Short Papers

Laser-Activated p-i-n Diode Switch for RF Application

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Abstract —There is a growing interest in optically controlled high-power switches from HF to millimeter wave. This paper deals specifically with the results obtained utilizing an optically activated RF switch in the 2–30 MHz range. Preliminary testing of a 0.25-mm-thick p-i-n device activated with 116 W peak optical power from a two-dimensional laser array in a 50 Ω system has yielded isolation between 20.8 and 49 dB, and an average insertion loss of 0.38 dB when measured between 2.5 and 30 MHz.

I. Introduction

There has been continued and increasing interest over the past few years in the area of high-power, low-loss HF and microwave/millimeter-wave switches. In the area of HF switching, optical techniques are superior to conventional electrical methods. The main advantages are small size, jitter-free switching, fast rise time (usually the rise time of the optical pulse), high power handling capability, large dynamic range, noise immunity, and high voltage isolation between the control and switching circuits.

The p-i-n diode was first proposed in the form of a fused germanium power rectifier [1], [2]. The intrinsic region allowed reverse-bias specifications to significantly exceed existing p–n junction reverse-bias capabilities. From its inception, the p-i-n was identified as a kW device.

In the early 1960's, several researchers began using the p-i-n diode for optical applications to detect microwave beats in photomixing applications, as well as for detecting light modulated at microwave frequencies [3]–[5]. During the 1970's, bulk switches fabricated from silicon and GaAs were being developed for high-power picosecond optoelectronic switching applications [6]–[8]. Using a Nd:glass laser, Nunnally and Hammond later extended this concept to a 100 kV, 1.8 kA silicon bulk switch [9]. The major drawback of a silicon bulk switch is the need to pulse bias the device to prevent thermal runaway (which occurs if the device is dc biased). In this paper we have demonstrated the use of a vertical p-i-n diode illuminated by an array of diode lasers as a high-voltage HF switch.

II. Switch Configuration and Results

The RF switch (Fig. 1) consists of two semiconductor structures: the p-i-n device (Fig. 2: 0.25 mm thick and 3.7 mm in diameter) [10] and the 2-D laser array (measuring about 2 mm × 5 mm). Depletion-layer photodiodes are essentially reverse-biased semiconductor diodes whose reverse current is modulated by electron–hole pairs produced in or near the depletion layer by the absorption of light. For a given semiconductor, the wavelength range in which appreciable photocurrent can be generated is limited. For light waves whose energy is less than the band gap energy, the intrinsic optical absorption coefficient, α, is too small to give appreciable absorption. For high-energy photons, α is very large and absorption takes place near the surface where the recombination time is short. The photocarriers thus recombine before they are swept out [11]–[13]. The 2-D laser array used, Fig. 3(a) and (b) in our experiments, delivered 116 W of optical power (the pulse width was 10 μs) at 808 nm, where the depth of penetration in silicon is 10 μm. Fig. 4 depicts the configuration for measuring switch parameters such as insertion loss versus laser power (Table I), insertion loss versus diode bias voltage (Table II), and isolation versus frequency (Table III). Note that the p-i-n diode can withstand peak-to-peak voltages of 320 V (80 percent of maximum dc bias voltage). This corresponds to a power-handling capability of 250 W. A heat sink was not incorporated into our configuration during these preliminary tests.

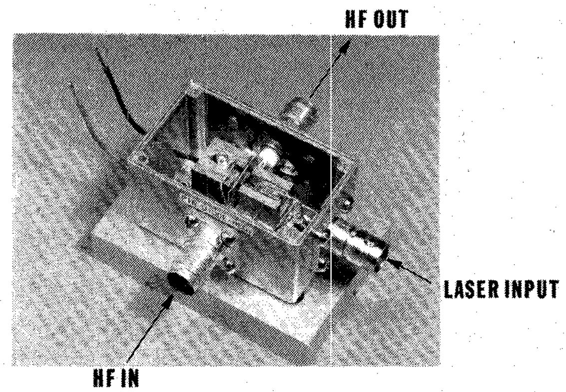

Fig. 1. Laser-activated p-i-n diode switch.

