

Description

The invention relates to a display device comprising an electro-optical medium between two supporting plates, a system of picture elements arranged in rows and columns, in which each picture element is formed by two picture electrodes provided respectively on the facing surfaces of the supporting plates, a system of row and column electrodes for driving the picture elements, the row electrodes being provided on one supporting plate and the column electrodes being provided on the other supporting plate, and a system of switching elements in which a switching element is incorporated between a row electrode and a column electrode in series with each picture element, the said switching elements being formed by two series-arranged, oppositely directed diodes, the said two diodes being formed by a semiconductor region of the first conductivity type, which in two separate plates forms a p - n junction with two respective semiconductor regions of the second conductivity type.

Such a display medium is suitable for displaying alphanumerical information and video information by means of passive electro-optical display media, such as liquid crystals, electrophoretic suspensions and electrochromic materials.

The known passive electro-optical display media generally have an insufficiently steep threshold with respect to the applied voltage and/or have an insufficient intrinsic memory. In multiplexed matrix display devices these properties are the cause that the number of lines to be driven is small. Due to the lack of memory, the information presented to a selected row electrode via the column electrodes has to be written over and over again. Moreover, the voltages presented to the column electrodes are present not only across the picture elements of a driven row electrode, but also across the picture elements of all the other rows. As a result of this picture elements, during the time they are not driven, experience an effective voltage which may be sufficient to bring a picture element to the on-condition. Furthermore, the ratio of the effective voltage which a picture element experiences in the on- and off-conditions, respectively, decreases when the number of row electrodes increases. Due to the lack of a sufficiently steep threshold, the contrast between picture elements in the on- and off-condition decreases thereby.

It is known that the number of rows to be driven may be increased by integrating an extra switch per picture. This switch ensures a sufficiently steep threshold with respect to the applied voltage and ensures that the information presented to a driven row electrode remains across a picture element during the time the remaining row electrodes are driven. The switch also prevents a picture element from experiencing an effective voltage during the time this is not driven.

A display device of a kind mentioned in the opening paragraph is disclosed in "Neues aus der Technik", no. 3, 15 June 1981, pp. 2-3. This

known display device uses as switching elements two series-arranged, oppositely directed diodes (back-to-back diodes). These switching elements are symmetrical with respect to a voltage zero, which is desired because liquid crystal display devices are operated with alternating voltage to prevent degradation of the liquid crystal in the case of direct voltage control. One of the two back-to-back diodes is always in the reverse direction so that the threshold voltage is determined by the breakdown voltage of that diode.

These known back-to-back diodes are formed by two p - n junctions which are interconnected by a common p -type region. However, this structure has the disadvantage that the p - n structures have a voltage-dependent series resistance which is particularly large when one of the p -type or n -type regions is lightly doped, notably in amorphous and polycrystalline semiconductor materials. This means that upon energizing a picture element at the threshold voltage of the electrooptical effect, the voltage drop across the series resistance of the switching element has to be added in addition to the threshold voltage of the switching element, so that the resistance in the on-condition is unfavourably influenced and an unfavourable switching ratio is obtained. The switching ratio is the ratio between the resistance of the switching element in the on- and off-state.

It is therefore the object of the invention to provide a switching element with which a better switching ratio is obtained and with which lower voltages for driving the display device are possible.

A display device of the kind mentioned in the opening paragraph is for that purpose characterized in that, the distance between the two p - n junctions is so small that in the operating condition punch-through occurs between the two p - n junctions before one of the two p - n junctions breaks down. In such a switching element the two diodes are integrated to form one assembly with a semiconductor region (21) of the first conductivity type which is common to the two diodes. As is known, a depletion layer in which no free charge carriers are present is situated at the area of a p - n junction. Hence two depletion layers extend in the common semiconductor region of the first conductivity type. When a voltage is applied across the two diodes, the width of the depletion layer of the reverse-biased p - n junction increases to a greater extent when the voltage increases than the width of the depletion layer of the forward-biased p - n junction decreases. According to the invention, the thickness of the common semiconductor region (21) of the first conductivity type is chosen to be so small that before the reverse biased p - n junction breaks down the depletion layers in the common semiconductor region of the first conductivity type meet each other or overlap each other. As a result of this, punch-through occurs between the two semiconductor regions (22) of the second conductivity type. As a result of the punch-through effect, the common semiconductor region of the first

conductivity type obtains a negligibly small resistance. As a result of this construction of the diodes, the series resistance across the switching elements disappears so that a better switching ratio is obtained and a picture element can be driven with lower voltages than before.

