Photonic InP/InGaAs HBT for radio-on-fiber applications

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Abstract — **We present the photodetection and optoelectronic up-conversion characteristics of photonic InP/InGaAs heterojunction bipolar transistor (HBT) for radio-on-fiber applications. The photonic HBT exhibits the intrinsic optical gain of 23dB and the optical cutoff-frequency of 18GHz. Utilizing it as an optoelectronic mixer, we obtained the conversion gain of 6dB at 17GHz band up-conversion.**

I. Introduction

The needs for broad-band data wireless communication have driven the intensive development of millimeter-wave radio-on-fiber systems. In these systems, a large number of antenna base stations (BS) are located under the coverage of a single central station (CS) due to the high atmospheric loss of millimeter-wave. Therefore, low-cost BS structures are key issues for their practical implementation.

There are two major approaches to simplify BS architecture. In one configuration, called optical millimeter-wave system, a BS performs only photo-detection to optical millimeter-wave signals originated from a CS. However, chromatic dispersion and phase noise degradation are limiting factors for increasing optical transmission distance [1].

In the other approach, called remote up-conversion system, a BS performs the frequency up-conversion of optically transmitted data signal into the millimeter-wave band with the help of local oscillator (LO) and mixer. Although it alleviates above-mentioned problems, complex BS architectures still remain as severe obstacles to construct cost-effective radio-on-fiber system. Therefore, one-chip integration of BS is essentially required.

However, it is difficult to integrate a photodetector and microwave devices on a single substrate because they are different epitaxial layer structures. InP-based hetero-junction bipolar transistors (HBTs) are promising candidates since they not only perform the photodetection with intrinsic gain but also have the compatibility to conventional MMIC process [2]. In addition, they provide additional functionalities including optoelectronic mixing and optically injection-locked oscillation. In this work, we investigate the photodetection and 17GHz optoelectronic up-conversion characteristics of photonic InP/InGaAs HBT. In addition, the bias condition of HBT is optimized for maximum conversion gain of optoelectronic mixer.

II. Experimental Setup

Fig. 1 illustrates the InP/InGaAs HBT used in our experiment. Under illumination, the optical absorption occurs in $In_{0.53}Ga_{0.47}As$ base-collector junction. In common-emitter configuration, output collector currents are the product of transistor intrinsic gain and photocurrents at base region. The emitter size of HBT is $2\times10\mu m^2$. The experimental arrangements are shown in Fig. 2. Because of the large optical insertion loss due to emitter contact-metal, EDFA was used for optical amplification. All measurements were performed in common-emitter configuration by using on-wafer GSG probes. For optoelectronic up-conversion demonstration, a frequency synthesizer as an LO source was connected to base port. A vector network analyzer was used to measure the optical modulation responses of HBT.

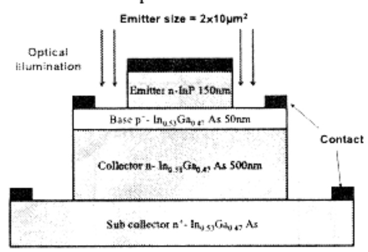

Fig. 1: Schematic cross-section of fabricated InP HBT

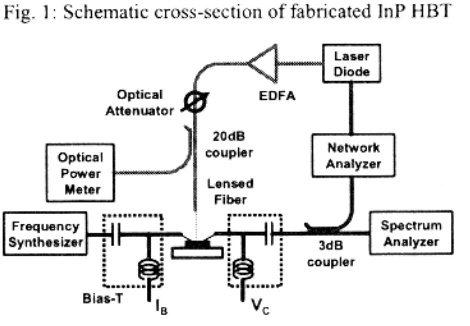

Fig. 2: Experimental setup for optoelectronic up-conversion using photonic InP HBT

III. Result and Discussion

Fig. 3 shows the collector current (I_C) as a function of collector-emitter voltage (V_{CE}) of HBT with I_B=100μA under different incident optical powers. As increasing optical power, I_C also increases. The increased collector currents are 23dB higher than photocurrent at base region, which indicates the DC optical gain of photonic HBT. The optical modulation responses of the HBT are displayed in Fig. 4. Under the PD-mode which is realized by setting V_{BE}=0, HBT operates as a photodiode without optical gain. The Tr-mode indicates that the HBT was actively biased, V_{BE}>0, which results in providing optical gain by the transistor operation. The optical gain is defined as the photoresponse ratio between Tr-mode and PD-mode. The result shows that the HBT provide optical gain of 22dB at 1GHz. The optical cutoff frequency where the HBT cannot provide optical gain is approximately 18GHz.

