76GHz FLIP-CHIP MMICS FOR AUTOMOTIVE RADARS

T. Shimura, Y. Kawasaki, Y. Ohashi, K. Shirakawa, T. Hirose, S. Aoki, H. Someta, K. Makiyama, and S. Yokokawa*

Fujitsu Laboratories Ltd.
4-1-1 Kamikodanaka, Nakahara-ku, Kawasaki 211-8588, Japan
*Fujitsu Quantum Devices Limited
10-1 Morinosato-Wakamiya, Atsugi 243-0197, Japan

ABSTRACT

Using the flip-chip bonding technique, we developed a 76-GHz MMIC chip set for automotive radars. A chip set consists of a 76-GHz amplifier, a 76-GHz mixer, 76-GHz SPDT switches, a 38/76-GHz doubler, a 38-GHz voltage-controlled oscillator and a 38-GHz buffer amplifier.

INTRODUCTION

The millimeter-wave automotive radar is expected to improve driving safety. In order to make installation practical and widespread, developing a lower cost, reliable millimeter-wave module is necessary [1],[2]. Many kinds of MMICs for the millimeter-wave automotive radar have already been developed. In general, however, these MMICs are assembled on a substrate using a conventional face-up wire bonding technique. MMICs cannot be assembled on a substrate with a short interconnection length using an automatic wire bonding tool. Many studies already have indicated that interconnection using a wire bonding technique leads to a drastic increase in the loss and reflection coefficient, especially at high frequencies [3],[4]. The flip-chip bonding technique is one of the keys for solving the above problems since it has a shorter interconnection length and an automatic bonding procedure. The mechanical and thermal reliability of the flip-chip bonding technique for millimeter-wave applications which uses gold pillars has been reported on [5]. By applying this technique, it is possible to reduce the assembly costs and realize low-cost RF modules.

In order to actually develop the flip-chip MMIC, it is necessary to model the flip-chip transmission line and optimize the structure of the signal transition part between the mounting substrate and the MMIC chip. This is because of coupling effects which exit between the ground and the line, and between the ground and the pillars.

We developed a 76-GHz MMIC chip set for automotive radars using the flip-chip bonding technique and the 0.15-μm InGaP/InGaAs HEMT process. We characterized the flip-chip transmission line and optimized the structure of the signal transition part in order to design flip-chip MMICs accurately and realize high RF performance. Our chip set consists of a 76-GHz amplifier, a 76-GHz mixer, 76-GHz SPDT switches, a 38/76-GHz doubler, a 38-GHz voltage-controlled oscillator (VCO), and a 38-GHz buffer amplifier.

FLIP-CHIP MMIC TECHNOLOGY

Figure 1 shows an example of the flip-chip MMIC on the mounting substrate. The mounting substrate, which is made of alumina ceramic, has DC and RF feed lines with the coplanar waveguide (CPW) transmission lines and Sn bonding pads on its surface. The MMIC chip having gold pillars which are 40 μm in diameter and 20 μm in height was mounted on the alumina substrate using a pulse-heat tool [5].

We adopted the CPW transmission line on the MMIC chip and mounting substrate for the following two reasons. First, using pillars, it enables short interconnections between CPW transmission lines.

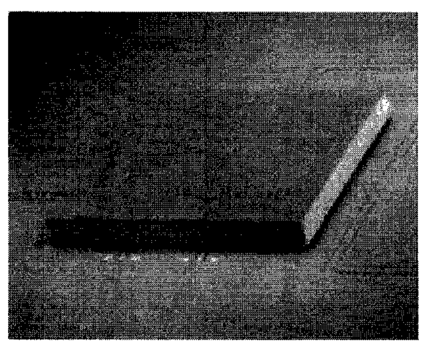

Figure 1. SEM microphotograph of the flip-chip MMIC on the mounting substrate.

0-7803-4471-5/98/$10.00 (c) 1998 IEEE

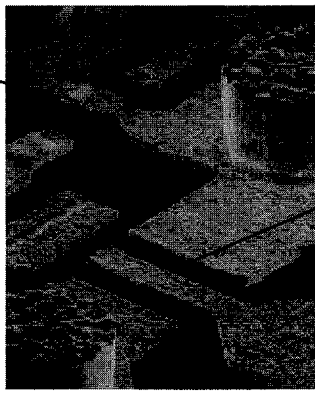

Figure 2. SEM microphotograph of the grounded pillars beside the HEMT.

