Optically CW-Mode Controlled Microwave Switches with Carrier-Confinement on a Coplanar Waveguide

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Abstract

A new design for optically controlled microwave switches on a semiconductor coplanar waveguide (CPW) with carrier-confinement using a CW laser is presented. The CPWs having a different gap on each signal line are designed and fabricated on a high-resistivity silicon wafer with micro-fabrication technology. To minimize the insertion loss and to obtain a higher ON/OFF ratio with the same optical power, the gap areas between the signal line and the ground plane are etched out using an isotropic-etching technique, and the generated free carriers can be confined. As a result, the insertion loss can be reduced more than 4 dB with the same optical power. The design for the etching area and the depth will be optimized with the numerical simulation results for the generated free-carrier distribution and transmission characteristics.

I. Introduction

There has been an increasing interest in photoconductivity effect to control microwave solid-state devices which offers several advantages such as fast response, immunity from electromagnetic interference, high power handling, good isolation between controlling and controlled devices, and possibilities for monolithic integration[1]. The basic application for the photoconductivity effect is an optically excited gap in a semiconductor transmission line. Thus, the transmission characteristics can be controlled by gap excitation with light which can be used for a switching device or an attenuator. Initially, the picosecond switches using pulsed laser sources were developed as a very attractive and practical technique, and intensive research in these fields was initiated[2-7]. Later, CW induced optically controlled microwave devices were observed for the prospect of novel components[8-10]. However, with CW illuminations, the optically excited carriers will be diffused and undergo various adverse influences. Therefore, the carrier diffusion, surface recombination process and the photo-induced carrier penetration depth need to be considered[8].

In this paper, we introduce optically controlled microwave switches on a semiconductor CPW and a new design to confine the photo-induced free carriers with substrate etching around the gap area. Both devices are fabricated with micro-fabrication techniques, and the transmission characteristics are measured and compared. As a result, the insertion loss can be reduced more than 4 dB and also ON/OFF ratios are improved. The design for the etching area and depth will be optimized with the numerical simulation results of photo-induced carrier distribution and transmission characteristics.

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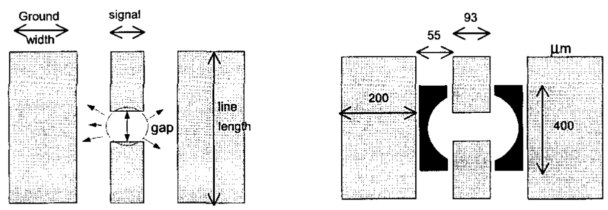
II. Optically CW-Mode Controlled CPW Switches

Optically CW-mode controlled microwave switches on a semiconductor coplanar waveguide (CPW) are designed and fabricated as shown in Fig. 1. (a).



(a) (b)

Fig. 1. Coplanar waveguide design without grooves (a) and with grooves (b).

A high-resistivity (>1000 Ω.cm), float zone <100> silicon wafer (HR-Si) is used as a substrate to build CPWs. Four different gap sizes, 0, 25, 50 and 75 µm on a 50 Ω signal line of the CPWs are designed, and the line without a gap is used for a reference line. To build metal line patterns on a HR-Si substrate, a simple micro-fabrication technique is applied.

Au is deposited for 1500 A° and line patterns are obtained with a lift-off process. A He-Ne laser (λ= 632 nm) is used as a light source, and the light is guided through the optical fiber. The maximum power at the tip of the fiber is about the 3 mW. The transmission characteristics are measured with vector a network analyzer (HP8510C) at a frequency range from 500 MHz to 20 GHz and with a 3D µ-wave probe station.

Fig. 2 shows one of the measured transmission characteristics. All the measurements are 'Thru' calibrated with a reference line, and the insertion loss can be

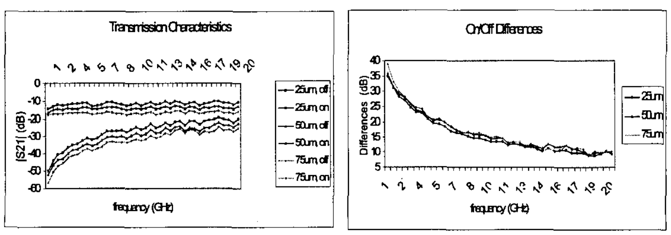


Fig. 2. Measured transmission characteristics with different gap sizes.

read directly from the plot. The line length of the measured device is 2.5 mm and the signal line width is 93μm. The applied optical power density from the tip of the fiber is about 3 mW/(100 μm)^2, and the 10 to 35 dB ON/OFF differences depending on the frequency are obtained with this power density. The measured lowest insertion loss is about the 10 dB with a 25 μm gap. Although all the measured data show good consistencies, the insertion loss is still too high to be used practically, and the ON/OFF differences are less than 20 dB at the frequency range from 6 GHz. This problem can be solved with either higher optical power, which is not recommended, or a better device design. Hence, we propose a newly designed, carrier-confined CPW switch.

III. Carrier-Confined Optically CW-Mode Controlled CPW Switches

To improve the transmission characteristics of the optically CW-mode controlled CPW switches without increasing the input optical power, a new design with carrier confinement is suggested. The basic idea to confine the optically induced carriers is making grooves around the gap areas between the signal line and ground plane which can be done by silicon substrate etching. Fig. 1. (b) shows a proposed groove design. The silicon etching can be done by either isotropic or anisotropic etching, but a <110> float zone wafer for vertical silicon etching is not available which limits the efficiency of the carrier-confinement. Thus, isotropic plasma etching is applied even though there is an under cutting problem. However, it is acceptable because under cutting can be used for further carrier-confinement under the signal line in our application.

Fig. 3 shows one of our preliminary measured results with a carrier-confined device and comparison with the previous results. Both devices are measured in the same condition. The gap size of the measured device is 50 μm, and the applied input power is 2.5 mW without grooves and 2.2 mW with grooves. With this plot, the improved results with the carrier-confined devices are observed. The insertion losses are decreased about 4 dB and the ON/OFF differences are increased with lower optical power. However, the design with grooves is not yet optimized with simulation results. The numerical simulations for the optically induced carrier distribution and the transmission characteristics will be developed. With simulation results, the carrier-confinement can be optimized, and they will be compared with the measured results.

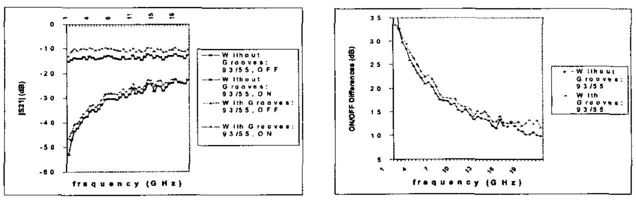


Fig. 3. Measured transmission characteristics for the carrier-confined CPW

IV. Conclusions

Optically CW-mode controlled microwave switches on a semiconductor CPW are presented, and a new design for carrier-confinement is proposed. Preliminary measurements show the insertion loss is decreased about 4dB and the ON/OFF differences are increased with lower optical power. The new design can be optimized with simulation results, and the numerical simulations for the optically induced free-carrier distribution and the transmission characteristics will be developed. Thus, the optimized device will be measured, and the characteristics will be compared.

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