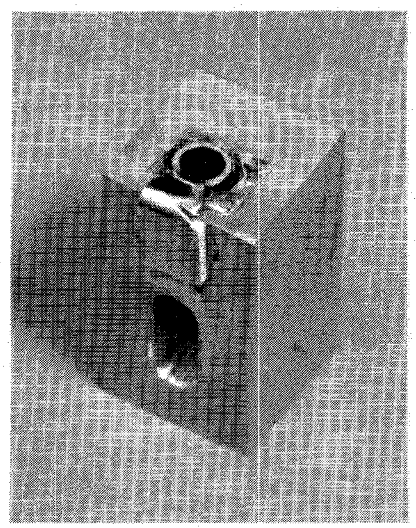

Fig. 2. p-i-n diode.

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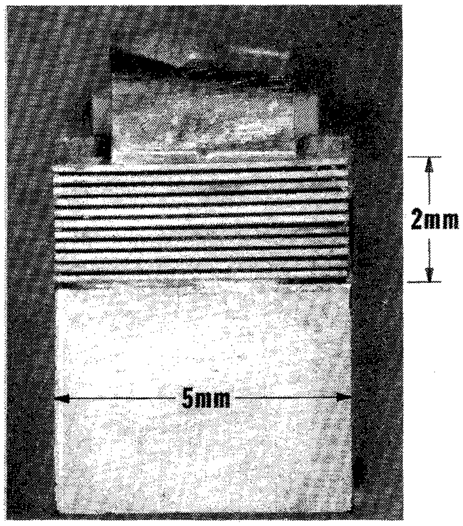
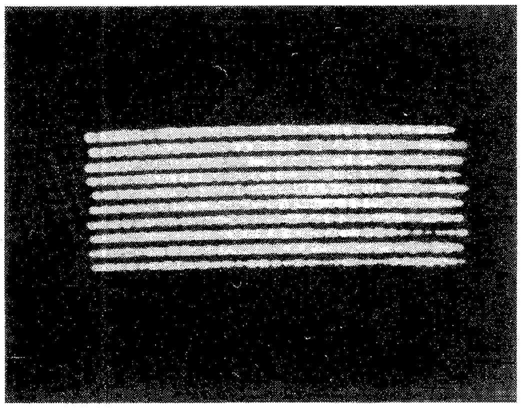


(a)



(b)

Fig. 3. (a) Photograph of 2-D laser array. (b) Near-field photograph of 2-D laser diode array.

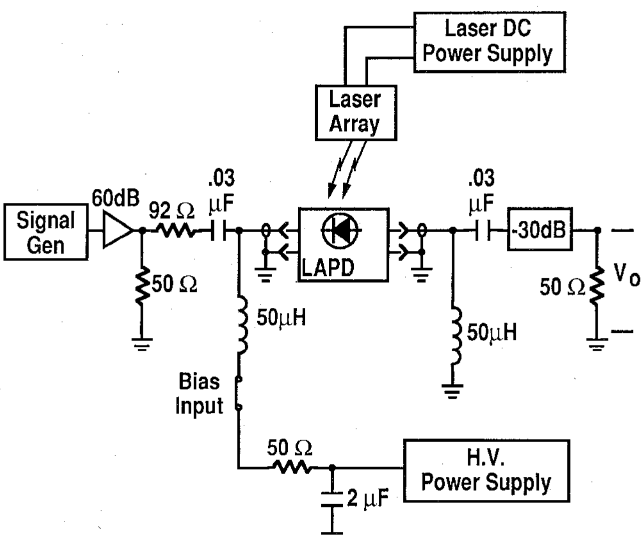


Fig. 4. Laser-activated p-i-n diode test configuration.

