InP MMICs FOR V-BAND FMCW RADAR

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ABSTRACT

We have developed InP based MMICs for V-band frequency modulated continuous waves (FMCW) radar. For the transistor of these MMICs, we used the InAlAs/InGaAs on InP pseudomorphic high electron mobility transistor (HEMT) with a 0.5μm gate length. Because of the high electron mobility and the high sheet charge density, the HEMT performed with sufficient output power gain in the millimeter-wave frequency range. Millimeter-wave circuitry consists of four kinds of MMIC chips; 30GHz voltage controlled oscillator (VCO), 30/60GHz frequency doubler, 60GHz amplifier and 60GHz single-balanced mixer. And we have made a prototype experiment of radar transceiver utilizing these MMICs and confirmed FMCW radar operation.

INTRODUCTION

Recently there has been considerable interest in developing millimeter-wave radar for the intelligent cruise control and the collision avoidance systems. Various research on the automotive millimeter-wave radar has been carried out [1][2], but the automotive radar systems have not yet gone into production. Low productivity and the high costs of the millimeter-wave devices have prevented the practical use of the automotive radar.

The millimeter-wave MMIC is one potential solution. In the MMIC, all the devices such as transistors, transmission lines, stubs and capacitors are integrated into the chip during the IC process. The MMIC technology enables the minimization of the millimeter-wave circuit, thus resulting in a reduction in cost and improvement in production yield.

We are developing MMICs for the FMCW radar. As the transistors in the MMICs, we used the HEMTs with the InAlAs/InGaAs pseudomorphic heterostructure on the InP substrate. In order to achieve higher productivity, the gate length of the HEMT was set to 0.5μm, and was formed using conventional photo-lithography. Because of the high mobility and the high sheet charge density of the InAlAs/InGaAs pseudomorphic structure, the HEMT showed sufficient performance for the V-band transceiver.

In the following section, we describe the configuration of the FMCW radar, the structure and performance of the HEMT, the design and performance of the MMICs , and the prototype experiment of the radar transceiver.

FMCW RADAR TRANSCEIVER

The FMCW radar transceiver has a simple configuration and requires less output power than other radar systems, such as pulsed radar [3]. In addition, the distance and the velocity of the target can be detected simultaneously. Figure 1 shows the configuration of the FMCW radar transceiver.

The VCO outputs 30GHz-band frequency modulated signal, and the frequency doubler doubles 30GHz signal up to 60GHz-band RF signal. Next, it is amplified by the amplifier and transmitted from the antenna. The received RF signal, which is reflected from a target, is amplified by the low noise amplifier (LNA) and mixed with the local signal, which is fed from the output terminal of the frequency doubler, in the homodyne mixer. And the beat signal is output from IF terminal.

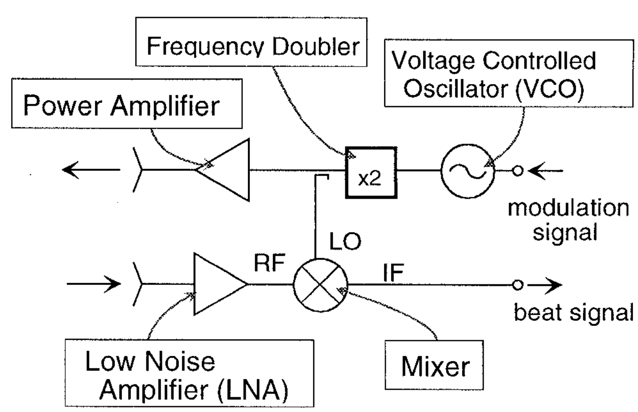

Figure 1. Configuration of the FMCW Radar

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ACTIVE DEVICE AND PASSIVE ELEMENT

For the active device of the MMICs we used a HEMT. Figure 2 shows the cross-sectional view of the HEMT. This HEMT is characterized by the 0.5μm-long rectangular gate electrode. In general, a 0.1 to 0.2μm T-shaped gate is used for the microwave or millimeter-wave transistors in order to achieve the high frequency operation. However, the formation of such a short and complex-shaped gate requires using the electron beam (EB) lithography technique. A gate longer than 0.5μm, that could be formed using the conventional photolithography technique, would be more easily produced than a T-shaped gate.

