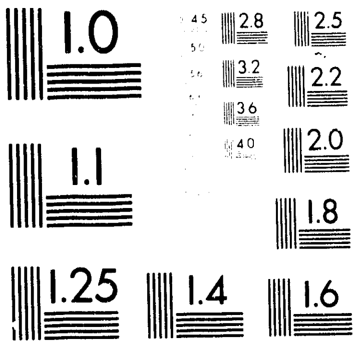
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High Current Density Contacts for Photoconductive Semiconductor Switches

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ABSTRACT

The current densities implied by current filaments in GaAs photoconductive semiconductor switches (PCSS) are in excess of 1 MA/cm^2. As the lateral switches are tested repeatedly, damage accumulates at the contacts until electrical breakdown occurs across the surface of the insulating region. In order to improve the switch lifetime, the incorporation of n- and p-type ohmic contacts in lateral switches as well as surface geometry modifications have been investigated. By using p-type AuBe ohmic contacts at the anode and n-type AuGe ohmic contacts at the cathode, contact lifetime improvements of 5-10x were observed compared to switches with n-type contacts at both anode and cathode. Failure analysis on samples operated for 1-1000 shots show that extensive damage still exists for at least one contact on all switches observed and that temperatures approaching 500 °C are can be reached. However, the n-type AuGe cathode is often found to have no damage observable by scanning electron microscopy (SEM). The observed patterns of contact degradation indicate directions for future contact improvements in lateral switches.

INTRODUCTION

Photoconductive semiconductor switches (PCSS) based on the lock-on effect are being investigated for high gain, high voltage switching applications. The devices are switched from a high voltage, high resistance state by triggering with a low level light pulse in the presence of an externally applied voltage. In the "on" state the switches sustain a high current and exhibit a characteristic electric field termed the "lock-on" field. This field is determined by the properties of the switch material, is not related to the light triggering, and only requires the externally applied voltage to exceed a minimum value. Semi-insulating GaAs PCSS show lock-on fields of 3.6-4.5 kV/cm.

Though the high current output of the switch is a desirable aspect of the device, enormous current densities result. Pulsed external voltages are employed in order to prevent imminent destruction of the switches, but even so, the switch lifetime is a critical issue. Lateral switches are particularly susceptible to damage and surface flashover. It has been observed that contact failure is the main failure mechanism.[1] We present the results of a study aimed at understanding the failure mechanisms and improving the contacts of the high gain, high voltage PCSS.

EXPERIMENTAL

The semi-insulating GaAs wafers were of the liquid encapsulated czochralski (LEC) type, which contain 1-2 x 10^{16} cm^{-2} EL2 traps to obtain high resistivity in excess of 10^7 Ω-cm. Prior to switch fabrication the surfaces were etched for 3 minutes in a 5:1:1::H_2SO_4:H_2O_2:H_2O solution at 70 °C in order to remove polishing damage and surface contamination. Lateral switches were fabricated with microelectronic fabrication techniques. Contact photolithography was used to pattern 2.5 mm wide switches with a 2.5 mm gap. Ohmic metal was then evaporated with an electron beam deposition system and lifted off with

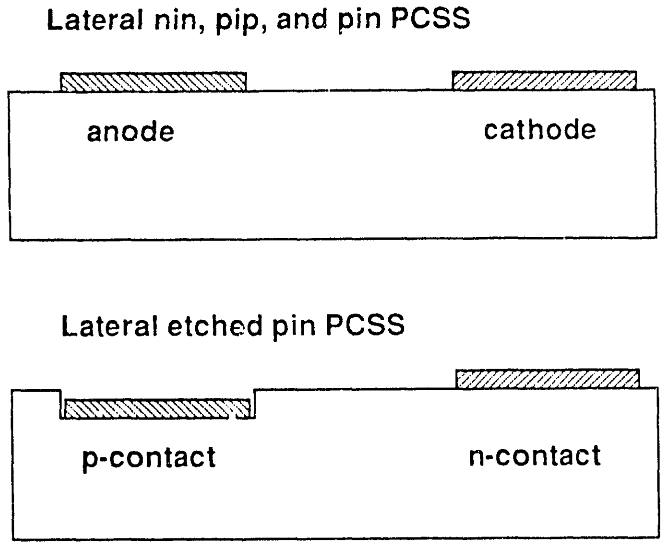


Figure 1. A schematic of the lateral PCSSs. In the planar configuration nin, pip, and pin switches were fabricated and tested. In addition to these, an etched pin switch was fabricated and tested.