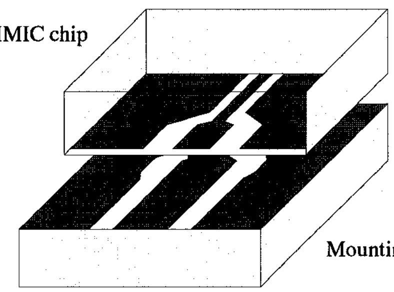

Figure 3. Signal transition part between the mounting substrate and the MMIC chip.

It can minimize the influence of the ground transition between the mounting substrate and the MMIC chip on account that it shortens the interconnected length between each ground as well as between signal lines. Secondly, we can place the pillars flexibly on the MMIC chip. To stabilize the MMIC ground, to avoid the excitation of unexpected modes and to radiate heat which active devices generate, the grounded pillars inside MMIC chip as well as near chip edge are necessary. Figure 2 shows a SEM microphotograph of the grounded pillars beside the HEMT.

Actually in order to develop the flip-chip MMIC, it is necessary to optimize the structure of the signal transition part between the mounting substrate and the MMIC chip, and to model the flip-chip transmission line. The coupling effects between a signal transmission pillar and the ground on the mounting substrate, and between a signal transmission pillar and the ground on the MMIC chip cause an unexpected impedance mismatch. To reduce the unexpected mismatch, we widened the CPW line-to-ground gaps on the MMIC chip and the mounting substrate slightly as shown Figure 3. The proximity of the CPW transmission line on the MMIC chip to the ground on the mounting substrate due to the shortening of the pillar height induces little change in the propagation constant and characteristic impedance. To design circuits accurately, we modeled the flip-chip CPW transmission line from the simulation and measurement. We fabricated test modules without the signal transmission pillars in order to extract the parameters of the flip-chip CPW transmission line. The test module consists of a GaAs chip with the CPW transmission lines and pillars, and a metal lid. The effective dielectric constant and characteristic impedance were extracted as 5.4 and 49 ohm, respectively, from the measured data for a line width of 20 μm, a gap of 20 μm, and a distance of 20 μm from the line to the metal lid.

We fabricated the MMICs using the 0.15-μm pseudomorphic InGaP/InGaAs HEMT process. The HEMT having a 0.15 μm long and 80 μm wide gate has a maximum stable gain of 10 dB at 77 GHz. Gold pillars were fabricated on the MMICs by electroplating.

FLIP-CHIP MMIC CHIP SET

[76-GHz amplifier]

Figure 4 shows a microphotograph of the amplifier. The amplifier has a two-stage configuration with 80-μm HEMTs. An open-circuited stub is used in the input matching circuit. To reduce the chip size, short-circuited stubs are used in the inter-stage and output matching circuits. Each short-circuited stub is composed of a transmission line and a grounded MIM capacitor. To avoid unexpected lower frequency oscillation, stability circuits are used in bias circuits. these are composed of capacitors and resistors. Figure 5 shows the measured S-parameters of the amplifier. The amplifier has a small-signal gain of 10.6 dB at 76.5 GHz.

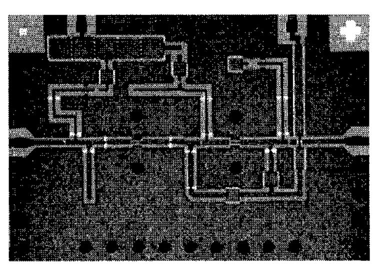

Figure 4. Microphotograph of the 76-GHz amplifier. The chip area is 1.2 x 1.9 mm^2.

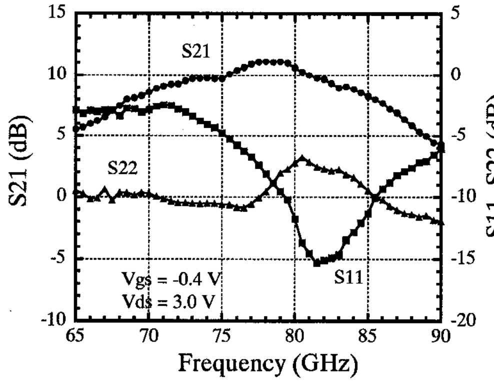

Figure 5. Measured S-parameters of the 76-GHz amplifier.

