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Published in:
Proceedings of 21st International Conference on Transparent Optical Networks

Publication date:
2019

Document Version
Peer reviewed version

W-Band Heterodyne Wireless System with 2.3 GHz Intermediate Frequency Driven Entirely by ErAs:In(Al)GaAs Photoconductors

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ABSTRACT

We demonstrate a heterodyne wireless system using only ErAs:In(Al)GaAs photoconductors driven by two independent telecom laser signals. The maximum Intermediate Frequency (IF) was 2.3 GHz, only limited by the bandwidth of the post-detection electronics. The maximum signal-to-carrier ratio achieved was 42.6 dB.

Keywords: THz heterodyne detection, photomixers, THz wireless communications, ErAs:In(Al)GaAs photoconductors.

1. INTRODUCTION

The demand for faster data rates in wireless communications has been one of the major forces leading the development of efficient room-temperature sub-THz systems and components. At these frequencies, purely electronic or hybrid optoelectronic/electronic systems have dominated the field, but the recent improvements in optoelectronic coherent detectors have made purely photomixing systems an attractive option given their potential advantages: (i) direct down-conversion of 1550 nm signal to a sub-THz carrier, (ii) coherent down-conversion of the sub-THz signal to baseband after reception, and (iii) increased sensitivity due to the mixing with an optical local oscillator. So far, all purely optoelectronic systems have used UTC-PDs for both the transmitter and the receiver [1], or a UTC-PD for the transmitter and an LTG-InGaAs photoconductor for the receiver [2],[3]. Here, we present a true heterodyne system working between 77.626 and 79.626 GHz with an IF of more than 2 GHz, using ErAs:In(Al)GaAs photoconductors for both the transmitter and receiver. This work shows the potentialities of ErAs:In(Al)GaAs photoconductors in heterodyne systems, and paves the way for future applications in sub-THz and THz wireless communications.

2. HETERODYNE SYSTEM SETUP

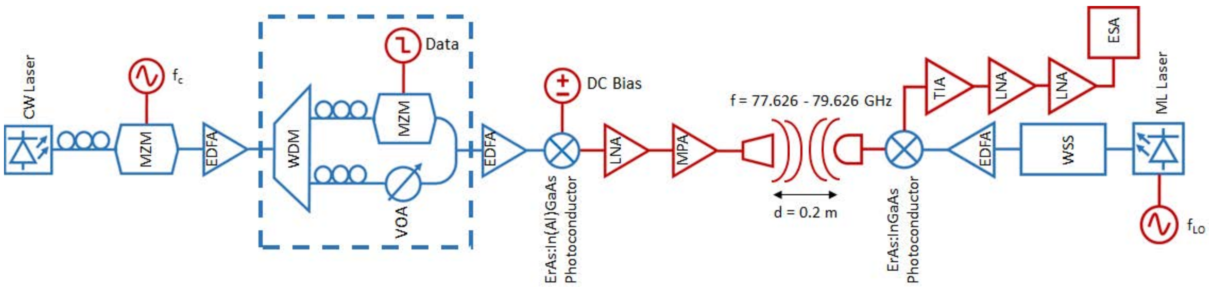

Figure 1. Schematic diagram of the W-band heterodyne setup. The components enclosed by the dashed lines are required for incorporating data modulation.

The heterodyne system setup consists of two ErAs:In(Al)GaAs photoconductors, each one driven by an independent laser system. A schematic diagram is shown in Fig. 1. The transmitting photoconductor is a superlattice structure composed of 90 periods of 1.5 nm of InAlAs, 0.8 monolayers of C-delta-doped ErAs, 1.5 nm of InAlAs, and 15 nm of InGaAs, similar to one used in the transmitter of [4]. The 10 µm by 10 µm photoconductive area of the device is covered with a finger-like electrode configuration where each electrode has a length of 7 µm, a width of 1 µm, and separation of 2 µm. The electrodes are connected to a coplanar waveguide (CPW) patterned on the same substrate. This waveguide-coupled photoconductor is bonded to a CPW circuit that includes a feeding network, a bias tee and an E-plane-probe transition to a WR10 waveguide. The circuit allows to apply the necessary bias to the electrodes patterned on the photoconductor, and at the same time allows to guide the generated sub-THz signal to a WR 10 waveguide. Once the sub-THz signal has transitioned to a WR10 waveguide, it is amplified by two cascaded W band amplifiers: a low noise amplifier (LNA) with a gain of 40 dB, and a medium power amplifier (MPA) with a gain of 12 dB. After amplification, the sub-THz signal is emitted by a rectangular horn antenna with a gain of 22 dBi.

