Conversion Gain Enhancement of a UTC-PD-Integrated HEMT Photonic Double-Mixer by High-Intensity Optical Subcarrier Signal

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Abstract: We experimentally investigate the effect of high-intensity subcarrier signal input to the UTC-PD-integrated HEMT working for optical-to-wireless carrier frequency down-conversion on enhancement of its double-mixing conversion gain. The fabricated UTC-PD-integrated HEMT demonstrated the linear increase in the conversion gain by up to +7 dB with increasing the subcarrier signal intensity without saturation, and the conversion gain enhancement of +6.8 dB from -51.0 dB to -44.2 dB was achieved.

1. Introduction

Future ultra-broadband ubiquitous, resilient beyond 5G (B5G) communication networks require full-coherent convergence between optical and wireless links [1] to realize ultra-broadband, ultra-low latency, and ultra-massive connectivity with extremely reduced power consumptions. One of the key devices for the realization of the full-coherent convergence is the carrier frequency down-converter from optical data signals to wireless data signals that can preserve their data modulation format (e.g., QPSK or QAM). We have studied the so-called photonic double-mixing functionality of graphene-channel FETs and InGaAs high-electron-mobility transistors (InGaAs-HEMTs) to perform the conversion of the 1.5-μm bands to the sub-THz/THz bands [2-4]. The photonic double-mixing comprises two mixing functionalities: usual photomixing of an optically coded carrier signal and an optical subcarrier signal, which generates the difference-frequency beat-note sub-THz/THz data signal, and RF mixing of the beat-note signal and an RF local oscillator (RF-LO) signal, which generates an IF data signal (i.e., a double-mixed signal) with a desired frequency. The photomixing can be realized using a transistor structure with high-speed and highly sensitive photodetection functionality, if the photomixed current is generated either by the direct photoabsorption in the channel or by the injection from a certain absorption layer into the channel, while the RF mixing can be realized by impinging the RF-LO signal to the gate and utilizing the nonlinear I-V characteristics of the transistors.

For enhancement of the double-mixing conversion gain, we have developed an InGaAs-channel HEMT with integration of the uni-traveling-carrier photodiode (UTC-PD) structure into its source side (UTC-PD-integrated HEMT, see Fig. 1) [5]. In this structure, the input optical signals are mainly absorbed in the p-$In_{0.53}Ga_{0.47}As$ absorption layer and only photogenerated electrons are injected into the i-InP carrier-collection layer and photogenerated holes are extracted very quickly to the source contact, as in standard UTC-PDs [6]. Recently, we have succeeded to enhance the double-mixing conversion gain of the UTC-PD-integrated HEMT up to -53 dB by reducing the UTC-PD mesa size close to the optical diffraction limit [7]. However, to achieve the higher conversion gain required for the B5G network systems, -30 dB, Further approaches for the enhancement are needed.

In this work, we examine the employment of high-intensity subcarrier signal input to enhance the double-mixing conversion gain of the UTC-PD-integrated HEMT. First, we discuss about a method of generating a high-intensity, low-noise subcarrier signal that can be used in real B5G network systems. Then, to validate the effectiveness of the high-intensity subcarrier signal, we measured the dependence of the double-mixing conversion gain of a UTC-PD-integrated HEMT on subcarrier signal intensity. We demonstrated that the conversion gain increases linearly by up to +7 dB with the subcarrier signal intensity up to +6.63 dBm without saturation in the experimentally allowable range and that the conversion gain enhancement of +6.8 dB from -51.0 dB to -44.2 dB was achieved.

2. Generation of optical subcarrier signal without increasing noise

In the full-coherent B5G network systems, we assume that phase-locked, wavelength-division multiplexed (WDM) optical signals are transmitted from a baseband unit (BBU), and a pair of optical (coded) carrier and subcarrier signals are extracted as input signals for a double-mixer in a single remote radio head (RRH) for optical-to-wireless carrier frequency down-conversion (see Fig. 2). Due to the losses in optical fibers for transmission and by an arrayed waveguide grating for demultiplexing the WDM signals, intensities of both the optical carrier and subcarrier signals are estimated to be at most 0 dBm. Amplification of either or both of the carrier and subcarrier signals by a semiconductor optical amplifier in the RRH is effective in enhancing the output IF intensity but causes significant increase in the amplified-stimulated-emission (ASE) noise. Another way is local generation of a subcarrier signal in the RRH, instead of a subcarrier signal being delivered from the BBU, but it causes a large phase noise in the photomixing process. Alternatively, a method to phase-lock a high-intensity, low-noise optical LO signal generated in the RRH with the low-intensity subcarrier signal delivered from the BBU has been proposed [8]. With this method, generation of a high-intensity optical subcarrier signal can be accomplished without increasing ASE or phase noise. Since the photomixing conversion gain and, in turn, the double-mixing conversion gain are proportional to the subcarrier intensity, the double-mixing conversion gain is expected to increase linearly with it, as long as the photocurrent saturation does not take place.