It is to be noted that punch-through effects in series-arranged and oppositely arranged *p-n* junctions are known *per se* from Netherlands Patent Application 7801532 which relates to a ROM (read-only-memory). However, this does not include the use as a switching element in a passive electro-optical display device.

A first embodiment of a display device in accordance with the invention is characterized in that the two semiconductor regions (22) of the second conductivity type are situated in the same plane as the semiconductor region (21) of the first conductivity type. The switching elements are constructed as a completely flat structure. This embodiment has the advantage that symmetrical switching elements can be manufactured in this flat structure in a simple manner.

A second embodiment in which the switching elements have a laminated structure is characterized in that the second semiconductor region of the second conductivity type is provided at least partly on the first semiconductor region on the second conductivity type, the said two regions being separated from each other by the semiconductor region of the first conductivity type. This embodiment has the advantage that very small distances can be realized between the two semiconductor regions of the second conductivity type.

Embodiments of the invention will now be described by way of example, with reference to the accompanying drawing, in which:

Figure 1 is a diagrammatic sectional view of a part of a display device of the type to which the invention relates;

Figure 2 is a sectional view of a first embodiment of a switching element for the display device shown in Figure 1;

Figure 3 is a plan view of the structure shown in Figure 2;

Figure 4 shows a voltage-current characteristic of the switching element shown in Figures 2 and 3;

Figure 5 shows the driving diagram of the display device shown in Figure 1;

Figure 6 is a sectional view of a second embodiment of a switching element for the display device shown in Figure 1.

Figure 1 is a sectional view of a part of a display device 1 having two supporting plates 2 and 3 between which a liquid crystal 4 is present. The inner surfaces of the supporting plates 2 and 3 have electrically and chemically insulating layers 5. A large number of picture electrodes 6 and 7 arranged respectively in rows and columns are provided on the supporting plates 2 and 3, respectively. The oppositely located picture electrodes 6 and 7 form the picture elements of the display device. Strip-shaped column electrodes 11 are provided between the columns of picture electrodes 7. The column electrodes 11 and the

picture electrodes 7 can advantageously be integrated to strip-shaped electrodes. Strip-shaped row electrodes 8 are provided between the rows of picture electrodes 6. Each picture electrode 6 is connected to a row electrode 8 by means of a switching element 9 shown diagrammatically. The switching elements 9 give the liquid crystal 4 a sufficiently steep threshold with respect to the applied voltage and give the liquid crystal 4 a memory. Liquid crystal-orienting layers 10 are furthermore provided on the inner surfaces of the supporting plates 2 and 3. As is known, another orientation condition of the liquid crystal molecules and therewith an optically different condition can be obtained by applying a voltage across the liquid crystal layer 4. The display device can be realized both as a transmissive and as a reflective device.

Figure 2 is a sectional view of a first embodiment of the switching elements 9 shown diagrammatically in Figure 1, in which like components are referred to by like reference numerals. A 0.2 μm thick electrically and chemically insulating layer 5 of silicon nitride is provided on the supporting plate 2. A 1 μm thick layer of preferably already *p*-doped polysilicon is then provided on the layer 5, in which former layer polysilicon islands 20 are formed by means of a photolithographic process. If the starting material is undoped polysilicon, a *p*-doping is provided in the islands, for example by ion implantation of boron, to give an active doping concentration of $1 \times 10^{15}/\text{cm}^3$. A mask is provided on the polysilicon islands 20 by means of a photolithographic process for providing in the regions 22 and 23 and *n*⁺ doping, for example by ion implantation of phosphorus, to give an active doping concentration of $1 \times 10^{16}/\text{cm}^3$. By providing the *n*⁺ doping, a flat *n*⁺-*p*-*n*⁺ structure is formed in the islands 20. The assembly is then annealed for 1 hour at a maximum temperature of 1,000°C. A 0.2 μm thick covering layer 24 of silicon oxide or silicon nitride is then provided over the *p*-doped region 21 and partly over the *n*⁺-doped regions 22 and 23. The picture electrodes 6 and the row electrodes 8 of indium oxide and/or tin oxide are then provided in a thickness of 0.15 μm in such manner that a picture electrode 6 covers the exposed surface of the *n*⁺-doped region 22 and a row electrode 8 covers the exposed surface of the *n*⁺-doped region 23. A 0.1 μm thick orienting layer 10 of a polyimide is then provided over the whole structure.