The optical signal driving the photoconductor is generated by modulating the output of a continuous-wave

(CW) laser using a Mach-Zehnder Modulator (MZM) with a modulating signal of frequency f_c. The MZM modulator is biased at the null point for optical carrier suppression [5]. This produces two highly coherent tones separated by $2f_c$, resulting in an ultra-narrow-linewidth sub-THz signal after optical amplification and subsequent photomixing in the photoconductor. The incorporation of data modulation can easily be achieved by demultiplexing the two optical tones and then using a second MZM modulator in one of the arms, as shown by the square in dashed lines in the diagram of Fig. 1.

The receiving photoconductor is a superlattice structure composed of 90 periods of 10 nm of InGaAs and 0.8 monolayers of Be-delta-doped ErAs. The size of the photoconductive area and the electrode structure are the same as in the transmitter, but in this case the photoconductor is connected to a substrate-integrated logarithmic-periodic antenna. To improve coupling, the incoming sub-THz radiation is collected and focused by a hyper-hemispherical silicon lens attached to the back of the substrate. This photoconductor is identical to the one used in the characterization presented in [6], including the electrode structure, the antenna, the silicon lens, and the packaging. For post-detection, the antenna is connected to a transimpedance amplifier (TIA) with a bandwidth of 2 GHz and a gain of 20 dB. Its output is then connected to two cascaded LNAs, each with a bandwidth of 4 GHz and gain of 20 dB. The optical signal driving the receiving photoconductor is generated by selecting two consecutive odd modes of a mode-locked (ML) laser with a repetition rate f_{LO}. The selection is done using a wavelength selective switch (WSS) with a channel bandwidth of 50 GHz. The output of the WSS is amplified and then mixed by the receiving photoconductor in order to produce another ultra-narrow-linewidth signal that will act as local oscillator (LO) at a frequency equal to $2f_{LO}$. The photoconductor then mixes the optical signal at $2f_{LO}$ with the narrow-linewidth signal at frequency $2f_c$ received by the logarithmic-periodic antenna. The result is the coherent down-conversion of the transmitted signal at an IF of $f_{IF} = 2f_{LO} - 2f_c$.

3. EXPERIMENTAL RESULTS

In principle, the sub-THz signal could have any frequency within the W band, given that the CPW feeding network, the E-plane-probe transition, and the amplifiers in the transmitter side could work over the entire band. However, the mode-locked laser used to drive the receiving photoconductor had a fixed repetition rate of 39.813 GHz, leading to a W-band frequency of $2f_{LO}$ = 79.626 GHz. Furthermore, the IF of the down-converted signal was limited to 2.3 GHz due to the bandwidth of TIA. Hence, for coherent detection, the effective bandwidth of the transmitted sub-THz signal in the implemented heterodyne system was constrained to 77.326 – 81.326 GHz for optimum performance.

For testing, the IF frequency was swept from 1 to 2.3 GHz by sweeping the frequency of the transmitted signal from 78.626 to 77.326 GHz. This was done by decreasing f_c from 39.313 GHz to 38.313 GHz in 50 MHz frequency steps. A sample spectrum of the optical signal generated in this way is shown in Fig. 2 (a). Its power at the input of the photoconductive transmitter was 32.88 mW. The power of the resulting sub-THz signal was not measured, but it was estimated to be below 16 mW before being radiated by the horn antenna. This, assuming that the photoconductor alone emits less than 100 nW prior to amplification.

