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Development of planar antennas integrated quantum well phase modulator for 60GHz band signals

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Abstract

We reported the fabrication and demonstration of the antenna-coupled quantum well optical phase modulator on a Fe-InP substrate, which is a semi-insulating compound semiconductor. We have confirmed that carrier light undergoes the phase shift of $\phi = 2.02 \times 10^{-3}$ rad by radiating 60 GHz wireless signals. In addition, we have successfully demonstrated the demodulation of wireless signals with an S/N ratio of 7dB and a bandwidth of 50 MHz or more.

1 Introduction

Even though Millimeter wave band wireless communication is a system with excellent capacity and high speed, it is difficult to diffract the shielding object, and the attenuation in the atmosphere is large. The radio over fiber (RoF) technology, which converts radio signals into optical signals and transmits them, can compensate for the drawbacks of the millimeter wave band wireless communication. For the RoF system, a high-performance optical modulator integrated with an antenna is required. So far, we have proposed and demonstrated an antenna-integrated optical modulator using a five-layer asymmetric coupled quantum well (FACQW) [1] for the waveguide core layer [2]. However, in this device, there were some issues, such as the use of an n-type InP (n-InP) substrate, which has poor insulating properties, and a complicated fabrication process using a glass substrate was required.

In this study, we improve the optical modulation characteristics of the modulator and simplify the fabrication process. We fabricated and characterize an antenna-integrated quantum well optical modulator with a planar antenna using a semi-insulating Fe-doped InP (Fe-InP) substrate.

2 Device Structure

Figure 1 shows a schematic diagram of a fabricated device. Fe-InP is used for the substrate. Al and Au are used for an antenna and ground metal, respectively. The device, especially the part of antennas, was designed using the finite element method analysis simulator Ansys HSFF.

The antenna was designed to resonate strongly with a 60 GHz radio signal. A small gap is provided in the central part of the planar antenna, and an FACQW optical waveguide with a PIN junction is located directly under this gap. With this structure, when a wireless millimeter-wave signal is received, the resonant electric field is amplified in the gap, and the electric field is applied perpendicularly to the waveguide directly below. This applied electric field induces the unique quantum confined Stark effect (QCSE) in the FACQW, causing a large refractive index change in the waveguide. This allows phase modulation, and as a result, the information of the radio signal to be superimposed on the optical signal.

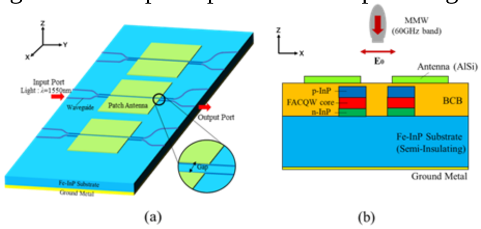


Figure 1 Schematic diagram of device.
(a) Overall view, (b) Cross-Sectional view.

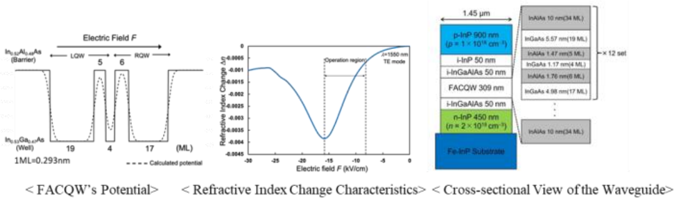


Figure 2 FACQW waveguide structure and its electric-field induced refractive index change characteristics.

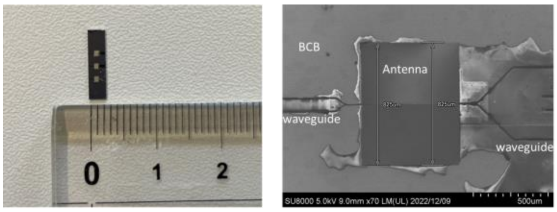
Figure 2 shows the FACQW waveguide structure and its electric-field induced refractive index change characteristics. This FACQW structure is designed for low electric field push-pull operation. By stacking 12 sets of this FACQW, waveguides can obtain sufficient light confinement for transmission. The thickness and doping concentration of other layers are determined by the light absorption loss and a built-in electric field.