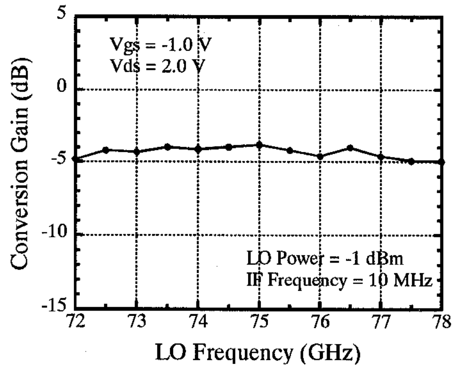

Figure 7. Measured conversion gain of the 76-GHz mixer.

[76-GHz mixer]

Figure 6 shows a microphotograph of the mixer. The mixer has a singly balanced configuration. The mixer consists of a pair of 80-μm HEMTs, a 0-π hybrid circuit, and matching circuits. The RF and LO signals are fed into each HEMT's gate through the 0-π hybrid circuit. The 0-π hybrid circuit consists of a quarter-wavelength transmission line and a branch line hybrid circuit. The mixer using the 0-π hybrid circuit exhibits good isolation between the RF and LO ports even if the unit mixers have large reflection coefficients. Also, the mixer reduces AM noise from the LO in cooperation with an external IF 180-degree hybrid circuit. Figure 7 shows the measured conversion gain of the mixer. The mixer has a conversion gain of -4 dB at 76-GHz LO frequency for an LO power of -1 dBm.

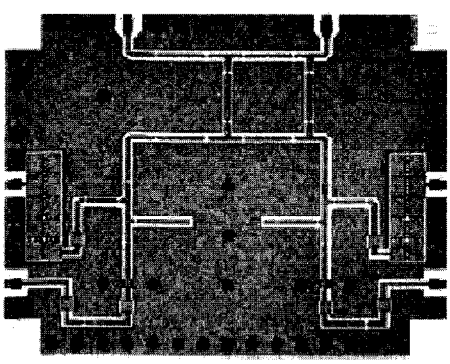

Figure 6. Microphotograph of the 76-GHz mixer. The chip area is 1.9 x 2.4 mm^2.

[76-GHz SPDT switches]

We developed two types of 76-GHz SPDT switches. Figure 8 shows microphotographs of the 76-GHz SPDT switches. Type I consists of two parallel-resonated 160-μm HEMTs. The transmission line connected to the drain and source terminals of the HEMT is employed as the resonant inductor in parallel with the fringing capacitance [6]. The obtained insertion loss and isolation are 3.4 dB and -17 dB, respectively, at 76.5 GHz. Type II consists of two parallel-resonated 80-μm HEMTs. To improve isolation, the short-circuited stub is joined at the center of the transmission line connected to the drain and source terminals of the HEMT. The switch has an insertion loss of 5.0 dB with an isolation of -28 dB at 76 GHz.

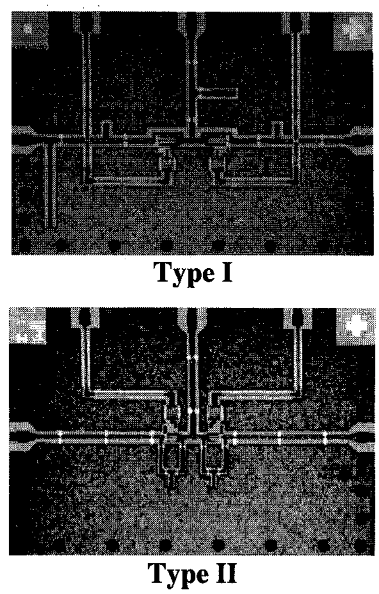

Figure 8. Microphotographs of the 76-GHz SPDT switches. Each chip has an area of 1.2 x 1.9 mm^2.

[38/76-GHz doubler]

Figure 9 shows a microphotograph of the doubler. The 38/76-GHz doubler chip consists of two single-ended 80-μm HEMT frequency doublers and a branch line hybrid circuit. This circuit configuration leads to low input return and high isolation between the two output ports. Open-circuited stubs are used in the single-ended doubler to reject fundamental frequency signals on the output side and 2nd harmonic signals on the input side. Short-circuited stubs act as bias circuits and as matching circuits in cooperation with open-circuited stubs. Figure 10 shows the measured frequency response of the doubler. The doubler has a conversion gain of -3.7 dB for a 3-dBm, 38.25-GHz input signal.