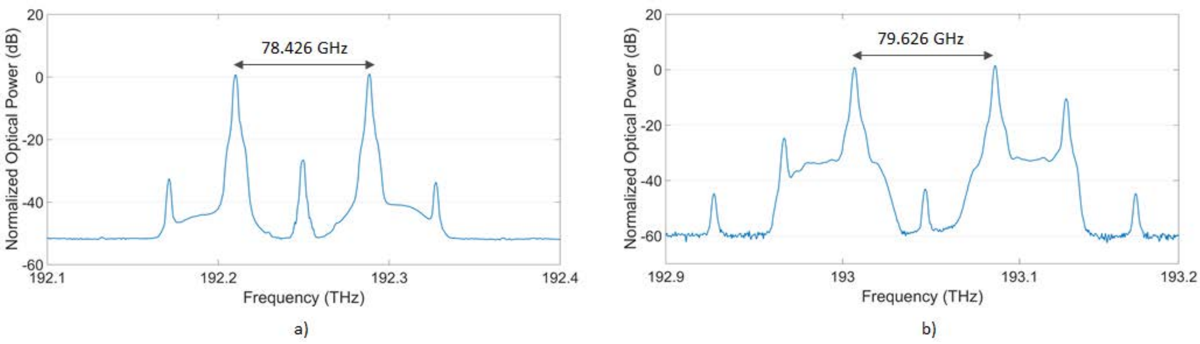

Figure 2. Spectrum of the optical signals used to drive: (a) the photoconductive transmitter, and (b) the photoconductive receiver for an IF of 1.2 GHz.

The spectrum of the optical signal from the ML laser, after mode selection, is shown in Fig. 2 (b). Its power at the input of the photoconductive receiver was 28.93 mW. The recorded spectra of the down-converted signal for two sample IFs are shown in Fig. 3. The origin of the additional carriers around the central frequency is unknown and requires further investigation. They were spaced by 880 Hz, and were present before transmission, as shown by the obtained RF spectrum from a high-speed photodiode fed by the optical signal driving the transmitter.

Finally, the maximum signal-to-carrier ratio for each intermediate frequency is shown Fig. 4. The variations as function of frequency were caused by three factors: power fluctuations in the transmitted sub-THz signal, power fluctuations in the optical signal driving the photoconductive receiver, and the limited bandwidth of the TIA used for post-detection. The fluctuations in the transmitted sub-THz signal occurred due to the non-flat response of the horn antenna and the W-band amplifiers. The fluctuations in the optical signal at the receiver occurred because the central frequency of the ML laser drifted while the frequency response of the WSS (used to select the two modes) stayed the same. The steady decrease after 2 GHz corresponds exactly to the limit in bandwidth of the TIA. The variations before 2 GHz are the result of both power fluctuations in the sub-THz signal and power fluctuations in the optical signal at the receiver, although at this point it is difficult to quantify the influence of each factor separately.