solvent soaks. Both n-type GeAuNiAu, hereafter referred to as AuGe, and p-type AuBe(2% Be) industry standard ohmic metals were employed. The n-type ohmic contact was evaporated as follows: 260 Å Ge, 540 Å Au, 150 Å Ni, and 2000 Å Au. The AuBe were evaporated concurrently to a total thickness of 3000 Å. The lateral switches, illustrated in Figure 1, are designated according to the contact configuration as nin, pin, or pip, representing the ohmic contact type at each electrode and the intrinsic semiconductor between electrodes. On some pin switches a wet etch was employed to remove ≈ 4000 Å of GaAs before the p-type contact evaporation and are designated as etched pin samples. The PCSS ohmic contacts were alloyed at temperatures of either 370°C or 470°C for 15 seconds with a rapid thermal annealer. A TiPtAu bond pad layer was then patterned and lifted off. The switches were then diced, soldered to a test fixture, and tested in flowing, room temperature fluorinert.

The device lifetime test procedure has been described previously.[2] Briefly, a 904 nm laser diode array operable up to 1 KHz is used to trigger the switch with the circuit illustrated in Figure 2.

LIFETIME TESTS

We performed device lifetime tests of a number of lateral PCSS with the aim of improving their reliability. Vertical PCSSs show much greater lifetimes at present than lateral PCSSs.[3] The nin contact is the most commonly employed contact, with Schottky or clamped contacts also having been reported. We performed a limited number of lifetime tests on pin contacts alloyed at 370°C and 470°C for 15 seconds. The contact alloy process is a complex solid state reaction which forms AuGa phases among others. The 470°C alloy reacts deeper, ≈ 3000 Å

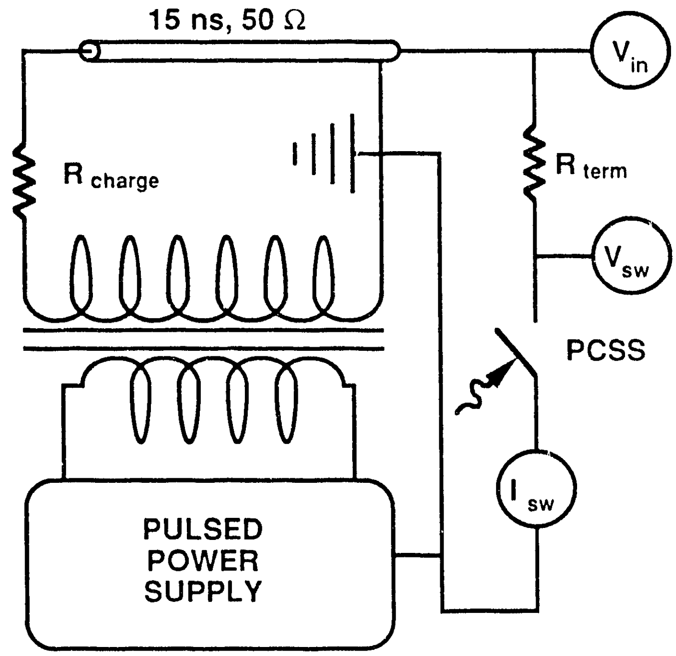


Figure 2. A schematic of the circuit used in device lifetime testing. A high voltage transmission line is used to store a 30 ns long "square pulse to characterize switching properties. R_{term} is chosen such that its resistance (27 Ω in the present work) and the switch resistance are approximately 50 Ω. Note that during high gain switching the switch resistance depends upon the initial voltage. A laser diode array operated up to 1 KHz is used to trigger the switch.

vs. ≈ 500 Å for the 370°C alloy. The higher ohmic alloy temperature gave better lifetime test results and was taken as the standard for the re t of the testing. A deeper initiation of filamentation in the higher temperature alloyed contacts may be the reason for the improved device lifetimes.

