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D E C I S I O N
of 9 March 2000

Case Number: T 0617/96 - 3.4.3

Application Number: 91119957.8

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Language of the proceedings: EN

Title of invention:
Electrically device with a doped amorphous silicon channel

Applicant:
MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 56

Keyword:
"Inventive step (yes)"

Decisions cited:
-

Catchword:
-

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Beschwerdekammern | Boards of Appeal | Chambres de recours

Case Number: T 0617/96 - 3.4.3

D E C I S I O N
of the Technical Board of Appeal 3.4.3
of 9 March 2000

Appellant: MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 20 February 1996 refusing European patent application No. 91 119 957.8 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: R. K. Shukla
Members: M. Chomentowski
M. J. Vogel

Summary of Facts and Submissions

I. European patent application No. 91 119 957.8 (Publication No. 0 487 101) was refused by a decision of the examining division dated 20 February 1996 on the ground that it did not involve an inventive step having regard to documents

D1: Journal of Applied Physics, vol. 67, No. 6, 15 March 1990, S. Thakoor et al., "Solid-State thin-film memistor for electronic neural networks", pages 3132 to 3135

and

D2: Solid State Communications, vol. 73, No. 5, 1990, R. Könenkamp et al., "Reversible Doping of Hydrogenated Amorphous Silicon", pages 323 to 326.

The only independent claim 1 of the set of 5 claims forming the basis of the decision under appeal reads as follows:

"1. An electrical device with reversible doping of an amorphous active layer, comprising

an amorphous silicon semiconductor layer (3) formed between a pair of electrodes (1, 2) and including movable dopant to impart electric conductivity;

a movable dopant supporting layer (4) adjacent said amorphous silicon semiconductor layer (3), said movable dopant coming from said movable dopant supporting layer (4); and

at least one gate electrode (5) formed on said amorphous silicon semiconductor layer (3) through an insulating layer (6);

whereby the operation of said gate electrode (5) controls the dopant distribution of said amorphous semiconductor layer (3), thereby varying the electrical conductivity thereof;

characterized in that

the device has a MOS-FET structure, wherein said movable dopant supporting layer (4) comprises at least one element selected from the group consisting of an alkali ion conductor based on β - aluminum oxide, a redox ion conductor including Ag^+ or Cu^+, and a porous ceramic."

II. The reasoning in the decision under appeal can be summarised as follows:

The features distinguishing the claimed device from the device of document D1 are the following:

- the use of an amorphous silicon semiconductor in place of tungsten oxide WO_3 for the active layer,

- a MOS-FET structure, related in particular with the use of silicon; and

- a movable dopant supporting layer comprising one of the particular materials listed in claim 1, as against the known movable dopant supporting layer material Cr_2O_3 containing H^+ ions.

The replacement of the tungsten oxide WO_3 by amorphous silicon for the active layer is obvious in view of the established technology and industrial applicability of silicon.

Indeed, amorphous silicon is used for reversible doping in document D2, wherein moreover the movable dopant supporting layer is one of the plurality of materials (soda glass) cited originally in the present application and is thus to be considered as equivalent to the remaining materials now cited in the claim.

Therefore, the person skilled in the art of reversible doping would at least consider the use of the material structure of document D2 for a transistor device according to document D1 in order to obtain a device which can be manufactured according to existing technology.

For the skilled reader, a difference in the current conduction mechanisms between documents D1 and D2, i.e. ions vs. electrons, respectively, is not derivable and thus cannot be used as an argument against such a combination.

Consequently, the subject-matter of the application lacks an inventive step.

III. The applicant lodged an appeal against the decision on 22 April 1996 paying the appeal fee the same day. The statement of the grounds of appeal was filed on 1 July 1996.

IV. During the oral proceedings held before the Board on 9 March 2000 the appellant requested that the decision under appeal be set aside and a European patent be granted on the basis of the following application documents:

Claims: Nos. 1 to 4 as filed during the oral proceedings of 9 March 2000;

Description: Pages 1, 2, 4, 7 and 14 as filed on 20 May 1995 with letter dated 19 May 1995;
Page 8 as filed on 9 February 2000;
Pages 3, 5, 6 and 9 to 13 as filed during the oral proceedings of 9 March 2000;

Drawings: Sheets 1 to 3, as filed.

