An Advanced Millimeter-Wave Flip-Chip IC Integrating Different Kinds of Active Devices

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Abstract

On the basis of our proposed Millimeter-wave Flip-chip IC (MFIC) concept, K-band receiver front-end circuits integrated with both HFETs and HBTs using flip-chip bonding on the same Si substrate are newly developed. Two key technologies are newly introduced for the advanced MFIC structure.

(1) BCB (Benzocyclobutene) is adopted to the dielectric material to produce low-loss lines.

(2) Thin-film technology is introduced for the integration of a bias network.

The newly developed advanced MFIC shows good performance, such as 1dB of conversion loss and 6dB of noise figure. The advanced MFIC is also expected as a low-cost millimeter(mm)-wave device for use in V-band as well as K-band.

Introduction

The demand for commercial use of mm-wave radio systems such as high-speed wireless communication and collision avoidance is increasing. In order to accelerate the development of mm-wave system applications, there is a great need for mass production of high-performance mm-wave devices at reduced cost is strongly demanded. Although various MMICs have been developed to satisfy these demands, the reduction of production costs still remains as a serious problem because MMICs are fabricated on an expensive hetero-structure substrate and have poor design flexibility. We have already proposed an original mm-wave IC[1] structure, named MFIC (Mm-wave Flip-chip IC), which uses flip-chip bonding technology[2] on the thin film microstrip line. MFIC is a very compact hybrid IC constructed by bonding a mm-wave transistor or its IC chips upside down on thin-film microstrip lines formed on a Si substrate. Production costs of this IC are expected to be remarkably reduced as compared with those of conventional MMICs because the passive elements, which usually occupy a large chip area, are formed not on the expensive hetero-structure substrate but on a low-cost Si substrate. Although a conventional MFIC has been proposed for its flexibility in active device selection, the highest performance of the selected device could not be realized due to loss of the microstrip line. In this work, two improved components such as low-loss microstrip lines and thin film devices are introduced for the advanced MFIC. The advanced MFIC is integrated with different kinds of devices such as HFET[3] and HBT[4] for a 30GHz receiver front-end.

Advanced MFIC structure

Figure 1 shows the advanced MFIC newly developed. BCB (Benzo Cyclo Buthene) is adopted for the dielectric material to reduce loss. Thin-film technology is introduced to make passive components for the integration of a bias network on a Si substrate. This advanced MFIC can realize both excellent performance and high-density integration.

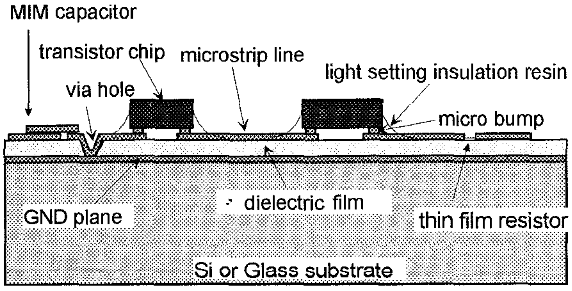

Fig.1 Cross-sectional view of the advanced Millimeter-wave Flip-Chip IC

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Dielectric film

Although we have already reported that SiO_2 dielectric film is one of the most effective materials for realizing the MFIC concept, conductor loss and dielectric loss remain high, from limitations of dielectric thickness and its tanδ. In order to improve these problems, BCB dielectric film was adopted instead of p–CVD SiO_2, which has recently attracted much attentions as a new isolation film for multi–level interconnection or passivation for ULSIs. Table 1 compares the characteristics of both materials. Figure 2 compares the losses of a 50Ω transmission line for dielectric film thickness at 60GHz. The insertion loss has been reduced to less than 1/3 that of SiO_2, because considerably thick films can be utilized. Another dominant reason is the difference in tanδ. Thus, MFIC has become more effective for devices which demand low losses.

The impedance difference between the bonding pad and the microstrip line is neglected because the width of the bonding pad approaches the width of the 50Ω line in the case of BCB film. Adopting BCB film is effective for not only reducing losses but also realizing good performance of micro bump bonding in the mm–wave region.

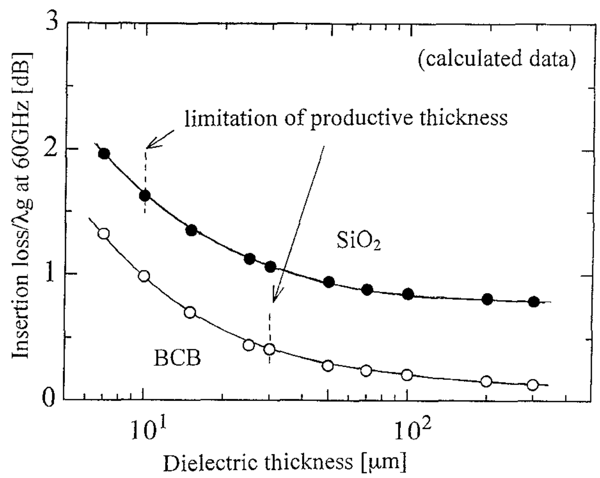

Fig. 2 Transmission losses of BCB and SiO_2 microstrip line versus dielectric thickness.

