Optoelectronic generation and Sensing of Millimeter Waves

Charles R. Lutz and A. P. Defonzo
University of Massachusetts
Department of Electrical Engineering
Amherst, Ma 01003

Abstract

Broadband tapered slot antennas, monolithically integrated with picosecond optoelectronic switches, are used to generate, control and sense millimeter wave radiation. These devices can be easily integrated with millimeter wave circuit components due to their planar geometry. This method of transmitting information eliminates many of the limitations inherent with transmission line structures and demonstrates the potential for controlling extremely wideband electrical signals.

Introduction

The use of photoconductivity to generate millimeter wave radiation is a relatively new concept in picosecond electronics. Experiments have shown that fast optoelectronic switches, monolitically integrated with an appropriate guiding structure, can be used to optically generate and detect picosecond bursts of electromagnetic energy [1-3]. The primary advantage of such a device is the ability to transmit wide bandwidth electrical signals with limited distortion caused by dispersion and other frequency-dependent losses. In addition, planar technology will allow such devices to be easily integrated with millimeter wave circuits and should prove useful as electro-optic samplers and interconnects in various applications. However, in order to control the spatial and temporal distribution of the radiated field, it is necessary to employ more sophisticated antenna elements than simple gap discontinuities in microstrip transmission lines.

In this paper, we present the results of a study conducted using planar antenna structures deposited on radiation damaged silicon on sapphire (SOS) substrates to generate, transmit, and detect ultrafast electrical pulses. This approach allows extremely large bandwidth electrical signals, greater than 200 GHz, to be transmitted from point to point without the use of transmission lines thus avoiding the problem of signal dispersion. Furthermore, in contrast to microstrip gaps [1], our antennas are designed for radiation of picosecond transients but are by no means limited to this particular frequency spectrum.

Experimental Design

Our experimental configuration is illustrated in Fig. 1. A standard pump/probe arrangement was used to obtain the experimental measurements[1-3,9]. The dimensions of the antenna were obtained by scaling down the design of the Vivaldi airial first proposed by Gibson[4]. The length l, height h, and aperture sizes a1 and a2 were as follows: l= 2.96mm, h=3.8mm, a1=25um, a2=1.9mm. Two antenna shapes were investigated. One was an Exponentially Tapered Slot Antenna (ETSA) and the other was a Linear Tapered Slot Antenna (LTSA). The transmitting antenna is dc biased and can be discharged by photoconductively shorting the transmission line gap with a picosecond optical pulse The resulting current pulse is guided into the antenna region where it radiates an electromagnetic field which is directed toward an opposing antenna. An intervening air gap separates the transmitting and receiving antennas. When the field reaches the receiving antenna, it impresses a transient bias voltage proportional to the strength of the field, across the gap of the transmission line. This voltage is photoconductively sampled by illuminating the semiconductor material between the gap with a second picosecond laser pulse derived from the same source as the pump pulse but delayed by a variable time tau. The functional dependence of the received signal is determined by varying the time delay over the duration of the transient. The width of the photoconductive pulses is controlled by bombarding the silicon epilayer with high energy O+ ions. Ion energies of 100 Kev and 200 Kev at dosages of 10^15 ions cm^-2 were used in our experiments.

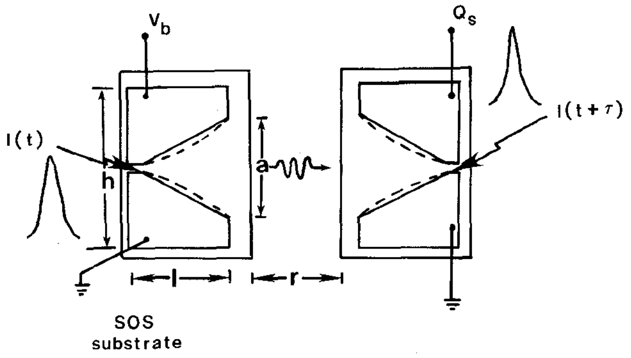
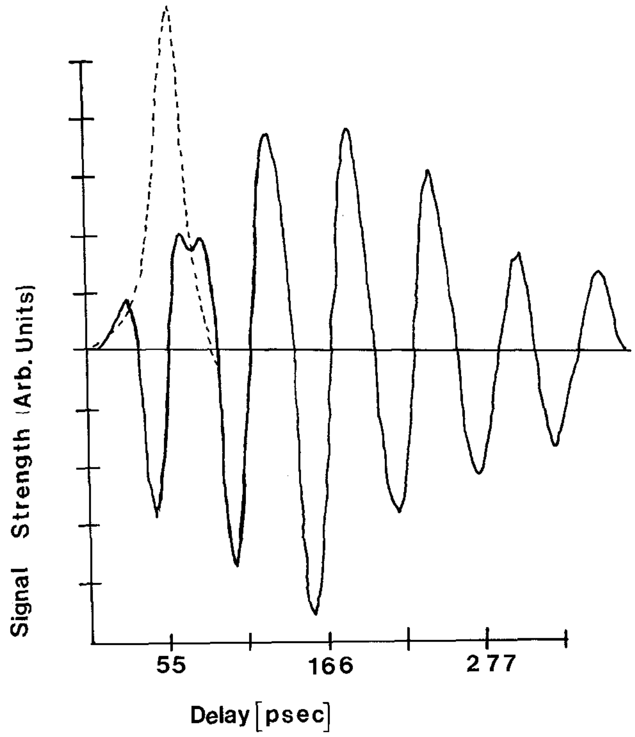


