Investigation of Optically Induced Avalanching in GaAs

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Abstract

This paper discusses preliminary results of the investigation of optically induced avalanching in bulk GaAs switches. An experimental arrangement with sub-nanosecond resolution has been devised that can evaluate the avalanche phenomena as a function of time. This permits characterization of the temporal variation in the avalanche breakdown. The system arrangement, measurement techniques, and experimental data are presented.

Introduction

Linear photoconductive switches, in which one photon produces one electron-hole pair, have been discussed for pulse power systems[1,2] for a number of years. The advantages of the linear photo-conductive switch include closure and jitter times of several tens of ps, a wide range of voltage operation, and sub-nH inductances. However, their application has been limited by the optical power required to those systems in which the closure performance, risetime, or relative jitter could not be obtained in any other fashion.

Avalanche-like or non-linear photoswitches, in which the electron-hole pair produced by one photon is multiplied through an avalanche-like process, have been operated[3-6] using reduced optical energy levels for initiation of switch closure. However, the operation of the avalanche-like process, the conduction process, the recovery phenomena are not well understood. In addition, the conduction voltage of an avalanche switch is larger than desirable for efficient operation and the spatial current distribution in the device is not well defined.

The objective of this research is to develop a better understanding of the carrier initiation process, the avalanche process, and the carrier density maintenance process through investigation of a number of materials, contact and material geometries, optical wavelengths and fabrication processes.

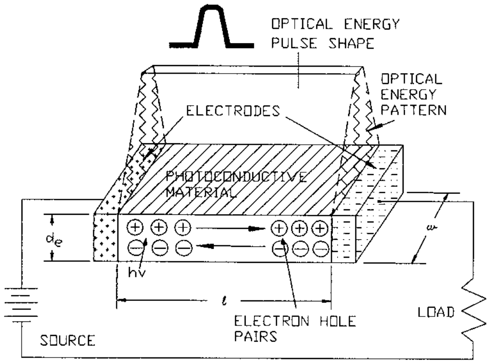

Figure 1.
Linear Photoconductive Switch

Background

Linear, photoconductive switches similar to that shown in Fig. 1, have many advantages when used in pulse power systems including 10's of ps closure times, sub-nH inductances and 10's of ps relative jitter times. These advantages are related to the rate and location of carrier generation in a linear photo-conductive switch which is dependent upon the external optical source of energy, usually a high power laser. The temporal closure time is directly related to the integral of the optical power absorbed in the switch or the total optical energy. Thus, the operation of the linear switch is nearly independent of the applied voltage indicating that the temporal closure should be similar in the range of 1-100 percent of the maximum voltage.

In a linear switch, after the laser energy is used to close the switch and the laser power is removed, the carrier recombine in a characteristic time determined by the semiconductor material. For example, the characteristic recombination time for intrinsic silicon can be milliseconds while the characteristic recombination time for direct bandgap materials such as GaAs is much smaller in the range of 0.1-5 ns.

To date, the use of linear photo-conductive switches has been limited by the amount of optical energy required for closure <u>and</u> the pulse length is limited by the recombination time of the carriers in the photoconductor material.

An alternative method of generating and maintaining the carrier density in a solid state switch is the avalanche of optically produced carriers (electrons) in a large electric field.

There are two possible avalanche schemes. These are dependent upon the incident optical wavelength and the bandgap of the material (i.e. the depth of penetration of the optical energy into the substrate). Figure 2 shows the depth of optical penetration in Si and GaAs versus wavelength (GaAs bandgap ≈ 0.89 um).

When the optical wavelength is above bandgap wavelength as illustrated in Figure 3a the optical energy is transmitted through the GaAs until reaching the cathode contact region where carriers (electrons) are generated. The electrons produced then avalanche toward the anode.

When the optical wavelength is below bandgap wavelength as shown in Figure 3b the optical energy is absorbed near the surface and cathode where carriers (electrons) are generated. The carriers then avalanche toward the anode.

