An Optoelectronic Attenuator for the Control of Microwave Circuits

Stephen E. Saddow, Bruno J. Thedrez, and Chi H. Lee

Abstract— **An optoelectronic technique suitable for the control of microwave circuits has been demonstrated. Using a coplanar waveguide-photoconductive switch (CPW-PCS), the RF impedance is varied with a laser diode is varied. Using a fiber pigtailed AlGaAs laser diode and a silicon CPW-PCS, it is shown that 30 dB of RF attenuation can be achieved with a laser peak power of 375 mW. Intensity saturation of the Si:CPW-PCS was also observed and characterized to improve the attenuator performance.**

I. Introduction

THE USE of optoelectronic techniques to control microwave circuits and systems continues to be an area of intense research and development [1]–[3]. Besides the inherent speed advantages of this approach, use of a laser to control multiple microwave circuits permits both a high degree of electrical isolation between the control signal and the microwave circuit, and timing precision that can easily be in the picosecond regime [4].

This letter describes a hybrid optoelectronic attenuator scheme suitable for controlling microwave integrated circuits. By optically controlling the microwave impedance of a coplanar microwave transmission line fabricated on a silicon substrate, we have demonstrated up to 30 dB of RF attenuation using a commercial fiber pigtailed AlGaAs laser diode operating at 375 mW, the highest attenuation ever reported for an optoelectronic microwave attenuator [5]–[6]. Earlier work by Platte and Sauerer [6] utilized a similar technique with CW optical illumination; however, they achieved a maximum attenuation of less than 1.8 dB.

A coplanar microwave transmission line is fabricated on a photoconductive substrate, such as silicon (Si) or gallium-arsenide (GaAs). Fabrication of high-speed transmission lines on these materials yields imbedded photoconductive switches resident in the transmission line structure. Illumination of these switches by the appropriate light source creates a conductive plasma in the switch gap, and since this switch is between the transmission line's conductors, the plasma changes the transmission line's characteristic impedance. Thus the creation of a plasma within the transmission line causes the propagating wave to be reflected, with the degree of attenuation a function of the induced plasma density (in the extreme case, the microwave signal is shorted to ground). The attenuation value is roughly an exponential function of the shunt RF impedance (i.e., the induced plasma density), which can be accurately controlled by varying the incident laser pulse intensity.

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S. E. Saddow is with the Army Research Laboratory, 2800 Powder Mill Road, Adelphi, MD 20783.
B. J. Thedrez and C. H. Lee are with the University of Maryland, Department of Electrical Engineering, College Park, MD 20782.
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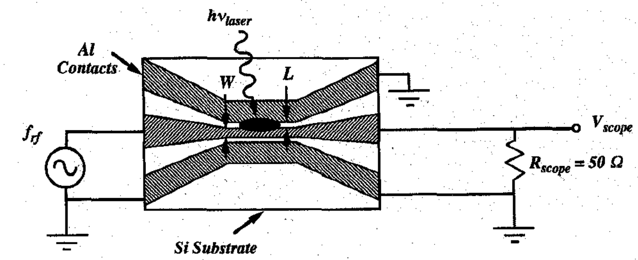

Fig. 1. Hybrid optoelectronic attenuator setup showing placement of Si:CPW-PCS, RF connection to 375 MHz source, and RF connection to matched 50-Ω oscilloscope load. Si:CPW-PCS 1.6 cm × 5 mm.

II. CPW-PCS Device Design and Fabrication

The coplanar transmission line geometry facilitates the use of broad-area laser diodes which can be easily focused onto the gap(s) between the coplanar conductors. Both Si and GaAs can be used as the substrate material, with the primary difference being the carrier recombination lifetime of 5 ns for GaAs and 10 μs for Si. Fig. 1 shows a cross section of the Si:CPW-PCS in the hybrid attenuator circuit. To achieve ohmic contact to the high resistivity substrate ($\rho_{Si} \geq 6 \times 10^3 \Omega$–cm), the contact region was ion-implanted using Boron to create a P^{++} region. Aluminum contacts were then deposited onto the ion-implanted regions to form the coplanar waveguide structure. Current-voltage measurements indicate that ohmic contact to the substrate was indeed achieved.

To properly connect the Si:CPW-PCS into a hybrid attenuator circuit, the coplanar structure was flared to permit connection via an SMA connector. The W/L ratio was kept constant to maintain a 50-Ω characteristic impedance at the design frequency of 3 GHz. Consequently, the overall device length was 1.6 cm, resulting in a large parasitic center conductor resistance (59.5 Ω). Fortunately this parasitic resistance would not be present in an operational device since the device length need only be equal to the laser spot size. Scalar network analyzer measurements showed the Si:CPW-PCS has an insertion loss of 4 dB at 10 GHz (once the parasitic resistance contribution is removed).