To attain sufficient output power gain in the HEMT for the millimeter-wave FMCW radar with a 0.5μm-long rectangular gate, we used the InAlAs/InGaAs pseudomorphic heterostructure for the active layer. The heterostructure for the HEMT was grown using molecular beam epitaxy on the semi-insulating InP substrate. The HEMT is characterized by the original $In_{0.52}Al_{0.48}As/In_{0.8}Ga_{0.2}As$ on InP structures. In this structure, the pseudomorphic $In_{0.8}Ga_{0.2}As$ channel has the higher electron mobility and the higher electron sheet charge density compared with the $In_{0.53}Ga_{0.47}As$ lattice-matched channel because of the high indium content in InGaAs[4]. In addition, the $In_{0.53}Ga_{0.47}As$ sub-channel, inserted at the $In_{0.52}Al_{0.48}As/In_{0.8}Ga_{0.2}As$ hetero-interface, enhances the electron mobility by reducing the electron diffraction. As a result, the excellent performance of the mobility (13,000cm^2/Vs) and the sheet charge density ($3\times10^{12}cm^{-2}$) are obtained at room temperature. Due to the excellent InAlAs/InGaAs structure, the HEMT performs well in millimeter-wave range in spite of long gate length.

Figure 3 shows the measured output power gain of the InAlAs/InGaAs pseudomorphic HEMT. The gate length is 0.5μm and the total gate width is 50μm with two fingers. In spite of the longer gate, this HEMT showed good performance in the millimeter-wave frequency range. The maximum stable power gain Gms was 15dB at 30GHz and 11dB at 60GHz, respectively. This performance was due to the excellent mobility and sheet charge density of the InAlAs/InGaAs pseudomorphic heterostructure.

The HEMTs are integrated onto the InP substrate with the passive elements such as transmission lines, stubs and resonators. All the passive elements are formed by the co-planner waveguide (CPW). In general, the microstrip configuration is widely used for the passive elements. However, for the formation of the microstrip structure, the electrode must be fabricated both sides of the substrate, and via-holes are needed. These complicated structure and manufacturing process are the problems of MMICs production. Compared with the conventional MMICs, our MMICs has the simple configuration of rectangular-gate-HEMTs and CPW components. These structures will improve the productivity of MMICs.

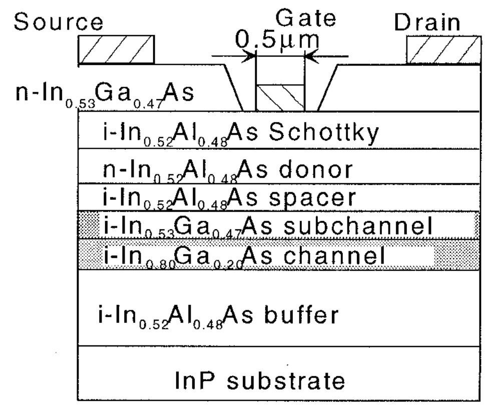

Figure 2. Cross-sectional View of the HEMT

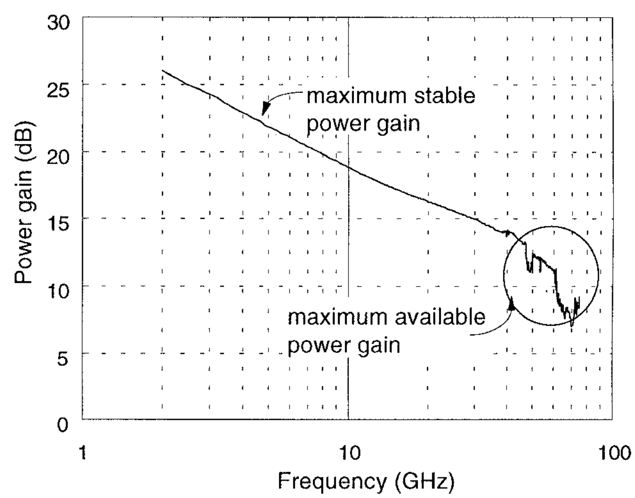

Figure 3. Measured Power Gain of the HEMT

MMIC DESIGN

We have developed four kinds of MMIC chips; 30GHz VCO, 30/60GHz frequency doubler, 60GHz amplifier and 60GHz single-balanced mixer. The schematic designs of the power amplifier and the LNA are same. Because the output power of the power amplifier was less than 10dBm, we adopted low noise designing for the power amplifier. The central frequency of circuit design is 59.5GHz, because the Japanese regulated band for millimeter-wave experiment is from 59 to 60GHz. Therefore the oscillation frequency of the VCO is 29.75GHz. The circuit designs were carried out by using microwave circuit simulation programs named "Libra". Because there were not so many CPW element models in the circuit simulation programs, we extracted original CPW passive element models using electromagnetic field simulation programs named "HFSS" and "em".

