Picosecond Photoconductive Switches Designed for On-Wafer Characterization of High Frequency Interconnects

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Abstract

Photoconductive switches fabricated by compatible microwave device processing techniques are used for on-wafer characterization of a long high-frequency interconnect exceeding 160-GHz measurement bandwidth. Full characterization of this interconnect structure is important for determining cycle time of the future high speed computer.

I. Introduction

One of the main parameters limiting the performance of an on-wafer photoconductive (PC) sampling system is the response of the switches utilized for exciting the device under test and sampling the time-domain input and output waveforms. In this paper, we experimentally study the pulsewidth and DC line resistance dependence of the amplitude of the resistive tail of switches fabricated by compatible microwave processing techniques. The switches which generate 7-ps electrical pulses were ion-damaged semi-insulting Gallium Arsenide (SI GaAs) surface switches fabricated in a coplanar transmission line. Shorter electrical pulse is not preferable to test high frequency interconnects with long propagation distances due to strong attenuation and dispersion. On-wafer characterization of a high frequency interconnect is performed over a considerably long distance. The attenuation and phase characteristic of the lines are presented for frequencies up to 160 GHz. Accurate determination of the transmission line parameters is important for future high speed computers [1].

II. Experiment

Figure 1 displays a schematic of the switches used for this experiment. The switches, which are ion-damaged SI GaAs surface switches, were proton bombarded at 50 keV and 150 keV with $1 \times 10^{15} cm^{-2}$ dose to produce a penetration depth of 1.1 μm. This implantation density was used to produce deep-level traps in the semiconductor thereby reducing the recombination time of the photoexcited carriers. The fabrication process used to produce these switches is compatible with established microwave device techniques. Typically, this type of ion implantation is used to produce isolation in monolithic microwave integrated circuits (MMICs) devices.

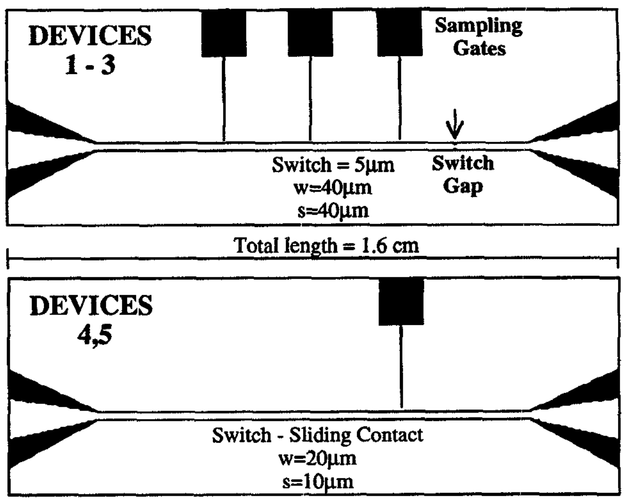

Fig. 1. *Schematic of switches tested.*

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Switches were designed to study the resistive tail normally associated with coplanar strip transmission lines by varying the electrical pulsewidth and reducing the DC line resistance. Additionally, a switch with sliding contact excitation was used to determine the attenuation and phase constant of a coplanar transmission line interconnect.

The switches were tested using photoconductive sampling techniques. The laser produces 3-ps pulsewidth, 150-mW average power, and a 76-MHz repetition rate at a wavelength of 0.527 μm.

III. Results and Discussion

Electrical waveforms generated from switches fabricated as part of coplanar transmission lines have always possessed a long tail. The dependence of the DC resistance and pulsewidth on the ratio of the tail amplitude to the peak amplitude is described by Scheuermann [2].

$$A_{tail} \simeq \frac{R_s}{Z_0 + R_s}$$
$$R_s \simeq r_{dc}\lambda_p$$

where R_s is the effective resistance, Z_0 is the transmission line characteristic impedance, r_{dc} is the DC line resistance per unit length, and λ_p is the spatial extent of the pulse on the line.

By utilizing the velocity saturation effect in the PC switch, the pulsewidth of the generated electrical pulse can be varied by changing the applied bias [3]. When electric field in the switch becomes larger than the saturation field, higher bias voltage will result in smaller carrier velocity and longer carrier transit time. Consequently, the pulsewidth becomes wider. The normalized cross-correlated waveforms from a 5-μm switch gap biased with a voltage ranging from 5 V to 30 V are displayed in Figure 2. The cross-correlated pulse width varies from 8.3 ps to 12.7 ps. As the pulsewidth is reduced, a reduction in the peak amplitude/tail amplitude ratio is observed. This is consistent with Scheuermann's simple model with the exception that we see a larger peak/tail ratio. This confirms that DC line resistance causes the tail. To eliminate the tail, the DC line resistance is reduced from 145 Ω/cm to 19 Ω/cm by electric plating of the metal from 1000 Å to 9000 Å. The waveform shown in Figure 3 (a) illustrates this. Reducing the DC resistance greatly suppresses the tail. The frequency content of the electrical pulse exceeds 160 GHz.

