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## Datasheet for the decision of 23 April 2008

**Case Number:** T 1290/07 - 3.4.03

**Application Number:** 99965373.6

**Publication Number:** 1151477

**IPC:** H01L 29/76

**Language of the proceedings:** EN

**Title of invention:**
Quantum-size electronic devices and operating conditions thereof

**Patentee:**
Ilyanok, Alexandr Mikhailovich

**Opponent:**
-

**Headword:**
-

**Relevant legal provisions (EPC 1973):**
EPC Art. 52(1), 56

**Keyword:**
"Inventive step (no)"

**Decisions cited:**
-

**Catchword:**
-

**Case Number:** T 1290/07 - 3.4.03

# D E C I S I O N
**of the Technical Board of Appeal 3.4.03**
**of 23 April 2008**

**Appellant:** Ilyanok, Alexandr Mikhailovich
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**Representative:** Finck, Dieter
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**Decision under appeal:** **Decision of the Examining Division of the European Patent Office posted 10 April 2007 refusing European application No. 99965373.6 pursuant to Article 97(1) EPC.**

**Composition of the Board:**

**Chairman:** T. Bokor
**Members:** R. Bekkering
G. Eliasson

## Summary of Facts and Submissions

I. This is an appeal against the refusal of application 99 965 373 for *inter alia* lack of novelty over

D7: Randall J. N. et al, "Nanostructure Fabrication of Zero-Dimensional Quantum Dot Diodes", Journal of Vacuum Science and Technology: Part B, Melville, New York, US, 1 November 1988, pages 1861 to 1864.

II. At the oral proceedings before the board, the appellant requested that the decision under appeal be set aside and a patent granted in the following version:

*Main request:*

Claims 1 to 26 of the main request filed with the letter dated 20 March 2008;
Description pages 1 to 62 as published with an amendment to page 31 as requested by letter dated 20 March 2008;
Drawing sheets 1/10 to 10/10 as published.

*First auxiliary request:*

Claims 1 to 24 of the first auxiliary request sent with the letter dated 20 March 2008;
Description and drawings as for the main request.

*Second auxiliary request:*

Claims 1 to 18 of the second auxiliary request filed at the oral proceedings on 23 April 2008;
Description and drawings as for the main request.

III. Claim 1 of the main request reads:

"*1. An electronic device comprising at least one cluster (1, 7) and electrodes (3, 4, 5, 6, 9, 10, 11) connected to the cluster (1, 7) through a tunnelling gap (2, 8),*
*characterised in that*
*- the cluster (1, 7) has*
*— a spherical form having a cross section size (r) within the range 7,2517 nm < r ≤ 29,0068 nm, or*
*— an cylindrical form having a cross section size (r) within the range 14,5034 nm ≤ r ≤ 29,0068 nm,*
*- wherein at least two electrodes (3, 4, 5, 6, 9, 10, 11) are connected to the at least one cluster (1, 7), wherein at least one of the electrodes (3, 4, 5, 6, 9, 10, 11) is a control electrode (6, 11),*
*- wherein the spacing between the electrodes (3, 4, 5, 6, 9, 10, 11) is more than 7,2517 nm,*
*- wherein the thickness of the tunnelling gap (2, 8) is not more than 7,2517 nm.*"

IV. Claim 1 of the first auxiliary request corresponds to claim 1 of the main request with the following additional features:

"*- wherein the magnitude of a control field strength applied at one cluster (1, 7) lies in the range* $1{,}37 \cdot 10^{5}$ *V/cm ≤ E ≤* $1{,}494 \cdot 10^{6}$ *V/cm,*
*and wherein the cluster (1, 7) is made of material selected from the group comprising superconductor or high molecular organic substance*".

V. Claim 1 of the second auxiliary request corresponds to claim 1 of the first auxiliary request with the following additional feature:

"*wherein the clusters with tunnelling gaps are integrated into groups to form one-dimensional and/or two-dimensional and/or three-dimensional structures*".

VI. Reference is also made to the following prior art documents:

D8: US-A-5 731 598

D9: Patent Abstracts Of Japan, Vol. 18, No. 066 (E-1501), 3 February 1994, and JP-A-05 283 759

D10: K. K. Likharev, "Possibility of Creating Analog and Digital Integrated Circuits Using the Discrete, One-Electron Tunneling Effect", Soviet Microelectronics, Plenum Publishing Press, US, Vol. 16, No. 3, May 1987, pages 109 to 121, (Translated from Mikroelektronika, Vol. 16, No. 3, May-June 1987, pages 195 to 209).