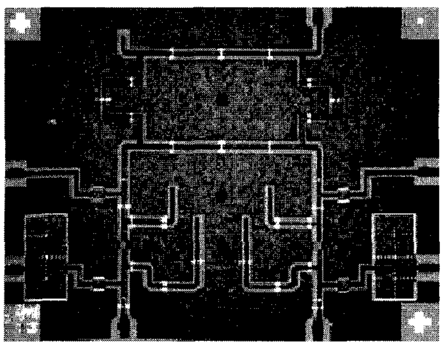

Figure 9. Microphotograph of the 38/76-GHz doubler. The chip area is 1.9 x 2.4 mm^2.

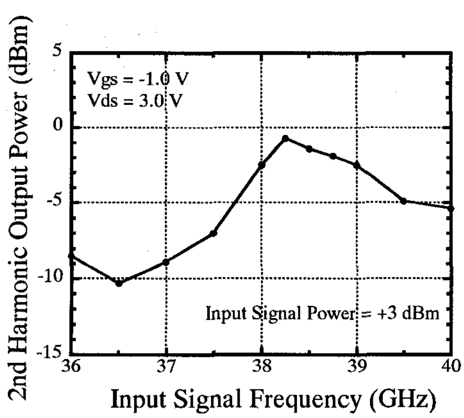

Figure 10. Measured frequency response of the 38/76-GHz doubler.

[38-GHz VCO and 38-GHz buffer amplifier]

Figure 11 shows a microphotograph of the 38-GHz VCO. An 80-μm HEMT is used to generate negative resistance. To generate enough negative resistance and reduce the source feedback circuit size, we adopted the reverse channel HEMT configuration [7]. The oscillator uses the transmission line resonator terminated by a 160-μm schottcky-barriar diode as a varactor. The 38-GHz buffer amplifier has a single-stage configuration with an 80-μm HEMT. The amplifier provides impedance isolation between the oscillator and the external load. The oscillator followed by the amplifier has an output power of -0.7 dBm at 39.6 GHz.

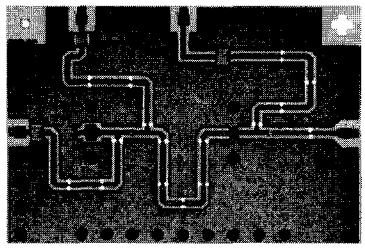

Figure 11. Microphotograph of the 38-GHz VCO. The chip area is 1.2 x 1.9 mm^2.

CONCLUSION

Using the flip-chip bonding technique, we developed a 76-GHz MMIC chip set for automotive radars. The flip-chip MMIC technology promises to reduce the total RF module cost.

REFERENCES

[1] H. H. Meinel, "Commercial Applications of Millimeterwaves History, Present Status, and Future Trends," IEEE Trans. MTT, Vol. 43, No. 7, pp. 1639-1653, 1995.

[2] N. Okubo, "Millimeter-Wave Automotive Radar," MWE'96 Microwave Workshop Digest, pp. 370-375, 1996.

[3] F. Alimenti et al., "Quasi Static Analysis of Microstrip Bondwire Interconnects," IEEE MTT-S Intl. Microwave Symp. Digest, pp. 679-682, 1995.

[4] H.-Y. Lee, "Wideband Characterization of a Typical Bonding Wire for Microwave and Millimeter-wave Integrated Circuits," IEEE Trans. MTT, Vol. 43, No. 1, pp. 63-68, 1995.

[5] S. Aoki et al., "A Flip Chip Bonding Technology Using Gold Pillars for Millimeter-Wave Applications," IEEE MTT-S Intl. Microwave Symp. Digest, pp. 731-734, 1997.

[6] W. V. Mclevige et al., "Microwave switching with parallel-resonated GaAs FETs," IEEE Electron Device Lett., Vol. EDL-1, pp. 156-158, 1980.

[7] Y. Kawasaki et al., "30-GHz Oscillators for a Millimeter Wave Monolithic Transceiver," Asia-Pacific Microwave Conference Proceedings, pp. 931-934, 1994.

0-7803-4471-5/98/$10.00 (c) 1998 IEEE