3. Experiment and Result

To validate the effectiveness of the high-intensity subcarrier signal for enhancement of the double-mixing conversion gain of the UTC-PD-integrated HEMT, we measured its dependence on the input intensity of the subcarrier signal. Figure 1(a) shows a scanning-electron-microscope image of a fabricated UTC-PD-integrated HEMT. The double-mixing measurement was conducted as follows. A pair of optical carrier and subcarrier signals with the difference frequency 110 GHz were generated from a set of a 1.55-μm tunable CW fiber laser source, a frequency comb generator, an optical splitter, optical filters, optical amplifiers, and an optical coupler (see [5] in details). The optical beam is then irradiated onto the absorption layer of the UTC-PD structure from the backside. We focused the optical beam with the spot diameter of 4.3 μm by using a lens module. The carrier intensity was fixed to +0.63 dBm while the subcarrier intensity was varied from +0.63 dBm to +6.63 dBm. An RF signal with the frequency of 90 GHz and the power of +1.5 dBm was impinged to the gate. The HEMT was biased in a common-source configuration with a DC gate bias V_{GS} varied from -0.8 to +0.4 V and a DC drain bias V_{DS} varied from +0.6 to +0.8 V. Finally, the IF output from the drain electrode at 20 GHz was measured by an RF spectrum analyzer.

Figure 3 shows the double-mixing conversion gain ($C.G_{DM}$) as a function of the subcarrier intensity (P_{sub}). As seen, the conversion gain increases linearly with the subcarrier intensity without saturation, which is inherited from the UTC-PD structure [6]. The highest conversion gain of -44.2 dB was marked at the subcarrier intensity of +6.63 dBm, achieving the conversion gain enhancement of +6.82 dB from -51.0 dB. Note that the maximum subcarrier intensity was only limited by the measurement setup, and the further enhancement by the higher subcarrier intensity is expected. Figure 4 depicts the gate bias voltage vs the double-mixing conversion gain with different subcarrier intensities. From Fig. 4, it is shown that the conversion gain exhibits a peak at a certain gate voltage which does not change with the subcarrier intensity. Also, at gate voltages below the peak, the linearity of the conversion gain no longer holds at high subcarrier intensities. Those results show that, with a proper gate bias voltage application, the adoption of the high-intensity subcarrier signal to the UTC-PD-integrated HEMT double-mixer is very effective to enhance its double-mixing conversion gain.

4. Conclusions

We examined the employment of high-intensity subcarrier signal input to enhance the double-mixing conversion gain of the UTC-PD-integrated HEMT for optical-to-wireless carrier frequency down-conversion. The fabricated device showed a linear increase in the conversion gain with increasing the subcarrier signal intensity without saturation in the experimentally allowable range, up to +6.63 dBm and the conversion gain enhancement of +6.82 dB from -51.0 dB to -44.2 dB, demonstrating the effectiveness of the high-intensity subcarrier signal.

Acknowledgments

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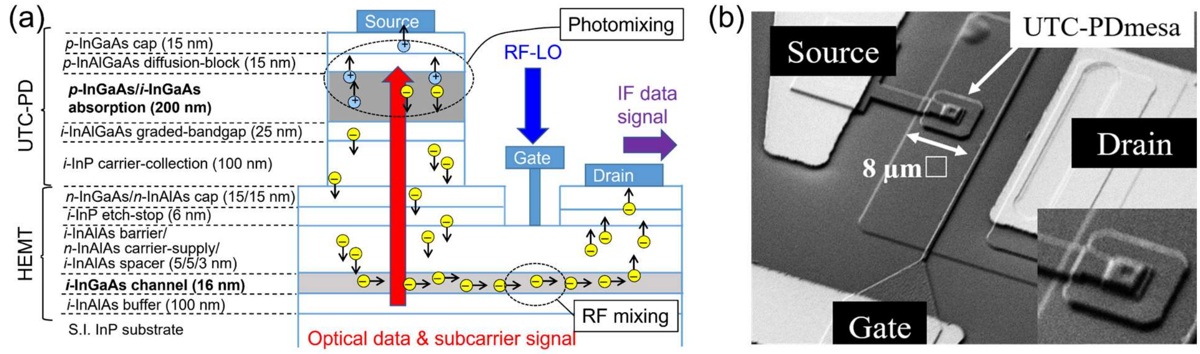