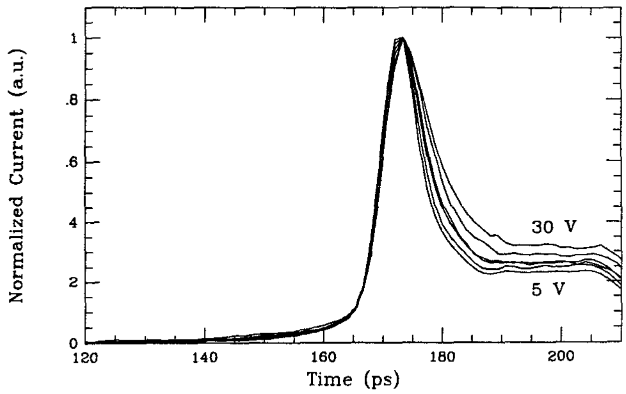

Fig. 2. *Effect of pulsewidth on the tail amplitude.*

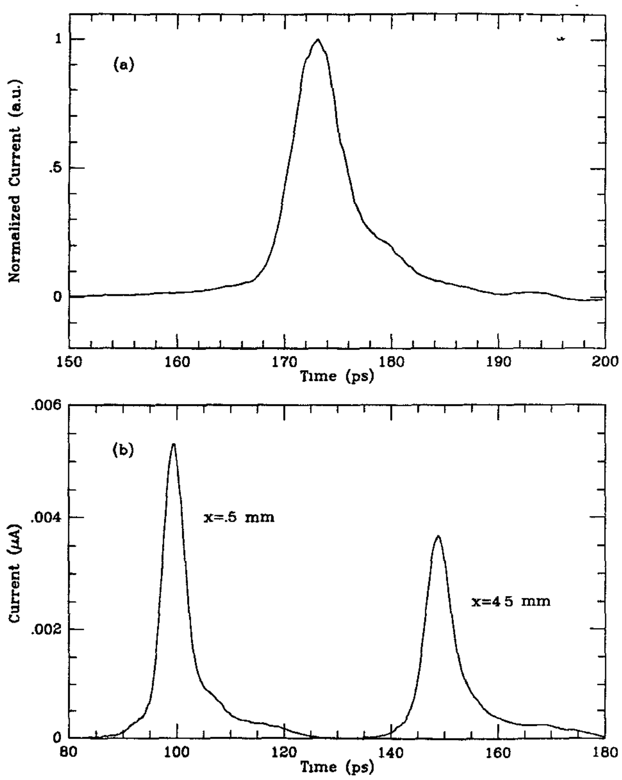

Fig. 3. *(a) Time-domain response from switch with DC resistance of 19 Ω/cm. (b) Time-domain waveforms used to determine interconnect characteristics.*

The picosecond electrical pulses described in this paper are used to determine the attenuation and phase constants of a high frequency interconnect. The interconnect tested is a coplanar transmission line in which a switch is embedded. The device is biased at 30 V and is switched by sliding contact and sampled at a side line. To determine the attenuation and phase constants, two separate measurements must be performed. Initially, a waveform is acquired from a switching position only 0.5 mm from the sampling gap. The sliding contact is then moved away from the side line to facilitate a second measurement with a propagation distance of 4.5 mm. Figure 3 (b) shows these two time domain waveforms.

Using this information and the following formula, the attenuation and phase constants of the interconnect can be computed.

$$\alpha(f) + j\beta(f) = -\frac{1}{l_1 - l_2} ln \frac{A_1(f)}{A_2(f)} + j\frac{\phi_1(f) - \phi_2(f)}{l_1 - l_2}$$

where A_1 and ϕ_1 are the amplitude and phase of the Fourier transform of the pulse generated 0.5 mm from the sampling gap, A_2 and ϕ_2 are the amplitude and phase of the Fourier transform of the pulse generated 4.5 mm from the sampling gap, l_2=4.5 mm and l_1=0.5 mm.

The attenuation and phase constants can also be theoretically predicted by taking into account DC resistive losses, skin depth resistive losses, dielectric losses, and radiation losses [4]- [6]. The theoretical and experimental attenuation and phase constants are shown in Figure 4. Both attenuation and phase give very good agreement between experiment and theory.

IV. Conclusion

In this work, we experimentally investigated the origin of the unwanted resistive tail of coplanar strip lines. We also fully characterized the interconnect coplanar strips in terms of the attenuation and phase constants up to 160-GHz with a long propagation distance. Accurate characterization of the complex propagation constant can be used to refine the theoretical model, and estimate the machine cycle time for future high-speed computers.

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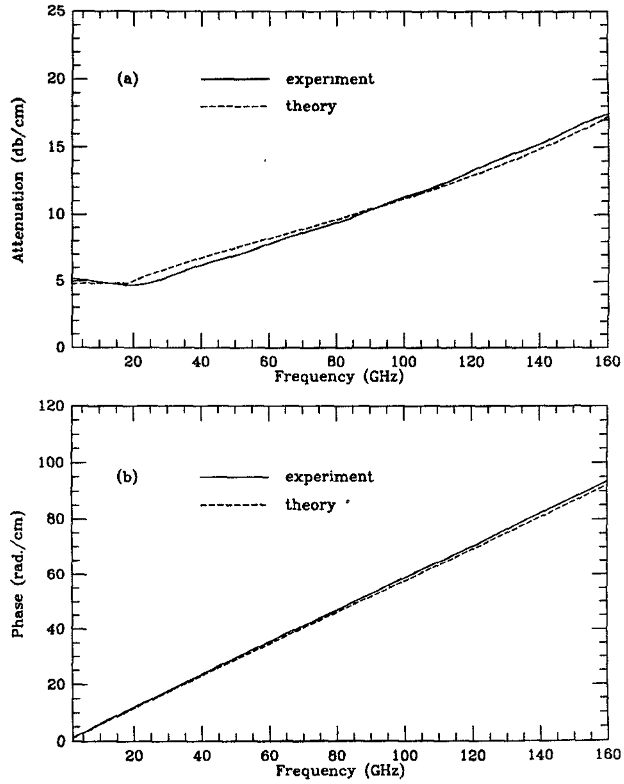

Fig. 4. *Experimental and theoretical (a) attenuation, (b) phase constants.*

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