VII. The appellant applicant argued as follows:

The subject-matter of claim 1 was new and involved an inventive step over the cited prior art.

Document D7 disclosed a quantum dot diode formed in a mesa with a diameter of about 100 nm. The quantum dot, formed by a layer within the mesa, however, was not a cluster and had dimensions outside the claimed range. The term "*cluster*" denoted in physics a conglomeration of atoms or molecules having a particle number between 3 and a few millions and having typical characteristics stemming from its surface being relatively large compared to its volume. Accordingly it did not make sense to define as a cluster the inner part of a bulk material as was the case in D7.

Document D8 disclosed a single electron tunnel device with particles having a diameter between 1 and 50 nm. With respect to D8, the application provided an inventive selection of the cluster diameter with diameters ranging from about 7 to 30 nm, based on the insight that electrons could be conceived as rings with equally distributed rotating charge with a radius $r_o$ = 7.2517 nm. This selection provided in particular a very low resistance. Moreover D8 failed to disclose any criteria for the spacing between the electrode and the cluster and did not relate to a single cluster contacted by electrodes.

D9 disclosed a single electron tunnel transistor with particles of superconductive material. However the dimensions indicated were different. Finally, document D10 disclosed single electron tunnel devices based on macromolecules. However, the dimensions indicated, of the order of 1 nm, were different. Accordingly, neither of these documents could be combined with documents D7 or D8.

## Reasons for the Decision

1. The appeal is admissible.

2. *Main request*

2.1 *Novelty*

2.1.1 *Document D7*

Document D7 discloses a quantum dot diode device consisting of a mesa structure comprising a stack of epitaxial layers. In particular, the device consists of a lower n+ GaAs electrode layer, an overlying 4 nm AlGaAs tunnel barrier layer, a 5 nm undoped InGaAs quantum well layer thereon, an overlying 4 nm AlGaAs tunnel barrier layer, and a top n+ GaAs electrode layer (see figures 1, 2 and page 1861, right-hand column, third paragraph). According to D7, "*To observe lateral quantization of quantum well state(s), the physical size of the structure must be sufficiently small that quantization of the lateral momenta produces energy splittings > kT. Concurrently, the lateral dimensions of the structure must be large enough such that pinchoff of the column by the depletion layers formed on the sidewalls of the GaAs column does not occur*" (page 1862, right-hand column, first paragraph). Moreover, according to D7, "*Assuming that the current density through the structure is approximately the same as a large area device, measurement of the peak resonant current implies a minimum (circular) conduction path core of 130 Å for this structure; thus, a lateral parabolic potential approximation seems reasonable. This implies a depletion depth W of 430 Å*" (page 1862, right-hand column, second paragraph and figure 2). Hence, D7 discloses a conduction path core having a cylindrical form with a diameter of about 13 nm (and a length of about 5 nm corresponding to the quantum well layer thickness). The dimensions of the core are thus comparable to that of the cluster according to claim 1.

Furthermore, in D7 the electrodes of the diode, one of which can be said to be a control electrode, are spaced by the two 4 nm tunnel barrier layers and the 5 nm quantum well layer, with a total thickness of 13 nm. Hence, the spacing between the electrodes is more than 7.2517 nm, thus complying with claim 1. Moreover, the tunnelling gap provided by the 4 nm tunnel barrier layer is not more than 7.2517 nm, also complying with claim 1.

2.1.2 The appellant applicant argued that the core of D7 could not be considered a cluster. The term "*cluster*" denoted in physics a conglomeration of atoms or molecules having a particle number between 3 and a few millions. Because of their small size, clusters had characteristics deviating from those of the bulk material. These particular characteristics of clusters stemmed from the surface of the cluster being relatively large compared to its volume.

The board notes in this respect that the application as originally filed includes under the term "*cluster having a cylindrical form*" a number of structures such as fibres, wires, cables and micro tubes of great length, which do not fall under the above more narrow definition of a cluster argued by the appellant, in view of their macroscopic sizes (see page 41, line 20 to page 42, line 29; page 57, line 32 to page 59, line 2; figures 34, 35). In fact, the appellant conceded during the oral proceedings that a number of embodiments presented in the original application such as those pertaining to the above cables and those corresponding to figures 5 to 10 and figure 15 did not form part of the invention as claimed.

