SAND99-2051C

DOPED CONTACTS FOR HIGH-LONGEVITY OPTICALLY ACTIVATED, HIGH GAIN GaAs PHOTOCONDUCTIVE SEMICONDUCTOR SWITCHES

A. Mar, G. M. Loubriel, F. J. Zutavern, M. W. O'Malley, W. D. Helgeson,
D. J. Brown, H. P. Hjalmarson, and A. G. Baca
Sandia National Laboratories, Albuquerque, New Mexico 87185-1153

R. L. Thornton, R. D. Donaldson,
Xerox Palo Alto Research Center, Palo Alto, California 94304

RECEIVED
AUG 18 1999
OSTI

ABSTRACT

The longevity of high gain GaAs photoconductive semiconductor switches (PCSS) has been extended to over 50 million pulses. This was achieved by improving the ohmic contacts through the incorporation of a doped layer beneath the PCSS contacts which is very effective in the suppression of filament formation and alleviating current crowding to improve the longevity of PCSS. Virtually indefinite, damage-free operation is now possible at much higher current levels than before. The inherent damage-free current capacity of the switch depends on the thickness of the doped layers and is at least 100A for a dopant diffusion depth of 4μm. The contact metal has a different damage mechanism and the threshold for damage (~40A) is not further improved beyond a dopant diffusion depth of about 2μm. In a diffusion-doped contact switch, the switching performance is not degraded when contact metal erosion occurs. This paper will compare thermal diffusion and epitaxial growth as approaches to doping the contacts. These techniques will be contrasted in terms of the fabrication issues and device characteristics.

I. BACKGROUND

The subject device of this paper is the optically triggered, high-gain lateral GaAs photoconductive switch (PCSS). They are constructed using semi-insulating (SI) GaAs of high resistivity $>10^7$ Ω-cm and metal contacts that are used to connect the switch to an energy source and a load. At electric fields above 4 to 6 kV/cm these switches exhibit high gain.[1] In the "on" state the field across the switch stabilizes to a constant called the lock-on field. During high gain switching, the PCSS emit bandgap radiation by carrier recombination. This radiation under high gain operation, when imaged, is in the form of filaments.[2]

Although such high-gain operation is useful for many applications, the filamentary nature of this current impacts negatively the operational lifetime of the switches. This is manifested in the form of damage of the semiconductor to metal interface that initially appears as a trench, metal erosion, or damage in the GaAs away from the contacts (in the gap between the contacts). Contact erosion is an important damage mechanism since it is the main cause of degradation of switching characteristics, resulting in higher on-state resistance and voltage drop, and ultimately the cease of switch functioning.

II. DOPED CONTACTS FOR PCSS

Damage to the PCSS contacts occurs due to current crowding at the point of filament termination at the edge of the contact. This is exacerbated by the difficulty in making low-resistance ohmic contacts to SI GaAs. We have therefore sought to incorporate doped layers under the contact regions to reduce the contact and spread the current, as shown in Figure 1. The doped regions also serve to transfer the point of filament termination from the metal - semiconductor interface to a doped semiconductor - semiconductor interface which is more robust against damage. Another embodiment of this idea under investigation involves the use of a thick less conductive layer grown on top of the highly doped layer. This serves to strongly favor lateral current spreading as this vertical resistance serves to equalize the voltage drops among different current paths from the switch gap to different points on the metal contact. Such a "current

leveling layer" has been demonstrated in vertical cavity semiconductor lasers to improve current injection uniformity in edge-injected structures.[3]

Two main approaches for the fabrication of switches with doped contact layers are being developed. The first is epitaxial growth using MOCVD to incorporate grown layers of highly doped material under the contacts. In one such approach, n-type (Si-doped) material is first deposited over the entire wafer and then etched away except in the regions where the switch cathodes are formed. This process is then repeated for a p-type growth (Zn-doped) for the anodes and then ohmic contacts are made to the doped material. Because this process results in a non-planar surface, another preferred approach under development utilizes patterned epitaxial regrowth. In this process, the contact regions are etched to some depth (a few microns) and highly doped GaAs is then regrown into these regions by the same thickness as the etch depth using a growth mask (SiO_x) that prevents growth elsewhere. This process is also repeated for the two different contact polarities and ohmic contacts made to the doped layers, which results in a planar structure. Because of non-idealities associated with the patterned regrowth, this process is still in development to overcome the issues of conductive material grown on the growth mask (into the switch gaps), and growth non-planarity.