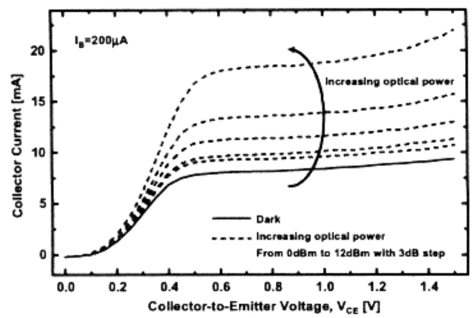

Fig. 3: I_C -V_{CE} characteristics of HBT under different incident optical power (I_B=200μA)

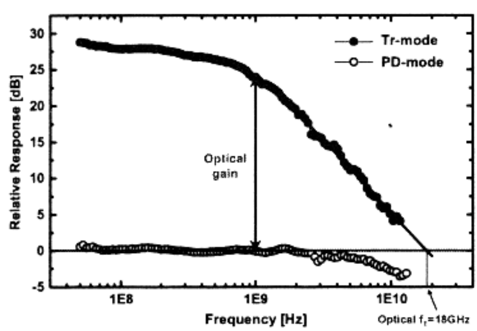

Fig. 4: Optical modulation response of photonic HBT under transistor mode (I_B=100μA) and PD mode (V_{BE}=0V).

By utilizing these photodetection characteristics incorporating with the intrinsic nonlinearity of HBT, an optoelectronic up-conversion to 17GHz band is successfully demonstrated. For the experiment, 17GHz LO source with 3dBm power was applied to base port and 500MHz optical IF signal was illuminated to the HBT. Fig. 5 shows the 17GHz band optoelectronic up-converted signal spectrum using HBT under I_B=100μA and V_C=1V.

In order to evaluate the performance of optoelectronic up-converter, we defined the conversion gain as the output power ratio of up-converted signals to primary photodetected signals without optical gain, which was measured under PD-mode operation. During the measurement, the 500MHz photo-detection signal power is -26.83dBm. Therefore, we obtained the 6dB conversion gain in HBT optoelectronic up-converter. In order optimize bias condition for maximum conversion gain, we measured the dependence of up-converted signals on applied base currents, which is shown in Fig. 6. From these results, large base currents are beneficial for the high conversion gain of the HBT optoelectronic up-converter.

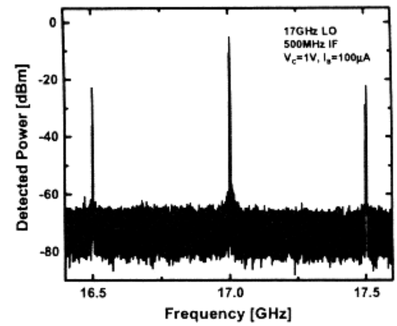

Fig. 5: 17GHz optoelectronic up-converted spectrum. LO frequency and IF are 17GHz and 500MHz, respectively.

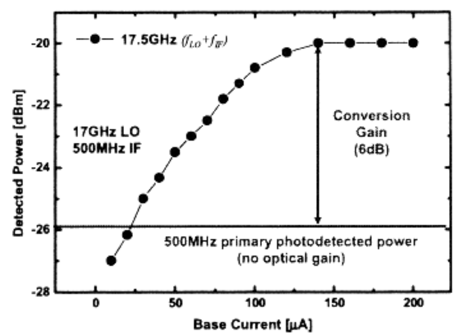

Fig. 6: The dependence of up-converted signal power at 17.5GHz on base current bias (V_{CE}=1V).

IV. Conclusion

We investigated the photonic HBT for radio-on-fiber applications. It can be operated as not only a phototransistor but also an optoelectronic up-converter with high conversion gain. These results confirm the potential of photonic HBT to be used in the one-chip integration of photonic and RF components for antenna base staion in radio-on-fiber system.

References

[1] A. J. Seeds, IEEE MTT., pp. 877, 2002

[2] H. Kamitsuna et al., IEEE MTT., pp. 1921, 2001