Claim 1 of the appellant's request reads as follows:

"1. An electrical device with reversible doping of an active layer, comprising

an active layer (3) formed between a pair of electrodes (1, 2) and including movable dopant to impart electrical conductivity;

a movable dopant supporting layer (4) adjacent to said active layer (3), said movable dopant coming from said movable dopant supporting layer (4); and

at least one gate electrode (5) formed on said active layer (3) through an insulating layer (6);

whereby the operation of said gate electrode (5) controls the dopant distribution of said active layer (3), thereby varying the electrical conductivity thereof;

characterized in that

the device has a MOS-FET structure, wherein said active layer is made of an amorphous silicon semiconductor, and said movable dopant supporting layer (4) comprises at least one material selected from the group consisting of an alkali ion conductor based on β - aluminum oxide, a redox ion conductor including Ag^+ or Cu^+, and a porous ceramic, and wherein said amorphous silicon semiconductor layer is superposed on said movable dopant supporting layer (4)."

In independent claim 2, it is specified that the electrical device has a FET structure and that the at least one gate electrode (5) is formed on the amorphous silicon semiconductor active layer through a high resistance layer (8). Claim 2 reads as follows:

"2. An electrical device having a FET-structure with reversible doping of an active layer, comprising

an active layer (3) formed between a pair of electrodes (1, 2) and including movable dopant to impart electrical conductivity;

a movable dopant supporting layer (4) adjacent to said active layer (3), said movable dopant coming from said movable dopant supporting layer (4); and

at least one gate electrode (5) formed on said active layer (3) through a high resistance layer (8);

whereby the operation of said gate electrode (5) controls the dopant distribution of said active layer (3), thereby varying the electrical conductivity thereof;

wherein said active layer is made of an amorphous silicon semiconductor, and said movable dopant supporting layer (4) comprises at least one material selected from the group consisting of an alkali ion conductor based on β - aluminum oxide, a redox ion conductor including Ag^+ or Cu^+, and a porous ceramic, and wherein said amorphous silicon semiconductor layer is superposed on said movable dopant supporting layer (4)."

V. The appellant submitted essentially the following arguments in support of his request:

In the device of document D1, the active layer is not made of amorphous silicon semiconductor, but of WO_3, and the movable dopant supporting layer does not comprise at least one element selected from the group consisting of an alkali ion conductor based on β - aluminum oxide, a redox ion conductor including Ag^+ or Cu^+, and a porous ceramic, but is made of an hygroscopic chromium trioxide Cr_2O_3 used as source of ions H^+.

Moreover, the known device does not have a MOS-FET structure and the active layer is not superposed on said movable dopant supporting layer, i.e. is not arranged between the movable dopant supporting layer and the gate. In the known arrangement, it is the movable dopant supporting layer of Cr_2O_3 used as source of ions H^+ which is located between the gate electrode and the active layer.

Furthermore, the current in the active layer is ionic, which essentially consists in both vertical and lateral motion of the H^+ ions; this results in the formation of hydrogen gas in the known device. Moreover, the layer

of Cr_2O_3 used as source of H^+ has to be replenished with hydrogen ions. However, such a mechanism is incompatible with a long term use of the device as a solid-state thin film memistor for electronic networks.

A combination of the teaching of document D2 with that of document D1 would not be obvious because the device known from document D2 has no gate electrode and, moreover, the mechanism of electrical conductivity in the amorphous silicon active layer of the device is based on electron movement, which is thus different from the mechanism of document D1, based on the movement of ions.

It is further to be noted that the mechanism of conductance in the device of document D2 results from the application of a process comprising heating the device and then freezing it, thus creating a laterally varying conductance profile, which is different not only from the conductance mechanism of the claimed device but also from that of the device of document D1.

Reasons for the Decision

1. The appeal is admissible.

2. *Admissibility of the amendments*

Present claim 1 is based on claim 1 of the application as filed and on the embodiments illustrated by Figures 1, 2 and 4 where the device has a MOS-FET structure having an amorphous silicon semiconductor layer (3) superposed on a movable dopant supporting

layer (4). Moreover, the materials for the movable dopant supporting layer as specified in the claim are disclosed in the above mentioned embodiments and in the dependent claim 4 or 6 of the application as filed.

Present claim 2 is based on claim 7 of the application as filed and on the device illustrated by original Figure 5 having a FET structure wherein the gate electrode is formed on the amorphous silicon semiconductor layer through a high resistance layer.

The amendments in the description are for adapting it to the present claims, in particular for restricting the materials of the movable dopant supporting layer to those mentioned in the present claims.

Therefore, in the Board's judgement, the present application satisfies the requirement of Article 123(2) EPC that a European patent application may not be amended in such a way that it contains subject-matter which extends beyond the content of the application as filed.

3. *Inventive step*

The only issue in the present appeal is that of inventive step.