The second technique we are pursuing for doped PCSS contacts is dopant diffusion. In this process, SiN_x is deposited and patterned to serve as a diffusion mask. An Si source layer and SiN_x encapsulation layer are then deposited and the Si driven in using a tube furnace at 800°C. These layers are left in place and patterned to serve as a diffusion mask for Zn. Vaporized Zn is diffused into the substrate in an open tube furnace at approximately 600°C. Further details regarding the diffusion processing can be found in reference [4]. Ohmic contacts are then made to the doped regions to complete the fabrication. A microphotograph of such a completed device is shown in Figure 2.

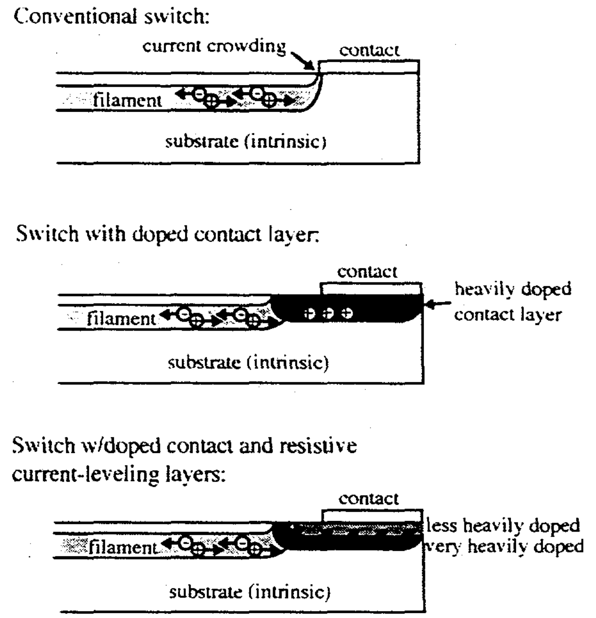

Figure 1. Current crowding and effect of doped contacts.

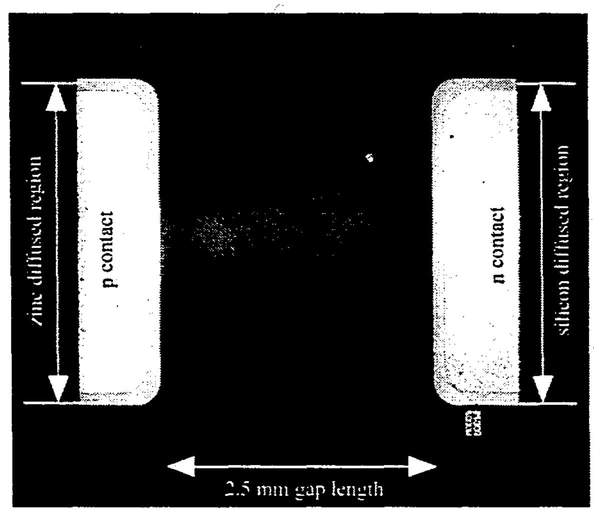

Figure 2. Microphotograph of completed PCSS with diffusion –doped contacts.

III. PERFORMANCE OF PCSS WITH DOPED CONTACTS

The recombination radiation in PCSS filaments affords the ability to image them using an IR sensitive video camera. Such imagery of a filament in a PCSS with doped contacts is shown in Figure 3. The image shows that the doped layers are highly effective in the suppression of the filament formation near the contacts at peak current levels of up to approximately 60A. In this regime, virtually indefinite, damage-free operation of the switch is obtained.

