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PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES FOR PULSED POWER APPLICATIONS*

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Abstract: Photoconductive Semiconductor Switches (PCSS) are being used in, or tested for, many different pulsed power applications as diverse as ultrawideband (UWB) transmitters and high current pulsed. Some aspects of the switches that are relevant to most of the applications are: switch lifetime (longevity), switch opening time (related to the lifetime of carriers in the semiconductor), switching jitter, and the required laser energy. This paper will emphasize the results that we have obtained with Si switches for UWB applications. These include: measurement of switch longevity (a total of 80 Coulombs or 40 C/cm for a 2 cm wide switch and 18.4 Coulombs or 73 Coulombs/cm for a 0.25 cm wide switch), switching at high repetition rates (up to 540 Hz), measurement of carrier lifetime decay rates (a fast one of a few μ s, and a slow one of about 330 μ s), and measurements on the effect of neutron irradiation on carrier lifetimes. The total charge switched seems to be the highest ever reported for a PCSS. We have used these Si switches in a variety of circuits to produce: a monocycle with a period of about 10 ns corresponding to a center frequency of about 84 MHz, and ringing (many pulse) waveforms with periods of about 1 ns and 7.5 ns corresponding to center frequencies of 770 MHz and 133 MHz. We will also discuss recent studies on the switching properties of GaP.

Introduction

Photoconductive Semiconductor Switches (PCSS) offer improvements over existing pulsed power technology: higher voltage, higher current, more efficient, faster turn-on, faster turn-off, higher repetition rates, easier control, more precise timing control, more reproducible operation, longer device longevity, smaller size, and lower cost. The most significant possibilities are: 100 ps risetime, kilohertz (continuous) and megahertz (burst) repetition rates, scalable or stackable to hundreds of kilovolts and tens of kiloamps, optical control and isolation, and solid state reliability. The switching properties that have been achieved with our lateral Si (in the linear mode¹) and GaAs (in the non-linear, high gain switching mode^{2,3}) are summarized in Table I. In this paper, we present experimental results

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MASTER

which demonstrate some of these, and other (data on switching GaP), improvements.

The PCSS are being tested for use in applications such as: ultrawideband (UWB) transmitters, firing sets, electro-optic drivers, current interrupters, and pulsed power applications that require MV switching. Each of these applications imposes a different set of requirements on switch properties. The sections below emphasize those properties that are related to the generation of fast, high power impulses that are typical of those required for UWB transmitters or fast pulsers.

Si- Linear Switching- High Voltage Operation

The concept of linear photoconductive semiconductor switching is described in several references¹. This switching mode is characterized by the creation of one electron- hole pair for nearly every photon absorbed in the semiconductor. Because the resistance of the switch is inversely proportional to the number of carriers, the risetime of the switch is typically proportional to the optical pulse width. This effect was demonstrated⁴ using a 200 ps optical pulse that triggered a Si switch to produce a 270 ps (bandwidth limited by the scopes) current risetime. This same size switch has been used to switch up to 123 kV. For Si, our highest switch field and current are⁵: 82 kV/cm (123 kV) and 2.8 kA (not simultaneous). Figure 1 shows the voltage waveforms for the Si PCSS that switched 123 kV. This demonstrates that the PCSS can switch high voltages even when using a single device. For impulse transmitters, this voltage limitation is not a barrier that limits the transmitted power because the low jitter of the switches allows for a modular design of transmitter arrays. For more conventional pulsed power applications, the switches can be stacked to switch higher voltages. Nonetheless, the demonstration of MV switching with PCSS has not been carried out, mainly because of the large laser powers required.

