A WR-4 Optically-Tunable Waveguide Attenuator with 50 dB Tuning Range and Low Insertion Loss

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Abstract—We report the development of a compact WR-4 (170-260 GHz) optically-tunable waveguide attenuator based on the interaction between electromagnetic waves and photo-induced free carriers in semiconductors. This approach is promising for achieving superior performance, including a ~50 dB tuning range, low insertion loss, low return loss (VSWR), and high tuning speed. Based on full-wave simulation results, an average attenuation level of ~50 dB can be achieved using a 1 mm long Ge absorber at a light intensity of 1 W/cm². By employing an E-plane taper design and energy absorption mechanism, return loss lower than -13 dB have been achieved. A prototype attenuator with Si absorber has been implemented using an E-plane split waveguide design. Initial measurement results show that ~14 dB attenuation can be achieved using a single illumination spot. The attenuation level can be improved by increasing the illumination region length employing multiple fibers.

I. INTRODUCTION

Tunable attenuators/modulators are important components in millimeter wave and terahertz (THz) wave systems because many applications require the capability of controlling and varying the power of THz signals. Mechanically tunable waveguide attenuators have been widely used at microwave frequencies[1]. However, mechanically tuning approaches have the disadvantages of low tuning speed and high insertion loss. Although free space optically- and electronically-tunable attenuators have been demonstrated at THz range [2], [3], they have not yet been applied in waveguide configurations due to the challenges associated with feeding light and integrating circuits and components into waveguide structures.

In this paper, we report the development of optically-tunable terahertz waveguide attenuators with superior performance including high tuning speed, low insertion loss, low return loss and large tunable range. This is achieved using E-plane tapered high-resistivity semiconductor chips (absorbers) aligned in the wave propagation direction. The tunability is realized by illuminating the semiconductor chip using fiber-guided IR laser diode for providing different levels of light intensity. For a prototype demonstration, a WR-4 waveguide attenuator has been designed and fully simulated, presenting lower than 1 dB insertion loss, lower than -15 dB reflection and a tuning range of ~20 dB using a Si absorber. A prototype tunable waveguide attenuator employing Si absorber has been implemented. Initial measurement results show that ~14 dB attenuation can be achieved using a single illuminationspot of ~0.5 mm × 0.5 mm. This tuning range can be further increased to larger than 50 dB using germanium (Ge) absorber and/or longer illumination region based on simulation.

![Fig. 1. The structure of a WR-4 tunable waveguide attenuator using photo-induced Si as absorber: (a) 3-D, (b) top view.](image-url)
absorber is chosen to have a thickness of only ~70 μm with both ends trimmed to be 4 mm long taper structures. As shown in fig. 1(b), the center region of the absorber is designed to be approximately 1 mm long for a maximum attenuation of ~20 dB (for Si absorber). This region will be illuminated by optical fiber guided laser diode through the narrow wall of the waveguide.

The s-parameters of tunable attenuators implemented with Si and Ge absorbers have been simulated in HFSS at different levels of light intensity, as shown in fig. 2. Over the entire WR-4 frequency band, the attenuation can be continuously tuned with a maximum averaged value of ~20 dB for Si based attenuator. More than 50 dB attenuation level can be achieved using Ge absorber at a lower illuminating intensity due to Ge material’s longer free carrier lifetime and higher carrier mobility. Owing to the E-plane tapered structure, THz reflection at the interface can be minimized resulting in a low simulated insertion loss. Taking into account the ohmic loss introduced by the waveguide walls, the overall device insertion loss is estimated to be lower than 1 dB for Si based absorber. Additionally, the return loss without light is lower than -13 dB owing to the absorption-dominated mechanism. The proposed attenuator can be easily implemented using E-plane split waveguide design and scaled to higher frequencies.

III. PROTOTYPE AND INITIAL MEASUREMENT

A prototype Si based WR-4 tunable waveguide attenuator based on the above design has been implemented as shown in fig. 3(a). A Si chip with taper structure and 1 mm long absorbing region was fabricated and installed to the block. The absorbing region was designed to be illuminated by two optical fibers through the holes. Initial measurements of tunable attenuation performance with only one illuminating spot have been performed and the results are shown in fig. 3(b). During this testing, the Si chip was illuminated by a fiber-coupled 808 nm laser diode under various biasing currents (light power levels). The quick initial test was performed using a WR-5 VDI source and a WR-10 Erickson powermeter. Therefore, the measured transmission curves show strong standing wave effect due to the reflection at both ends of the attenuator. It can be seen that tunable attenuation with a tuning range of up to ~14 dB can be achieved using a single illuminating spot of ~0.5 mm × 0.5 mm. We expect that ~20 dB tuning range can be achieved with a device VSWR smaller than 1.2 by using lower levels of light intensity and two illuminating spots. This result demonstrated that the proposed approach was promising for realizing THz tunable waveguide attenuator with high performance.

IV. CONCLUSIONS

A novel approach for developing optically-tunable terahertz waveguide attenuators has been reported. A prototype high-speed tunable waveguide attenuator at WR-4 band has been designed and simulated. Based on the full-wave simulation results, an average of 20 dB attenuation level with an insertion loss lower than 1 dB can be achieved using Si absorber. Higher attenuation level can be obtained using longer absorber or semiconductor materials (e.g., Ge) with longer free carrier lifetime and higher carrier mobility. A tuning speed of ~30 kHz has been estimated based on the linear recombination coefficient in silicon. Initial measurement results show that ~14 dB attenuation can be achieved using a single spot (~0.5 mm × 0.5 mm area) for illumination. Improved attenuator with longer absorber region employing 4 illuminating fibers (2 mm absorber region length) that can achieve ~50 dB attenuation will be fabricated and fully characterized soon.

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REFERENCES


