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It has been previously shown that semi-insulating GaAs can give rise to RF oscillations when the sample is optically activated[1]. The typical frequency range for the observed oscillation is several hundred megahertz. An intriguing feature of these oscillations is that the observed frequency far exceeds the frequency associated with Gunn effects, i.e., the transit time of the sample (typically 1 cm long) was much longer than the observed RF period. Another important characteristic is that the oscillations persist during the lock-on of the current pulse, which can continue for hundreds of nanoseconds or even microseconds. In addition, under certain conditions, the depth of modulation (RF amplitude) occasionally observed was very large, approaching 20% or so. However, the results (although promising) have been inconsistent and not reproducible, particularly in regard to the RF amplitude. One reason for the inconsistency may be connected with the fact that the previous tests were conducted using a lumped circuit, and no attempt was made to couple the semiconductor to an RF cavity. In this paper, preliminary experimental results are reported in which an optically activated GaAs sample is coupled to the fields in an RF quarter wave cavity. The cavity frequency is manually adjustable from 0.2 to 1.0 GHz. Unlike the previous test circuits, the use of an RF cavity technique allows one to decouple the video pulse from the RF and also facilitates the maximization of the RF signal. A description of the cavity and preliminary results are presented. In particular, the dependence of the oscillations on bias voltage, optical wavelength and intensity, sample size, and its relationship to lock-on, are discussed.

Introduction

Recent investigations with light activated semi-insulating gallium arsenide have demonstrated a lock-on effect [1], i.e., a sudden increase in recovery time once a voltage threshold, ≈ 4 kV/cm, is achieved. The lock-on is achieved readily observed with surface devices, in which the generation is close to the surface (≈ 0.5 mm) and the carrier concentration is relatively large. Large carrier density concentrations may be achieved by choosing the proper wavelength for the light signal. The doubled frequency of a Nd:YAG, Q-switched laser, for example, is a convenient choice. A phenomena which often occurs concurrently with lock-on is the onset of oscillations which appear on the current waveform. The oscillations, whose frequency is typically larger than that associated with a Gunn domain, possibly stems from a quenched domain, or LSA behavior. Regardless of their origin, however, the main interest in such oscillations stems from the fact that they occur in large samples (1 to 10 mm), which are able to withstand relatively large voltages (1 to 20 kV). Further, relatively large depths of modulation ($\geq 20\%$) have, on occasion, been observed. Such oscillations could possibly provide a multi-kilowatt source of RF energy. A distinguishing feature of this RF source, however, is the exploitation of the lock-on to provide RF during the entire pulse period, well beyond the pulse width of the Q-switched light pulse, which is typically less than 10 ns wide. Indeed the oscillation occurs for as long as the lock-on is maintained, which can be hundreds of nanoseconds or even microseconds long. In this study we explore the possibility of triggering centimeter long samples with a few millijoules of light into lock-on, and to extract the RF produced during this time. In order to study the oscillations, it was decided to investigate the coupling of the gallium arsenide to a quarter wave coaxial cavity with an adjustable frequency. The RF extracted from the cavity is then decoupled from the video pulse, which makes the interpretation of the experimental results hopefully more straight

forward. Further, the coupling of the GaAs to the cavity field provides a feedback path, whereby the cavity fields lock-on to the dominant frequency in the GaAs, and thus the possibility for enhancing the depth of modulation of the current exists for that particular frequency.

One should also mention that the lock-on phenomena also occurs in other geometries and indeed occurs readily in gridded devices[2]. However, oscillations were not apparent in these type of switches, and therefore such devices were not used in the investigation.

Experimental Setup

The laser setup consisted of a 1 joule 3 ns wide Q-switched Nd:YAG laser pumping a tunable dye laser with Rhodamine 6G as the dye. The Nd:YAG pumps the dye laser with the second harmonic, which has an energy of 500 mJ and a wavelength of 532 nm. The tuned wavelength used to activate the switch was 559 nm, which is the peak of the Rhodamine 6G. The energy of this beam is about 110 mJ per pulse. The optical beam was coupled into a fiber bundle which provided flexibility in the experimental setup and allowed one to easily steer the beam to the semiconductor switch we wished to illuminate. The energy out of the fiber bundle incident on the switch was typically 1 - 5 mJ.

