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Datasheet for the decision of 1 September 2017

Case Number: T 2062/13 - 3.4.03

Application Number: 00944328.4

Publication Number: 1134814

IPC: H01L31/09, G01J1/44, G01J1/02, H01L29/76

Language of the proceedings: EN

Title of invention:
MILLIMETER WAVE AND FAR-INFRARED DETECTOR

Applicant:
Japan Science and Technology Agency

Headword:

Relevant legal provisions:
EPC 1973 Art. 54(1), 54(2), 56, 84
EPC Art. 123(2)

Keyword:
Novelty - (yes)
Inventive step - (yes)
Amendments - added subject-matter (no)

Decisions cited:

Catchword:

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Case Number: T 2062/13 - 3.4.03

D E C I S I O N
of Technical Board of Appeal 3.4.03
of 1 September 2017

Appellant: Japan Science and Technology Agency
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted on 17 May 2013 refusing European patent application No. 00944328.4 pursuant to Article 97(2) EPC.**

Composition of the Board:

Chairman G. Eliasson
Members: M. Stenger
C. Heath

Summary of Facts and Submissions

I. The appeal concerns the decision of the examining division refusing European patent application no. 00944328, for the reasons that the requirements of Articles 123(2) and 84 EPC were not met.

II. In a communication the board expressed its preliminary opinion that the application according to the main request filed with the notice of appeal did not comply with the requirements of Article 84 EPC.
The board further indicated that it was however inclined to concur with the arguments brought forward by the appellant with respect to the available prior art, provided that all issues concerning Article 84 EPC were overcome.

III. With letter of 1 June 2017, the appellant filed a new main request comprising an amended set of claims 1 to 23 as well as amended description pages.

IV. The appellant's main request is the grant of a patent on the basis of the following application documents:

Description, pages:
- 1, 8, 11, 20, 24, 26-29, 35 filed with entry into the regional phase before the EPO

- 14-17 filed with letter dated 23 May 2011
- 2a filed with letter dated 26 September 2012
- 2,3,6 filed with letter dated 11 March 2013.
- 4, 5, 7, 9, 10, 12, 13, 18, 19, 21-23, 25, 30-34 filed with letter dated 1 June 2017

Claims:
- 1 to 23 filed with letter dated 1 June 2017

Drawings, sheets:
- 1/12-12/12 filed with entry into the regional phase before the EPO

V. It is referred to the following documents:

D1: GB2306772 A

D2: S. Komiyama et al., "Detection of single FIR-photon absorption using quantum dots", Physica E vol. 7, no. 3, 12 July 1999, pages 698-703, XP2465110

D3: DE19522351 A1

VI. The wording of independent claim 1 of the main request reads (board's labelling):

An MW(millimeter wave)/FIR (Far Infra red) light detector comprising:
(a) an electromagnetic-wave coupling means for concentrating an electromagnetic wave in a small spatial region of a sub-micron size;
(b) a first quantum dot for absorbing the electromagnetic wave concentrated by said electromagnetic wave coupling means to bring about an ionization thereof;
and
(c) a single electron transistor including a second quantum dot electrostatically coupled to said first quantum dot,
wherein the first and the second quantum dot are arranged such that
(d1) if said electromagnetic wave of MW/FIR light having an amount of electromagnetic photon energy greater than the ionization energy of said first quantum dot is absorbed, a positive hole and an

electron are created separately in the inside and outside of the first quantum dot
(d2) by excitation of an electron in a quantized bound state of said first quantum dot to a free electron state of an electron system outside of said first quantum dot bringing about the ionization of said first quantum dot,
and
(e) the electric conductivity of said single-electron transistor is varied with a change in electrostatic potential of said second quantum dot consequent upon the ionization of said first quantum dot, whereby said electromagnetic wave is detectable.

VII. The appellant's arguments, insofar as they are relevant to the present decision, may be summarized as follows:

According to D1, a photon absorbed in a quantum dot excited an electron in the dot to an energy state such that it could leave the quantum dot. This electron was then swept away by the source drain bias voltage and the remaining electron hole was filled by an electron from the source. Each absorbed photon of radiation thus resulted in an effective photocurrent consisting of only one electron from source to drain. Such a photocurrent was not measurable.
The detector according to the invention used the ionized state of a first quantum dot having absorbed a photon to change the electrical conductivity of a single electron transistor SET including a second quantum dot electrostatically coupled to the first quantum dot. Thus, a change in the current flowing through the SET could be observed during the whole lifetime of the ionized state of the first quantum dot. Thus, the detector of the present application was based on a completely different principle by means of which a

single absorbed photon could give rise to a current of up to one million electrons, thereby increasing the sensitivity.

Reasons for the Decision

1. Article 123(2) EPC

The application as originally filed mentions two groups of light detectors.
The detectors of the first group represented by figures 3A, 3B and 3C each comprise one quantum dot. These detectors are not covered by the present set of claims and were not covered by the claims on which the contested decision was based.
The detectors of the second group of detectors each comprise a first and a second quantum dot. The five detectors shown in figures 7A, 7B, 8A, 8A' and 8B all represent specific embodiments of detectors of that second group.

