Waveguide Optical-to-THz Signal Converter using Ring-shaped Microstripline

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Abstract: We report a waveguide optical-to-THz (200 GHz to 300 GHz) signal converter using ring-shaped microstripline with GaInAs photoconductive mesa structure. A maximum extinction ratio of 16.8dB in THz band was obtained with light irradiation of 15dBm.

OCIS codes: (230.0230) Optical devices; (350.4010) Microwaves

1. Introduction

Fiber-based optical communication systems are being installed in mobile back-haul networks because of the high capacity of their data rate. On the other hand, recent advances in terahertz-wave (THz-wave) technologies have attracted attention due to the huge bandwidth of THz waves and its potential for use in wireless communications. In the foreseeable future, a seamless fusion of wired optical communication systems and wireless THz communication systems will occur.

Towards this goal, our group have proposed a direct optical-to-THz signal conversion method using photo-generated carriers in III-V semiconductors [1, 2]. In this paper, we demonstrate a waveguide optical-to-THz signal converter using ring-shaped microstripline with GaInAs photoconductive mesa structure. As a result, a maximum extinction ratio of 16.8dB in THz band was obtained with light irradiation of 15dBm.

2. Device structure and Simulation result

Figure 1 shows a schematic image of our waveguide-type-optical-to-THz signal converter. In the device, an input THz wave propagates through a ring-shaped Au/SiO_2/Au microstripline with a gap consisting of a GaInAs/InP photoconductive mesa structure. The ring-shaped microstripline works as an ultra-wideband band-stop filter whose center frequency can be controlled by scaling the ring [3]. If controlling light (λ = 1.55μm) is applied to the gap region from an optical fiber above the device, a gap is short-circuited by excited carriers in GaInAs layer, and consequently a stopband vanishes. In this way, the input THz wave can be switched directly by the controlling light.

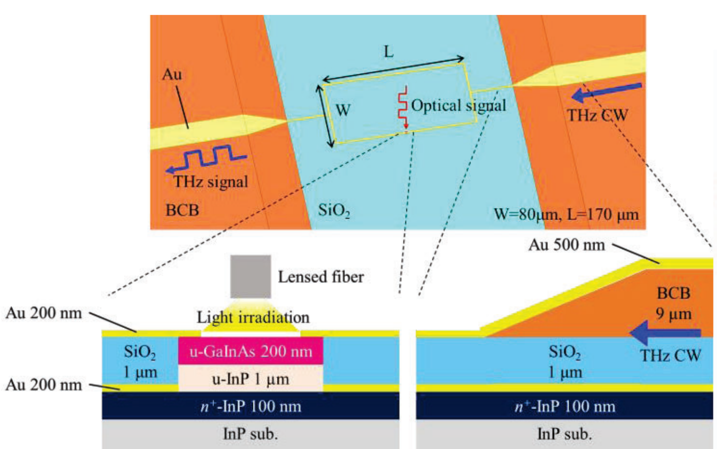

Fig. 1. Schematic image of waveguide optical-to-THz signal converter.

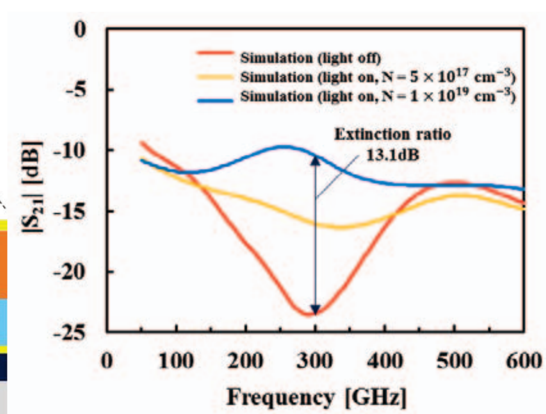

Fig. 2. Simulated transmission spectra of device.

