22} (c) S_{11} (d) S_{12}

The extracted the equivalent circuit parameters of the Au/Sn flip-chip model are listed in Table I.

TABLE I

Extracted parameters for Au/Sn Flip-chip model

Parameters	Value
L_1 (pH)	30
R_1(Ω)	0.4
C_1 (fF)	10
C_2 (fF)	11
L_2 (pH)	30
R_2 (Ω)	0.4
C_3(fF)	11.67
C_4 (fF)	10.26

Flip-chip assembled Circuit performance

A single transistor with negative resistance combined with resonant network is designed for Ka-band oscillator [6]. A 0.15 µm pHEMT of 4×75 µm was used to simulate and implement the circuit with rf pads effect and flip-chip assembly equivalent circuit model. Fig. 5 shows the circuit diagram including device rf pad effect and flip-chip model.

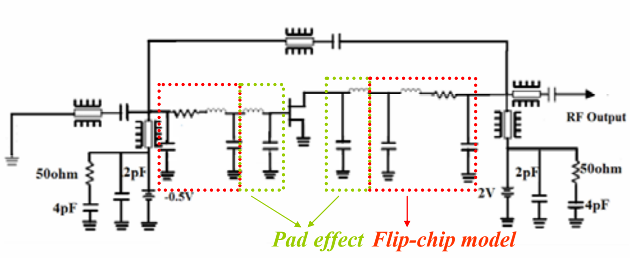
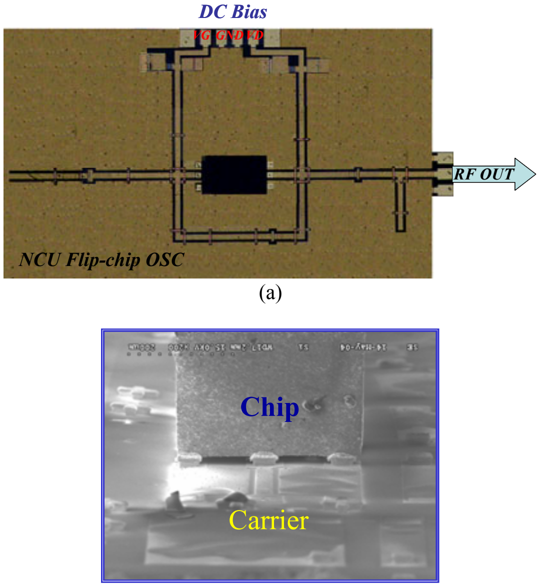


Fig. 5 The circuit diagram for a Flip-Chip Assembled pHEMT Oscillator

CPW passive elements and connections on Al_2O_3 substrate (carrier) were simulated by EM simulator. The equivalent circuit model for flip-chip assembly was implemented by series resistor and inductor with parallel capacitors. The bump material is Au/Zn and its height and size are 30 and 50µm, respectively, to obtain the lowest reflection while matching to 50Ω at Ka-band. Fig. 6 (a) shows the optical photo for the fabricated passive components and CPW connections on Al_2O_3 substrate (carrier) without pHEMT device. The size of the whole carrier is 2×2 mm. Fig. 5 (b) shows the SEM of the flip-chip assembled chip and carrier.



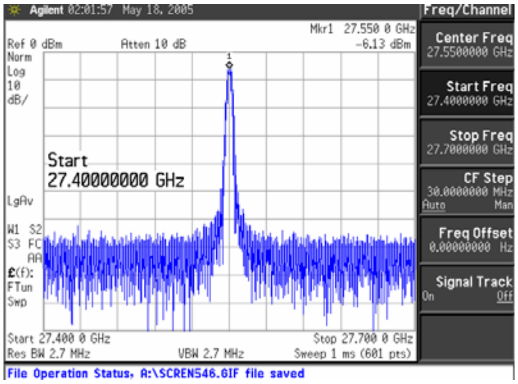
(a)

(b)

Fig.6 (a) Fabricated CPW passive elements and connections on Al_2O_3 substrate. The shadow area is dedicated for flip-chip

ASSEMBLED pHEMT. (B) SEM ON FLIP-CHIP ASSEMBLED CHIP FLIP-CHIP ASSEMBLED pHEMT OSCILLATOR

The designed oscillation frequency was at 30 GHz with 2 V power supply. The measured output signal was at 27.55 GHz while biasing at V_{DS} = 2 V and I_D = 50 mA (V_{GS} = -0.5 V), respectively. The measured signal output power without calibration is -6.13 dBm and 1.87 dBm with consideration of cable loss. Fig. 7 shows the measured output signal at 27.55 GHz with un-calibrated output power of -6.13 dBm. The measured results demonstrated the good agreement with simulation and feasibility of flip-chip technology for high-frequency circuit applications.



Start
27.40000000 GHz

Center Freq 27.5500000 GHz
Start Freq 27.4000000 GHz
Stop Freq 27.7000000 GHz
CF Step 30.0000000 MHz Auto Man
Freq Offset 0.00000000 Hz
Signal Track On Off

Start 27.400 0 GHz
Stop 27.700 0 GHz
Res BW 2.7 MHz
VBW 2.7 MHz
Sweep 1 ms (601 pts)

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FIG.7 MEASURED OUTPUT SIGNAL AT 27.55 GHZ

CONCLUSIONS

We have demonstrated a flip-chip assembled pHEMT oscillator at 27 GHz. A single transistor (0.15 µm-gate pHEMT) was used to implement a Ka-band oscillator with negative resistance combined with resonant network. The passive components and CPW connection were designed and fabricated on Al_2O_3 substrate first with consideration of bump transition. The measured output signal was at 27.55 GHz with output calibrated power of 1.87 dBm and phase noise of -84 dBc/Hz@1MHz offset, respectively. This flip-chip assembled pHEMT oscillator demonstrates the capability in integrating different components at high-fluency circuits.

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ACRONYMS

pHEMT: pseudomorphic High Electron Mobility Transistor
CPW: Coplanar Waveguide