Fig. 1. (a) A schematic view of the UTC-PD-integrated HEMT and (b) a scanning-electron-microscope image of a fabricated UTC-PD-integrated HEMT.

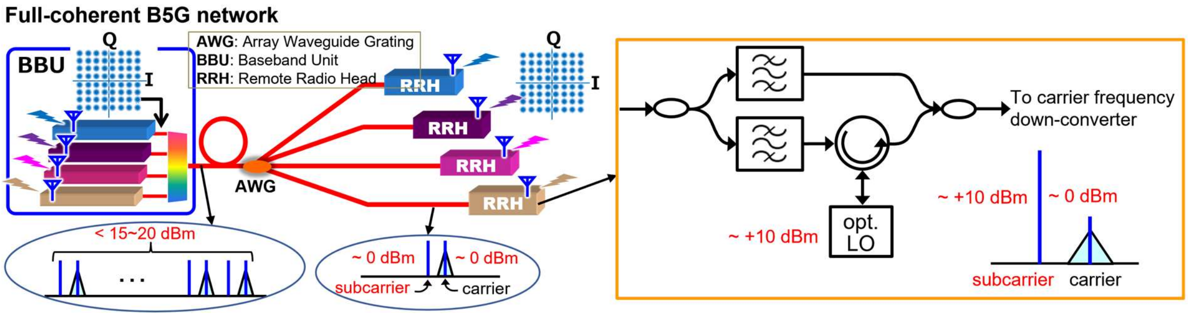

Fig. 2. A schematic view of a full-coherent B5G network system and a method to generate a high-intensity, low-noise optical subcarrier signal by a phase-locking technique [8] at a remote radio head.

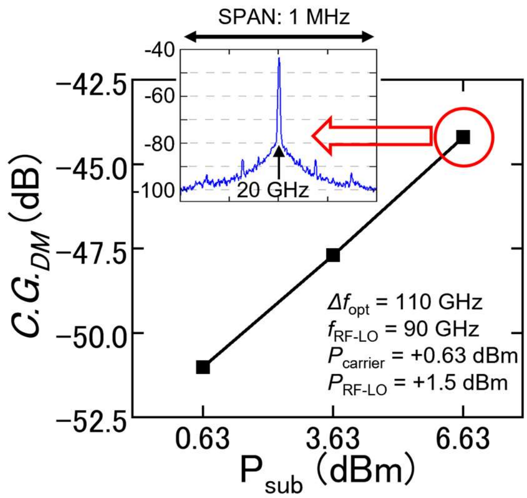

Fig. 3. Measured double-mixing conversion gain of a UTC-PD-integrated HEMT as a function of the subcarrier intensity (the inset shows a measured spectrum of the IF signal at P_{sub} = +6.63 dBm).

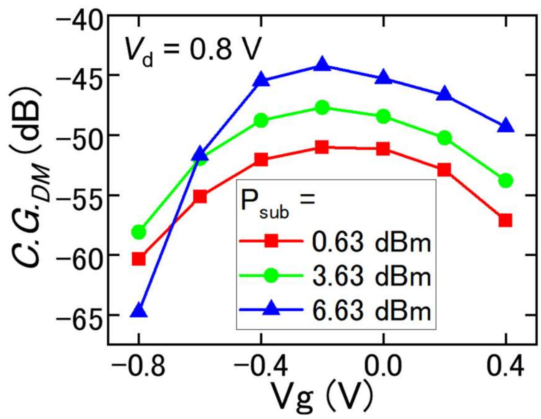

Fig. 4. Measured double-mixing conversion gain of the UTC-PD-integrated HEMT as a function of the gate voltage.