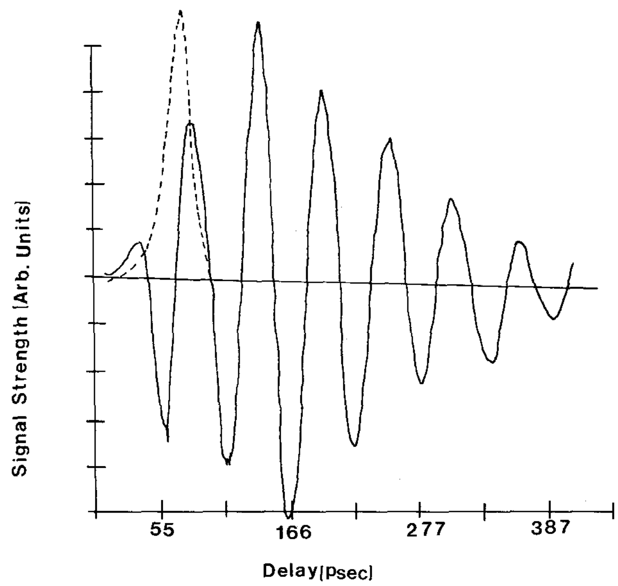
Fig. 1 Schematic of experimental configuration using matched optoelectronic antennas.

Results

The measured correlation trace shown in Fig. 2 is the result obtained when the transmitting and receiving antennas were separated by an air gap of approximately 1.0 cm. Fig 2(a) represents the LTSA and Fig 2(b) is the signal obtained for the ETSA. In each case the dashed curve represents the correlation of the photoconductive driving pulse measured on the same type of material using a conventional microstrip "cross-corrleator" [5]. This data clearly indicates the presence of a fast transient followed by a decaying oscillation of much lower frequency. Direct comparison of the photoconductive drive signal with the received signal suggests tnat the initial transient is the derivative of the photoconductive driving pulse. This data can be predicted using a model response function derived from antenna theory [3]. Figures 3(a) and 3(b) are the results predicted by this model for the LTSA and ETSA respectively.



[a]



(b)

Fig. 2 Correlation trace of the radiated electric field from the structure shown in Fig. 1, (a) LTSA (b) ETSA. The dotted line indicates the correlation of the photoconductive drive pulse.

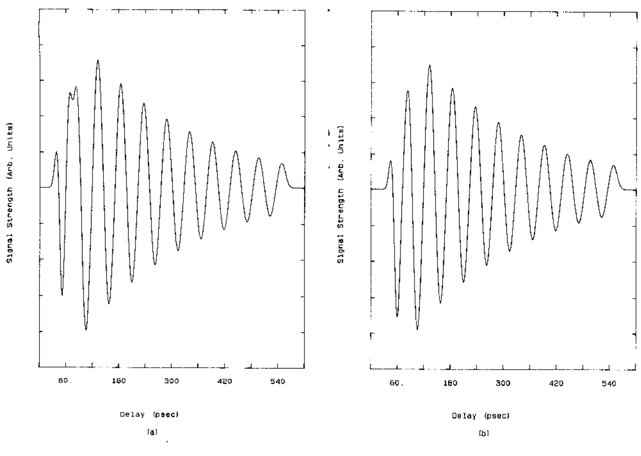


Fig. 3 Calculated response based on theoretical model for (a) LTSA (b) ETSA

A second generation of optoelectronic antennas was developed based on the modeling of the radiation mechanisms present in the original device. The geometry of this new antenna is illustrated in Fig. 4 and consists of an exponentially flared coplanar transmission line, with a design impedance of 100 ohms. The overall length of the structure was 7.9 mm and the width of the aperture was 1.9 mm. The photoconductive generator consists of a relatively long 4 mm section of coplanar line, 12 um wide with a gap separation of 25 um. This structure drives the radiating element which is formed by flaring the remaining 4 mm of transmission line.