Repetitive Switching of Si Switches- Carrier Lifetime

Another aspect of linear switching that is relevant to pulsed power applications is the ability of the switches to be repetitively switched. After being switched, the semiconductor must recover its original (high) resistivity prior to the application of the next voltage pulse. This implies that the exponential carrier lifetime must be much smaller than the time between pulses. For a typical value of 1 kHz, carrier lifetimes of tens of microseconds are required. Carrier lifetime is determined by effects that are intrinsic to the semiconductor and by defects and impurities. We have studied the carrier lifetime of Si by applying laser pulses and measuring the switch resistance after a known delay. The conductance is given by the inverse of the intrinsic dark resistance (R_0) plus that due to the laser pulse, whose decay in time is exponential. Figure 2 shows $(1/R)-(1/R_0)$ as a function of delay time for a silicon switch. There are two slopes: A fast decay of 4.3 μ s and a slow one of 335 μ s. To understand why there are two

slopes, the Si material was subjected to various neutron bombardment fluences (10^{11} , 10^{12} , 10^{13} , and 10^{14}). Figure 3 shows $(1/R)-(1/R_0)$ for these switches. The fast decay implies carrier lifetimes of 4.3 μ s, 2.6 μ s, 560 ns, and <500 ns. We attribute the fast decay to recombination via defects that are created by the neutron bombardment. The slow decay is not affected by the neutron bombardment. Lifetimes of 392, 319, and 360 μ s were measured for fluences of 10^{11} , 10^{12} , and 10^{13} . We attribute the slow decay to deep level (impurity) decay because the number of impurities is not affected by the neutron bombardment.

Longevity of Si Switches- Tests of Contact Metallization

The ability to obtain short carrier lifetime Si allows the switch to be repetitively triggered. We have been able to trigger the Si switch at a laser limited repetition rate of 540 Hz. Extensive switch lifetime tests have been carried out⁶. Figure 4 shows the electrical circuit used for most of the switch lifetime tests. The pulsed power source charged a 50 Ω coaxial cable in about 1 μ s. This was discharged by the switch into a 50 Ω load in about 20- 30 ns. The system had a switch voltage monitor and a current viewing resistor. Figure 5 shows representative voltage and current waveforms. To trigger the switches we used a Nd:YAG laser that produced 50 mJ pulses of 10 ns duration at a repetition rate of 540 Hz. Many different metallizations were tested to determine the wear mechanism and the best contact metallization. The switches wear at the contact metallization, at the interface between the metallization and the Si. For the Si switches, the current is uniform across the width of our lateral switches. The current density, thus, is the same at either the anode or cathode. Because the wear occurs preferentially at one or the other contact (dependent on the metallization) the wear is not due to an excessive current density in the metal film. We believe that current bunching at the edge of the contact metallization is responsible for the wear. Auger studies show no electromigration of the contact metallization. The Auger data is consistent with heating by elevated, short duration, temperatures at the contact edge which results in vaporization or delamination.

The switches with Cr-Cr-Mo-Au metallization survived 6×10^6 pulses at up to 22 kV/cm (5.5 kV) and 160 A/cm (40 A). The waveforms for this switching are shown in figure 5. The total charge switched was about 8.4 Coulombs which corresponds to a charge per unit width of 33.6 C/cm. Figure 6 shows the current waveform for a switch with Cr-Cr-Mo-Au metallization that had dimensions of 1.5 cm by 2.0 cm so that we could switch higher voltages. The switched field was 20 kV/cm (30 kV), the peak current density was 187 A/cm (375 A). This system had a 50 Ω load so that the power was about 7 MW. The total number of pulses on this larger switch was 11 million, so that the total charge switched was about 80 Coulombs (40 C/cm). Although both of these switches were still running after these pulses, there was severe degradation of the metallization with preferential damage on the positive contact. Severe degradation and similar lifetimes are also observed when thick films (Mo layer of 6500 Å) are used.

We have also plated the Cr-Cr-Mo-Au switches to obtain a much thicker Au film. Again, the results do not differ much from those with the standard Cr-Cr-Mo-Au metallization.

