United States Patent [19]

Hagen

[11] **3,727,165**

[45] **Apr. 10, 1973**

[54] **VOLTAGE-DEPENDENT RESISTOR**

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Related U.S. Application Data

[63] Continuation of Ser. No. 6,203, Jan. 27, 1970, abandoned.

[30] **Foreign Application Priority Data**

Feb. 1, 1969 Netherlands 6901659

[52] **U.S. Cl.** **338/20,** 338/223, 338/325, 338/328

[51] **Int. Cl.** **H01c 7/10**

[58] **Field of Search**....................338/13, 20, 21, 100, 338/325, 223, 328; 29/621; 317/234 V

[56] **References Cited**

UNITED STATES PATENTS

3,210,831	10/1965	Johnson et al.	29/621
3,212,043	10/1965	Johnson	338/20
3,448,246	6/1969	Armbruster	219/528

Primary Examiner—C. L. Albritton
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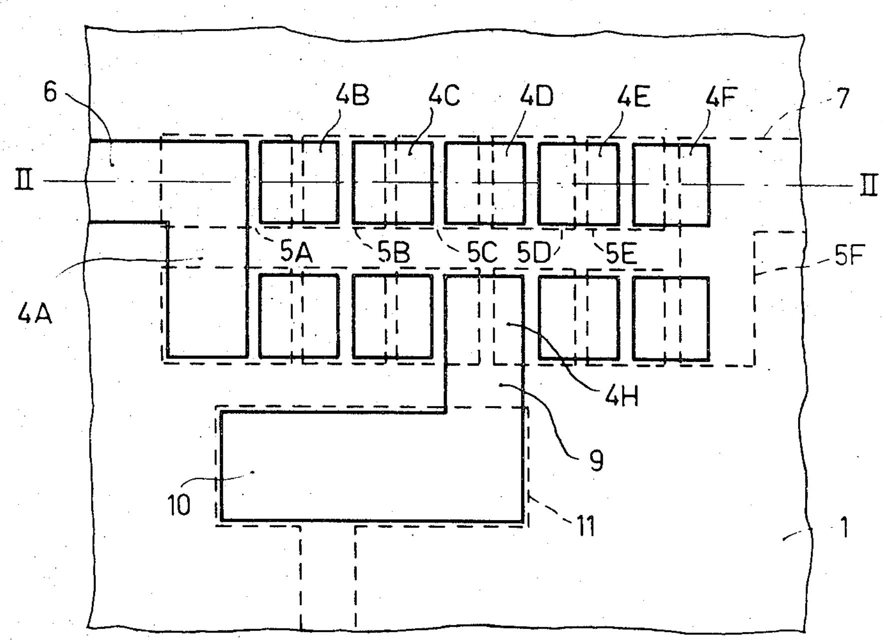
[57] **ABSTRACT**

Voltage-dependent resistor comprising a one-grain-thick layer provided with electrode layers which are in contact with the grains and which are arranged in a pattern of islands partly overlapping each other and located on either side of the layer, so that mutually insulated parts of the grain layer can be connected in series.

9 Claims, 5 Drawing Figures



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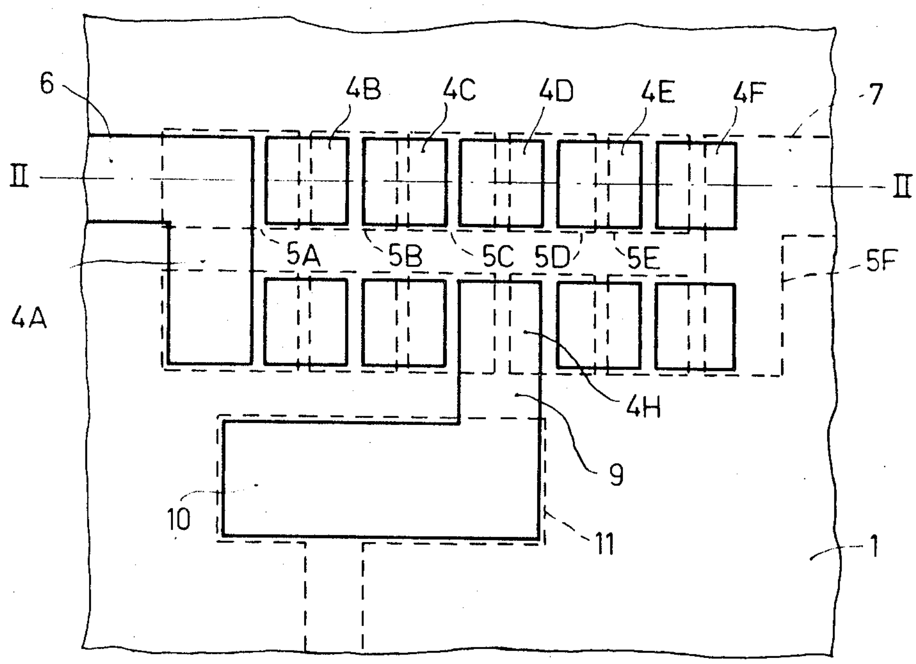