Table 1 Comparison between BCB and SiO_2

	BCB	SiO_2
deposition process	spin coat and baking	p–CVD
dielectric constant	2.7	4.0
tanδ	0.004	0.03
possible thickness	26μm	9μm
loss/λg	0.4dB	1.7dB

Passive components

Lumped passive components can be formed concurrently on the dielectric film such as MIM capacitors and thin–film resistors. SiN is used for the insulation film, and NiCr for the resistor. These passive components can be formed on a low–cost Si substrate. MIM capacitors, in particular which usually occupy a large chip area, are useful to reduce chip costs. In advanced MFIC, higher density integration becomes possible by combining various kinds of active devices, lumped and distributed passive components without having to worry much about chip area.

Receiver front–end IC using multi chip configuration

Design concept

A 30GHz receiver front–end IC is designed and fabricated. Design concepts are listed as follows.
1)Integrating both HFETs for an LNA and a mixer and HBTs for an LO amplifier on the same substrate.
2)Suppression of lower frequency oscillation by optimum bias network.
3)Adopting a resistive configuration and a drain LO injection for the mixer.

HBT is expected as a high–power efficiency device, so that it would be useful for an LO amplifier which needs relatively higher output power. HFET is suitable for a low noise amplifier. The advanced MFIC having BCB dielectric makes it possible to improve the noise figure of LNA and the efficiency of high power amplifier. Figure 3 shows a calculated performance of the HBT amplifier on both conventional SiO_2 and proposed BCB dielectric. Small signal gain improves up to 1.2dB with the proposed BCB dielectric at 30GHz.

Figure 4 shows the block diagram of the

receiver front–end IC. Figure 5 shows the schematic diagram of the receiver front–end IC. Common source or emitter configurations are adopted for amplifiers. Bias network employs MIM capacitors, resistors and external capacitors to realize high stability at lower frequency.

From the viewpoint of isolation between RF and LO signals without filter and unnecessary DC power supply, a drain LO injection for the down mixer is introduced. When a large LO signal is applied to the drain, the drain current occurs in the condition of $V_{gs}>V_{th}$. The condition of $V_{gs}=V_{th}$ is set not to occur the drain current for its stability.

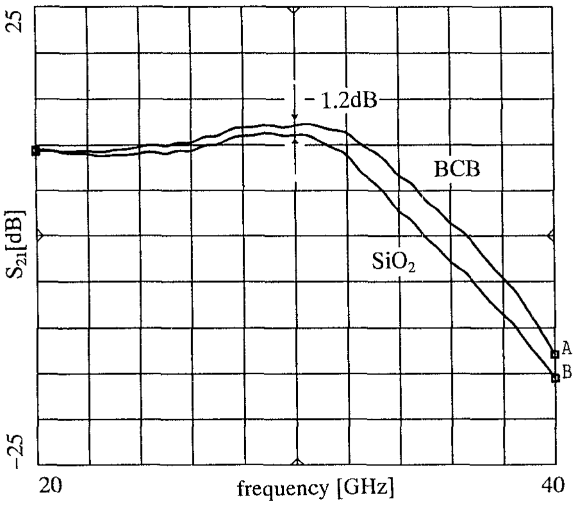

Fig.3 Comparison between HBT amplifier on BCB and SiO_2.

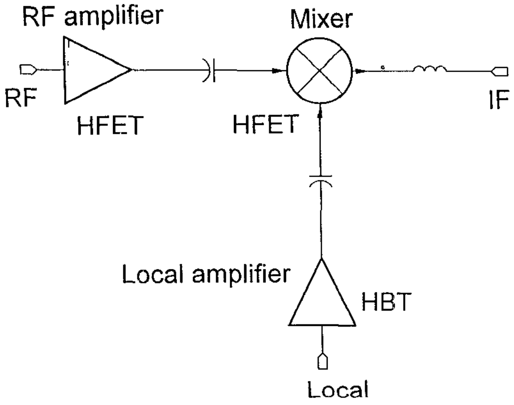

Fig.4 Block diagram of the receiver front–end IC

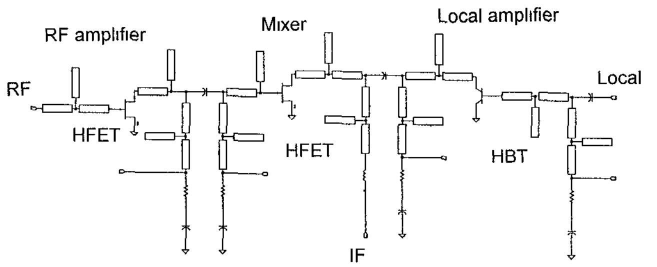

Fig.5 Schematic diagram of the receiver front–end IC

Performance

Figure 6 shows a microphotograph of the receiver front–end integrating two HFETs and one HBT chip. Figure 7 shows HBT amplifier output power characteristics versus input power. Small signal gain is obtained up to 8dB and saturation power is obtained up to 5dBm. This is enough power for local input to drive the subsequent resistive mixer. Figure 8 shows conversion loss and noise figure characteristics versus frequency for the HFET mixer itself. The conversion loss obtained is less than 1dB at a lower LO injection level of –2dBm. SSB noise figure obtained is less than 6dB. Figure 8 shows frequency responses of the RF/LO port. It shows good agreement between measured and designed data in the case of port impedance matching. The RF/LO amplifier and over all performances are listed in table 2. Good performances are obtained on the proposed and fabricated advanced MFIC structure.