TABLE I
INSERTION LOSS VERSUS LASER POWER

P1 (W)	Loss (dB)
1.0	9.93
22.1	2.46
53.1	1.21
85.2	0.79
116.7	0.52

Conditions: $V_b = 200$ V.

TABLE II
INSERTION LOSS VERSUS DIODE BIAS VOLTAGE

Vbias (V)	Loss (dB)
100	0.39
200	0.53
300	1.23
400	1.84

Conditions: $P1 = 116.7$ W; $F = 2.5$ MHz.

TABLE III
ISOLATION VERSUS FREQUENCY

f (MHz)	Isolation (dB)
2.5	49.1
5.0	43.5
10.0	37.5
15.0	28.7
20.0	---
25.0	21.6
30.0	20.8

Conditions: $V_b = 200$ V.

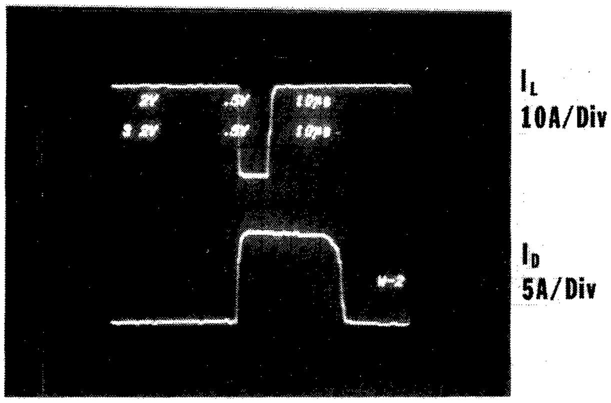


Fig. 5. Laser current pulse versus ON time of a p-i-n diode.

Thus, we have limited our measurements to a window of 10 μs pulse width and 1 Hz repetition rate.

As the laser power increases, more electron–hole pairs are created in the i region of the p-i-n diode and the resistance, and hence the insertion loss, drop. Table I illustrates this effect and shows that at an incident laser power of 116.7 W the insertion loss is still dropping. At the time of these measurements, 116.7 W was the maximum available power. Table II depicts the change (increase) in insertion loss with bias voltage. To minimize the insertion loss at higher voltages (which are needed as the RF power requirement is increased), the 50 Ω bias resistor (see Fig. 4) should be increased proportionately. Isolation (switch off, no light) decreases with frequency (Table III); in the OFF state the p-i-n diode is similar to a fixed capacitor.

It is important to note at this point that many applications require CW switching. The HF antenna coupler is one important application (an antenna coupler is a tunable matching circuit between a high-Q antenna and a generator across a very wide band). For this application, we have chosen to use a silicon p-i-n diode in order to take advantage of the long carrier lifetime.

Fig. 5 depicts the laser current pulse of 10 μs (top) versus the p-i-n diode's ON time. This ON time is more than three times the duration of the laser pulse. We have utilized this concept by using pulse 2-D laser arrays having an optical power output of 116 W to close a switch for a duration of about twice that of the laser pulse itself. This technique is very important in reducing the complexity of the antenna coupler system, and in realizing a CW switch with a pulsed laser array. It is conceivable to increase this ratio, which is a function of the carrier lifetime and the voltage applied. Fig. 6 depicts the ON state of a p-i-n switch, lower trace (the OFF point of the laser is indicated), and the HF signal propagating through the switch at 400 V bias voltage. The laser diode is on for 10 μs, while the switch (p-i-n device) is on for an additional 15–20 μs.

III. Conclusion

We have demonstrated, for the first time, the feasibility of a laser-activated semiconductor switch at low frequencies (2–30 MHz) with an RF power capability of up to 250 W. This approach, when fully developed, will have the following advantages: small size, jitter-free switching, fast rise time, noise immunity, and high voltage isolation, in addition to having a CW switch by utilizing pulsed laser.