fig.1

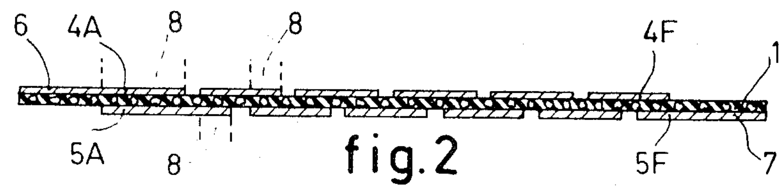

fig.2

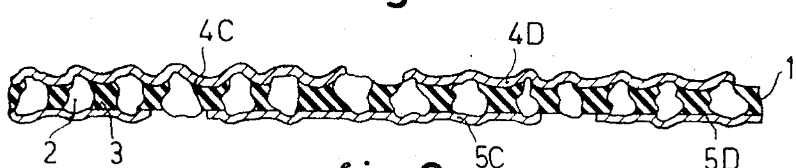

fig.3

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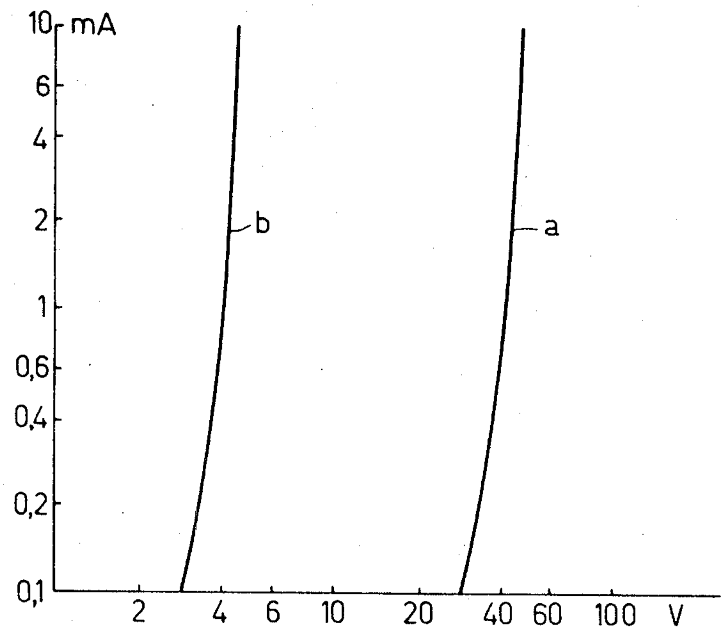

fig.4

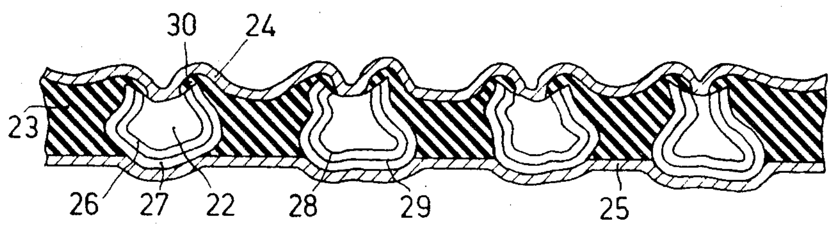

fig.5

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VOLTAGE-DEPENDENT RESISTOR

This is a continuation of application Ser. No. 6,203, filed Jan. 27, 1970, and now abandoned.

The invention relates to a voltage-dependent resistor comprising a one-grain-thick layer comprising grains, preferably semiconductive grains, embedded in an electrically insulating binder and projecting on either side from the binder, an electrode layer being applied to either side of said grain layer, said electrode layers being completely separated from each other by the grain layer and establishing contacts with the projecting parts of the grains.

Voltage-dependent resistors of the kind set forth are known, for example, from U.S. Pat. No. 3,210,831. This Specification discloses a voltage-dependent resistor comprising a one-grain-thick layer of silicon carbide grains embedded in a synthetic resin and projecting on either side therefrom. This grain layer is covered on either side with a coherent electrode layer. In operation a voltage difference is applied between these two electrode layers.