Figure 3 is a plan view of the structure shown in Figure 2. The surface area of the picture electrodes is approximately $250 \times 250 \mu\text{m}^2$. The polysilicon islands 20 have a length $a=50 \mu\text{m}$ and a width $b=20 \mu\text{m}$. The islands occupy only a very small area with respect to the area of the picture electrodes 6 so that the islands 20 are substantially unnoticeable in the observed picture. The distance between the connections of the picture electrodes 6 and the row electrodes 8 is $c=20 \mu\text{m}$. The width of the *p*-doped region 21 is $d=1 \mu\text{m}$.

Figure 4 shows the current voltage characteristic of the described switching element with the said

doping concentrations. The punch-through or threshold voltage of the switching element is $V_{pt}=6$ V. Above V_{pt} the voltage V is substantially independent of the current I , so that the series resistance of the switching element is negligibly small. This is the result of the very small width d of the p -doped region 21. Under the influence of the applied voltage, the depletion layer of the reverse bias p - n junction expands to a greater extent in the region 21 than the depletion layer of the forward biased p - n junction decreases in the region. As a result of the small width d of the region 21, the two depletion layers contact each other and overlap each other, respectively, before breakdown occurs. As a result of this, punch-through occurs between the two p -regions 22 and 23, so that the two n -regions 22 and 23 are short-circuited as it were. As appears from the Figure, the characteristic is completely symmetrical, which is desirable because the display device is operated with alternating voltage so as to prevent undesired electrode processes by direct voltage drive. The value of the punch-through voltage V_{pt} which is independent of the dimensions a and b of the switching element, can be adjusted by means of the doping concentrations and the width d of the region 21. The occurring reverse current can be minimized by suitable choice of the width b and the thickness of the switching elements.

The driving of the display device will be described in greater detail with reference to Figure 5. The picture elements formed by the picture electrodes 6 and 7 are connected between the row electrodes 8 and the column electrodes 11, a switching element 9 being connected in series with each picture element. Upon driving the display device, successively the row electrodes 8 are driven by voltage pulses $+V_s$. During the time a row electrode 8 is energized, voltage pulses $-V_d$ are applied to selected column electrodes 11. A voltage difference V_s+V_d then exists across said selected column electrodes 11 and the associated row electrode 8. This voltage difference also exists across the series arrangement of the picture elements and the switching elements 9. The voltage difference V_s+V_d is larger than the threshold voltage V_{pt} of the switching elements 9. As a result of this a part of the voltage difference V_s+V_d comes across the driven picture elements, which is sufficient to bring the liquid crystal 4 at the area of the picture elements to a different orientation condition. Voltage pulses $+V_d$ are applied to the non-selected column electrodes 11. A voltage difference V_s-V_d then exists across said column electrodes 11 and the row electrodes 8. This voltage difference V_s-V_d is smaller than the threshold voltage V_{pt} of the switching elements so that they are not energized. The voltage pulses $\pm V_d$ are smaller than the threshold voltage V_{pt} of the switching elements 9. This prevents information being written in picture elements of non-driven row electrodes 8. After the information has been written on a driven row electrode 8, the next row electrode 8 is energized. As a result of this, the voltage across the switching elements 9 of

the row electrode 8 driven earlier becomes smaller than the threshold voltage V_{pt} of the switching elements, so that one of the p - n junctions is reverse-biased and the written information cannot leak away directly via the switching elements 9. This results in a long retention time which is determined by the reverse current of the switching elements 9. As a result of the long retention time it is possible to successively drive a very large number of rows and to provide them with information. It is to be noted that both the row electrodes and column electrodes may serve as control electrodes or information electrodes.

