Thermal pinching of current in long silicon diodes having a single-valued current-voltage characteristic

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We observed experimentally thermal instability of the current in long silicon diodes with positive differential resistance. It is shown that this effect is due to the difference between the spatial dispersions of the intrinsic and the nonequilibrium conductivities in the weakly doped region of the diode.

In a recent article, [1] Kerner and Osipov predicted theoretically the possible onset of current instability in a system whose properties depend on two parameters having different spatial dispersions, even if the current-voltage characteristic is single-valued.

This phenomenon was observed by us experimentally in long $p^+sn^+(p^+sR^+)$ silicon diodes (p^+, n^+—strongly doped regions, s—slightly doped region, R^+—Ohmic junction of the recombination type).

Figure 1 shows the CVC of p^+sn^+ structures plotted at the end of a rectangular pulse of 0.5 msec duration (the arrows show the instants when the diodes were damaged by local burning). We see that in the diodes with $d/L = 1.4$ and $d/L = 4.4$ (d is the thickness of the s region and L is the ambipolar diffusion length) the thermal breakdown set in on the CVC section with negative differential resistance (NDR), while in the diode with $d/L = 12$ it occurred on the CVC section with positive differential resistance (PDR).

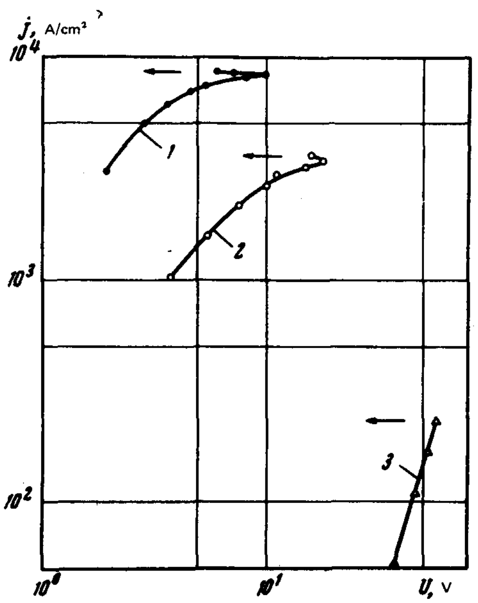

FIG. 1. Current voltage characteristics of p^+sn^+ structures, plotted at the end of a rectangular current pulse of duration 0.5 msec (the arrows show the instant at which the diode was damaged by local burning): 1- $d/L = 1.4$, 2- $d/L = 4.4$, 3- $d/L = 12$.

To explain this fact, we turn to the model of a real p^+sn^+ structure, shown in Fig. 2. The solid curve in this figure shows the distribution of the concentration of the injected carriers ($\Delta p = \Delta n$), while the dashed curve shows the distribution of the concentration of the intrinsic carriers ($p_i = n_i$) in the s-region of the device. The forms of these distributions are governed respectively, by the presence of injection from the strongly doped p^+ and n^+ layers and by the heat dissipation in the tungsten thermal compensators W.[1)]

It is obvious that such a distribution of the concentrations of the intrinsic and injected electrons and holes leads to the formation of local NDR in the region of maximum heating of the base and to minimal modulation of its conductivity by the injected carriers, $\sigma_2 \approx q(\mu_n + \mu_p)p_i \sim \exp(-1.16/2kT)$ [3] (T is the temperature in °K). Connected in series with this region are sections of the

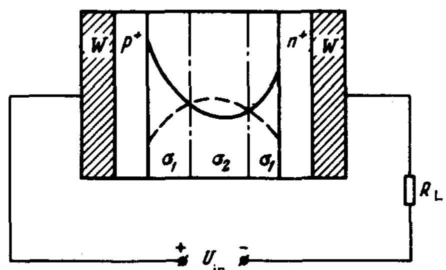

FIG. 2. Model of real p^+sn^+ structure and its connection circuit. Solid curve—distribution of the concentration of the injected carriers, dashed—distribution of the concentration of the intrinsic carriers.

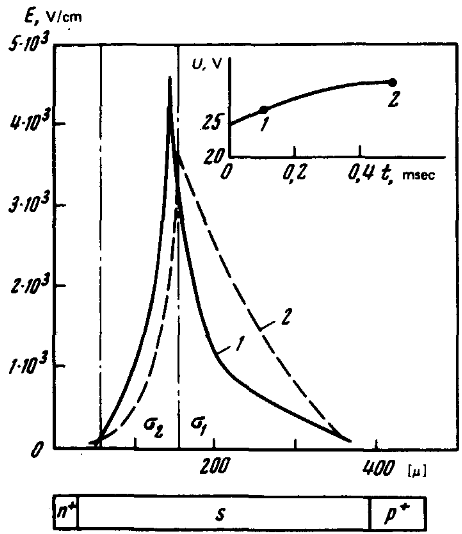

FIG. 3. Distribution of field intensity along the base region of the sample for instants of time corresponding to weak (curve 1) and strong (curve 2) heating of a p^+sn^+ diode. Upper corner—oscillogram of the voltage pulse on the diode.

p^+sn^+ structure with PDR, having a conductivity $\sigma_1 \approx q(\mu_n + \mu_p)\Delta p \sim T^{-5/2}$ [4] (see Fig. 2). Consequently, in our case the conductivities σ_1 and σ_2 are parameters that have different spatial dispersions, [1] and, depending on the ratio of the dimensions of the regions with σ_1 and σ_2, the pinching of the current in such a system can occur both in the case of PDC (for diodes with not too large a ratio d/L—curves 1 and 2 of Fig. 1) and in the case of NDR (for diodes with $d/L \gtrsim 10$—curve 3 of Fig. 1).

The validity of the model proposed by us confirmed by probe measurements of the potential along the base of the p^+sn^+ structure (the procedure for such measurements is described in[5]). Figure 3 shows the distributions of the field intensity for two instants of time, obtained by graphic differentiation of the potential-distribution curve. The first curve corresponds to slight heating of the structure ($\Delta p \gg p_i$), and the second to strong heating ($\Delta p_{\min} \sim p_i$). We see that the conductivity has increased in the region $\sigma_2 \sim E^{-1}(p_i \sim \Delta p_{\min})$ and decreased in the region $\sigma_1 \sim E^{-1}(\Delta p \gg p_i)$.

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1)The large value of the intrinsic concentration is due to the strong heating of the silicon diode by the direct current. [2]

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