Such a known voltage-dependent resistor exhibits within a given voltage range a very strong, non-linear current increase with an increasing voltage. With voltage-dependent resistors having a one-grain-thick layer of the kind set forth this voltage range is restricted for a given grain layer to comparatively low voltage values, for example, of the order of a few volts.

The invention has for its object inter alia to provide a construction of a voltage-dependent resistor in which by using a one-grain-thick layer the operational voltage at which the resistor exhibits very useful, non-linear properties is considerably higher than in the known devices described above.

The invention is based inter alia on the recognition of the fact that by using electrode layers of particular structure on a voltage-dependent resistor having a one-grain-thick layer of grains embedded in insulating material the operational voltage of the resistor can be materially raised in dependence upon the fastening area of the connecting conductors as compared with the value obtained in the known devices, whilst in addition tappings can be provided on the voltage-dependent resistor.

Therefore, according to the invention a voltage-dependent resistor of the kind set forth is characterized in that each of the electrode layers comprises a number of island-shaped regions arranged in one or more rows, at least one island of each row partially overlapping two consecutive islands belonging to a second row and located on the opposite side of the grain layer, whilst at least two islands belonging to said rows are provided with a connecting conductor so that between these connecting conductors all parts of the grain layer located between the overlapping parts of the islands located between the connecting conductors are connected in series with each other.

The present invention provides inter alia the important advantage that the satisfactory, reproducible, non-linear properties obtained in a one-grain-thick layer at a comparatively low voltage can be utilized for obtaining a very satisfactory, non-linear current-voltage characteristic curve at higher voltages. By connecting in series, in accordance with the invention, a plurality of one-grain-thick regions electrically insulated from each other in the direction of the layer a considerably better characteristic curve can be obtained than by using a layer more than one grain thick because in a voltage-dependent resistor in accordance with the invention junctions between grains having poorly reproducible and undesirable electric properties do not occur.

A further important advantage is that tappings can be provided on a voltage-dependent resistor in accordance with the invention, which is in general not possible with the known voltage-dependent resistors described above. For this purpose one or more of the further islands located between said connecting conductors may be provided with a further connecting conductor. The connecting conductors may have the form of metal tracks applied to the grain layer, which may be connected, if desired, to an electrode system provided on the grain layer. In this way composite circuit arrangements can be provided on a single grain layer.

It should be noted that said rows of islands need not be rectilinear; they may form sequences of consecutive islands along curved or lines consisting of consecutive linear segments in different directions. If an electrode layer is formed by more than one row of islands, the series combination of grain layer portions in one row may be combined with the parallel connection of rows or of parts of rows with each other.

The grains may be made of silicon carbide or other suitable materials, preferably semiconductor materials, which together with the electrode layers applied thereto from voltage-dependent resistors having satisfactory characteristic curves. Very satisfactory, non-linear characteristic curves are obtained by using grains consisting, for example, of zinc-doped gallium phosphide or n-type silicon. The grains may be homogenous, in which case the non-linear current-voltage characteristic curve is obtained by the metal-semiconductor junctions between grains and electrode layers. In a further preferred embodiment semiconductor grains having a pnp- or npn-structure are advantageously used, the two regions of the same conductivity type of which establish a contact with an electrode layer on opposite sides of the grain layer. Between electrode layers located on either side of the grain layer a breakdown voltage appears in both senses, the value of which is determined by the pn-junctions of the grains.

In a further preferred embodiment an even number of grain layer portions located between overlapping islands of a voltage-dependent resistor in accordance with the invention are connected in series between two connecting conductors. This embodiment is particularly advantageous when the current-voltage characteristic curve measured between the two electrode layers located opposite each other on either side of the grain layer is asymmetrical, which will be explained more fully hereinafter.

The invention will now be described more fully with reference to the examples and the drawing, in which

FIG. 1 is a schematic plan view of a device having a voltage-dependent resistor in accordance with the invention,

FIG. 2 is a schematic cross sectional view of the device of FIG. 1 taken on the line II—II,

FIG. 3 is a schematic cross sectional view of a detail of the sectional view of FIG. 2,

FIG. 4 illustrates current-voltage characteristics measured on the device shown in FIGS. 1 to 3 and

FIG. 5 is a schematic cross sectional view of a detail of a voltage-dependent resistor in accordance with the invention, comprising grains having a pnp-structure.

The Figures are schematic views and are not to scale and for the sake of clarity particularly the dimensions in the direction of thickness are strongly exaggerated. Corresponding parts are designated in the Figures by the same reference numerals.