The carrier generation rate in an avalanche system is dependent upon the electric field in the switch and is very similar to the gas breakdown mechanism in a gas spark gap. Since the avalanche process multiplies the initial carrier density, the optical energy must produce only a small fraction of the

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14. ABSTRACT
This paper discusses preliminary results of the investigation of optically induced avalanching in bulk GaAs switches. An experimental arrangement with sub-nanosecond resolution has been devised that can evaluate the avalanche phenomena as a function of time. This permits characterization of the temporal variation in the avalanche breakdown. The system arrangement, measurement techniques, and experimental data are presented.

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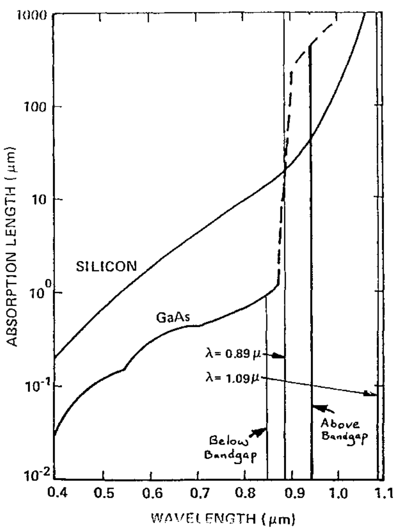


Figure 2.
Optical Penetration vs. Wavelength

required final carrier density and the optical energy requirements are greatly reduced. In addition, the carrier density can be maintained for much longer than the characteristic recombination time through the avalanche process. The geometries that have been used for optically induced avalanche-like switch operation are illustrated in Fig. 4. Mourou[3] first demonstrated the avalanche-like behavior using the configuration of Fig. 4a where the optical energy was uniformly injected in the switch volume, between the contacts. This configuration has also been used by Zutavern and Loubriel[6] and more recently by Druce[7]. The configuration shown in Fig. 4b was used by Bovino, et al[4] to increase the hold off voltage. The button switch design of Fig. 4c has been used by several researchers[5,7] to obtain the maximum hold off voltage. A solid state laser system was used at the optical energy source in configurations 4a and 4b while both solid state and semiconductor lasers have been used with configuration 4c. Research at the University of Texas at Arlington has concentrated on the button switch because surface flashover is not a problem.

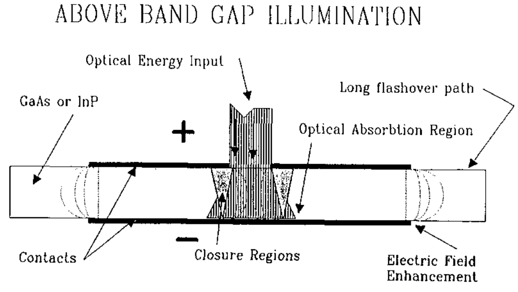


Figure 3a.

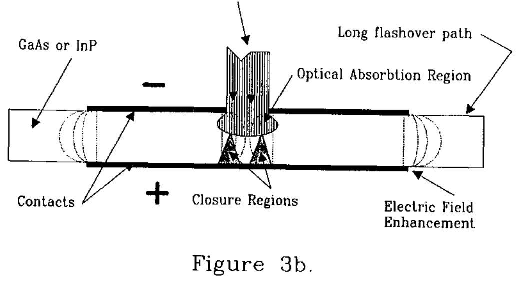
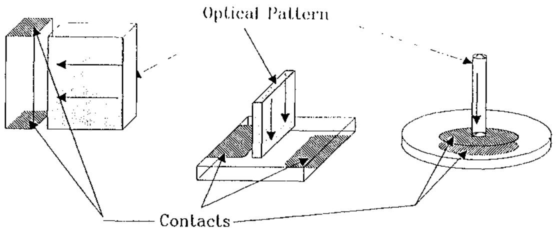


Figure 3b.



a. Mourou Switch b. Bovino Switch c. Button Switch

Figure 4.
Photoconductive Switches

If the carrier multiplication process is similar to that observed in a gas breakdown, eventhough optically initiated, several disadvantages common to a gas spark gap are possible, including 1) a narrow voltage operating range at high field is required to insure carrier multiplication, 2) filamentary current conduction as a result of avalanche streamers, and 3) exponential carrier generation rates which result in exponential decay in switch resistance. The variation in device to device closure time may also be temperature and material dependent.

