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DIRECT DC TO RF CONVERSION BY PICOSECOND OPTOELECTRONIC SWITCHING

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ABSTRACT

Conversion of dc energy to RF pulses has been demonstrated by picosecond optoelectronic switching in silicon. Sequential waveform of two and one half cycles has been generated with voltage conversion efficiency better than 90%. This type of device has the potential of generating megawatt power at frequencies extending into the millimeter-wave region.

INTRODUCTION

The direct conversion of dc energy to RF pulses with high efficiency has many potential applications. They include: 1. the use of high-power electrical pulses for pulsed power devices and plasma-physics experiments; 2. various applications in high resolution radar and time domain metrology; and 3. the generation of mega-watt level microwave and millimeter-wave pulses. All of these experiments require the development of an appropriate switch or an array of switches which can switch high power with extremely fast risetime and zero jitter. For sequential waveform generation several methods have been tried [1;2]. In reference (1), a series of step recovery diodes was used; however only low voltage switching has been demonstrated. The prospects to extend this technique to a high power switch are poor because the step recovery diodes encounter breakdown problems at high voltage. In reference (2), a frozen wave generator was used for sequential waveform generation. A frozen wave generator consists of many segments of transmission line charged alternately with positive and negative voltage (Fig. 1). Two adjacent segments are joined by a silicon switch which can be closed with a laser pulse. To maintain a high conversion efficiency and a good waveform it is essential that all the switches be closed simultaneously and rapidly. Jitter in the switching process produces random frequency modulation which removes energy from the fundamental. Picosecond laser activated semiconductor switches seem ideal for this application. However, in reference (2), Proud, Jr. and Norman used nitrogen laser which produced optical pulses with a time duration of a few nanoseconds. The advantage of the photoconductive switch was not fully utilized. In this work, we report the use of picosecond laser pulses for switching. A sequential waveform of two and one half cycles has been obtained with voltage conversion efficiency better than 90%.

FROZEN WAVE GENERATOR WITH OPTOELECTRONIC SWITCHES

The schematic of the frozen wave generator is shown in Fig. 1. It consists of three separate silicon switches and three charge line segments. Semi-rigid coaxial cables (O.D. 0.034") were used for interconnection between electrodes. They were charged alternately with positive and negative voltage (+10V and -10V respectively). The opto-electronic switches were fabricated by using a N-type high resistivity silicon (5200 Ω-cm [111] orientation) as a substrate, on top of which a 50 Ω line (ω/H = 0.8) was evaporated. 4000 Å of Titanium was first deposited at room temperature on top of the silicon substrate, followed by 4 μm of Aluminum. Next, 4-5 μm of silver was deposited to complete the tri-metal deposition. Then, the pattern of the electrodes pairs were defined by using photo-resist techniques. In order to increase the isolation between three-electrodes pairs, cuts were made between the electrodes. The gap length between electrodes pairs is 0.25 mm, the width and the length of the electrode is 0.4 mm and 3 mm.

EXPERIMENTAL RESULTS

The frozen wave generator shown in Fig. 1 is a pulse forming system of one and one quarter cycles with an open end. When the switches were activated by a single picosecond optical pulse (30 ps, 65 μJ at 1.06 μm) the pulse forming network generates a two and one half cycles electrical waveform. The length of the charged line was designed to produce ∿2 ns pulse so that the real time waveform could be clearly displayed on an oscilloscope (Tektronik 7834). The result (solid line) is shown in Fig. 2. According to theory, the maximum amplitude of the output waveform should be equal to one half of the charging voltage if the "on-state" resistances of the switches are equal to zero. In reality, none of these resistances became zero, resulting in a reduced amplitude. The conversion efficiency is defined as the ratio of the actual amplitude to the maximum possible amplitude in an ideal situation. From the data shown in Fig. 2, a voltage conversion efficiency greater than 90% has been achieved. The amplitude of the output voltage depended linearly on the biased voltage, up to a maximum bias of 40 volts.

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To facilitate the calculation of the output waveform, the value of the contact resistance at each switch must first be determined experimentally. This was done by performing the switching experiment with an individual switch. The voltage switch-out efficiency as a function of total laser energy for the center switch is plotted in Fig. 3. From the saturation portion of the curve one can estimate the contact resistance of the switch to be 5 Ω (3). Because of nonuniformity of the laser beam intensity, the contact resistances for the other two switches were estimated to be 6.5 Ω and 7 Ω respectively. Using these values in a SPICE 2 computer code, we can calculate the output waveform which is shown as a dotted curve in Fig. 2. In this calculation the effects of the oscilloscope and other bandwidth limited element were represented by a filter having 600 MHz bandwidth. A good agreement between the experimental waveform and that expected from a computer simulation is evident in Fig. 2.

CONCLUSION

A direct DC to RF conversion technique has been demonstrated by optoelectronic switching. Since a bulk semiconductor is used, the voltage holding capability should scale linearly with the dimension of the device (gap length). We anticipate that the switching of a few kilovolts is possible in the immediate future as it has been demonstrated in our laboratory for the switching of a single pulse (4).

A new switch is currently being processed to reduce even further contact resistance thus increasing device efficiency. The silicon switch is ion implanted 3'p through an SiO_2 mask (which defines the microstrip electrodes) with an energy of 100 Kev and a dose of $1 \times 10^{16} cm^{-2}$ Tri-metal evaporation as described before.

REFERENCES

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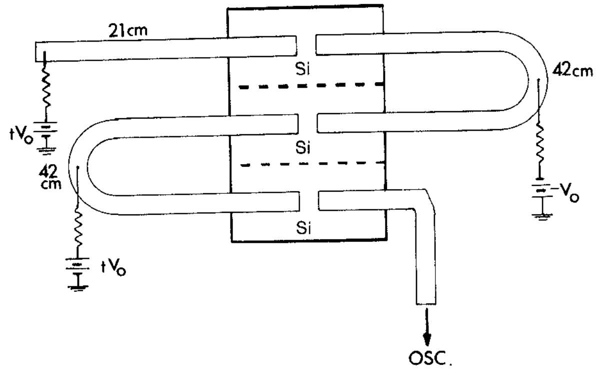

Fig. 1 The schematic of the frozen wave generator.

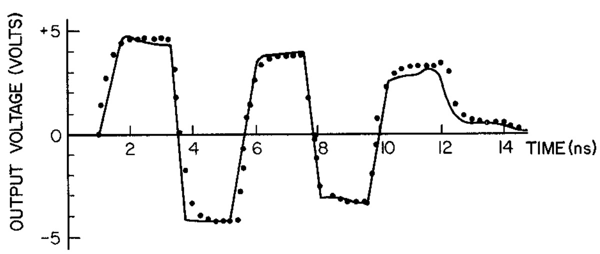

Fig. 2 The experimental (solid curve) and theoretical (dotted curve) waveforms.

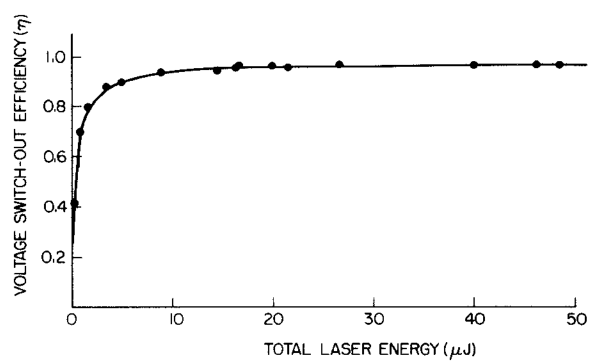

Fig. 3 The voltage switch out efficiency of the center switch verse total laser energy.