The lifetime was approximately 1000 shots for the nin switches, as high as 14,000 shots for the pip switches, and as high as 34,000 shots for the pin contacts, with the p-contact positively biased. The pin contacts with the reverse polarities showed lower lifetimes. The pin contact lifetime was further increased to 57,000 by etching a pit 4,000 Å deep and 2 μm from the edge of metal, as illustrated in Figure 1. However, some pin switches were destroyed after only a few shots because of a tendency to surface flashover. The etched pin switch should be able to sustain lock-on deeper into the GaAs and this may explain the better lifetimes than the unetched pin switch. Other nin switches fabricated previously with a slightly different process and tested with the present methodology showed lifetimes of 4000-6000 shots.[1] Previously quoted lateral switch lifetimes of up to 10^5 shots were obtained with a shorter voltage pulse of 3 ns, or optical triggering near one contact,[1, 2] in contrast to 30 ns voltage pulses and uniform light triggering in the present study. The present set of tests demonstrate significant lifetime improvements with straightforward changes in the contacts.

FAILURE ANALYSIS

Visual and SEM observations were conducted on switches that had completed lifetime testing as well as switches that were operated for 1, 10, 100, and 1000 shots. All switches examined

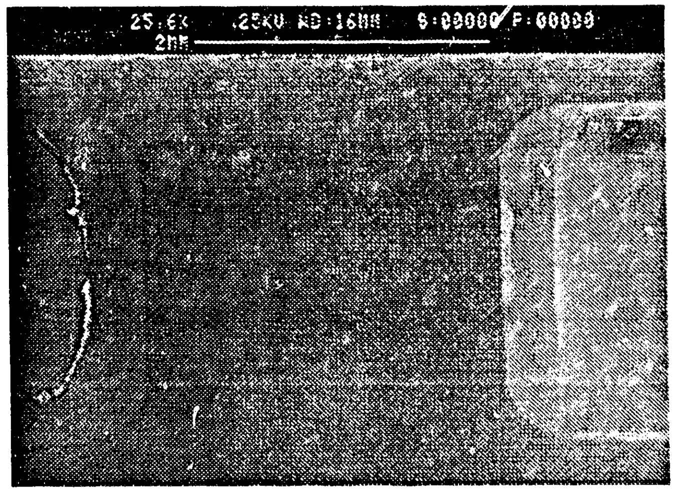


Figure 3. A 25x SEM image of an etched pin switch which was operated for 100 shots. The cathode is on the left and the anode on the right.