One of the major problems noted with the avalanche-like switch work to date is the large conduction voltage. For example, before closure, an avalanche switch must operate at an electric field of about 100 kV/cm. After closure, the electric field must be about 10 kV/cm to maintain the carrier density during conduction. The change in electric field corresponds to a switching efficiency of 90 % while a common thyristor, although voltage limited, has a switching efficiency of over 99 %.

The carrier density in a spark gap is maintained through collisional heating, optical coupling, and continued impact ionization processes. In a solid state device, especially a direct band gap material, optical coupling is a viable mechanism for spreading the initial avalanche channel. The effects of interband dopants on the optical coupling in the avalanche process is another area for investigation.

Research Objectives

The operation of an avalanche-like switch process is being investigated to improve the understanding of the carrier density initiation, avalanche multiplication, and maintenance processes in an optically initiated semiconductor switch and to determine the dependence of the process rates on the bulk material, doping densities, optical initiation wavelengths and switch geometries.

Experimental Arrangement

Initial experimentation was performed on the setup shown in Figure 5.

In the basic arrangement a coax cable (RG-214) was charged by a capacitor through a krytron switch. The krytron pulse charger charged the 10 ns long coax to 1.2-8 kV in 10 μs. This placed the voltage across the OIA switch which avalanched and discharged the

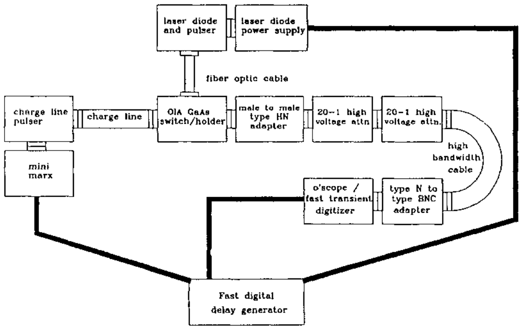


Figure 5.
Experimental Arrangement

voltage into the load/attenuators (Barth High Voltage Pulse Attenuators). This voltage signal was then carried to an oscilloscope through a high bandwidth cable.

The Optically Induced Avalanche (OIA) button switch held off the voltage on the charge line until switched by the laser diode (LD-66 from Laser Diode, Inc.). The laser diode delivered < 100 nJ at 904 nm for every shot. Note that the above bandgap illumination scheme was used.

The OIA switch itself is 1cm X 1cm X 0.98 mm thick with a donut contact in the center on both sides as shown in Fig. 6. The contacts were based upon work done at the U.S. Army Electronics Technology and Devices Laboratory, ERADCOM (by L. Bovino, et. all)[4].

The deposition recipe for the contacts is 1) 50 Å Ni (provides contact to GaAs), 2) 450 Å Au (diffusion barrier), 3) 200 Å Ge (carrier source), 4) 1000 Å Ag (diffusion barrier), 5) 4000 Å Au (contact surface also prevents silver from oxidizing).

The switch was placed into the microstrip line as illustrated in Fig. 7, at room temperature, after a small amount of Indium Gallium eutectic was placed on the contacts.

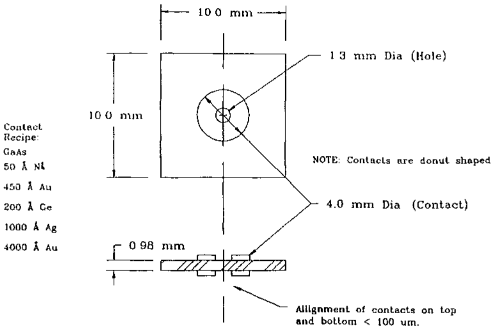


Figure 6.
GaAs Switch

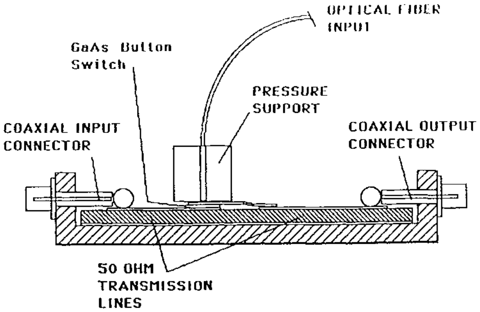


Figure 7.
Microstrip Line
(OIA Switch Holder)

The switching circuit is shown in Fig. 8. The voltage was measured at two points one before the charge line and one through the attenuators. The actual charge voltage (across the switch) was measured at the point before the charge line.