At sufficiently high currents, the filament is not sufficiently suppressed in the doped region to prevent damage to the contact. The nature of this damage and its effects however, is markedly different from that in a conventional PCSS. In the past, longevity tests have determined that damage due to current crowding in conventional PCSS contacts occurs first as a void or trench in the GaAs at the edge of the undoped contacts.

Presumably due to the lower mobility of holes in GaAs, more severe damage occurs first at the p-contact of the PCSS. At higher currents and shot counts, this damage is accompanied by damage to the contact metal, in the form of erosion or loss of adhesion to the GaAs. These types of damage are shown in Figure 4. In the case of doped-layer contacts, this trend is reversed, where damage to the metal occurs at lower currents than it takes to damage the bulk material. In a conventional switch, this causes increased voltage drop and decreased current as the metal erosion occurs. This is not the case with PCSS with doped contacts, where the point of filament termination is on the doped region and the switching behavior remains constant even if the metal contact is damaged, until the point where the external connection to the device is destroyed.

The level of current that can be switched without damage is dependent on the thickness of the doped layer beneath the contact. This was determined by preparing samples over a range of p-type anode diffusion depths (from ~1μm to ~4μm). The maximum current for operation with no detectable damage was then determined for the different diffusion depths. This was done accounting for two types of damage: damage confined to the contact metal (no switching current degradation), and damage to both the contact metal and bulk GaAs (switching current drop as damage accumulates). This characteristic is plotted in Figure 5. It is clearly seen that a thicker doped layer aids in suppressing damage to the bulk semiconductor. However, the improvement for damage to the contact metal tends to a limit of approximately 40A, with no further improvements with increasing diffusion depth. This implies a different

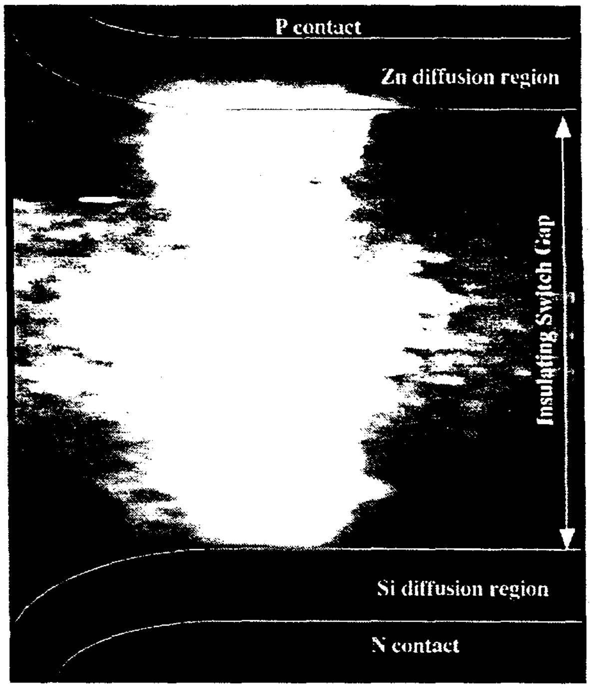

Figure 3. Filament suppression in the doped contact regions of a PCSS.

mechanism for damage to the metal that is not adequately addressed by the current spreading in the doped contact layer. This indicates the requirement for a separately engineered solution for the fabrication of the contact metals together with the doping in the semiconductor material, or the implementation of field-shaping to enhance the lateral spreading of current at the contact. Beyond such an improvement, the data indicate the need for yet deeper diffusion depths to increase the inherent current capacity of the switch.

Figure 4. Different types of damage to PCSS contacts.

