PREBREAKDOWN CONDITION IN SELENIUM RECTIFIERS

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This paper reports data from an experimental investigation of the prebreakdown and breakdown conditions of factory production selenium rectifiers in the temperature range from 100° to -196° C when a unit voltage pulse with steep leading edge (rise time about 10^{-8} sec) is applied to the rectifier in the non-conducting direction. Change in voltage across the rectifier and in current through it were recorded by a two-channel high-speed electronic oscilloscope. On the basis of this test data, the variation of discharge rise-time in the selenium p-n junction as a function of overvoltage and temperature was determined, the formation of current pulses was detected in the junction, both before and during breakdown in the temperature range from 100° to -196° C, and it was also established that breakdowns of selenium rectifier p-n junctions are due to joint action of the Zener effect and impact ionization.

INTRODUCTION

In order to establish a theory of electrical breakdown which takes account of the elapse of time, one must know the currents before breakdown, at the instant of breakdown, and also the discharge rise time as a function of temperature. Knowing the means by which a strong electric field brings about an increase of reverse conductivity in a selenium rectifier p-n junction at different temperatures, makes it possible to control this phenomenon and broaden the working temperature range.

At present, the most widely accepted theory of the p-n junction breakdown is that of impact ionization by electrons (excluding very narrow junctions) and therefore one may assume that certain laws already established for solid dielectrics are applicable also to p-n junctions.

Electrical breakdowns are generated in the interior of a semiconductor, and for this development a certain definite time is required. By taking account of the role of space charge, A. A. Vorob'ev was able to more fully describe the electrical breakdown of dielectrics.

Existing experimental data shows that this time is significantly decreased with increase in overvoltage across the dielectric, and increases as the latter's thickness decreases. It is known that the increase in breakdown voltage of solid dielectrics under voltage pulses 10^{-6}–10^{-7} sec and shorter is caused by a delay of the discharge.

Determination of the discharge rise time in p-n junctions has had little study [1, 2]. O. F. Goryunova made an experimental investigation of the duration of the growth of breakdown in germanium diodes [1]. According to her data, the discharge rise time is of the order of 10^{-9}–10^{-8} sec and rises with increase in the resistivity of the germanium.

By determining the temperature dependence of the discharge rise time, we make an addition to the theoretical interpretation of electrical breakdown in p-n junctions; particularly since this question, as far as we know, is not dealt with in the technical literature.

1. EXPERIMENTAL PROCEDURE

The determination of discharge rise time as a function of temperature was accomplished by a known method [2] which, by providing a pulsed cycle, prevents any marked heating of the specimen by current. The rectifier was placed in a cylindrical iron vessel provided with a hermetically sealed lid, through which passed a metal tube within which the leads from the rectifier and a thermocouple were placed (the tube
Temperature Dependence of Discharge Rise Time

<table>
<thead>
<tr>
<th>T°C</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>50</th>
<th>20</th>
<th>-40</th>
<th>-50</th>
<th>-100</th>
<th>-140</th>
<th>-196</th>
</tr>
</thead>
<tbody>
<tr>
<td>10^{-6} sec</td>
<td>44</td>
<td>40.5</td>
<td>40</td>
<td>41</td>
<td>44</td>
<td>42</td>
<td>40</td>
<td>40</td>
<td>37</td>
<td>30</td>
<td>30.8</td>
</tr>
</tbody>
</table>

opening was sealed with compound. The thermocouple was located directly beside the electrode of one of the test disks. When working down from 0°C to -196°C a small cup of P₂O₅ was placed in the vessel to absorb moisture. Variation of temperature upward from room temperature to +100°C was achieved by putting the vessel containing the rectifier into a thermostatically controlled oven.

Figure 1 shows the dependence of the discharge rise time on overvoltage. The latter was measured as the ratio of the breakdown voltage to the static voltage, i.e., \( \beta = \frac{U_{br}}{U_{st}} \). For the breakdown voltage, we took the amplitude of the pulse on the flat portion of which breakdown occurred, while for the static breakdown voltage, we took a value corresponding to a breakdown probability (\( \Psi = 90\% \)).