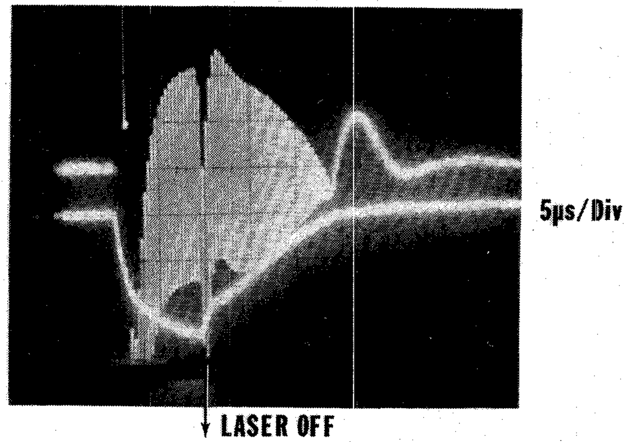


Fig. 6. HF signal after passing through the switch at 400 V bias voltage.

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References

[1] R. N. Hall, "Power rectifiers and transistors," *Proc. IRE*, vol. 40, pp. 1512–1518, Nov. 1952.
[2] M. B. Prince, "Diffused p-n junction silicon rectifiers," *Bell Syst. Tech. J.*, vol. 35, pp. 661–684, May 1956.
[3] G. Lucovsky, M. F. Lasser, and R. B. Emmons, "Coherent Light Detection Utilizing Solid State Photodiodes," in *Electrochem. Soc. Spring Meeting: Electron. Division Abstracts*, vol. 11, no. 1, pp. 284–285, May 1962.
[4] R. P. Riesz, "High speed photodiodes," *Rev. Sci. Instr.*, pp. 994–998, Sept. 1962.
[5] L. L. Anderson, "The PIN junction photodiodes as a detector of light modulated at microwave frequencies," in *1963 Int. Solid-State Circuits Conf. Dig.*, Feb. 1963, pp. 114–115.
[6] D. H. Auston, "Picosecond optoelectronic switching and gating in silicon," *Appl. Phys. Lett.*, vol. 26, no. 3, Feb. 1, 1975.
[7] P. LeFur and D. H. Auston, "A kilovolt picosecond optoelectronic switch and Pockel's cell," *Appl. Phys. Lett.*, vol. 28, no. 1, Jan. 1, 1976.
[8] C. Lee, "Picosecond optoelectronic switching in GaAs," *Appl. Phys. Lett.*, vol. 30, no. 2, Jan. 15, 1977.
[9] W. C. Nunnally and R. B. Hammond, "80-MW photoconductor power switch," *Appl. Phys. Lett.*, vol. 44, no. 10, May 15, 1984.
[10] A. Rosen, R. U. Martinelli, A. Schwarzmann, G. J. Brucker, and G. A. Swartz, "High-power low-loss PIN diodes for phased array radar," *RCA Rev.*, vol. 39, pp. 22–58, Mar. 1979.
[11] A. Rosen *et al.*, "Optically activated p-i-n diode switch utilizing a two-dimensional laser array at 808 nm as an optical source," *IEEE Trans. Electron Devices*, vol. 36, pp. 367–374, Feb. 1989.
[12] M. Caulton, A. Rosen, P. J. Stabile, and A. Gombar, "p-i-n diodes for low-frequency high-power switching applications," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 875–881, June 1982.
[13] A. S. Daryoush *et al.*, "Optically controlled three terminal microwave PIN diode and its application," in *Proc. 1985 SBMO Int. Microwave Symp.* (Campinas, Brazil), pp. 298–302.

Analysis of Rectangular Spiral Transformers for MMIC Applications

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***Abstract*—To evaluate rectangular spiral transformers for use in microwave monolithic integrated circuits (MMIC's) on GaAs substrate, we have calculated the chain matrices of multiconductor coupled line sections**

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