We have tried to eliminate current pinching at the edge of the contacts by using Al diffusion to create a conducting layer between the metallization and the high resistivity Si. We investigated two types of Al diffused contacts: deposition of a 1 μm thick layer of Al, followed by sintering for 20 minutes at 600 C, and deposition of 0.1 μm of Al, heating at 400 C for 20 minutes. These were covered with Cr(500 Å)-Mo(1500 Å)-Au(3000 Å) as above. The Cr-Mo-Au deposition was made with the same mask as the Al deposition so that it completely covers the area of the Si wafer that was covered with Al. The 1 μm switches survived 10^7 pulses at 34 kV/cm. Figure 7 shows the voltage and current waveforms. The total charge switched was about 11 C (44 C/cm). The 0.1 μm switches thick Al metallized switches survived 32 kV/cm for 2.4 million pulses, 36 kV/cm for 1.94 million, 40 kV/cm for 1.46 million, and only about 100,000 pulses at 44 kV/cm at which point the switch failed. The total number of Coulombs switched was 9.6 (38.4 C/cm). Both the Al diffused switches fared better than the non-diffused switches. Most of the damage occurs at the negative contact.

Even better results were obtained with an ion implanted contact (^{31}P Phosphorous) that was capped with Ti-Pt metallization. The ion implantation of ^{31}P was carried out at 175 keV for a dose of 2×10^{15} and at 60 keV for a dose of 1×10^{15} . The implant was then annealed for twenty minutes at 950 C. This resulted in an estimated ion implantation depth of 0.6 μm , and a dopant density of about 10^{20} carriers/cm³. The annealing is followed by deposition at 300 C of Ti-Pt using electron beam evaporation. This switch has now been run at 48 kV/cm for 0.9 million pulses (2.1 C), 44 kV/cm for 2.2 million pulses, and at 32 kV/cm for 10^7 pulses (18.4 C). The latter corresponds to 73 C/cm. In the last test the switch was removed before failure and showed only minor damage to the contact. Most of the damage was in the positive contact. Figures 8 and 9 show the voltage and current waveforms for the tests carried out with this switch. The switched voltage was 8.5 kV (34 kV/cm), and the switch current was 77 A (308 A/cm) which lasted for about 27 ns.

The Ti-Pt metallization in these switches does not cover the total area that is ion implanted. The ion implanted region extends 0.05 mm beyond the TiPt. The damage observed after 10^7 pulse at 32 kV/cm is mostly in one corner of the positive contact where there is damage in the metallization and at the interface of the Si and ion implanted regions. There is almost no damage in the 0.05 mm of the ion implanted region. It is not clear why there is damage at the interface between the Si and the ion implanted region. The degree of current bunching there depends on the ratio of the resistivities. No current bunching will be observed if the conductivity of the ion implanted layer is lower than that created by the light in the semiconductor. We estimate that the density of photo-generated carriers in this experiment is about 5×10^{19} cm⁻³. Thus, the carrier density generated

by the light is about the same as that in the P-doped region and there should be little or no current bunching if the carrier mobilities are the same. The ion implanted region may have lower mobility due to damage.

The metallizations that were described above involved the deposition of the dopants and metal on one face of a Si wafer. The depth of the contact is determined by the diffusion or implantation parameters. Because the penetration of the Nd:YAG radiation is larger than the typical wafer thickness (from 254 to 635 μm), it would be preferable to dope throughout the thickness, eliminating current pinching. One way to achieve this is to cleave the wafer and metallize the edges. We have attempted to fabricate and test this "edge contact" using Cr-Cr-Mo-Au metallization. Several practical problems have arisen. First, that the metallization always tends to coat the edge and about 0.5 mm of the surface. Second, edges are not uniform so that the metallization tends to be uneven. Third, that it is hard to make good electrical contact to the edge because the switches are fragile. We are still pursuing this promising method.

