MILLIMETER-WAVE THREE-DIMENSIONAL MASTERSLICE MMICS

Kenjiro Nishikawa, Kenji Kamogawa, [1]Koh Inoue, [2]Kiyomitsu Onodera, [1]Makoto Hirano, Tsuneo Tokumitsu, and [3]Ichihiko Toyoda,

NTT Wireless Systems Laboratories
1-1 Hikari-no-oka, Yokosuka-shi, Kanagawa, 239-0847 JAPAN
Phone:+81-468-59-3464, Fax:+81-468-55-2106, E-mail: nisikawa@mhosun.wslab.ntt.co.jp
[1]NTT System Electronics Laboratories, [2]NTT Optical Network Systems Laboratories, [3]NTT Electronics Corporation

Abstract

The three-dimensional (3D) masterslice MMIC technology has, even in the millimeter-wave region, the advantages of high integration levels, simple design procedures, short turn-around-time, and low fabrication cost. Fabricated V-band amplifiers achieve an 8-dB gain and a 5.3 dB noise figure in an area of 0.27 mm^2. A U-band single-chip downconverter is also demonstrated.

I. Introduction

In the millimeter-wave frequency region, many commercial wireless applications such as vehicular radar, wireless LAN, wireless CATV have been proposed and developed. These applications have similar requirements to those for mobile communication systems which use low frequencies: high integration levels, compact chip size, low fabrication cost, and quick development. However, reported millimeter-wave MMICs[1],[2] were implemented as large chips, low integration level, even though the wavelength was short. This is because the coupling between line segments and discontinuities at bends degrade circuit performance. The MMIC design procedure is also extremely complex due to the transmission lines discontinuities.

Three-dimensional (3D) masterslice MMIC technology[3]-[5] is very effective in developing compact high-density millimeter-wave MMICs. The narrow line width, thin dielectric layers used as a substrate, and the low effective dielectric constant materials make millimeter-wave MMICs very compact without the need for intricate designs. The masterslice methodology based on the 3D MMIC technology also enables the design of MMICs utilizing circuit libraries such as ASIC and ensures high yields from devices resulting in a simple design method, low fabrication cost, and short turn-around-time (TAT). First, this paper compares the 3D MMIC characteristics with planar conventional MMIC characteristics in the millimeter-wave frequency range and clarifies the advantages of the 3D masterslice MMIC technology. Second, 50- and 60-GHz-band amplifiers are demonstrated. A U-band single-chip downconverter is also presented. Finally, the advantages are effectively used and implemented in a single-chip downconverter exemplifying the possibilities of 3D MMIC for millimeter-wave wireless systems such as ITS and LMDS.

II. Features of three-dimensional MMIC in millimeter-wave region

A 3D masterslice MMIC consists of a GaAs substrate on which transistors, resistors, and lower metals of an MIM capacitor are fabricated; four 2.5-µm-thick dielectric films, and five 1-µm-thick metals (top surface conductor is 2-µm thick) are formed on the GaAs substrate. The substrate thickness of the transmission lines is less than 10 µm. This structure is advantageous in constructing compact millimeter-wave MMICs. Figure 1 shows the coupling between adjacent line segments. The coupling length is λ/8

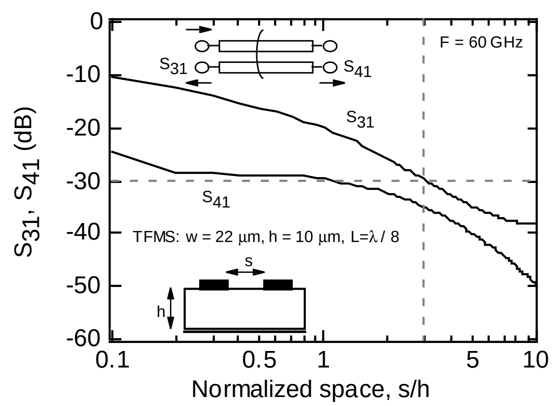


Fig. 1 Coupling of adjacent line segments at the coupling length of $\lambda_g/8$.

at 60 GHz and line width is 22 μm. The horizontal axis shows the normalized spacing between adjacent line segments and the vertical axis shows feedback and forward coupling values. The coupling is less than -30 dB when the spacing, s/h, is more than 3. This means that the spacing of just 30 μm is enough to render coupling insignificant in terms of design. The coupling value decreases when the line length decreases. Table 1 compares three 50-Ω transmission lines at 60 GHz: a thin-film microstrip (TFMS) line with a 10-μm-thick polyimide substrate, a microstrip line with a 100-μm-thick GaAs substrate, and a coplanar waveguide with a 20-μm signal-line width and 600-μm-thick GaAs substrate. In addition, the 20-μm-wide microstrip line characteristics are shown in Table 1. The characteristics of the TFMS line and the CPW are measured results, while the characteristics of the microstrip lines are simulated results. The TFMS line shows relatively high transmission loss, dominated by conductor loss. However, it is not a serious matter to realize reasonable circuit performance for millimeter-wave wireless systems. The reason for this is that the difference in loss between TFMS and the other lines can be minimized by circuit design and active devices used, resulting in achieving nearly the same performance as that of active circuits employing other lines. The bend and the via sizes of the TFMS line are smaller than those of the conventional transmission lines. These results indicate that the TFMS lines have very high potential in achieving compact MMICs and much simpler design in the V-band due to its parasitic-free characteristic.