The light intensity incident on the sample could be controlled a number of ways. One technique was to use a $\lambda/2$ crystal following the cavity. The beam passes through the crystal, splitting the beam into 2 polarizations. One of the components is split off to a beam dump while the other is sent through a polarizer to vary the output. Another means for light attenuation involves offsetting the second harmonic generator from its maximum output. This puts less energy into the dye which results in less output. The light energy also is strongly affected by coupling into and out of the fiber bundles, as well as by diffraction effects at the output of the fibers. By placing the fibers nearer to or farther from the switch the energy density delivered to the switch can be somewhat controlled.

The switch was placed in a tunable coaxial microwave cavity (Figure 1). The cavity was designed for the frequency range, 0.2 to 1.2 GHz. The cavity was designed for these frequencies because it was noted in previous experiments that the frequencies of the oscillations in GaAs were in the 300 to 1000 MHz range. The cavity is a quarter wave type. The switch was placed in the open end of the cavity where the fields are strongest. This was done to maximize coupling between the GaAs and the cavity field. An E field probe was used to couple the RF out of the cavity. The E probe was optimized with regard to its depth into the cavity for the best possible output. A dc blocking frequency filter was connected to the end of the E probe to remove any low frequency and DC components. The RF was delivered to the 50 ohm input of a TEK 7104 oscilloscope. At first a crystal detector was used to detect the envelope of the oscillation. The crystal detector was discarded, however, when it was determined that the oscillations could be detected directly. A digitizing camera was used initially to record the oscillations at high frequencies. The computer, however, did not always resolve the oscillations. As an alternative measurement Polaroid Type 612 film was used, with a speed of 20,000 ASA, which helped to resolve the waveforms.

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE JUN 1989		2. REPORT TYPE N/A		3. DATES COVERED -	
4. TITLE AND SUBTITLE RF Oscillations In Optically Activated Semi-Insulating GaAs				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Electronics Technology and Devices Laboratory LABCOM, Fort Monmouth, New Jersey 07703-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.					
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15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

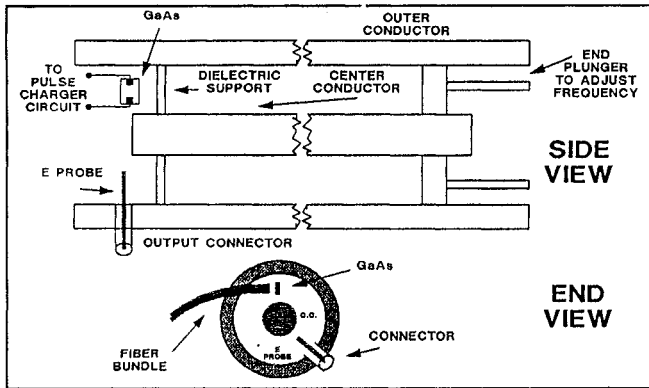


Figure 1. Experimental set-up showing coupling of quarter wave cavity to GaAs.

The electrical circuit employed to charge the PFL and to characterize the GaAs, was straightforward (Figure 2). The sequence of events begins by charging a pulse forming line which has a pulse width of 300ns. Once the line is charged the laser illuminates the switch which cause current flow in the circuit. A matched load of 50 ohms was employed. Current was measured using a Tektronix CT-1 current probe. The semi-insulating GaAs samples were made from 1/2 mm thick polished wafers. An evaporation technique was used to deposit the electrodes on the same side. Samples with inter-electrode distances of 2.9 mm and 9.0 mm were fabricated and tested. As alluded to previously, the combination of the surface design and short wavelength appeared to create conditions conducive to lock-on, once the electric field threshold was attained. A major concern was whether lock-on would inevitably damage the devices. It was found that the safe operating voltage sufficient to create lock-on, but not so large so as to result in damage or shortened lifetime, was approximately 2.5 kV for the 2.9mm device and 4.5 kV for the 9 mm one.

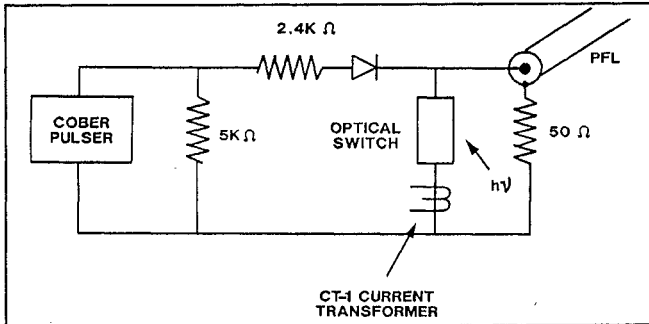


Figure 2. Electrical circuit used to charge PFL and to characterize GaAs.