For the rectifier discharge rise time we take the time elapsing from the instant of applying the static voltage to the instant of voltage collapse across the rectifier.

2. RESULTS AND DISCUSSION

For our tests we took factory production selenium rectifiers Types AVS-18-12 and AVS-15-12. The first were in the form of round disks with \( d = 18 \text{ mm} \), the second rectangular with \( l = 15 \text{ mm} \). During the tests with reverse voltages from 5V to breakdown voltage applied to the rectifier, the temperature was varied from +100°C to -196°C. More than 1000 oscillograms of breakdown for different disks were obtained and reduced.

A) TEMPERATURE DEPENDENCE OF THE DISCHARGE RISE TIME

The curve of the discharge rise time was a function of overvoltage (Fig. 1) shows an increase in the former as the overvoltage is decreased. This also takes place in dielectric breakdown (see Sonchik, [3]). As the overvoltage is varied from 1.05 to 1.2, the discharge rise time decreases very slowly. A decrease in this time parameter as the overvoltage across a selenium rectifier p-n junction is increased, is observed at both low and high temperatures. As the field intensity is increased, the strength of each avalanche process is increased along with its ability to produce breakdown; consequently, the number of avalanche processes necessary for breakdown will be decreased. In other words, the discharge rise time will be less.

Taking the interval from the start of the pulse to the first drop in voltage (Fig. 2) as the rise time of the electron avalanches, it is shown by our tests to vary from \( 9.5 \times 10^{-6} \text{ sec} \) to \( 0.8 \times 10^{-6} \text{ sec} \).

According to V. A. Chuenkov’s calculations [4], \( t_I = 1.56 \times 10^{-10} \text{ sec} \) for NaCl with \( L = 0.1 \text{ cm} \). The discrepancy between the theoretical estimate and the experimental value in this case may apparently be explained as follows; in the first place, according to Chuenkov’s theory, the value of \( t_I \) always depends substantially on the average time (\( \tau \)) between two consecutive ionizing encounters with lattice vibrations. As the author himself notes, if for NaCl with \( L = 0.1 \text{ cm} \) in place of \( \tau = 1.43 \times 10^{-14} \text{ sec} \), we take the value \( \tau = 2.10^{-14} \text{ sec} \), we obtain \( t_I = 1.48 \times 10^{-14} \text{ sec} \); and in the second place, one must take into account that the discharge rise time increases with decrease in the thickness of the dielectric (see Vorob’ev and Kostrygin [5, 6]).

From the data of Table 1 showing the temperature dependence of the discharge rise time, it is apparent that at the given overvoltage, there is a moderate tendency to increase with temperature. This may probably be explained by an increase in lattice thermal vibration, which hinders passage of an electron avalanche [3].

Current and Average Current Pulse Duration for Different Temperatures

<table>
<thead>
<tr>
<th>T°C</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>50</th>
<th>20</th>
<th>-40</th>
<th>-50</th>
<th>-100</th>
<th>-140</th>
<th>-196</th>
</tr>
</thead>
<tbody>
<tr>
<td>( l ), electron avalanche current, ( \text{mA} )</td>
<td>300</td>
<td>300</td>
<td>400</td>
<td>400</td>
<td>700</td>
<td>500</td>
<td>600</td>
<td>1000</td>
<td>2000</td>
<td>1500</td>
<td>2500</td>
</tr>
<tr>
<td>( \Delta T ), duration, ( \text{\mu sec} )</td>
<td>0.8</td>
<td>0.8</td>
<td>1</td>
<td>0.4</td>
<td>4</td>
<td>4</td>
<td>0.5</td>
<td>1.6</td>
<td>1</td>
<td>1.4</td>
<td>2</td>
</tr>
</tbody>
</table>