The device shown in FIGS. 1 to 3 comprises a one-grain-thick layer 1 comprising grains 2 of a thickness of 40 to 60 μ (see FIG. 3), consisting of gallium phosphide doped with 5.10^{-4} percent by weight of zinc. The grains 2 are embedded in an electrically insulating binder 3 of polyurethane, the grains projecting on either side of the grain layer from the binder (see FIG. 3). The grain layer may be made for instance by one of the methods disclosed in French Pat. specification No. 1,519,072.

The grain layer 1 has applied to it on one side an aluminum electrode layer 4 of a thickness of about 1 μ. On the opposite side a similar electrode layer 5 is applied. The electrode layers 4 and 5 are completely separated from each other by the grain layer 1 and are in contact with the portions of the grains 2 projecting from the binder 3.

The electrode layers 4 and 5 (see FIG. 1) comprise each two rows of island-shaped regions 4A, B etc. and 5A, B, etc. respectively. The dimensions of the square islands are about 4.5 × 4.5 mms. In FIG. 1 the outlines of the metal layers 4 applied to the grain layer 1 are indicated by solid lines and those of the metal layers 5 located beneath the grain layer are indicated by broken lines.

FIG. 2 is a sectional view of two rows of islands 4A to F and 5A to F located on opposite sides of the grain layer. Each one of the islands 4B to 4F overlaps partially two consecutive islands 5A to F belonging to the second row on the opposite side of the grain layer. Conversely each one of the islands 5A to E overlaps partially two of the opposite islands 4A to F.

The islands 4A and 5F are provided with connecting conductors 6 and 7 (see FIG. 1). These connecting conductors are formed in this embodiment by aluminum layers located on the grain layer and connected to the islands. The connecting conductors may, as an alternative, be formed by connecting wires connected to an island and not located on the grain layer. It will be apparent from the Figures that (see FIG. 2) between the connecting conductors 6 and 7 all parts 8 of the grain layer 1 (in total 11) located between the overlapping parts of the islands 4A to 5F situated between the connecting conductors 6 and 7 are connected in series with each other.

On each side of the grain layer the two rows of islands have one island (4A and 5F respectively) in common. Between the connecting conductors 6 and 7 two sequences of series-connected regions 8 are thus connected in parallel with each other. When a voltage difference is applied between the connecting conductors 6 and 7, the voltage difference across each of the regions 8 is therefore approximately one eleventh of the total voltage difference between the connecting conductors 6 and 7.

FIG. 4 shows by way of comparison the current-voltage characteristic curve (a), measured between the connecting conductors 6 and 7, and the current-voltage characteristic curve (b), measured across a single region 8 (FIG. 2) between opposite islands. It will be apparent that the operational voltage may be any multiple of that obtained by a voltage-dependent resistor comprising only one region 8, in accordance with the number of islands located between the conductors 6 and 7.

The non-linear resistance characteristics shown in FIG. 4 are obtained owing to the non-linear contact junctions between the electrode layers and the gallium phosphide grains. An important advantage of the voltage-dependent resistor according to the invention is that even when a plurality of one-grain-thick regions 8 are connected in series the over-all resistance is determined substantially only by the metal-semiconductor junctions, whilst junctions between the grains themselves are avoided, which might adversely affect the reproducibility.

In the embodiment shown in FIGS. 1 to 3 (see FIG. 1) one of the islands 4 located between the conductors 6 and 7 is provided with a further connecting conductor 9, formed by a metal track. This conductor 9 constitutes a tapping of the voltage-dependent resistor between the conductors 6 and 7 and is connected to a metal layer 10 associated with a further electrode system provided on the grain layer. This electrode system is formed in this example by a further voltage-dependent resistor formed by the metal layer 10, a metal layer 11 on the other side and the portion of the grain layer 1 located between the layers 10 and 11. In this way a composite circuitry, part of which is shown in FIGS. 1 to 3, is obtained on the same grain layer 1.

Not only gallium phosphide, but also (preferably n-type conductive) silicon may advantageously be used for the grains, in which case also metal- semiconductor junctions of very satisfactory current-voltage characteristic curves can be obtained.

The device described may be manufactured by subjecting a one-grain-thick layer having grains projecting on either side from the binder to an ion or electron bombardment, after which the aluminum layers 4 and 5 are vapor-deposited through a mask to form the various islands and metal tracks. After the formation of the contact between the grains and the aluminum layer by means of a short current pulse across the grain layer between the aluminum layers 4 and 5, the desired current-voltage characteristic curve is obtained. This is described in U.S. Pat. No. 3,670,214 issued June 13, 1972. Then input and output wires are connected with the suitable places, after which the assembly may be arranged in an appropriate envelope.