III. Circuit performance

A. Amplifier

A millimeter-wave MESFET, the InGaP/InGaAs/GaAs HMESFET[6],[7] was used to demonstrate 3D masterslice MMIC amplifiers. The HMESFET has a double lightly-doped drain structure and 0.1-μm Au/WSiN T-gate[6]. The f_T and f_{max} of the HMESFET are 70 GHz and 130 GHz, respectively. Figure 2 shows millimeter-wave 3D MMIC amplifiers implemented on a master array. The master array comprises 100-μm gate-width HMESFETs, resistors, and lower metals of the MIM capacitors. The upper and lower areas of Fig. 2 contain the 60-GHz-band and 50-GHz-band amplifiers. The area for each amplifier is a mere 0.84 mm x 0.32 mm. The amplifiers comprise cascode-connected HMESFETs with a 70-Ω TFMS line, input- and output-matching circuits constructed using 50-Ω TFMS lines. The measured performances of the 60- and 50-GHz-band amplifiers are shown in Fig. 3 and Fig. 4, respectively. Solid lines and dotted lines represent the measured and simulated results, respectively. The simulations were

Table 1 Comparison of TFMS, microstrip line, and coplanar waveguide characteristics.

F = 60 GHz	TFMS h = 10 μm w = 22 μm	Microstrip h = 100 μm w = 75 μm (w = 20 μm)	CPW g = 16 μm w = 20 μm
Wavelength	2.96 mm	1.72 mm (1.81 mm)	2.03 mm
Electrical length of bend	2.3°	14.7° (4.0°)	9.4°
Electrical length of via	1.1°	21°	N/A
Loss per wavelength	2.00 dB/λ_g	0.46 dB/λ_g (0.71 dB/λ_g)	1.68 dB/λ_g

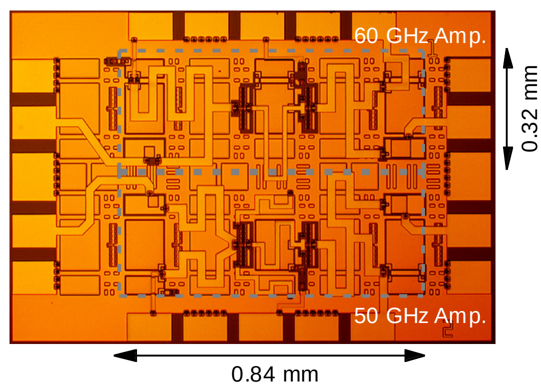
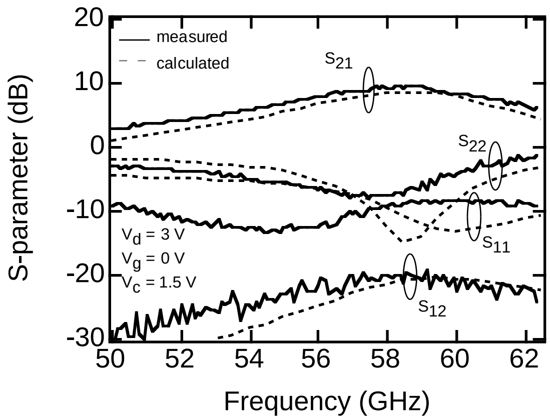
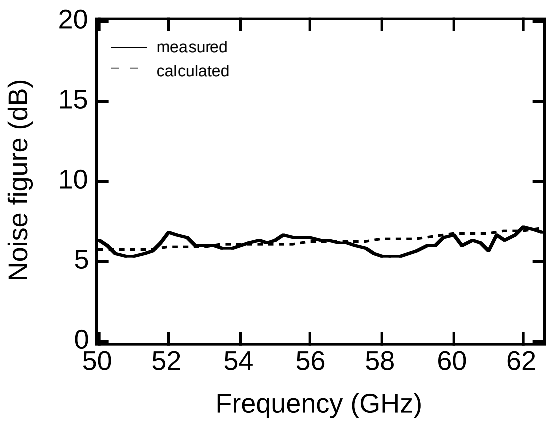


