낮은 변환손실과 높은 LO-RF 격리도 특성을 갖는 94 GHz Resistive Mixer 의 제작

이복형*, 이진구**
동국대학교 밀리미터파신기술연구센터

Fabrications of Low Conversion Loss and High LO-RF Isolation 94 GHz Resistive Mixer

Bokhyung Lee*, Jinkoo Rhee**
Millimeter-wave Innovation research center, Dongguk University
E-mail : *leebok@dgu.edu, **jkrhee@dgu.edu

Abstract

We report low conversion loss and high LO to RF isolation 94 GHz MMIC resistive mixers based on 0.1 μm InGaAs/InAlAs/GaAs metamorphic HEMT technology. The fabricated resistive mixers applied a one-stage amplifier on RF port of the mixer. By using the one-stage amplifier, we obtained the decrement of conversion loss and the increment of LO to RF isolation. So, we can obtain higher performances than conventional resistive mixers. The modified mixer shows excellent conversion loss of 6.7 dB at a LO power of 10 dBm. We also observed an extremely high isolation characteristic from the MMICs exhibiting the LO-RF isolation of 21 ± 0.5 dB in a frequency range of 93.7~ 94.3 GHz. The low conversion loss and high LO-RF isolation characteristics of the MMIC modified resistive mixers are mainly attributed to the performance of the MHEMTs exhibiting a maximum transconductance of 654 mS/mm, a current gain cut-off frequency of 173 GHz and a maximum oscillation frequency of 271 GHz .

I. Introduction

In the last decades, there have been exponential growths in the applications areas of millimeter-wave integrated IC(MIMIC) technology, such as military use (guidance weapons and radars), passive image sensor, and car accidents prevention system. In particular, a resistive mixer is widely used because of low distortion, good conversion loss, and no drain bias.

MMIC resistive mixers have been realized using high electron mobility transistor (HEMT) devices as the switching components. Therefore, a HEMT device with high switching performance is required to improve the conversion loss of resistive mixers. InP-based HEMTs can be employed for millimeter-wave resistive mixers due to their superior switching performance [1-2].

The HEMTs on InP substrates has demonstrated superior millimeter-wave and low noise performances compared to the PHEMTs on GaAs substrates.

The excellent device performances of the InP-based HEMTs operating in the W-band are mostly attributed to the high band-offset InGaAs/InAlAs/InP material system. However, compared to GaAs-based wafers, InP-based wafers have some critical drawbacks, such as the mechanical fragility of the wafers and the higher material cost. Moreover, InP-based HEMTs are not quite proper for large-scaled production because of the backside etching rate for the InP material is much slower. In recent decades, active research has been done on GaAs-based metamorphic HEMTs (MHEMTs) to address the needs for both high RF performance and low device cost.

The use of metamorphic buffers on GaAs substrates was introduced to accommodate the lattice mismatch between the substrate and the active layers, as well as to avoid the InP substrates. By using the metamorphic buffers, unstrained InGaAs/InAlAs hetero-structures could be grown over a wide range of indium contents for the InGaAs channels, thereby

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exhibiting device performances comparable to those of InP-based HEMTs. For this reason, significant effort has been made in the development of MHEMTs for millimeter-wave MMICs during the last decade [3-4], especially at a frequency of 94 GHz, where signal absorption is at a relative minimum.

In this paper, we have been designed and fabricated metamorphic MHEMT to develop a 94GHz MMIC resistive Mixer. We have been prepared CPW and passive components library to design the 94GHz MMIC mixer. We have been proposed a new circuit to reduce a disadvantage and problem of conventionally used single ended resistive and single balanced resistive mixer [5-6].

The disadvantages of above-mentioned mixers are follows: the single ended resistive mixer has a low LO to RF isolation property and the single balanced resistive mixer has a high LO to RF isolation property beside the Single-ended resistive but has a poor conversion loss property.

In this paper, the proposed mixer is constructed to add a MHEMT on RF port of single ended resistive mixer. The added MHEMT on RF port is to amplify RF signal, and this MHEMT can improve the LO to RF isolation performance because of the inherent S_{12} isolation characteristic.

II. DESIGN MOTIVATION AND PROCEDURE OF MODIFIED RESISTIVE MIXER

To improve isolation and conversion loss property of the mixer, we have been proposed a new design of 94GHz MMIC mixer. The proposed mixer has a good conversion loss property compare with a conventional single ended resistive mixer and has a good LO to RF isolation property compare with a conventional single balanced resistive mixer.