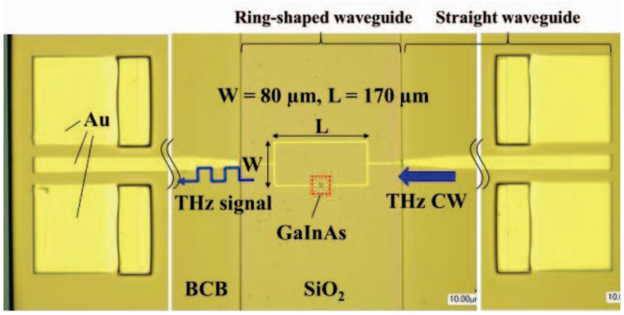

Fig. 3. Optical microscope image of waveguide optical-to-THz signal converter.

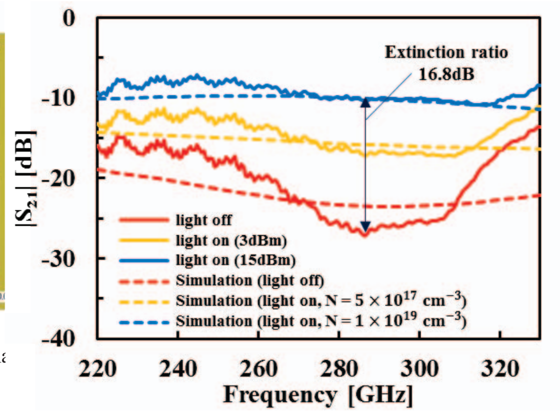

Fig. 4. Experimental transmission spectra of device.

We confirmed characteristics of the device through a simulation using a 3-dimensional finite element solver HFSS (Ansys, Inc.). From the free-carrier absorption model, the electric conductivity σ of the semiconductor GaInAs layer as functions of frequency f and carrier density N are given by

$$\sigma(f,N)=\frac{\sigma_{\mathrm{dc}}(N)}{1-i\omega(f)\tau(N)}\ , \qquad (1)$$

where σ_{dc} is the direct current conductivity, $\omega(f)$ is the plasma angular frequency, and $\tau(N)$ is the relaxation time [4]. In this simulation, the center frequency of the stop-band filter was set to 300 GHz by designing the ring size (W = 80 μm, L = 170 μm).

Figure 2 shows the simulated results without controlling light (red line) and with light (yellow and blue lines). A switching change in propagation intensity of 10dB or larger can be expected at 250-350 GHz frequency. Please note the conditions of light irradiation were emulated by changing carrier density N. In addition, the maximum extinction ratio of 13.1dB can be obtained at 300 GHz which corresponds to center frequency of the stop-band filter.

3. Fabrication process and Measurement result

In order to validate the simulation results, a prototype device was fabricated and measured. The device was fabricated as follows. First, an undoped InP layer (1-μm thick) and an undoped GaInAs layer (200-nm thick) were grown on a n-InP substrate (6×10^{18} cm^{-3}) in this order with organic-metal vapor phase epitaxy (OMVPE). After that, the photoconductive mesa structure was formed on the wafer, using reactive-ion etching and photolithography. Then, a 1-μm-thick SiO_2 layer was covered entirely after formation of a ground electrode. After removing SiO_2 on top of the mesa, the ring-shaped microstripline was formed using photolithography and lift-off process. Finally, a straight THz waveguide was attached on the device surface followed by formation of a benzocyclobutene (BCB) slope. Figures 3 shows the optical microscope view of the entire device. The dimensions of the ring were set to the values we used for the simulation in the previous sections.

Figure 4 shows a direct comparison between the measured and simulated transmission spectra for the device without light irradiation (red curves) and with light irradiation (yellow and blue curves) as a function of the frequency from 220 to 330 GHz. In this experiment, 1.52-μm light from a tunable laser was irradiated to the mesa through a lensed fiber. As a result, we successfully observed a maximum extinction ratio of 16.8dB caused by the irradiation with the light of 15dBm. The general concept and corresponding simulation results are validated through the satisfactory agreement between the simulation and measurement.

Acknowledgment

This research was financially supported by Japan Society for the Promotion of Science (JSPS), Grants-in-Aid for Scientific Research (#25709026, #15H05763).

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