The mechanisms that may result in damage to the PCSS are many. Initiation of the final breakdown appears to come from regions near the contacts which have been significantly damaged during previous pulses. Contact damage may be caused by large electric potential barriers at the metal-semiconductor interface, high current densities due to current pinching or filaments, and gradual degradation of the interface due to elevated instantaneous temperatures. Cr and P are donors to Si (n type) and Al is an acceptor (p-type). The damage to the Cr diffused and the ion implanted P switches is mostly on the positive contact (independent of whether the positive lead is at high voltage or ground) while the Al diffused switches (either the Al-Cr-Mo-Au or the Al-Pt-Ti-Pd-Au) show most damage on the negative contact. This would imply that the damage occurs most often at the reversed biased contact. It does not really explain the nature of the damage. The Auger data and the correlation of damage with type of contact imply that the damage occurs from local heating at the semiconductor-metal interface.

Table I summarizes the Si switch longevity tests. These switches are capable of switching a total of about 70 coulombs per centimeter of width for fields of 32 kV/cm (8 kV). As the field is increased, the total charge per unit width is reduced by an order of magnitude. It is not clear that the best way to judge a given PCSS is to compare their total current carrying capability. Joule heating of the semiconductor is the product of the switch resistance, the square of the current, and the duration of the pulse. But the damage is not in the semiconductor. Since the damage occurs at the metal semiconductor interface, it may be due to heating produced in a Schottky barrier. In this case, the amount of instantaneous heat is the product of the voltage in the barrier, the current, and the pulse duration.

Table I. Summary of tests of the longevity of Si switches

Contact Type	V(kV), I (A)	Total number of pulses (millions)	Total Switched Charge (C)	Charge / Switch Width (C/cm)
Cr-Cr-Mo-Au	5.5, 40	6	8.4	34
Cr-Cr-Mo-Au	30.0, 375	11	80	40
1.0 μ Al, CrMoAu	8.5, 77	10	11	44
0.1 μ Al, CrMoAu	8-11, 62-88	5.8	9.6	38
ion implanted P	8, 68	10	18.4	73
ion implanted P	12, 96	0.9	2	8

Generation of Ringing Waveforms with Si Switches

Linear switches have been used to produce current waveforms of high frequency and of varying bandwidth. Figures 10 to 12 show load voltage waveforms for a variety of systems that exhibit different ringing periods (10 ns, 7.5 ns, and 1 ns) corresponding to center frequencies of 84 MHz, 133 MHz, and 770 MHz. The 84 MHz data shows a monocycle voltage pulse with high bandwidth. The data at 133 MHz and 770 MHz show that the switches can be used in high frequency ringing systems with high Q.

Switching Properties of GaP

At low fields, GaAs exhibits linear switching with a carrier lifetime of a few nanoseconds. Above 8 kV/cm, non-linear switching was observed³. This non-linear, high gain, high field switching mechanism can be triggered with small laser energies from laser diode arrays⁷ and does not require uniform light illumination permitting the use of fiber optic triggering⁸. Since this mechanism exist for GaAs (and InP) but not in Si, we studied GaP. Like Si, it is an indirect bandgap semiconductor. Like GaAs and InP, it is a III-V semiconductor with a large (2.26 eV or 548 nm) bandgap and a zincblend crystal structure.

At low fields, GaP exhibits linear switching with a surprisingly short carrier lifetime. Figure 13 shows the current waveform for a 0.25 cm long by 0.25 cm wide GaP switch that was triggered with 532 nm radiation. The voltage is 1.5 kV (field of 6 kV/cm) when the laser pulse triggers the switch. The laser pulse has a duration of about 30 ns and is comprised of multiple peaks. The oscillations current show that the laser pulse generates carriers with a very short lifetime (<2 ns). Thus, the current pulse resembles the time profile of the laser pulse. This short carrier lifetime is surprising since indirect bandgap semiconductors should have a long carrier lifetime. This result may imply that the material has many impurities. The voltage waveform shows that in this case, the laser pulse energy was not sufficient to drop the switch voltage to zero. The reason for this is the low carrier mobility in GaP: $110 \text{ cm}^2/\text{V s}$.