In figure 1, we show the circuit structure of proposed 94GHz MMIC resistive mixer. The structure of proposed mixer is constructed to add a MHEMT on RF port of the single ended resistive mixer. The added MHEMT is a role to improve conversion loss property and to improve the LO to RF isolation performance because of the inherent S_{12} isolation characteristic and S_{21} amplifying characteristics of MHEMT. In circuit of mixer, The MHEMT channel has a very linear resistor characteristic because of There is no bias on the drain port of MHEMT.

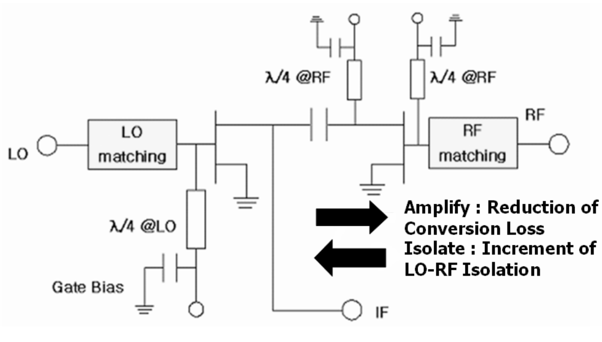


Figure 1. Proposed MIMIC Mixer Circuit Structure

This non-linearity characteristic of MHEMT arose at the fully accelerated condition of electron drift velocity. So, The MHEMT has a good linearity and the resistance of linear channel of MHEMT will modulate inducing a LO signal on gate port. The LO bias will change the total resistance of channel using a modulation of depletion region thickness.

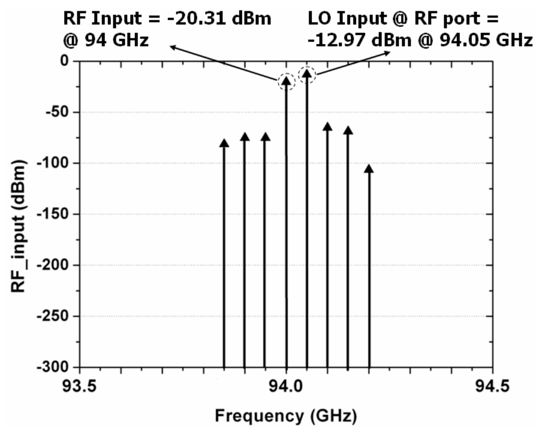
The resistances of MHEMT channel are modulated by gate bias. In the condition of over turn-on voltage, the channel resistance will be an infinity and the under turn-on voltage will be a few ohm. This modulation region of channel resistance will be a major role for good conversion loss characteristics of mixer.

Also, the MHEMT on RF port will be roles of RF signal amplification and isolation for the decrement of conversion loss and the increment of LO to RF isolation.

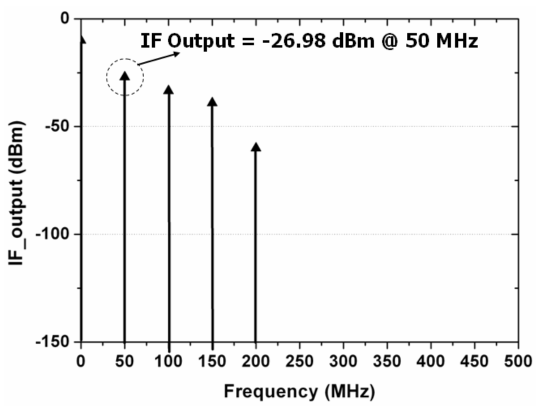
The LO and RF matching circuits have been designed by CPW lines and the bias circuits of LO, RF ports are designed by λ/4 short stub.

On the simulation results, we have been obtained conversion loss of -6.9 dB at 94 GHz on the conditions of the RF input of -20 dBm and LO input of 13 dB. The LO to RF isolation characteristics of mixer are obtained of 26 dB on the conditions of the LO input of 13 dBm and RF output of -12.9 dBm.

In figure 2, we show the simulation results of the input, output spectrum characteristics.



(a) RF spectrum



(b) IF spectrum

Figure 2. Input, Output Spectrum Simulation Results

The designed MMIC resistive mixer is consisted of the total seven pieces of Mask layout (Mesa, Ohmic, Ti resistor ,First metal, Dielectric via, PR via and Air-bridge) and the chip size of designed mixer is 2.2 mm × 1.2 mm.

III. FABRICATION AND MEASUREMENT RESULTS

In this paper, we have been designed and fabricated the 94 GHz region MMIC resistive mixer by using the metamorphic HEMT technology and the passive elements library.