3.1 From document D1 (see in particular the abstract; the introduction; page 3132, last paragraph to page 3133, first paragraph and Figure 1) an electrical device is known which comprises:

an active layer ("active layer WO_3") formed between a pair of electrodes ("Ni electrodes") and including movable dopant (H^+ ions) to impart electrical conductivity;

a movable dopant supporting layer (layer of Cr_2O_3: "source of H^+") adjacent said active layer ("active layer WO_3"), said movable dopant (H^+ ions) coming from said movable dopant supporting layer (layer of Cr_2O_3: "source of H^+"); and

at least one gate electrode ("gate Al") formed on said active layer ("active layer WO_3") through an insulating layer ("SiO");

whereby the operation of said gate electrode ("gate Al") controls the dopant distribution of said active layer ("active layer WO_3"), thereby varying the electrical conductivity thereof.

The gate electrode of the known device is used for injecting into the active layer of tungsten oxide (WO_3) H^+ ions from the intermediate layer of Cr_2O_3, or withdrawing again said ions from the active layer, so that the electrical device has reversible doping of the active layer.

However, the electrical device of present claim 1 is distinguished from the device known from document D1 in that

- the active layer is an amorphous silicon semiconductor layer, and not a layer of tungsten oxide WO_3;

- the movable dopant supporting layer comprises at least one element selected from the group consisting of an alkali ion conductor based on β - aluminum oxide, a redox ion conductor including Ag^+ or Cu^+, and a porous ceramic, and is not made of an hygroscopic chromium trioxide Cr_2O_3 used as source of H^+;

- moreover, the active layer is arranged between the movable dopant supporting layer and the gate, so that the movable dopant supporting layer of Cr_2O_3 used as source of H^+ is not between the gate and the active layer as in document D1;

- the claimed device has a MOS-FET structure.

3.2 Document D2 (see the abstract; page 323, left-hand column, line 14 to page 324, right-hand column, line 2; page 326, left-hand column, first paragraph to right-hand column, second paragraph; Figures 1 and 3) discloses a device wherein a voltage-controlled, reversible injection of ions in a thin film is used to provide a reversible change of electrical conductivity, and thus of the resistance of the thin film; the change in conductivity in the thin film is a laterally varying conductance profile of the conductivity which is related to the coplanar electric contact geometry. The active layer of the device of document D2 comprises hydrogenated amorphous silicon. Moreover, the dopant ions of Na transported into the amorphous silicon active layer are taken from the dopant reservoir consisting of a soda glass substrate supporting the active layer.

However, contrary to the device of present claim 1, the device of document D2 has no gate electrode used for extracting from the movable dopant supporting substrate the reversible ions and for controlling the current in the active layer of the MOS-FET. Moreover, contrary to the device known from document D1, in the device of document D2 hydrogen ions are not injected into the active layer. In the device of document D2 (see Figure 1), the only two electrodes, which are also the electrodes for transporting the dopant ions, are at the ends of the active layer, and there is no gate electrode whatsoever.

It is further to be noted that the mechanism of conductance in the device of document D2 (see the abstract; page 323, last paragraph to page 324, first paragraph; see also page 326, first and second paragraph) results from the application of a process comprising heating the device at for instance 455 K and then freezing it, thus creating a laterally varying conductance profile, which is therefore further different from the conductance mechanism of the presently claimed device as well as from that of the device known from document D1. Furthermore, it follows from the disclosure on page 323, left-hand column, last five lines in document D2 that the time constants for conductance change lie in the second range at high temperatures and increase to hours or days for room temperature. In document D1, on the other hand, the changes in conductance are not temperature dependent and are also not brought about by varying the voltage between the Ni - electrodes.

In view of the above differences, in the Board's view, the replacement of the active layer of WO_3 in the device of document D1 with the active layer of hydrogenated amorphous Si would not be regarded as obvious by a person skilled in the art.

3.3 Therefore, in the Board's judgement, having regard to the state of the art, the subject-matter of present claim 1 involves an inventive step in the sense of Article 56 EPC.

Consequently, present claim 1 is patentable in the sense of Article 52(1) EPC.

Since present claim 2 expresses the same invention in terms of a device having a FET structure and wherein the at least one gate electrode is formed on the amorphous silicon semiconductor layer through a high resistance layer, it is also patentable for the same reasons.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the first instance with the order to grant the patent on the basis of the following patent application documents:

Claims: Nos. 1 to 4 as filed during the oral proceedings of 9 March 2000;

Description: Pages 1, 2, 4, 7 and 14 as filed on 20 May 1995 with letter dated 19 May 1995;
Page 8 as filed on 9 February 2000;
Pages 3, 5, 6 and 9 to 13 as filed during the oral proceedings of 9 March 2000;

Drawings: Sheets 1 to 3, as filed.

The Registrar: The Chairman:

D. Spigarelli R. Shukla