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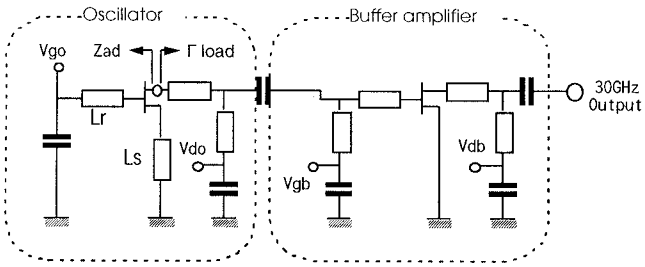
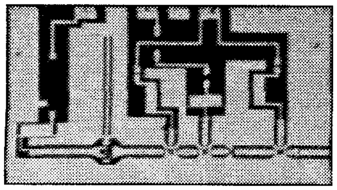
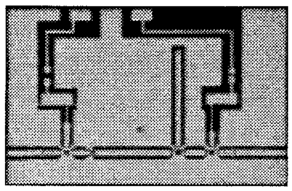


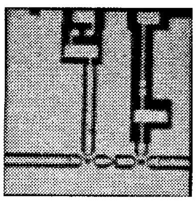
Figure 4. Schematics of the VCO



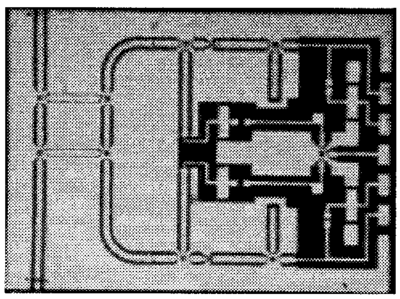
(a)VCO



(b)Frequency Doubler



(c)Amplifier



(d) Single-Balanced Mixer

figure 5. MMIC photographs

[VCO]

The VCO is composed of an oscillator and a buffer amplifier. The schematics of the VCO is shown in Figure 4 and the micrograph is shown in Figure 5(a). The VCO is integrated into the 3mm×1.7mm MMIC chip. The oscillator has a common-source series feedback configuration. The transmission line Lr, being connected to the gate, works as a resonator. The capacitive stub Ls is connected to the source as the feedback element. The gate bias Vgo works as a frequency control voltage for frequency modulation.

The oscillation frequency mainly depends on the length of Lr, and the feedback strength and the output power depend on both the output resistance of the HEMT Re(Zad) and the load impedance Γload. Tuning the output power to be maximum stabilizes the oscillation frequency, but the controllability of the frequency impaired. Because the linearity in the frequency sweep are important for the FMCW signal source, we arranged the feedback and matching circuit to lower the output power in order to maintain the linearity. The buffer amplifier is connected to the output terminal of the oscillator. This amplifier has a simple common source single-stage configuration.

[Frequency Doubler]

The micrograph of the frequency doubler is shown in Figure 5(b). The doubler has a common source configuration, and is integrated into the 2.7mm×1.7mm MMIC chip. The 30GHz input matching circuit is connected to the gate terminal. And a 30GHz shorted circuit and a 60GHz output matching circuit are connected to the drain terminal. The 30GHz shorted circuit is made using a quarter-wavelength open stub. For the purpose of improving conversion gain, we have inserted transmission line between the drain terminal and the 30GHz shorted circuit.

[Amplifier]

The micrograph of the amplifier is shown in Figure 5(c). The amplifier has a common source configuration, and is integrated into the 1.7mm×1.7mm MMIC chip. The amplifier is used for magnifying the output of frequency doubler and is also used for magnifying the received signal.

[Single-balanced Mixer]

The micrograph of the single-balanced mixer is shown in Figure 5(d). We used single-balanced mixer because of the reduction of local signal noise. The single-balanced mixer has a gate injection configuration, and is integrated into the 2.7mm×3.7mm MMIC chip. RF input and Local input are mixed through the 3dB CPW branch line coupler.

RESULTS

Figure 6 shows the measured oscillation frequency and output power of the VCO. The VCO oscillated at 29.726GHz at Vgo=-0.4V and 28.857GHz at Vgo=+0.1V, with an output power changing from 1 to 2dBm. By changing the gate bias voltage, the frequency is modulated quite linearly and the modulation bandwidth is over 800MHz.