In figure 3, we show the employed epitaxial structure of MHEMT for the designed 94 GHz MMIC resistive mixer. The epitaxial structures for the MHEMTs were grown on 4-inch semi-insulated (100) GaAs substrates by using a molecular beam epitaxy (MBE). Graded buffer layers of 1 μm thick $In_xAl_{1-x}As$ were grown on the substrates by linearly grading the indium mole fraction of x from 0 to 50 %; thereafter, 400 nm-thick $In_{0.52}Al_{0.48}As$ buffer was grown to protect the active layers from the potential impurities coming from the underlying structures.

On top of the buffers, active layers with 23 nm $In_{0.53}Ga_{0.47}As$ channel layer were grown with double Si delta-dopings. Very thin n+ $In_{0.53}Ga_{0.47}As$ cap layer was then grown to provide ohmic contacts at the source and the drain regions. The measured electron sheet density and Hall mobility of the grown epitaxial layers at room temperature were about 3.4×10^{12} /cm^2 and 9700 cm^2/V·sec, respectively

$In_{0.53}Ga_{0.47}As$	**6 x 10^{18}/cm^3**	**15 nm**
$In_{0.52}Al_{0.48}As$	**undoped**	**15 nm**
	δ-doping 4.5x10^{12}/cm^2	
$In_{0.52}Al_{0.48}As$	**undoped**	**3 nm**
$In_{0.53}Ga_{0.47}As$	**undoped**	**23 nm**
$In_{0.52}Al_{0.48}As$	**undoped**	**4 nm**
	δ-doping 1.3x10^{12}/cm^2	
$In_{0.52}Al_{0.48}As$	**undoped**	**400 nm**
$In_xAl_{1-x}As$ (x= 0～0.5)	**undoped**	**1000 nm**
	S.I. GaAs substrate	

Figure 3. Epitaxial Structure of Metamorphic HEMT

We have been fabricated the resistive mixer using a designed epitaxial layer shown in the figure 5, and the employed units processes are explained following sequences: First, Mesa etching process for the electric isolation between active device and other devices by removing an ~200 nm thickness in an etchant of phosphoric acid/H_2O_2/H_2O (1:1:60). And the ohmic contacts are constituted by using the thermal evaporation of AuGe/Ni/Au (125/28/160 nm) layers and rapid thermal annealing at 300 ℃ for 60 sec. The measured specific contact resistance of the ohmic contacts was ~1×10^{-7} Ω·cm^2. The 0.1 μm off-set Γ-shaped gate was patterned by lift-off with PMMA/P(MMA-MAA)/ PMMA(100/600/200nm) using an 30-keV electron beam lithography system and the remaining electron beam resist is removed on a O_2 plasma ashing process.

The gate recess was performed by selectively etching the cap layers in a succinic acid/H_2O_2/H_2O (1:5:10) solution. Gate Schottky metals were formed by evaporating Ti/Au (50/400 nm) stacks followed by the lift-off. Prior to the air-bridge interconnection, a 78 nm Si_3N_4 passivation layer was deposited in a plasma-enhanced chemical vapor deposition system

The DC and transfer characteristics of fabricated MHEMT are measured by using a HP 4156A semiconductor parameter analyzer. We show the measured DC characteristics of fabricated MHEMT. The pinch off voltage of -1.5 V, drain saturation current of 89.6 mA at V_{gs} of 0V, and maximum transconductance of 654 mS/mm are measured respectively.

The S-parameters of fabricated MHEMT are measured by suing a ME7808A Vector Network Analyzer from 0.1 to 65 GHz. In Figure 4, we show the RF characteristics of MHEMT. The S_{21} gain, f_t and f_{max} of the measured Mixers are S_{21} gain of 6.63 dB, f_t of 173 GHz, and f_{max} of 271 GHz, respectively.

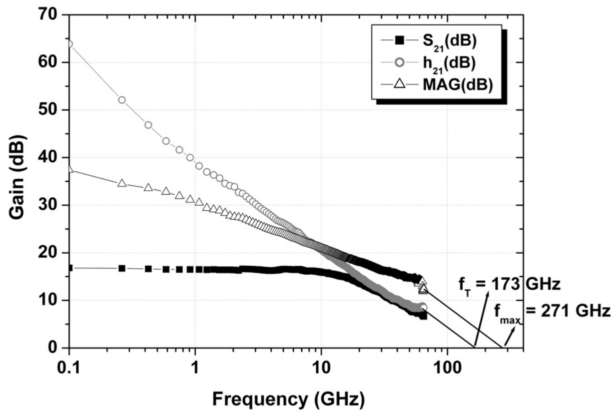


Figure 4. Mesured RF Characteristics of the Metamorphic HEMT

The fabrication processes of the MMIC resistive mixer consisted of the active device processes using a MHEMT and the passive device processes using the CPW line, resistor, and capacitor.