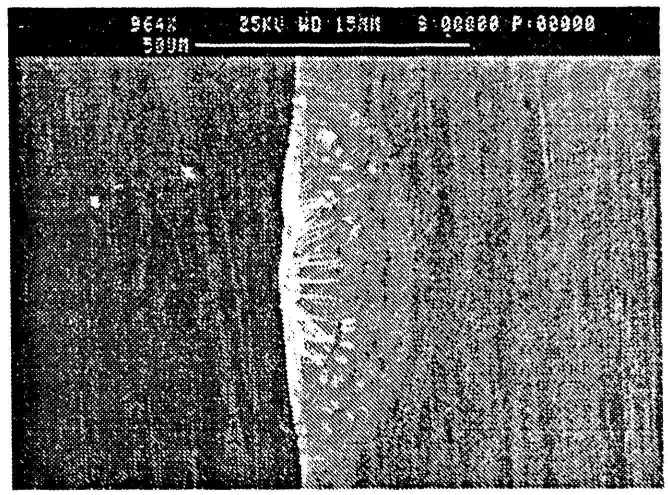
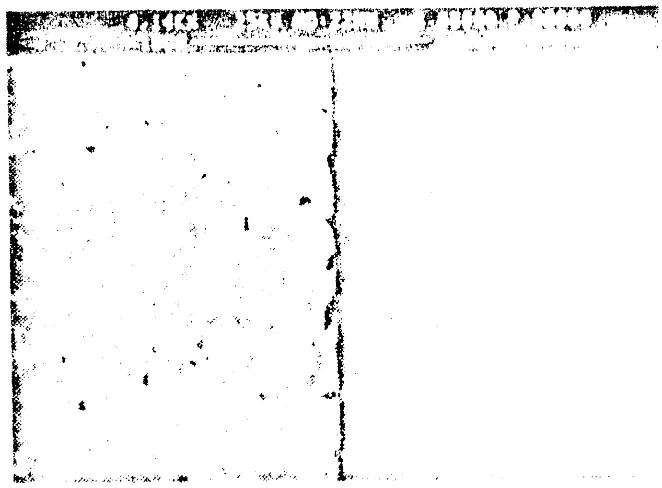
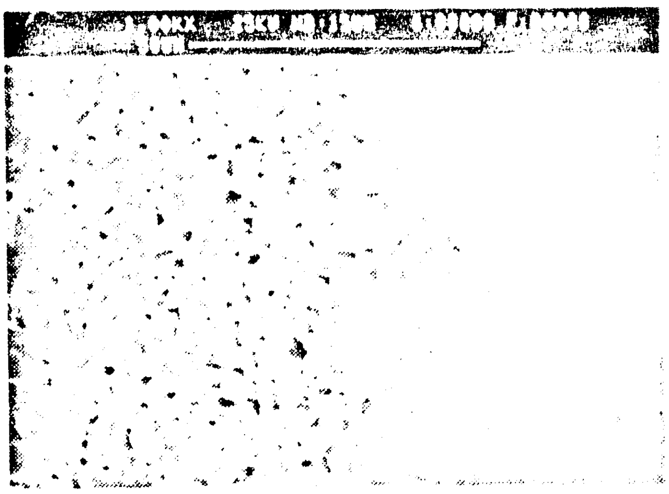


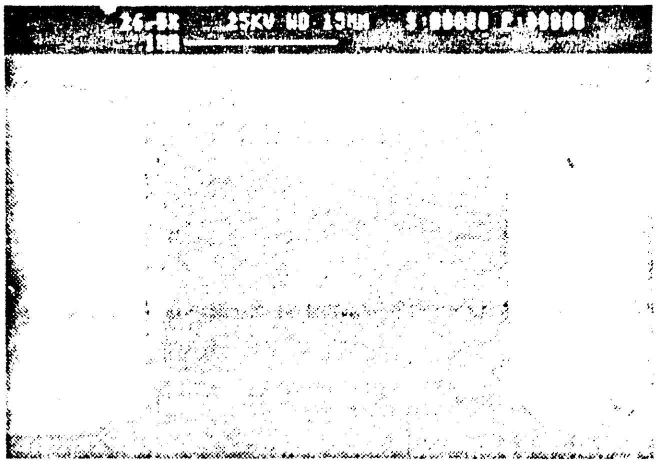
Figure 4. A 960x SEM image of the anode of a pin switch which was operated for one shot.

were imaged at a magnification of ≈ 3000x along the entire contact edge of 2.5 mm in order to identify any damage and in most cases the damage was visible at considerably less magnification. Each contact was also imaged at 25x to observe the entire switch. A typical image in shown in Figure 3 for an etched pin switch operated for 100 shots.

Visible damage was observed for all switches, even those operated only once. The pin switches showed damage predominantly at the anode (p-contact). After one shot damage such as that shown Figure 4 is observed. The damage typically consists of a semicircular area of metal 50-100 μm in diameter that appear to have melted. In the example of Figure 4, the metal appears to have flowed into the gap, but this is not always the case. A high magnification image of a damage region of the p-type AuBe contact typical of 10-100 shots is illustrated in Figure 5. The contact metal has flowed into the intrinsic region. Not all damage areas show the metal flow into the gap, but all show visible evidence of melting. After 1000 shots the contact show an accumulation of damage and evokes the "eroded" look similar to that in Figure 3 and seen in high magnification in Figure 6. Switches with 10 and 100 shots showed a progression of damage







ACKNOWLEDGMENTS

REFERENCES

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