Figure 6 shows a second embodiment of the switching elements 9 shown diagrammatically in Figure 1. Like components are referred to by like reference numerals as in Figure 1. First, a $0.2 \mu\text{m}$ thick electrically and chemically insulating layer 5 of silicon nitride is provided on the supporting plate 2. A $1 \mu\text{m}$ thick n^+ doped layer 30 of polysilicon, a 0.1 to $1 \mu\text{m}$ thick p -doped layer 31 of polysilicon and again a $1 \mu\text{m}$ thick n^+ -doped layer 32 of polysilicon are provided successively on the layer 5 by means of chemical vapour-deposition methods. The doping concentrations are in the same order of magnitude as in the embodiment described with reference to Figure 2. If desired, a $0.1 \mu\text{m}$ thick covering layer (capping layer) of undoped polysilicon may be provided between the two n^+ - p junctions. By means of a photolithographic process, polysilicon islands 20 are formed. A mask is then provided photolithographically so as to etch away a part of the polysilicon island 20 and to thus create a contact possibility with the n^+ -doped layer 30. A $0.2 \mu\text{m}$ thick capping layer 34 of silicon oxide or silicon nitride is then provided over the whole island 20. Contact holes are etched herein photolithographically for the $0.15 \mu\text{m}$ thick picture electrodes 6 and row electrodes 8 of indium oxide and/or tin oxide to be provided afterwards; in such manner that the picture electrode 6 covers the exposed surface of the n^+ -doped region 32 and the row electrode 8 covers the exposed surface of the n^+ -doped region 30. A $0.1 \mu\text{m}$ thick liquid crystal-orienting layer 35 of a polymer is then provided over the whole structure.

It is to be noted that the stacked n^+ - p - n^+ structure can also be realized by successively implanting a $2 \mu\text{m}$ thick undoped layer of polysilicon with, for example, phosphorus, boron, and again phosphorus with such an energy that the concentration maxima are sufficiently spaced to form separated n^+ , p and n^+ doped regions.

It will be obvious that the invention is not restricted to the above-described embodiments. In addition to the n - p - n structures shown, the switching elements may also be constructed in a p - n - p structure. Besides liquid crystal display devices, the switching elements may also be used with other display media showing substantially no threshold and/or no intrinsic memory, for example, electrophoretic and electroceramic display media.

Claims

1. A display device comprising an electro-optical display medium between two supporting plates, a system of picture elements arranged in rows and columns, in which each picture element is formed by two picture electrodes provided respectively on the facing surfaces the supporting plates, a system of row and column electrodes for driving the picture elements, the row electrodes being provided on one supporting plate and the column electrodes being provided on the other supporting plate, and a system of switching elements in which a switching element is incorporated between a row electrode and a column electrode in series with each picture element, the said switching elements being formed by two series-arranged, oppositely directed diodes, the said two diodes being formed by a semiconductor region of the first conductivity type which in two separate places forms a *p-n* junction with two respective semiconductor regions of the second conductivity type, characterized in that the distance between two *p-n* junctions is so small that in the operating condition punch-through occurs between the two *p-n* junctions before one of the two *p-n* junctions breaks down.

2. A display device as claimed in claim 1, characterized in that the two semiconductor regions of the second conductivity type (22, 23) are situated in the same plane as the semiconductor region of the first conductivity type (21).

3. A display device as claimed in claim 1, characterized in that the second semiconductor region of the second conductivity type (32) is provided at least partly on the first semiconductor region of the second conductivity type (30), the said two regions being separated from each other by the semiconductor region of the first conductivity type (31).

4. A display device as claimed in claim 1, 2 or 3, characterized in that the electro-optical display medium is a liquid crystal (4).

5. A display device as claimed in claim 1, 2 or 3, characterized in that the electro-optical display medium is an electro-phoretic suspension.

6. A display device as claimed in claim 1, 2 or 3, characterized in that the electro-optical display medium is an electrochromic material.