In figure 5, we show the plan view of the fabricated MMIC mixer.

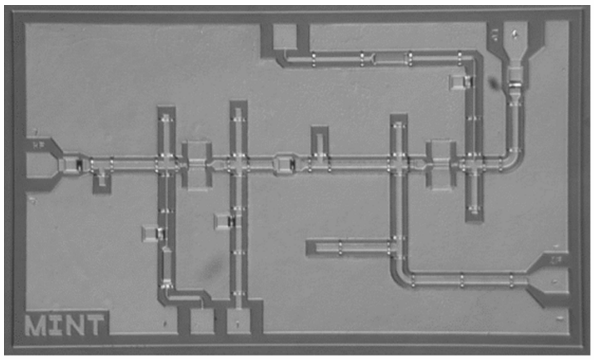


Figure 5. Fabricated MIMIC single-ended resistive mixer

The fabricated mixers were measured by using the probe station and the W-band region probe. To measure the IF signal power, we are used the RF input of 93.798 GHz and LO input power of 10 dBm. The measured conversion loss values are obtained of 6.7 dB and the input and output P1 dB are measured of 10 dBm and 1.6 dBm, respectively. The measured characteristics of the fabricated MMIC mixer have a good agreement compare to the design values. The conversion loss measurement results versus RF input are shown in figure 6 and the IF output power characteristics versus RF input are indicated in figure 7. In figure 8, we show the LO to RF isolation characteristics of MIMC resistive mixer.

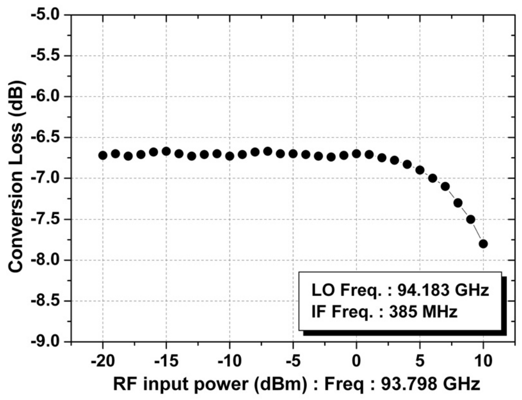


Figure 6. RF Input versus Conversion Loss

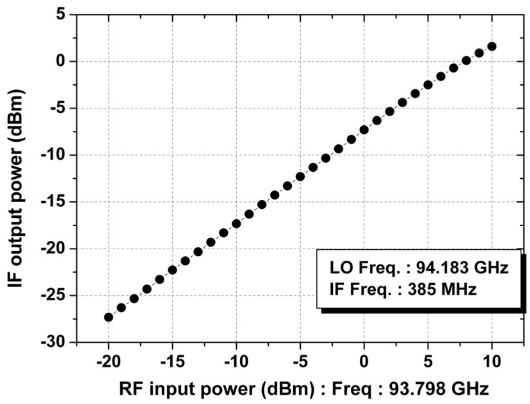


Figure 7. RF Input versus IF Output Power

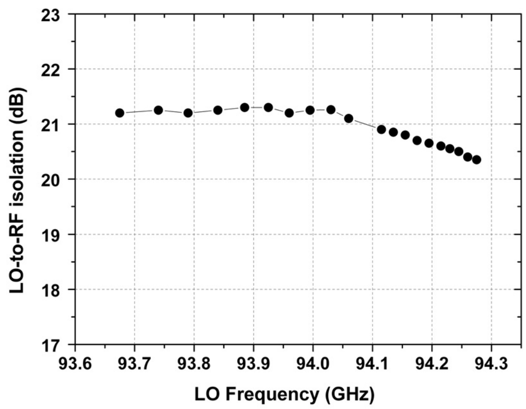


Figure 8. LO to RF Isolation Characteristic

IV. Conclusion

In this paper, we have been designed and fabricated the 94 GHz modified single resistive mixer by using a RF amplifier to improve the performances of conventional single resistive mixer. The DC performances of MHEMT on RF amplifier have been measured on the pinch-off voltage of -1.5 V, drain saturation current of 89.6 mA at V_{gs} of 0 V, and maximum transconductance of 654 mS/mm, respectively. And, we show the RF characteristics of MHEMT. The RF performances of the MHEMT are S_{21} gain of 6.63 dB, f_t of 173 GHz, and f_{max} of 271 GHz, respectively. The fabricated mixer has the excellent conversion loss and isolation property. The conversion loss of 6.7 dB at a LO power of 10 dBm and the LO-RF isolation of 21 ± 0.5 dB in a frequency range of 93.7~ 94.3 GHz. And the input, output P1 dB of 10 dBm and 1.6 dBm are measured, respectively.

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