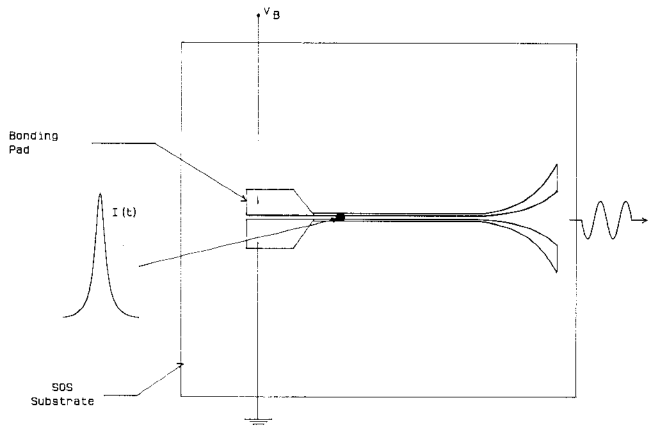


Fig. 4 Geometry of second generation antennas

Correlation measurements obtained for the field radiated by the new structure is shown in Fig. 5(a). The two antennas were separated by an air gap of approximately 0.7 cm and were identical. Illustrated in Fig. 5(b) is the correlation trace of the photoconductive drive pulse. This signal was measured by photoconductively sampling the current pulse propagating down the coplanar transmission line. This data clearly shows that the antenna structure does not introduce any significant broadening of the radiated pulse, indicating that the coplanar structure is a wide bandwidth configuration. The lack of any "internal" reflection components in the received signal imply that this antenna has a high radiation efficiency and totally suppresses any standing wave component[3]. The additional small features in Fig 5(a) are associated with external reflection sources and corresponds closely to the spatial separation of the pump and probe beams. The insets in Fig.5 show the "second harmonic generation" (SHG)[6] autocorrelation signal of the optical excitation pulses. These pulses were generated by an actively mode-locked dye laser and the pulse durations were measured to be less than 2 ps and could be lengthened to 6 ps by adjusting cavity parameters.

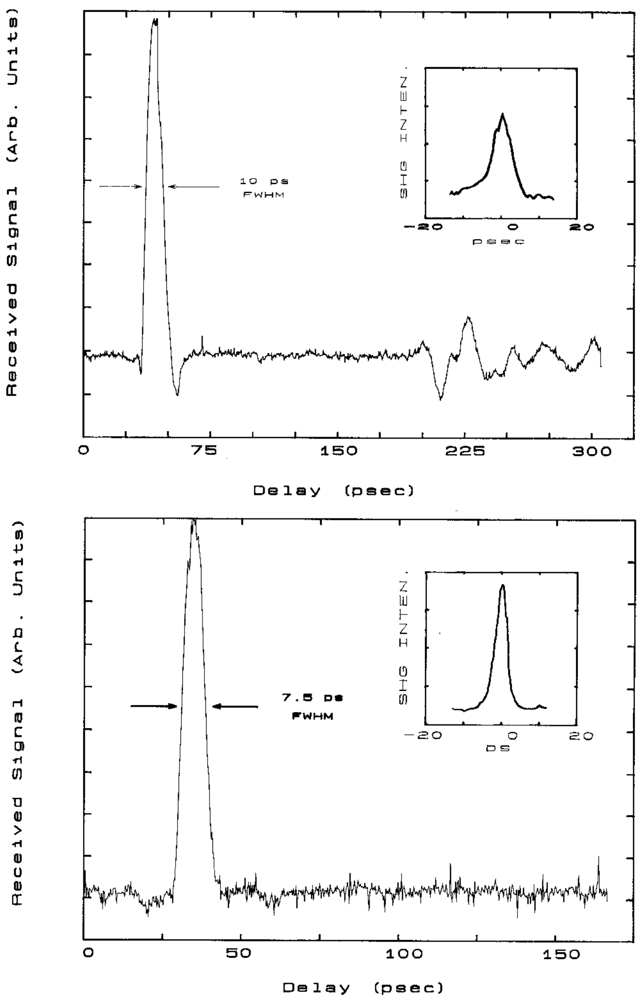


Fig. 5 (a) Correlation signal of the field radiated by the device shown in Fig. 3.
(b) Correlation signal of the photoconductive drive pulse. The insets illustrate the form of the optical pulses.

Recently reported work [7] using a similar material, but not containing any radiating elements, has demonstrated generation of photoconductive electrical pulses on the order of 600 fsec. These results support our previous findings and indicate that our antennas can be directly used in the femtosecond regime.

Conclusions

In summary, we have shown that a new class of picosecond optoelectronic devices capable of transmitting ultrafast electrical signals, can be fabricated using planar antenna technology. The second generation device eliminates the standing wave components in the radiated field and is extremely broadband. In addition, the radiated pulse was shown to be a replica of the optical excitation pulse and free of any distortion other than that caused by the inherent dispersion of the transmission line structure. This device exhibits electrical bandwidths in excess of 200 GHz and is one of the largest bandwidth antennas ever reported. We anticipate that with improved processing methods we will be able to generate and radiate sub-picosecond transients with these devices. This work was supported by the Air Force Office of Scientific Research under grant number AFOSR-84-0377.

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