2.1.3 Nonetheless, the board accepts that the term cluster as used in the application implies that the boundary of the material of the cluster is identifiable. In the case of the core of D7, the lateral extension of the core within the claimed range corresponds to the edge of the depletion layer. Although for the quantum size effect this is a boundary, arguably from the point of view of the constitutive material of the core it is not. Accordingly, in the board's judgement the core of D7 cannot be held to be a cluster in the conventional sense.

Hence, the subject-matter of claim 1 of the main request is new with respect to document D7 (Articles 52(1), 54(1), (2) EPC 1973).

2.2 *Inventive step*

2.2.1 Document D7 uses high resolution lithography to produce the mesa structure for the quantum dot diode and then uses lateral confinement in the InGaAs quantum well layer to produce resonant tunnelling diodes with lateral dimension small enough to create quantum size effects. The lateral confinement in fact allows lateral dimensions of the quantum dot beyond those achievable by lithography.

The use of a cluster as claimed, on the other hand, obviates the need for lithography in combination with lateral confinement in that it directly provides a quantum dot small enough to produce the required quantum size effects.

The objective problem to be solved relative to document D7 is thus to provide a simpler way of obtaining the quantum dot of D7.

2.2.2 As acknowledged in the application as originally filed, the use of clusters for forming quantum dot structures of single electron tunnelling devices is common general knowledge (application, pages 1, 2). For example, the application refers in this context to document D8 (cited as reference [4] in the description) showing that "*metal clusters of a size less than 50 nm were placed between two electrodes applied to a dielectric*" (application, page 2, lines 26 to 27).

Document D8 discloses a single electron tunnelling device including a multiple tunnel junction layer 6 having multiple tunnel junctions, a source electrode 2 and a drain electrode 3 for applying a voltage to the multiple tunnel junction layer 6, and a gate electrode 1 for applying an electric field to the multiple tunnel junction layer 6 via an insulating film 7 (column 5, lines 18 to 23 and figure 1). The multiple tunnel junction layer 6 consists of an electrically insulating thin film 4 and a number of particles 5 dispersed therein made of metal or semiconductor material. The distance between the particles is adjusted so that a tunnel current can flow in the electrically insulating thin film 4. The average distance between the particles is 5 nm or less (column 5, lines 37 to 39; column 2, lines 14 to 15).

According to D8, in order to obtain the Coulomb blockade effect, the charging energy required when one particle 5 is charged with one electron should be larger than the heat energy of the electron. Accordingly, in order to obtain a device operable at room temperature the particle size needs to be 50 nm or less. The size of the particles 5 is preferably in the range of about 1 to 50 nm (column 5, lines 40 to 49 and figure 10).

Document D8 thus recommends particle sizes comparable to those claimed and discloses a simple way of directly obtaining a quantum dot of the size required in D7.

2.2.3 Accordingly, it would be obvious to the skilled person to adopt particles as suggested in D8, which are clusters in the sense of the application, to obtain the quantum dots required in D7.

Any differences between the lateral dimension of the quantum dot of D7 (about 13 nm) and the range provided in claim 1 (about 14.5 to 29 nm), in so far as they do not fall within the measurement tolerances at these microscopic dimensions, lie, in the board's judgement, within the customary variations which an average practitioner would investigate as a matter of routine experimental practice in order to fine-tune the performance of the device.

Accordingly, the subject-matter of claim 1 of the main request is obvious to the person skilled in the art and, therefore, lacks an inventive step in the sense of Article 56 EPC 1973.

The appellant's main request is thus not allowable.

3. *First auxiliary request*

3.1 Claim 1 of the first auxiliary request, compared to claim 1 of the main request, contains the following additional features:

"- *wherein the magnitude of a control field strength applied at one cluster (1, 7) lies in the range* $1{,}37 \cdot 10^5$ *V/cm* $\leq E \leq 1{,}494 \cdot 10^6$ *V/cm,*
*and wherein the cluster (1, 7) is made of material selected from the group comprising superconductor or high molecular organic substance*".