3 Measurement

Figure 3 (a) shows the overall view of the fabricated device. There are three devices on a 2 mm×10 mm chip. Compared with the previous research [2], we were able to fabricate this chip in 5 fewer steps.

Figure 3 (b) shows a top scanning electron microscopic image of a middle device among the three. We confirmed that the devices were fabricated as designed.

Figure 4 (a) shows a modulation experiment system using 60 GHz band radio signals, and (b) shows a demodulation experiment system for the radio signals. In the modulation experiment, the TE mode light (λ=1550 nm) from a tunable semiconductor laser was incident into the device through an optical fiber. 60 GHz signals were emitted from a horn antenna from above the device. At that time, the transmitted light was measured.



(a) (b)

Figure 3 (a) Photograph of fabricated device (b) Top SEM image of fabricated device.

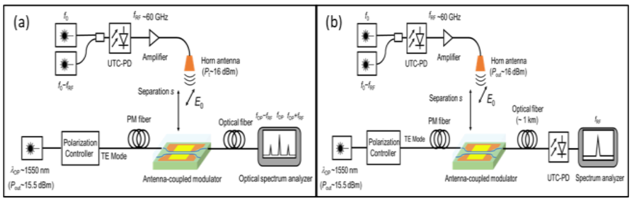


Figure 4 Measurement system. (a) Modulation experiment (b) Demodulation experiment.

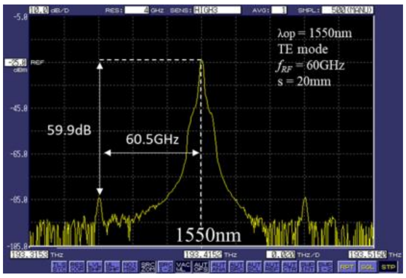


Figure 5 The result of modulation experiment

Figure 5 shows the measured spectrum of the transmitted light. It is known that when phase modulation occurs, sideband peaks are observed at a position separated from the carrier light by the optical modulation frequency. In this experiment, peaks are generated at positions separated by ±60.5 GHz from the carrier optical frequency. The ratio between the carrier light peak and the sideband peak is called CSR (career-to-sideband ratio) and is expressed by the following equation [3].

$$CSR\ [dB] = 20\log(2/m) \quad (1)$$

$$m = -k_{op}\Delta n_{core}\Gamma L\ sinc\left(\frac{k_{RF}uL}{2}\right) \quad (2)$$

In this formula, m is the degree of modulation, k is the wavenumber, Δn_{core} is the change in the refractive index in the optical waveguide core layer, Γ is the overlap coefficient, L is the length of modulation, and u is the value related to phase matching. From the experiment, the CSR was 59.9 dB from which it was confirmed that the modulation was 2.02×10^{-3} and the refractive index change was about 1.92×10^{-6}.

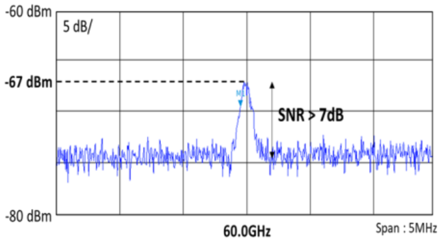


Figure 6 Result of demodulation experiment.

The demodulation experiment was also conducted. To convert the observed phase-modulated light into intensity-modulated light, a 1 km optical fiber was sandwiched between the device and uni-traveling carrier photodiode (UTC-PD) [4]. Due to the influence of chromatic dispersion caused by this fiber, the beat signals interfere with each other, making it possible to convert the modulation method. Figure 6 shows the results of demodulation experiments. We achieved the demodulation by using 60 GHz wireless signal with an S/N ratio of approximately 7 dB. In addition, we confirmed that demodulation was possible with a bandwidth of at least 50 MHz.

4 Conclusion

We reported the fabrication and demonstration the antenna coupled optical quantum well phase modulator using Fe-InP. In the fabrication, we can realize simplifying the process compared to previous research. In the demonstration, we have confirmed that carrier light undergoes a maximum phase shift of $\phi = 2.02 \times 10^{-3}$ rad by radiating 60 GHz wireless signal. In addition, we have achieved demodulation of wireless signals with an S/N ratio of 7dB and a bandwidth of 50 MHz or more.

Acknowledgements

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