Fig. 2 Microphotograph of 50- and 60-GHz 3D masterslice MMIC amplifiers.

performed without considering the effects of bends, vias and couplings between adjacent line segments. However, the measurement and the simulation results are in good agreement except for S_{11}. as shown in Fig. 3 (a) and Fig. 4 (a). This difference originates primarily from the fact that the device model was constructed prior to establishing the device process. The gain and the noise figure of the 60-GHz-band amplifier are more than 8 dB over 56 to 61 GHz and 5.3 dB at 58 GHz, respectively. The gain and the noise figure of the 50-GHz-band amplifier are more than 8 dB over 49 to 54 GHz and 5.5 dB at 51 GHz, respectively. These amplifiers can also offer more than 20-dB gain variation by controlling the second gate bias. These results are nearly the same as those of planar MMIC amplifiers using CPW[7], that is to say, the 3D masterslice MMIC technology is very

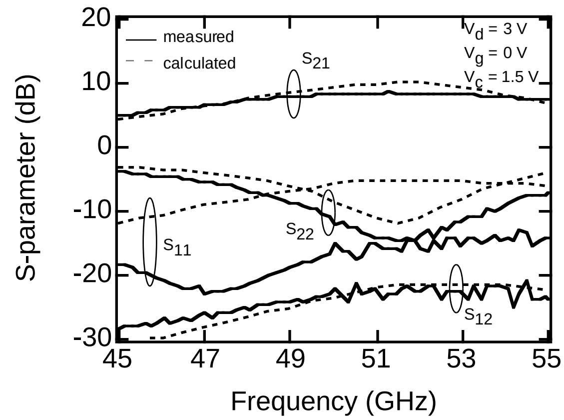


(a) S-parameter

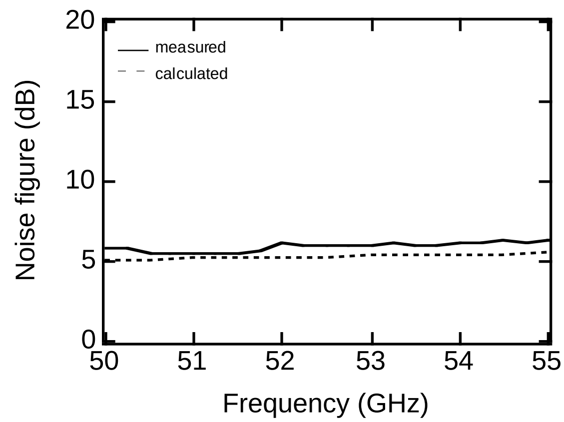


(b) Noise figure

Fig. 3 Measured performance of 60-GHz 3D masterslice MMIC amplifier.



(a) S-parameter



(b) Noise figure

Fig. 4 Measured performance of 50-GHz 3D masterslice MMIC amplifier.

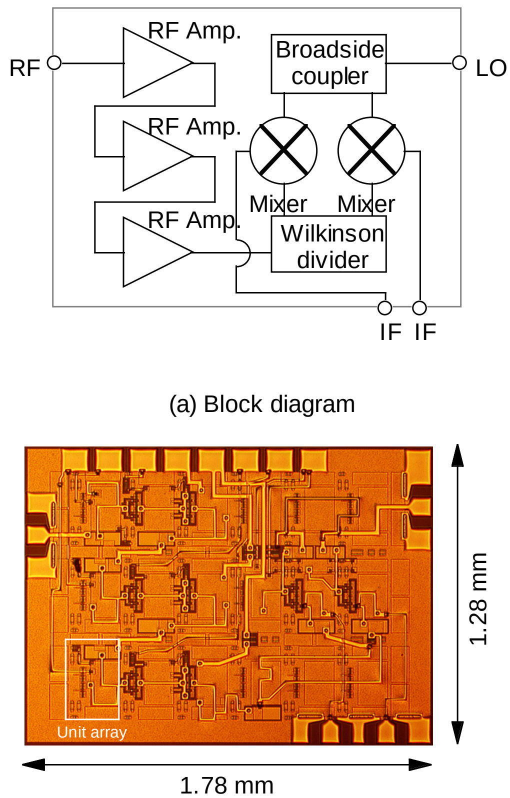
effective in achieving high compact millimeter-wave MMICs and easily achieves reasonable circuit performance.

B. Downconverter

Figure 5 shows the block diagram and microphotograph of a fabricated U-band single-chip downconverter. It consists of three RF amplifiers and an image-rejection resistive mixer on a master array that has 6 x 3 unit arrays with an area of 1.78 mm x 1.28 mm; a production-level 0.2-µm gate-length self-aligned GaAs MESFET[8] (f_T = 40 GHz and f_{max} = 80 GHz) with a 100-µm gate width was used for the master array. Figure 6 shows the measured performance of the downconverter. The conversion gain is 0 dB ± 1.5 dB and the image rejection ratio is better than 15 dB over 42.5 GHz to 47.5 GHz. As shown in the photograph, further reductions in chip size can be easily accomplished with a more condensed master array. In addition, a gain of more than 10 dB will be obtained, if high performance millimeter-wave devices such as HEMTs are used.