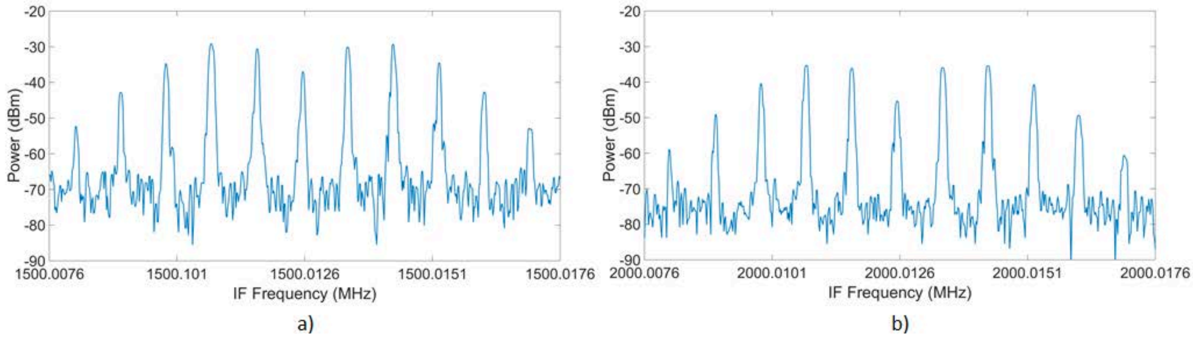

Figure 3. Power spectra of the received signal for two different IFs: (a) 1.5000126 GHz and (b) 2.0000126 GHz. The spectra were recorded using an electrical spectrum analyzer (ESA) with resolution bandwidth of 50 Hz and a span of 10 kHz.

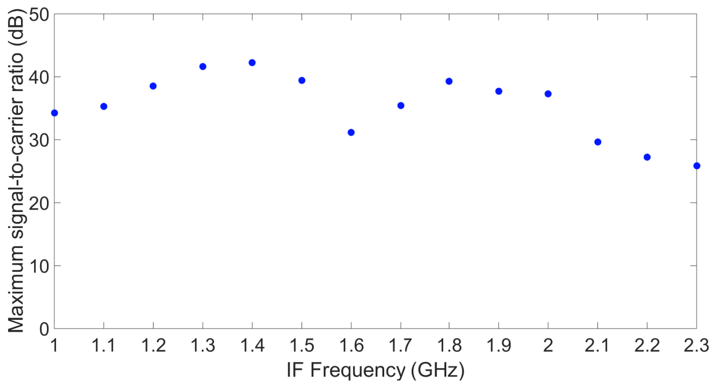

Figure 4. Signal-to-noise ratio of the carrier that showed the maximum power for all the IFs tested.

4. CONCLUSIONS

We have shown a sub-THz heterodyne system entirely driven by ErAs:In(Al)GaAs with an IF that exceeded 2 GHz and maximum signal-to-carrier ratio of 42.6 dB. Although its performance can still be improved by removing the additional carriers around the central frequency, the implemented system underscores the potential of ErAs:In(Al)GaAs photoconductors for wireless sub-THz communications. In particular, it emphasizes the advantages of waveguide-coupled photoconductors, whose performance can be greatly improved by the straightforward incorporation of amplifiers or more directive antennas.

ACKNOWLEDGEMENTS

We acknowledge the funding by the European Union Marie Curie Skłodowska Actions through the Innovative Training Network (ITN) with project number 675683 (CELTA).

REFERENCES

[1] A. W. Mohammad *et al.*: 60 GHz transmission link using uni-carrier travelling photodiodes at the transmitter and at the receiver, *J. Lightwave Technol.*, vol. 36., no. 19, pp. 4507-4513, Oct. 2018.

[2] T. Harter *et al*: Wireless multi-subcarrier THz communications using mixing in a photonconductor for coherent reception link utilizing non-zero dispersion-shifted fiber, in *Proc. IEEE Photonics Conference*, Orlando, FL USA, Oct. 2017.

[3] S. Nellen *et al*: Fiber-coupled, photoconductive heterodyne receiver operating at frequencies up to 1 THz, in *Proc. Conference on Lasers and Electr-Optics (CLEO)*, San Jose, CA, USA, Oct. 2017, paper SM3J.7.

[4] A. D. J. Fernandez Olvera *et al*: Continuous-wave 1550 nm operated terahertz system using ErAs:In(Al)GaAs photoconductors with 52 dB dynamic range at 1 THz, *Opt. Express,* vol. 25, no. 23, pp. 29492-29500.

[5] A. Morales *et al*: 1 Gb/s chaotic encoded W-band wireless transmission for physical layer data confidentiality in radio-over-fiber systems, *Opt. Express,* vol. 26, no. 17, pp. 22296-22306.

[6] A. D. J. Fernandez Olvera *et al*: International system of units (SI) noise-equivalent power and responsivity characterization of continuous wave ErAs:InGaAs photoconductive terahertz detectors, *Photonics,* vol. 6, no. 1.