The GaP switches were then tested at ever increasing fields in the hope that a high gain, high field switching mechanism would be found. The highest field we tested at was 11 kV. High gain switching was never observed. The lack of a high gain switching mode and the low mobility implies that GaP is not suitable for most pulsed power switching applications.

Conclusions

Si switches have been used to switch high voltages (123 kV), high currents (2.8 kA), at high repetition rates (540 Hz, laser limited). The carrier lifetime in the switches is composed of two decay rates: a fast one of 4 μ s and a slow one of about 330 μ s. The fast decay rate can be reduced to $\ll$ 500 ns. Tests of switch longevity show that the switches, when operated in the linear mode can switch a total of up to 73 C/cm at 8 kV, 68 A, with a pulse duration of 27 ns. For UWB applications we have been able to produce a monocycle with a period of about 10 ns corresponding to a center frequency of about 84 MHz and a high Q ringing waveforms with center frequencies of 133 and 770 MHz. The switching properties of GaP were also reported. The material exhibits a very short carrier lifetime (<2 ns) and does not exhibit high gain switching at fields as high as 44 k/cm. The lack of gain and the low carrier mobility in GaP make this material unsuitable for most pulse power switching applications.

Figure Captions

Figure 1. The voltage across a Si switch. The switched voltage was 123 kV, corresponding to a field of 82 kV/cm.

Figure 2. Plot of Si switch resistance versus time. To obtain the carrier lifetime we plotted $(1/R)-(1/R_0)$, where R_0 is the switch resistance in the dark (or long times). There are two components of the carrier lifetime.

Figure 3. The effect of neutron bombardment on the carrier lifetime in Si. The various curves correspond to neutron fluences of 0 (upper curve marked with hexagons), 10^{11} (+), 10^{12} (squares), 10^{13} (lower curve with hexagons), and 10^{14} (diamonds).

Figure 4. The electrical circuit used in the tests of Si switch longevity included a pulsed power source that charged a 50 Ω cable (10 feet long), a 50 Ω terminating resistor, a voltage monitor, the Si switch, and a current viewing resistor.

Figure 5. The switch with Cr-Cr-Mo-Au metallization switched a total of 8.4 C (33.6 C/cm). The peak switched voltage was 5.5 kV (22 kV/cm) and the current was 40 A (160 A/cm). The voltage, current, and time were recorded at 1 kV/div, 10 A/div, and 50 ns/div, respectively.

Figure 6. A 1.5 cm long by 2 cm wide switch with Cr-Cr-Mo-Au metallization switched a total of 80 C (40 C/cm) in 11 million pulses. The

peak switched voltage was 30 kV (20 kV/cm) and the current was 375 A (187 A/cm). The current waveform was recorded at 200 A/div and 20 ns/div.

Figure 7. A switch with 1 μm Al switched a total of 11 C (44 C/cm). The peak switched voltage was 8.5 kV (34 kV/cm) and the current was 77 A (308 A/cm). The voltage, current, and time were recorded at 2 kV/div, 20 A/div, and 20 ns/div, respectively.

Figure 8. Voltage waveform for switch lifetime tests carried out with the ion implanted P switch. The scales for the axis are 2.5 kV/div and 200 ns/div. The switched voltage was 12.15 kV (48.8 kV/cm). Prior to switch failure, there was no electrical degradation of the voltage pulse.

Figure 9. Current waveform for switch lifetime tests obtained with the ion implanted P switch and the voltage waveform of Figure 9. The current and time are shown at 20 A/div and 20 ns/div. The switched current was 96.4 A (386 A/cm). The total charge switched in this test was only 2 C (8 C/cm), a similar switch was tested at 8 kV, 68 A and switched a total of 18.4 C (73 C/cm).

Figure 10. The current on the load of a Si PCSS switched line showing the capability of the switches to produce a monocycle pulse with a center frequency of 84 MHz. This waveform has a very high bandwidth.