IV. Conclusion

Three-dimensional masterslice MMIC technology is very useful in developing millimeter-wave MMICs, greatly improving the integration level and simplifying millimeter-wave MMIC design. This paper demonstrated millimeter-wave amplifiers and a U-band downconverter. These MMICs exhibited a high level of compactness and reasonable performance. This technology promises cost effective MMICs for millimeter-wave wireless applications.



(a) Block diagram

(b) Microphotograph

Fig. 5 U-band single-chip downconverter.

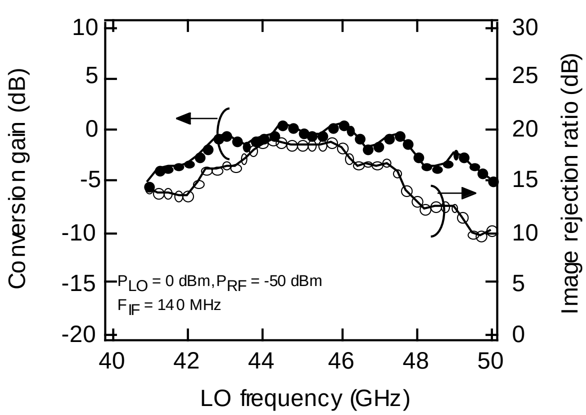


Fig. 6 Measured performance of single-chip downconverter.

Acknowledgment

The authors would like to thank Mr. M. Tanaka and Dr. K. Yamasaki for their constant encouragement.

References

[1] K. Ohata, T. Ion, M. Funabashi, A. Inoue, Y. Takimoto, T. Kuwabara, S. Shinozaki, K. Maruhashi, K. Hosaya, and H. Nagai, "Sixty-GHz-Band Ultra-Miniature Monolithic T/R Modules for Multimedia WIreless Communication Systems," IEEE Trans. Microwave Theory Tech., Vol. 44, pp. 2354-2360, Dec. 1996.

[2] U. Güttich, A. Plattner, W. Schwab, I. Telliez, S. Tranchant, P. Savary, P. Bourne-Yaonaba, B. Byzery, E. Delhaye, C. Cordier, and M. Chelouche, "60GHz GaAs MMIC Technology For a High Data Rate Mobile Broadband Demonstrator," in 1996 IEEE MTT-S Int. Microwave Symp. Dig., San Francisco, CA, pp. 495-498, June 1996.

[3] T. Tokumitsu, K. Nishikawa, K. Kamogawa, I. Toyoda, and M. Aikawa, "Three-dimensional MMIC technology for multifunction integration and its possible application to masterslice MMIC," in 1996 IEEE Microwave and Millimeter-Wave Monolithic Circuits Symp. Dig., San Francisco, CA, pp. 85-88, June 1996.

[4] T. Tokumitsu, M. Hirano, K. Yamasaki, C. Yamaguchi, K. Nishikawa, and M. Aikawa, "Highly Integrated Three-dimensional MMIC Technology Applied to Novel Masterslice GaAs- and Si-MMIC's," IEEE Journal of Solid-State Circuits, Vol. 32, pp. 1334-1341, Sep. 1997.

[5] M. Hirano, K. Nishikawa, I. Toyoda, S. Aoyama, S. Sugitani, and K. Yamasaki, "Three-dimensional Passive Circuit Technology For Ultra-Compact MMIC's," IEEE Trans. Microwave Theory Tech., vol. 43, pp. 2845-2850, Dec. 1995.

[6] Y. Yamane, K. Onodera, T. Nittono, K. Nishimura, K. Yamasaki, and A. Kanda, "A D-LDD (Double Lightly-Doped Drain) Structure H-MESFET For MMIC Applications," IEEE Trans. Microwave Theory Tech., vol. 45, pp. 2229-2233, Dec. 1997

[7] K. Onodera, K. Nishimura, T. Nittono, Y. Yamane, and K. Yamasaki, "Symmetric and Asymmetric InGaP/InGaAs/GaAs Heterostructure MESFET and Their Application to V-Band Amplifiers," to be published.

[8] Y. Yamane, M. Ohhata, H. Kikuchi, K. Asai, and Y. Imai, "A 0.2-μm GaAs MESFET technology for 10 Gb/s Digital And Analog IC's," in 1991 IEEE MTT-S Int. Microwave Symp. Dig., Boston, pp. 513-516, June 1991.