Patentansprüche

1. Anzeigevorrichtung mit einem elektro-optischen Anzeigemedium zwischen zwei Trägerplatten, einem System reihen- und spaltenartig gegliederter Bildelemente, wobei jedes Bildelement durch zwei auf den einander zugewandten Oberflächen der Trägerplatten vorgesehene Elektroden gebildet wird, einem System von Reihen- und Spaltenelektroden zum Ansteuern der Bildelemente, wobei die Reihenelektroden auf der einen Trägerplatte und die Spaltenelektroden auf der anderen Trägerplatte vorgesehen sind, und einem System von Schaltelemente, wobei zwischen einer Reihen- und einer Spalten-

elektrode in Reihe mit jedem Bildelement ein Schaltelement vorgesehen ist, wobei die genannten Schaltelemente durch zwei reihengeschaltete entgegengesetzt gerichtete Dioden gebildet werden, wobei die genannten zwei Dioden durch ein Halbleitergebiet vom ersten Leitungstyp gebildet werden, das an zwei voneinander getrennten Stellen einen PN-Übergang mit Halbleitergebieten vom zweiten Leitungstyp bildet, dadurch gekennzeichnet, dass der Abstand zwischen den zwei PN-Übergängen so gering ist, dass im Betriebszustand zwischen den zwei PN-Übergängen Durchgriff auftritt, bevor einer der PN-Übergänge in Durchbruch gelangt.

2. Anzeigevorrichtung nach Anspruch 1, dadurch gekennzeichnet, dass die zwei Halbleitergebiete vom zweiten Leitungstyp in derselben Ebene liegen wie das Halbleitergebiet vom ersten Leitungstyp.

3. Anzeigevorrichtung nach Anspruch 1, dadurch gekennzeichnet, dass das zweite Halbleitergebiet vom zweiten Leitungstyp wenigstens teilweise auf dem ersten Halbleitergebiet vom zweiten Leitungstyp vorgesehen ist, wobei die genannten zwei Gebiete durch das Halbleitergebiet vom ersten Leitungstyp voneinander getrennt sind.

4. Anzeigevorrichtung nach Anspruch 1, 2 oder 3, dadurch gekennzeichnet, dass das elektro-optische Anzeigemedium ein Flüssigkristall ist.

5. Anzeigevorrichtung nach Anspruch 1, 2 oder 3, dadurch gekennzeichnet, dass das elektro-optische Anzeigemedium eine electrophoretische Suspension ist.

6. Anzeigevorrichtung nach Anspruch 1, 2 oder 3, dadurch gekennzeichnet, dass das elektro-optische Anzeigemedium eine elektrochromes Material ist.

Revendications

1. Dispositif d'affichage muni d'un milieu d'affichage optique prévu entre deux plaques de support, d'un système d'éléments d'image disposés en rangées et en colonnes, dans lequel chaque élément d'image est formé par deux électrodes d'image disposées respectivement sur les surfaces situées vis-à-vis des plaques de support, d'un système d'électrodes de rangée et de colonne pour l'excitation des éléments d'image, les électrodes de rangée étant disposées sur une plaque de support et les électrodes de colonne étant disposées sur l'autre plaque de support, et d'un système d'éléments de commutation, dans lequel un élément de commutation est disposé entre une électrode de rangée et une électrode de colonne en série avec chaque élément d'image, lesdits éléments de commutation étant formés par deux diodes montées en série en sens opposés lesdites deux diodes étant formées par une région semiconductrice du premier type de conduction, qui forme une jonction pn en deux plaques séparées avec respectivement deux régions semiconductrices du second type de conduction, caractérisé en ce que la distance



comprise entre les deux jonctions pn est si petite qu'à l'état de fonctionnement, il se produit un effet de percement entre les deux jonctions p-n, avant que l'une des jonctions pn ne soit sujette à claquage.

2. Dispositif d'affichage selon la revendication 1, caractérisé en ce que les deux régions semiconductrices du second type de conduction se situent dans le même plan que la région semiconductrice du premier type de conduction.

3. Dispositif d'affichage selon la revendication 1, caractérisé en ce que la deuxième région semiconductrice du second type de conduction est réalisée au moins partiellement sur la première région semiconductrice du second type de

conduction, lesdites deux régions étant séparées l'une de l'autre par la région semiconductrice du premier type de conduction.

4. Dispositif d'affichage selon la revendication 1, 2 ou 3, caractérisé en ce que le milieu d'affichage électro-optique est un cristal liquide.

5. Dispositif d'affichage selon la revendication 1, 2 ou 3, caractérisé en ce que le milieu d'affichage électro-optique est une suspension électrophorétique.

6. Dispositif d'affichage selon la revendication 1, 2 ou 3, caractérisé en ce que le milieu d'affichage électro-optique est un matériau électrochromique.

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