Figure 11. The current on the load of a Si PCSS switched line showing the capability of the switches to produce a 3-cycle waveform with a center frequency of 133 MHz.

Figure 12. The current on the load of a Si PCSS switched line showing the capability of the switches to produce a multi-cycle pulse with a center frequency of 770 MHz.

Figure 13. Current waveform for a GaP switch. The voltage is shown here at 4 A/div and the time axis is 10 ns/div. The oscillations in the current, and the fact that the current returns to zero implies that the carrier lifetime in the GaP is < 2 ns.

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- ¹ See Picosecond Optoelectronic Devices, edited by C. H. Lee (Academic Press, New York, 1984), and High Power Optically Activated Solid State Switches, edited by A. Rosen and F. J. Zutavern (Artech House, Boston, 1993)
 - ² See proceedings from: 6-8th IEEE Pulsed Power Conf., 1987, 1989, 1991; 18-20th IEEE Power Modulator Symp., 1988, 1990, 1992; SPIE Optically Activated Switching I-III, (vol. 1378, 1632, 1873), 1990, 1992, 1993; and special issues in IEEE Trans. Elec. Devices, (vol. 37,38), 1990, 1991.

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- ³ First reported in: G. M. Loubriel, M. W. O'Malley, and F. J. Zutavern, "Towards Pulsed Power Uses for PCSS: Closing Switches," 6th IEEE Pulsed Power Conference, Arlington, VA, 1987, pp. 145-148.
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 - ⁶ G. M. Loubriel, F. J. Zutavern, G. J. Denison, W. D. Helgeson, D. L. McLaughlin, M. W. O'Malley, C. H. Sifford, L. C. Beavis, C. H. Seager, A. Rosen, and R. G. Madonna, "Long Lifetime Silicon PCSS," Proc. of SPIE's Optically Activated Switching Conference III, Los Angeles, CA, 1993.
 - ⁷ G. M. Loubriel, W. D. Helgeson, D. L. McLaughlin, M. W. O'Malley, F. J. Zutavern, A. Rosen, and P. J. Stabile, "Triggering GaAs Lock-on Switches with Laser Diode Arrays," IEEE Transactions Electron. Devices, Vol. 38, 1991, pp 692- 695.
 - ⁸ F. J. Zutavern, G. M. Loubriel, M. W. O'Malley, W. D. Helgeson, D. L. McLaughlin, and G. J. Denison, "Characteristics of Current Filamentation in High Gain PCSS," in Proc. 20th IEEE Power Mod. Symposium, Myrtle Beach, SC, 1992, p 305-311.

Figure 1

CLOSING Si SWITCH

(Cr-Mo-Au contacts, 530 nm light)

$I_{\text{max}} = 2.0 \text{ kA}$

V
O
L
T
A
G
E

8.4 kV

123 kV

82 kV/cm

50 ns/div

C
U
R
R
E
N
T

2.0 kA

50 ns/div

CONCLUSION: Si CAN BE OPERATED AS A CLOSING SWITCH AT FIELDS OF 82 kV/cm, AND VOLTAGES OF 123 kV.

CARRIER LIFETIME TESTS

WCL13192.DAT
[GJDNIS] 11 11:38:54 16-JUL-92

Figure 2

Waller, amended & mad

Figure 3

WCLJAN3192-.DAT
[GJDENIS] 5 08:52:29 24-JUL-92

$\text{Wacker}(t) = 0$
 $+ = 10^{11}$
 $\square = 10^{12}$
 $\text{Wacker}(t) = 10^{13}$
 $\diamond = 10^{14}$

RELIABILITY TEST SCHEME

Circuit

Fig 4

Data

Switch Reliability

6 Million Pulses

Parameters: 5.5 kV (22 kV/cm), 40 A (160 A/cm), and 540 Hz. Triggered with a 10 ns Nd:YAG laser. Cr-Cr-Mo-Au contacts.