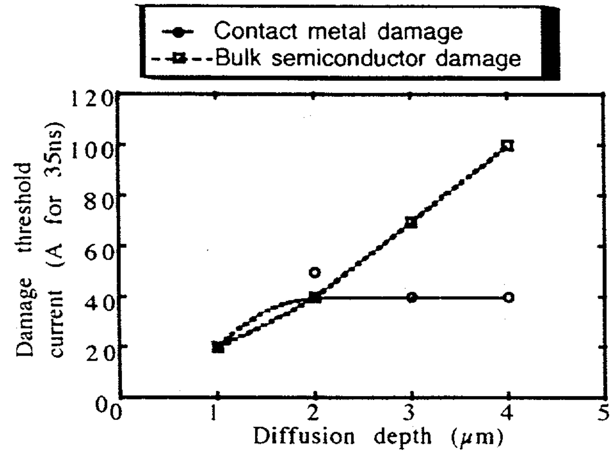

Figure 5. Effect of p-type dopant diffusion depth on maximum damage-free operating current.

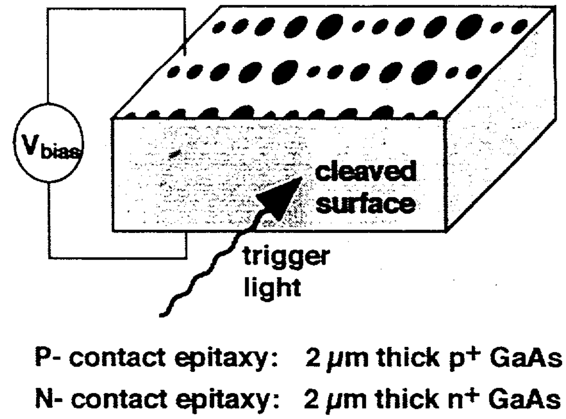

Figure 6. Laterally-triggered vertical switch with top and bottom doped contacts.

IV. SUMMARY AND FUTURE DIRECTIONS

The incorporation of a doped layer beneath PCSS contacts is shown to be very effective in the suppression of filament formation and alleviating current crowding to improve the longevity of PCSS. Virtually indefinite, damage-free operation is now possible at much higher current levels than before. The inherent current carrying capacity of the switch depends on the thickness of the doped layers and is at least 100A for a dopant diffusion depth of 4μm. The contact metal has a different damage mechanism and a threshold for damage (~40A) that is not further improved beyond a dopant diffusion depth of about 2μm. Further independent improvement of the contact metal itself is necessary to obtain further overall improvements in longevity. However, in a doped contact switch, the switching performance is not degraded when contact metal erosion occurs.

Non-coplanar switch geometries may offer some benefit for PCSS longevity. We are currently developing a vertical switch that also incorporates doped contact layers on both sides of the substrate. As shown in Figure 6, this switch is triggered laterally on a cleaved surface, which allows greater flexibility in controlling filament formation via tailoring of the trigger light across the entire gap. Varying the switch gap is accomplished through the use of different wafer thicknesses or by stacking. This geometry combines the advantages of a lateral switch with doped contacts of effectively infinite depth orthogonal to the filament. The initial testing of this switch shows damage-free operation at currents of up to at least 50A.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

V. REFERENCES

[1] G. M. Loubriel, M. W. O'Malley, and F. J. Zutavern, "Toward pulsed power uses for photoconductive semiconductor switches: closing switches," Proc. 6th IEEE Pulsed Power Conf., P. J. Turchi and B. H. Bernstein, eds., (IEEE, NY, 1987), Arlington, VA, June 29-July 1, 1987, pp. 145-148.

[2] F. J. Zutavern, G. M. Loubriel, M. W. O'Malley, W. D. Helgeson, and D. L. McLaughlin, "High Gain PCSS," Proc. 8th IEEE Pulsed Power Conference, R. White and K. R. Prestwich, eds., San Diego, CA, 1991, p. 23.

[3] J. W. Scott, R. S. Geels, S. W. Corzine, and L. A. Coldren, "Modeling Temperature Effects and Spatial Hole-Burning to Optimize Vertical-Cavity Surface-Emitting Laser Performance," IEEE J. of Quantum Elec., Vol. 29 (#5), pp. 1295-1308, 1993.

[4] R.L. Thornton, R.D. Burnham, T. L. Paoli, N. Holonyak Jr., and D. G. Deppe, "Optoelectronic device structures fabricated by impurity-induced disordering", J. Crystal Growth 77, pp. 621-628, 1986.