3.2 As far as the claimed field strength is concerned, document D7 discloses voltages applied to the diode of about 0.5 to 1.0 V (figure 3). As the n+ GaAs contact layers are highly conductive and separated by a 4 nm thick upper tunnel barrier layer, a 5 nm thick quantum well layer and a 4 nm thick lower tunnel barrier layer, the voltage drops substantially across the region between the electrodes. An applied voltage of 0.75 V and a 13 nm wide region yields a field strength of approximately $5.7 \times 10^5$ V/cm, which falls within the range of field strengths of claim 1.

3.3 As far as the claimed materials of the cluster are concerned, document D7 discloses semiconductor material for the quantum well and document D8 discloses both semiconductor material and metal as suitable materials for the particles.

It is noted in this respect that according to the appellant applicant, for the purposes of the application the cluster material is of no particular relevance.

The objective problem to be solved may thus be broadly formulated as finding further suitable materials for the clusters.

As there is no combinatory effect apparent between the claimed sizes and the choice of materials for the clusters, the skilled person would refer to prior art relating to materials for clusters in a broader size range.

Document D9 discloses a single electron tunnelling device, comparable to that of document D8, in which grains, i.e. clusters within the sense of the application, made of superconducting material (YBCO) with a diameter of about 30 to 50 nm are used (see abstract and figure 3 with corresponding description).

Document D9, thus, discloses clusters of sizes comparable to those claimed, made of superconducting material.

In the board's judgement it would thus be obvious to the person skilled in the art to use clusters of superconducting material for the quantum dot diode of D7.

3.4 Moreover, for the sake of completeness it is noted that document D10, cited in the originally filed application (page 1, lines 21 to 22; reference [2]) as "*Prior* *art* ...[describing] *a large class of electronic devices basing on single-electron tunnelling through a small size cluster*", mentions molecular structures in which discrete, one-electron tunnelling could be realised, with adjoining macromolecules isolated by tunnelling barriers (D10, page 119, third paragraph). The use of the claimed high molecular organic substances in quantum size effect devices is thus rendered obvious to the skilled person by document D10.

Regarding the appellant's argument that the sizes indicated in D10 were different, it is noted that the specified size of the order of 1 nm refers to the intersection of the macromolecules where discrete tunnelling takes place and not to the macromolecules themselves. As to the latter, it would be obvious to select sizes comparable to those of the quantum dots of the prior art cited above.

3.5 Hence, the subject-matter of claim 1 of the first auxiliary request is obvious to the person skilled in the art and, therefore, lacks an inventive step in the sense of Article 56 EPC 1973.

The appellant's first auxiliary request is, thus, not allowable.

4. *Second auxiliary request*

4.1 Claim 1 of the second auxiliary request corresponds to claim 1 of the first auxiliary request with the following additional features:

"*wherein the clusters with tunnelling gaps are integrated into groups to form one-dimensional and/or two-dimensional and/or three-dimensional structures*".

4.2 Both documents D8 and D9 disclose devices in which the particles or grains are arranged in a layer and thus are integrated into groups to form a two-dimensional structure as per claim 1 (D8, figure 1; D9, figure 1). Document D8 moreover also discloses devices in which the tunnel junction layer is composed of an insulating thin film with metal or semiconductor particles dispersed therein three-dimensionally (figure 7; column 8, line 66 to column 9, line 8).

4.3 The appellant applicant argued that above additional feature was directed in particular at the embodiments of the application integrating logic cells.

It is noted in this respect that claim 1 is not limited to the integration of a plurality of cells but also covers a single, e.g. two-dimensional device as discussed above.

Moreover, the integration of logic cells based on one-electron tunnelling effect devices into more complex logic circuits is already suggested in document D10 cited in the application as originally filed (D10, pages 116 to 188, chapter "Possible applications in digital electronics"). Furthermore, it is evident for the skilled person that it is precisely the need for large-scale integration, i.e. the arrangement of a large number of these devices in e.g. logical arrays, which is the main driving force behind most research on the single-electron transistor.

4.4 Accordingly, the subject-matter of claim 1 of the second auxiliary request is obvious to the person skilled in the art and, thus, lacks an inventive step in the sense of Article 56 EPC 1973.

Hence the appellant's second auxiliary request is also not allowable.

## Order

## For these reasons it is decided that:

The appeal is dismissed.

Registrar Chair

S. Sánchez Chiquero T. Bokor