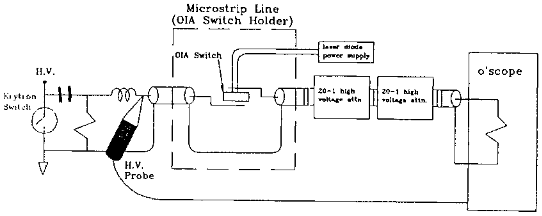


Figure 8.
OIA Switch Circuit Diagram

Initial Experimental Results

Initial results were very promising. Closure times of < 1 ns and electric field strengths of > 16.0 kV/cm were consistently observed (see Fig. 9 a,b). The best shot attained was 28.8 kV/cm in less than 1 ns. Jitter in switching times appeared to be small <1ns but a more controllable light source will be necessary to determine this more accurately.

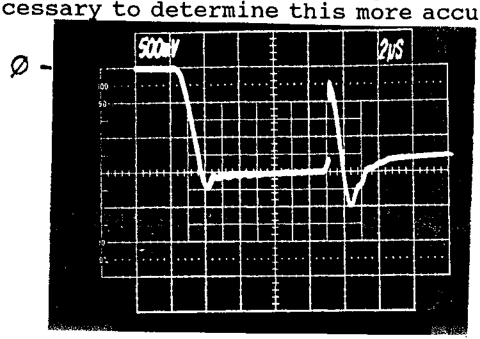


Figure 9a.
Voltage at HV Probe
(Field Strength of 15KV/cm across switch)

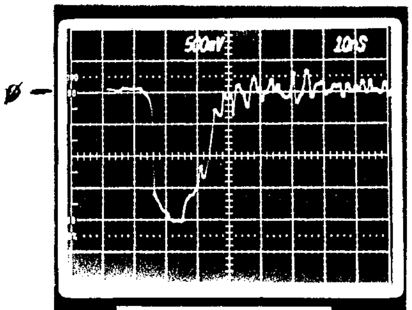


Figure 9b.
Voltage at Load
(200 V/div)

The electric field strengths necessary for proper switching fell in a small range. If the electric field across the switch was too low the switch would not avalanche (see Fig. 10a). If the electric field across the switch was too high the switch avalanched apparently due to self-breakdown (see Fig. 10b).

The major problem initially encountered was the breakdown occurring in the gap between the OIA switch contacts and the microstrip line. When arcing occurred it almost always happened just past the outside of the contacts.

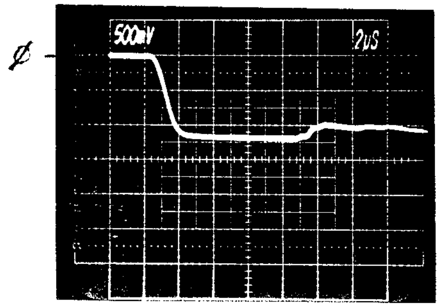


Figure 10a.
Insufficient Field Strength for Avalanche

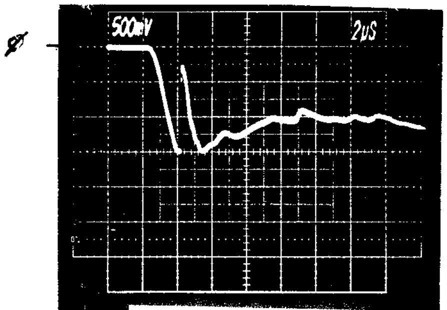


Figure 10b.
Self Breakdown

This breakdown usually caused catastrophic switch failure. The solution was a liberal application of Indium Gallium eutectic, vacuum grease and a good pressure contact from the switch to microstrip line. Further work is needed to prevent catastrophic arcing near the contacts (possibly by immersing the switch in SF_6 or Freon).

Conclusion

An avalanche-like process has been observed in the OIA switch that is consistent with other researchers. Switching speeds of <1ns at up to 28.8 kV/cm have been demonstrated. The carrier multiplication process appears to be reproducible. Improvement in the optical source temporal characteristics are being pursued to improve the understanding of the experimental results.

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