FIG. 5 is a schematic cross sectional view of a detail of a further embodiment of a voltage-dependent resistor according to the invention. The non-linear current-voltage characteristic curve is obtained by means of pn-junctions in the grains. In this example the grains consist of silicon and have a highly doped p-type core 22, partly surrounded by an n-type layer 26 and a p-type layer 27. The aluminum electrode layer 24 constitutes a practically ohmic contact with the core 22 and the aluminum layer 25 establishes a practically ohmic contact with the outermost p-type layer 27. The voltage-dependent resistor is otherwise analogous to that shown in FIG. 2. FIG. 5 only shows part of one of the grain layer regions **8** located between overlapping islands (see FIG. 2).

In this embodiment the grains have each a pn-junction **28**, located between the regions **22** and **26** and a pn-junction **29** between the regions **26** and **27**. Where these pn-junctions intersect the surface of the grains, they are covered by parts **30** of the binder **23**.

Since in general the pn-junctions **28** and **29** will not have the same breakdown voltage, the use of a single coherent electrode layer on either side of the grain layer would provide a voltage-dependent resistor having an assymmetric current-voltage characteristic curve. An important advantage of the invention in this embodiment is therefore that when grains are used which comprise each an asymmetric npn- or pnp-structure respectively a voltage-dependent resistor having a symmetric current-voltage characteristic curve can be obtained provided this voltage-dependent resistor comprises a series combination of an even number of regions **8** (see FIG. 2). This advantage also applies to homogeneous grains with metal-grain junctions (Schottky junctions), having different current-voltage characteristic curves on either side of the layer.

The granular layer structure of FIG. 5 may be obtained on the basis of p-type silicon grains, in which by methods generally used in semiconductor technology an n-type layer **26** and a p-type layer **27** are diffused.

Then in known manner a one-grain-thick layer is made from these grains, which project on either side from the binder **33**, after which on one side of the layer the cores **22** of the grains are exposed by etching for establishing contacts with the electrode layers applied subsequently.

It will be obvious that the present invention is not restricted to the embodiments described above and that within the scope of the invention many variants are possible to those skilled in the art. For example, other grain materials and other materials for the electrode layers may be used.

What is claimed is:

1. A voltage-dependent resistor comprising a one-grain-thick layer of semiconductor grains, embedded in an electrically insulating binder and projecting on either side from the binder, an electrode layer being applied to either side of this grain layer in contact with projecting grain parts, said electrode layers being completely separated from each other by the grain layer and exhibiting between them a non-linear voltage-current characteristic, each of the electrode layers comprising a plurality of island-shaped regions arranged in at least one row, at least one island of each row overlapping partially two consecutive islands belonging to a second row on the opposite side of the grain layer, while at least two islands belonging to said rows are provided with a connecting conductor so that between these connecting conductors all parts of the grain layer located between the overlapping parts of the islands located between the connecting conductors are connected in series with each other.

2. A voltage-dependent resistor as claimed in claim 1, wherein the grains have a pnp-structure, the two regions of the same conductivity type of said grains being in contact with an electrode layer on opposite sides of the grain layer.

3. A voltage-dependent resistor comprising a one-grain-thick layer of semiconductor grains, embedded in an electrically insulating binder and projecting on either side from the binder, an electrode layer being applied to either side of this grain layer in contact with projecting grain parts, said electrode layers being completely separated from each other by the grain layer and exhibiting between them a non-linear voltage-current characteristic, each of the electrode layers comprising a plurality of island-shaped regions arranged in at least one row, at least one island of each row overlapping partially two consecutive islands belonging to a second row on the opposite side of the grain layer, while at least two islands belonging to said rows are provided with a connecting conductor so that between these connecting conductors all parts of the grain layer located between the overlapping parts of the islands located between the connecting conductors are connected in series with each other, while between two connecting conductors an even number of parts of the grain layer located between overlapping islands are connected in series.

4. A voltage-dependent resistor as claimed in claim 1, wherein the grains have a npn structure, the two regions of the same conductivity type of said grains being in contact with an electrode layer on opposite sides of the grain layer.

5. A voltage-dependent resistor of claim 1 wherein at least one of the islands located between said connecting conductors is provided with a further connecting conductor.

6. A voltage dependent resistor of claim 5 wherein at least one of the connecting conductors is formed by a metal track applied to the grain layer.

7. A voltage-dependent resistor of claim 6 wherein said metal track is connected to an electrode system provided on the grain layer.

8. A voltage-dependent resistor of claim 1 wherein the grains consist of gallium phosphide.

9. A voltage-dependent resistor of claim 1 wherein the grains are made of silicon, preferably n-type conductive silicon.

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