Results

The coaxial cavity first was checked on a scalar network analyzer. The observed resonant cavity frequency varied from 0.2 to 1.3 GHz depending on the position of the adjustable plunger. The frequency dependence approximately followed the anticipated dependence on cavity length. Figures (3a) and (3b) show the change in the current waveform as the bias voltage on a 0.9 cm sample is changed from below lock-on threshold. Note that below threshold, the current quickly extinguishes as soon as the laser pulse has elapsed. When the field exceeds threshold (≈ 4 kV/cm) the switch, after making an initial attempt to recover, remains conducting, i.e., a current lock-on is achieved. The lock-on remains effective as long as the voltage needed to supply the minimum field is maintained. Note that the reappearance of the current, with its positive slope, may imply the existence of some sort of gain mechanism. It should also be mentioned that such a current re-start is not always observed. Under conditions where the voltage is initially very high, or when the light intensity is high, the current re-start phenomena is not observed.

Figure 3a. Current waveform below threshold. Sample length is 0.9 cm and load resistance is 50 Ω . The source voltage is 3kV

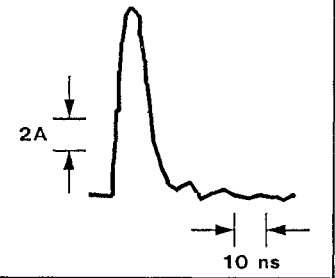
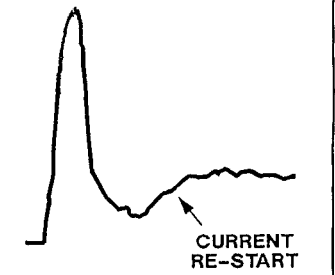


Figure 3b. Current waveform for same sample but at source voltage of 3.5kV. Voltage exceeds lock-on threshold.



The oscillations which occur during lock-on are shown in Figures (4a) and (4b) for two different plunger positions, corresponding to cavity frequencies of 646 and 974 MHz. The induced oscillations appear to be determined, over a large portion of the frequency range, by the cavity fields, and there appears to be little frequency pulling due to the interaction of the cavity field and the GaAs. The RF field is strongest in the region of 1 GHz, which possibly indicates a coupling between the GaAs and the cavity field. This is not altogether clear, however, since the cavity pick-up also is strongest at the higher frequencies. Thus far, at least, little or no intensification of the depth of modulation was observed in the video pulse, which would indicate feedback from the cavity field.

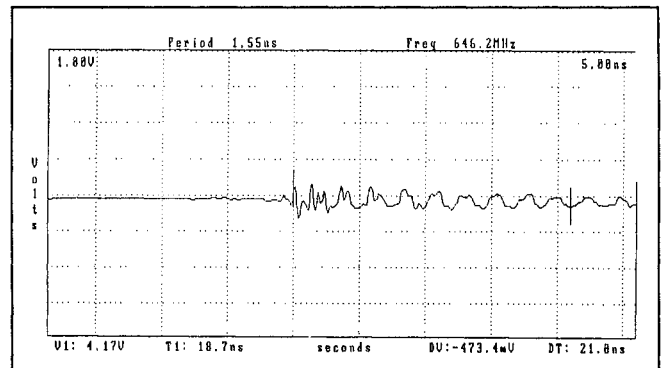


Figure 4a. RF signal for 2.9mm GaAs sample at 3.5kV. Frequency is 646MHz

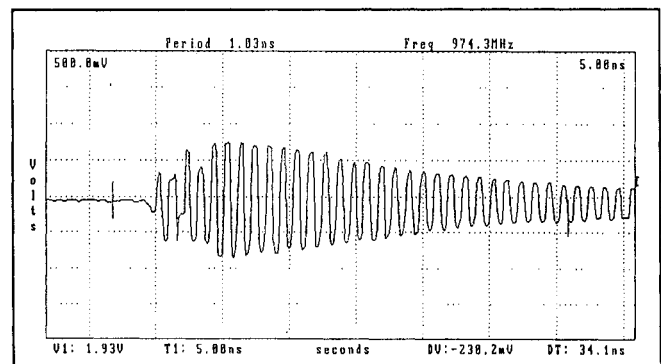


Figure 4b. RF signal for 2.9mm GaAs sample at 3.5kV for different plunger position. Frequency is 974MHz.