The examining division argued that the independent claims of the main and the auxiliary request combined individual features from different specific embodiments represented in figures 7A, 7B, 8A, 8A' and 8B in an unallowable manner. There was, e.g., no embodiment comprising a metal dot (being present only in the embodiments of figures 7B and 8B) on the one hand and a gate electrode as well as a dipole antenna on the other hand (these two elements not being present in the embodiments of figures 7B and 8B). This contravened the requirements of Article 123(2) EPC.

Independent claim 1 of the present main request was amended with respect to the independent claims of the requests on which the contested decision was based. It is based on claims 10 (features *a*, *b*, *c* and *e*) and 11 (feature *d2*) as filed with entry into the European phase.
Further, some elements (feature *d1* and the term *electrostatic potential* instead of *electrostatic state*) from paragraphs [48], [109], [141] and [145] were added for clarification purposes. These paragraphs relate generally to all detectors involving first and second quantum dots, not only to a subset of specific embodiments of the second group of detectors.

The board is thus satisfied that the corresponding objections of the examining division have been overcome.

Claims 2 to 23 correspond essentially to claims 12 to 33 as filed with entry into the European phase. Some of these claims have been clarified based on [49], [109], [111], [112], [119], [120] and [140].

Thus, the requirements of Article 123(2) are met by the set of claims according to the present main request.

2. Article 84 EPC 1973

The objections of the contested decision relating to Article 84 EPC concerned mainly

- inconsistencies between the claims and the description: the combinations of features objected to under Article 123(2) EPC were in contradiction to the description

and

- the use of method steps in the definition of device claim 1.

The claims and the description of the present main request have been amended with respect to the application documents on which the decision was based.

The objections under Article 123(2) EPC have been overcome. All embodiments comprising two quantum dots shown in figures 7A, 7B, 8A, 8A' and 8B are covered by the wording of present independent claim 1.
The dependencies of the dependent claims have been adapted to reflect the different specific embodiments shown in figures 7A, 7B, 8A, 8A' and 8B.
The detectors presented in figures 3A, 3B and 3C are not defined as being embodiments of the invention.
Thus, the objection by the examining division concerning inconsistencies between the claims and the description are have been overcome by the present application documents.

Further, present claim 1 defines the light detector only by means of structural features and does not comprise any method steps concerning how to operate such a detector.

The board is thus satisfied that the objections of the examining division with respect to Article 84 EPC have been overcome by the present application documents and that the application meets the requirements of Article 84 EPC.

3. Novelty, Article 54(1) and (2) EPC 1973

3.1 D1

D1 discloses a millimeter/far infrared light detector (page 1, second paragraph) comprising a number of elements 207 (see figure 4) with quantum dots. Each of these elements has an individual gate arrangement 217 used for creating the quantum dot.
When a photon with sufficient energy is absorbed in one of the quantum dots, an electron is excited out of the dot and swept away under influence of a source-drain bias voltage V_{sd} applied to a single source contact 211 and a single drain contact 215 on the wafer on which the plurality of elements 207 is arranged. A change in the current through the device is then detected as an indication of the photons absorbed.

In the wording of claim 1, D1 thus discloses the features *a* (see figure 5), *b*, *d1* and *d2* (see the paragraph bridging pages 13 and 14 as well as figure 2).

In a communication dated 16 May 2008, the examining division (citing figure 3 and 4 as well as page 13, line 27 to page 14, line 8 of D1) argued that D1 also disclosed a single-electron transistor including a second quantum electrostatically coupled to the first quantum dot, whereby the electromagnetic wave was detected on the basis of the fact that electric conductivity of the single-electron transistor varied with a change in the electrostatic state of said second quantum dot consequent upon an ionization of the first quantum dot.

D1 actually discloses a plurality of quantum dots. A dot array with a plurality of elements 207 is provided to boost the strength of the absorption signal (see figure 4 and page 13, penultimate paragraph).

However, all quantum dot elements 207 of the system shown in D1 are identical and only serve the purpose of absorbing photons. None of the elements 207 is provided with individual source and drain electrodes. Thus, none of these quantum dot elements 207 can be considered to be (part of) a single electron transistor serving the purpose of switching a current.

Further, no interaction/coupling between any two quantum dots is necessary at all in the light detection process according to D1. Instead, the electrons excited out of any of the dots by the absorption of a photon are detected directly as photosignal (see paragraph bridging pages 13 and 14).

The subject-matter of claim 1 of the main request therefore differs from the detector disclosed in D1 in that

(c) a single electron transistor is provided including a second quantum dot electrostatically coupled to said first quantum dot,

and in that the first and the second quantum dot are arranged such that

(e) the electric conductivity of said single-electron transistor is varied with a change in electrostatic potential of said second quantum dot consequent upon the ionization of said first quantum dot, whereby said electromagnetic wave is detectable.