Voltage and current waveforms:
Voltage is shown at 1 kV/division.
Current is shown at 10 A/division.
Time axis is at 50 ns/division.

fig 6

3-27-92 Same Semiconductor Processing 1" Sw. as tollon of page 5. Continuing run.
Soldered contact strip had to be re-soldered to lower switch contact

START @ 0917

STOPPED

STOPPED @ 1012 to call fluorescent, cooling system had shut down
Restarted @ 1016

Cr-Cr-Mo-Au 1" Semiconductor Processing 3/26/92

100 mV/div

@ 1213 Driver quit.
1215 Restart

Quit again at 12:20, restarted
Again @ 12:25, "

Stopped run @ 12:35 because of
driver failures (every few minutes)

Total run = 4 hr. 41 min
= 9.1×10^6

BACK ON @ 30 MV 1:50
Restarted run @ 2:25, driver failures

Amended total = 5 hr. 43 min
= 1.11×10^7

Cr-Cr-Mo-Au 1" Semiconductor Processing Sw. 3-26-92

Switch Reliability

10 Million Pulses

Parameters: 8.5 kV (34 kV/cm), 77 A (308 A/cm), and 540 Hz. Triggered with a 10 ns Nd:YAG laser. The switch was made by SNL's Thin Film and Brazing group. It had 1 μ of Al deposited and then heated at 600 C for 20 minutes followed by Cr-Mo-Au metallization.

The voltage and current waveforms shown below were taken at 2 kV/div and 20 A/div, and 20 ns/div. The duration of the current pulse is 17 ns. No degradation of the electrical pulse was observed.

948

B. B. M.

6-15-92
DSRI
switch

Fig 9

198.000 ns 1.19800 us 2.19800 us

. 1 = 2.500 kVolts/div Offset = 5.000 kVolts
nebase = 200 ns/div Delay = 1.19800 us
ta V = 12.15 kVolts
rker1 = -350.0 Volts Vmarker2 = 11.80 kVolts
Trigger mode : Edge
Pos. Edge on Trig
igger Levels
ig3 = 2.000 Volts
ldoff = 70.000 ns

B.B. [Signature]

6-15-72

DSRI
Switch

Fig 10

1.65120 us 1.75120 us 1.85120 us

. 2 = 20.00 Volts/div Offset = 60.00 Volts
mebase = 20.0 ns/div Delay = 1.75120 us

lta V = 96.40 Volts
arker1 = 800.0 mVolts Vmarker2 = 95.60 Volts

Trigger mode : Edge
Pos. Edge on Trig3
igger Levels
ig3 = 2.000 Volts
ldoff = 70.000 ns

3.3.30

Experimental data showing 100 MHz capability

1 ns laser pulse (risetime)

17 in. long charge plate (frequency)

$Z_1 = 5 \Omega$, $Z_2 = 16 \Omega$, $R_s = 1 \Omega$

fig 11

VOLTAGE ON LOAD

TIME (5 ns/div.)

fig 11

Ringling of an 11-inch center conductor

133 MHz

The switch was triggered at 5.9 kV.

The voltage on the load at the end of the Blumlein shows the expected waveform,

6th to 1st peak ratio: $R = 1/3$,
except for a peak spacing of 7.5 ns.

fig 12

For $Z_1 = 16.8 \Omega$, $Z_2 = 141 \Omega$,
 $R = [(Z_1 - Z_2) / (Z_1 + Z_2)]^2 = 0.30$

For 11", the four way transit time
is 5.2 ns, not 7.5 ns

3.2.2

3/2/99

9-9-13

770 MHz

4/30/93

cap #6

$I = 3.7 \text{ kV}$
 10 ns/div

cap #6

4/30/93

$I = 20 \text{ A/V}$
6.5/6

4/30/93

$I = 6.15 \text{ A}$

**DATE
FILMED**

10 / 20 / 93

END