Figures 5a and 5b shows the effect of voltage on RF output. As anticipated the RF increased rapidly once the current goes into lock-on. The sharp increase occurs both for the lower and higher cavity frequencies. The effect of light intensity on the amplitude of the RF also is pronounced, with RF signal arising from the RF noise level only when sufficient light intensity illuminates the sample; at least 1 mJ of light energy was required for the one centimeter long sample. After the laser pulse, one should expect to observe a build-up of oscillations to a steady-state value. Instead an unexplained lower frequency beating of the RF is observed, as noted in Figure 5b.

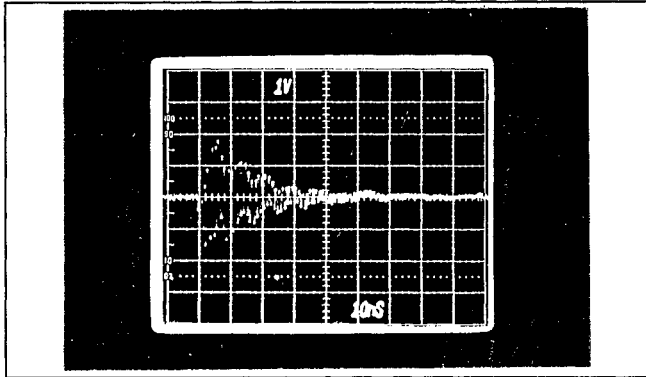


Figure 5a. RF output at 3.3 Kv/cm for 0.9 cm long sample

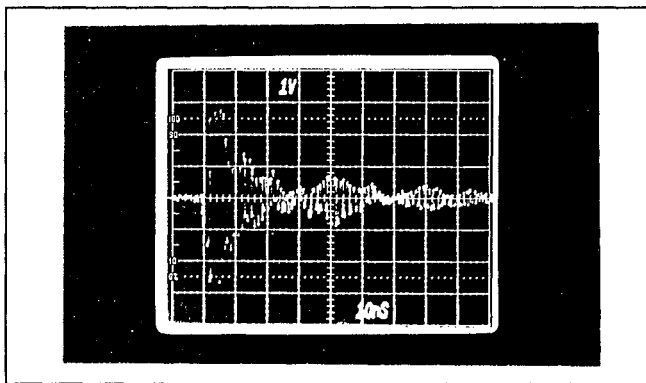


Figure 5b. RF output at 4.4kV/cm for same sample and under same conditions but with lock-on present.

Besides GaAs, similar measurements were taken with silicon. Although cavity oscillations were induced during the laser pulse, the oscillations which occurred afterward in time were considerably weaker (compared to GaAs) and did not show any enhancement by voltage. The results obtained with silicon, therefore, indicate that the particular properties of light triggered GaAs enhance the RF output, probably stemming from its material properties.

Conclusions

Preliminary measurements have been performed on large optically switched GaAs switches coupled to cavity fields. Emphasis was placed on devices triggered into lock-on. During this switching mode, oscillations have previously been observed. By using the cavity approach, oscillations are decoupled from the video pulse, thus allowing the investigation of RF properties to proceed while isolated from the pulse properties. For the bulk of the frequency range from 0.2 to 1.2GHz, the oscillations appear to be dominated by the cavity field, indicating the possibility that the modes originate from LSA or quenched domain behavior. At about 1 GHz the RF coupled out was strongest. At this frequency a beat effect was evident, indicating a periodic build-up of the oscillations. Conceivably the beat frequency may be associated with the growth time in the cavity, although the

reason for the periodic decline is not clear. The beat frequency may also be associated with low frequency quenched domain or Gunn oscillations. The coupling out of large amplitude oscillations, corresponding to large depths of modulation seen occasionally in previous equipments, has not yet been observed here. Maximum output coupled out of the cavity was limited at best to a few hundred milliwatts. Also, no significant feedback from the cavity onto the video pulse was observed.

The low RF power may be due to insufficient light intensity needed to create the necessary carrier densities. In addition, previously observed large depths of modulation have been associated with fields at or near avalanche conditions. Experiments at various wavelengths and higher fields will be pursued.

Finally, an alternate means of coupling of the semiconductor to the cavity fields will be considered. Thus far, we have only considered the situation in which the cavity current is totally isolated from the semiconductor, which couples to the cavity via displacement current. In follow-on work the electrode of the semiconductor will be connected to the conductor of the coaxial cavity, thus providing a path for the RF cavity current thru the semiconductor. In utilizing this technique, however, extra care must be exercised to ensure that inevitable high voltage transients picked up by the E probe do not obscure the measurement.

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