3.2 D2

D2 discloses a far infrared light detector using a quantum dot. The quantum dot is subjected to a relatively high magnetic field of about 4 Tesla. When a

photon of sufficient energy is absorbed by the quantum dot, it excites an electron-hole pair and thus induces a strong polarization within the dot. This affects the conductivity of the (same) quantum dot when it is operated as a single electron transistor. The elevated lifetime of the excited, polarized state makes it possible to detect single photons.
The detectors disclosed in D2 actually correspond to the first group of detectors presented in figures 3A, 3B and 3C of the application. As mentioned before, these detectors are not covered by the present set of claims.
Although these detectors, just like the detectors defined in the claims of the present application, aim at detecting single photons, they do so by a different principle involving only a single quantum dot subjected to a magnetic field. In the wording of claim 1, D2 thus only discloses feature *a* (see abstract).

3.3 D3
D3 is directed at (the manufacturing of) quantum structures in general (see abstract). In one embodiment, an optical detector (see figure 16) is suggested where a gate 24 is capacitively coupled to a quantum dot 52. The quantum dot 52 is provided with a drain 54 and a source 56 and is operated as a (single electron) transistor. When light impinges on the gate, charge carriers are created which influence the conductivity between drain 54 and source 56 (see column 12, lines 24 to 36). The quantum dot of D3 thus serves the purpose of switching a current.
However, D3 does not disclose any details concerning the gate 24. In the wording of claim 1, D3 thus discloses only the part of the features relating to the single electron transistor including the (second) quantum dot.

4. Inventive Step, Article 56 EPC 1973

4.1 Closest state of the art

D1 discloses a millimeter/far infrared light detector. It is thus directed at the same purpose as the invention. Further, the detector of D1 has more features in common with present claim 1 than the detectors of D2 or D3. D1 is thus suitable to be taken as closest prior art for the purpose of the problem-solution approach.

4.2 Technical effect, objective technical problem to be solved

The technical effect of features *(c)* and *(e)* differentiating the subject-matter of claim 1 from D1 is that the current to be measured need not be created by the absorption of radiation, but is switched by means of the single electron transistor including the second quantum dot.

The objective technical problem to be solved may then be formulated as how to increase the sensitivity of the detector of D1 in order to detect single photons. This corresponds to the problem mentioned in the application (see [8-9]).

4.3 D1, D2, D3

As mentioned above, D1 suggests to use a quantum dot array to boost the strength of the absorption signal (page 13, penultimate paragraph). This necessitates, however, the absorption of more photons and relates thus to a completely different detecting principle, as pointed out by the appellant. D1 does not provide any hint concerning increasing sensitivity for detecting single photons.

D2 deals with the objective technical problem as defined above (see section 1. of D2). To solve that problem, D2 suggests to use a single electron transistor with a (single) quantum dot (see section 2. of D2). However, according to D2, this single quantum dot is, during use, subject to a relatively high magnetic field of about 4 Tesla (see the part of the description relating to figure 6) to enable polarization.
D2 might thus suggest to the skilled person to modify the individual quantum dot elements 207 of D1 by subjecting them to a magnetic field and operating them as single electron transistors. No hint can be found in D2, however, to provide for a given (first) quantum dot a single electron transistor including a second quantum dot and arrange both quantum dots such that they are electrostatically coupled in a way that the conductivity of the SET changes when the (first) quantum dot is ionized.

In document D3, the sensitivity of light detectors is not an issue at all. This document only mentions that a quantum dot operated as a transistor can be used in an optical detector (column 12, lines 24 to 36). It is thus questionable that the skilled man would even consult D3, when starting from D1 and being confronted with the objective technical problem defined above. Moreover, no details at all are given in D3 concerning the gate 24. Thus, even if the skilled person consulted D3, he would not get any suggestion of how to integrate the quantum dot 52 of D3 into the detector of D1.

To summarize, D1 discloses a single type of quantum dots which serves to absorb photons. D2 discloses a single type of quantum dots which serves to both absorb photons and switch a current. D3 discloses a single type of quantum dots which serves to switch a current. None of the available prior art documents D1, D2 and D3 discloses or suggests a combination of two (different) types of (electrostatically coupled) quantum dots, the first one of which serves to absorb photons and the second one of which serves to switch a current (when the first one has absorbed a photon).

The board does not consider such a combination as part of the general knowledge of the skilled person at the priority date of the present application, either.

For these reasons, the subject-matter of claim 1 of the present application is considered to involve an inventive step in view of the available prior art.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the department of first instance with the order to grant a patent in the following version:

   Description, pages:
   - 1, 8, 11, 20, 24, 26-29, 35 filed with entry into the regional phase before the EPO

   - 14-17 filed with letter dated 23 May 2011
   - 2a filed with letter dated 26 September 2012
   - 2,3,6 filed with letter dated 11 March 2013.
   - 4, 5, 7, 9, 10, 12, 13, 18, 19, 21-23, 25, 30-34 filed with letter dated 1 June 2017

Claims:
- 1 to 23 filed with letter dated 1 June 2017

Drawings, sheets:
- 1/12-12/12 filed with entry into the regional phase before the EPO

The Registrar: The Chairman:

S. Sánchez Chiquero G. Eliasson

Decision electronically authenticated