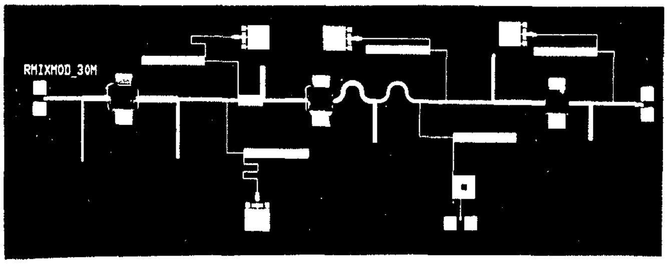

Fig.6 Microphotograph of the receiver front–end IC

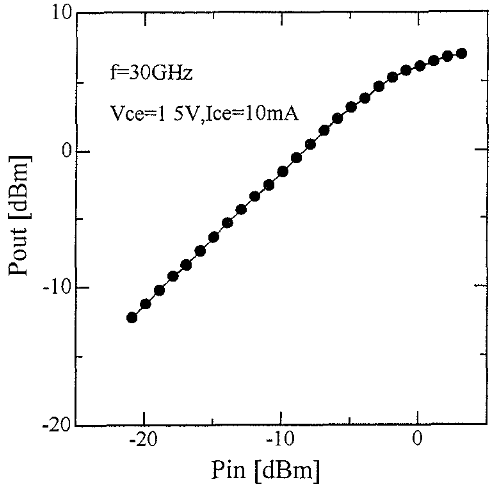

Fig.7 HBT amplifier output power characteristics versus input power.

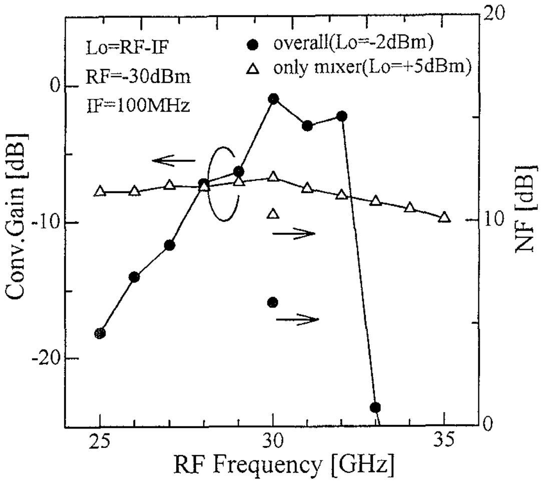

Fig.8 Frequency response of overall conversion loss and noise figure.

Table 2 30GHz receiver front-end IC performances

RF amplifier	active device	HFET
	supply current	10mA
	gain	5dB
LO amplifier	active device	HBT
	supply current	10mA
	small signal gain	8dB
	Psat	5dBm
Over all	IF frequency	100MHz
	conversion loss	1dB
	noise figure	6dB

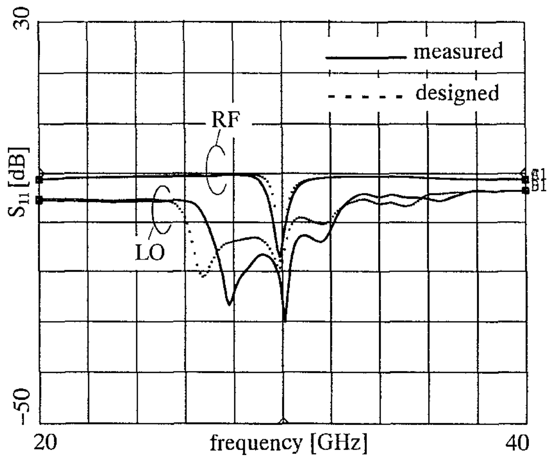

Fig.9 Frequency responses of the RF and LO port.

Conclusions

By introducing an effective material, BCB as a dielectric film for MFIC, the insertion loss of the thin–film microstrip line in the MFIC is remarkably reduced as compared with that of conventional p–CVD SiO_2 film. In addition, thin–film lumped components, such as MIM capacitors and resistors are also integrated on the MFIC. The advanced MFIC is developed using such technologies. A designed and fabricated 30GHz receiver front–end IC consists of HFETs, HBTs and various lumped components. The most important features are the flexibility of active device selection. Measured data show good performances. These results indicates that an advanced MFIC will be able to become a more effective solution for reducing costs and improving the productivity of millimeter–wave devices.

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