GaAs CPW-PCS devices were characterized using both single-stripe broad-area laser diodes and a tunable titanium sapphire laser [7]. However, the short carrier lifetime of semi-insulating GaAs (~ 5 ns) caused the RF attenuation to be low (less than 0.5 dB) for the available laser power. Thus,

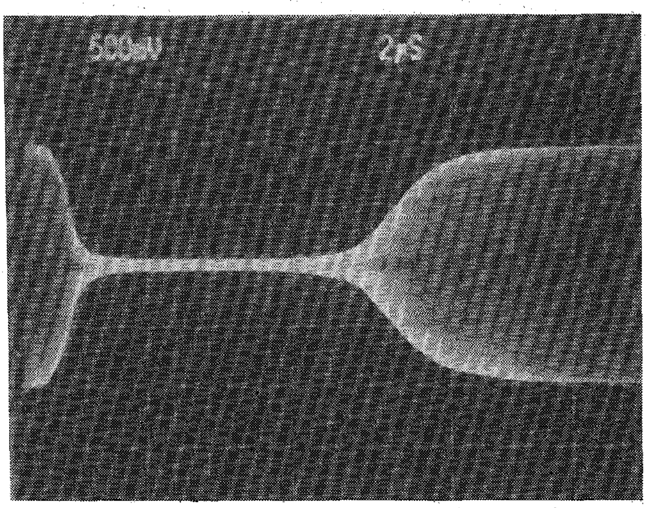

Fig. 2. Si:CPW-PCS output waveform showing attenuation of a 500-MHz envelope of 26 dB using a linear AlGaAs diode array. Pulse width = 3 μs, RF power = 18 dBm.

in this paper, results using a 10-μm gap Si:CPW-PCS will be presented, since the carrier lifetime ($\sim$10 μs) permitted efficient attenuation to be achieved.

III. Optoelectronic Attenuator Experimental Results

Using a 1-cm linear AlGaAs laser diode array provided by David Sarnoff Research Center [2], 26 dB of RF attenuation was achieved for an optical peak power of 5 W (see Fig. 2). Attenuation is defined as $S_{21} = 20 \cdot \log_{10}(V_{\text{on}}/V_{\text{off}})$, where V_{on} and V_{off} are the peak RF voltage with the laser on and off, respectively. Both gaps of the Si:CPW-PCS were illuminated due to the rather large spot size (100 μm $\times$ 5 mm) on the switch.

A commercially available fiber pigtailed AlGaAs laser diode (Spectra Diode Labs no. SDL-2372-P3) was then used to improve the attenuator performance. The laser was operated with a pulse width of 200 μs at a repetition rate of 375 Hz. Using a $\times$20 microscope objective (10μm spot size), we observed a saturation effect as a function of laser intensity, as shown in Fig. 3.

In order to optimize the attenuator performance, we used a cylindrical lens to expand the beam in one dimension. The measured spot size was 10 μm $\times$ $\sim$2 mm. The attenuation increased to 30 dB, thus validating the saturation hypothesis (see Fig. 3).

IV. Conclusion

Silicon was used since the long carrier lifetime in this material yielded better performance. Semi-insulating GaAs devices, also fabricated, performed poorly due to the materials short carrier lifetime. However, it is possible to use GaAs–AlGaAs superlattice structures to increase the lifetime to values exceeding that of silicon [8].

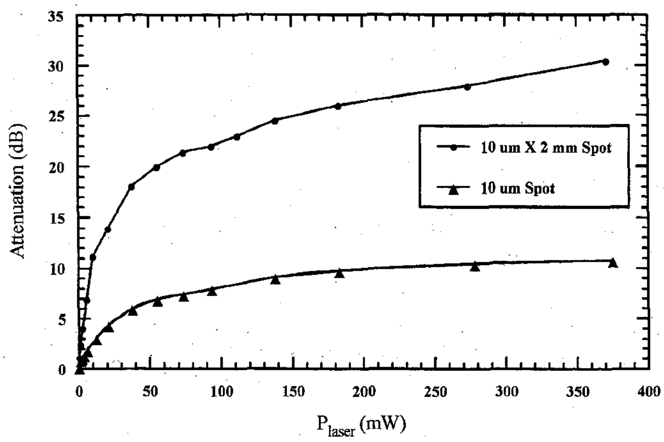

Fig. 3. Si:CPW-PCS attenuation versus incident laser diode peak power with 10-μm spherical spot size (curve with solid circles) and with 10 μm $\times$ 2 mm spot size (curve with solid triangles).

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