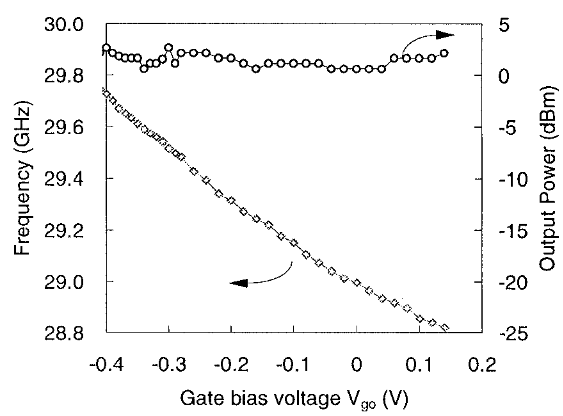


Figure 6. Measured Data of the VCO

Table 1 shows the main performances of MMICs. The conversion gain of the frequency doubler is 3.7dB and the output power is 1dBm. The small-signal gain of the amplifier is 7dB and the saturation output power is 8dBm. And the single-balanced mixer performed with the conversion gain of -5dB with the 0dBm local input power.

Table 1. Characteristics of MMICs

30GHz-VCO	Oscillation Frequency	28.857-29.726[GHz]
	Output Power	2[dBm]
30/60GHz-Doubler	Conversion Gain	3.7[dB]
	Output Power	1[dBm]
60GHz-Amplifier	Small Signal Gain	7[dB]
	Output Power	8[dBm]
60GHz-Mixer	Conversion Gain	-5[dB]
	Local Power	0[dBm]

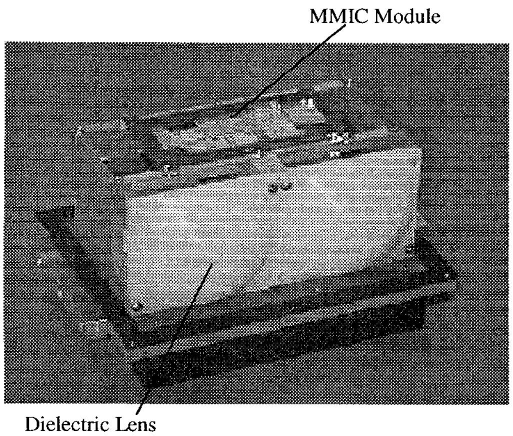


Figure 7. Photograph of the FMCW Radar Transceiver

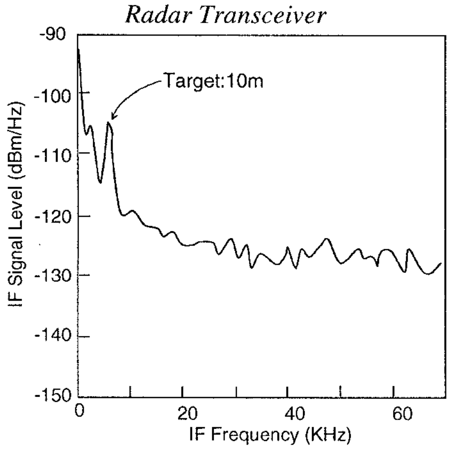


Figure 8. Measured IF Spectrum of the FMCW Radar

We also developed 60GHz-band microstrip antennas fed by co-planar waveguide slot. These antennas, which are worked as radiators, are combined with the dielectric lens and built the lens antennas. And finally, a FMCW transceiver is assembled by mounting all the MMICs such as VCO, frequency doubler, amplifiers and mixers on the metal carrier and connecting them to the antennas (Figure 7). The transmitted frequency of the FMCW transceiver is controlled in the 60GHz band by applying triangular waves into the VCO. The reflected signal from the experimental target is received by the transceiver and we confirmed FMCW radar operation by observing the IF spectrum(Figure 8). Therefore our InP based MMICs, which has the simple configuration of rectangular-gate-HEMTs, are sufficient for V-band radar.

CONCLUSIONS

We have developed a InP based V-band MMICs; 30GHz VCO, 30/60GHz frequency doubler, 60GHz amplifier and 60GHz single-balanced mixer for the automotive FMCW radar transceiver.

We used the InAlAs/InGaAs pseudomorphic HEMT on the InP substrate as the transistors in the MMICs. The gate electrode of the HEMT was a 0.5μm-long rectangular gate which could be formed using the conventional technique. Because of the high electron mobility and the high sheet charge density of the InAlAs/InGaAs pseudomorphic heterostructure, the HEMT showed excellent performance of the maximum stable power gain.

The VCO oscillated from 28.857GHz to 29.726GHz with 2dBm output power. The frequency doubler converted 29.75GHz input with 3.7dB gain. Small signal gain of the single-stage amplifier was 7dB and maximum output power was 8dBm. The single-balanced mixer converted 59.5GHz input with 5dB loss.

And we have made a prototype experiment of radar transceiver utilizing these MMICs and confirmed FMCW radar operation.

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