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(C) [X] To Chairmen

D E C I S I O N
of 12 October 1994

Case Number: T 0184/93 - 3.4.1

Application Number: 85109626.3

Publication Number: 0172464

IPC: H01L 31/10

Language of the proceedings: EN

Title of invention:
Femto diode and applications

Applicant:
Marks, Alvin M., Dr.

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 83

Keyword:
"No disclosure of the invention in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art"

Decisions cited:
-

Catchword:
-

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Beschwerdekammern | Boards of Appeal | Chambres de recours

Case Number: T 0184/93 - 3.4.1

D E C I S I O N
of the Technical Board of Appeal 3.4.1
of 12 October 1994

Appellant: Marks, Alvin M., Dr.
Advanced Research Development
359 R. Main St.
Athol
Massachusetts 01331 (US)

Representative: Mr P. Wenzel and Mrs H. Gray
Patentanwälte Wenzel & Kalkoff
Postfach 73 04 66
Grubes Allee 26
D-22124 Hamburg (DE)

Decision under appeal: **Decision of the Examining Division of the European Patent Office dated 1 October 1992 refusing European patent application No. 85 109 626.3 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: G. D. Paterson
Members: H. J. Reich
Y. J. F. van Henden

Summary of Facts and Submissions

I. European patent application No. 85 109 626.3 (publication No. 0 172 464) was refused by decision of the Examining Division.

II. The decision was based on Claim 1 filed on 3 June 1991. Claim 1 reads as follows:

"1. Light frequency responsive tunnel junction diode (femtodiode) comprising a first metal strip (1) and a second metal strip (2), both being arranged on a common axis such that their adjacent ends (4, 5) are formed by a first face of the first strip and second face of the second strip, said first and second faces having first and second work functions, respectively; insulating means (3) arranged between said adjacent ends (4, 5); and input and output terminals (15, 16) connected to said diode, one (15) of said terminals being connected to said first strip and the second (16) of said terminals being connected to said second strip (2), c h a r a c t e r i z e d i n that means are provided for introducing an energetic electron (11) travelling along the axis of said strip, said metal having a long mean free path (12); that the combination of said insulating means and said work functions on said faces provides a unidirectional semipermeable tunnelling barrier (4, 5) to an energetic electron (11) in said first metal strip (1); and that the said combination (4, 3, 5) between said first and second faces constitutes a tunnel junction which provides total transmission or total reflection according to the laws of quantum mechanics."

Claims 2 to 21 are dependent on Claim 1 or incorporate its subject-matter respectively.

III. The reason given for the refusal was that there are not adequate instructions in the contested application which would lead the skilled person necessarily and directly towards a functioning femtodiode, so that the invention is not disclosed in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art within the meaning of Article 83 EPC. A process with which a spatial resolution of 2.79 to 3.2 nm - being of paramount importance to the operation of the device - could be realised, does not seem to have existed at the priority date of the application. Document

D1: Journal of Vacuum Science and Technology, Vol. 19, No. 4, November/December 1981, pages 1117 to 1120

cited by the Appellant, reports the etching of lines and holes in NaCl crystals of the 2 nm scale. However, the thickness of the insulating means enabling tunnelling of electrons is dependent on the work function of the neighbouring second metal strip (**and** on the wavelength of the incident photons, which was not taken into account at all). The particular oxide layer thicknesses needed for a particular work function and wavelength region are for instance a thickness of 2.79 nm corresponding to a work function of 3.2 eV and a thickness of 3.24 nm necessary for a work function of 1.7 eV. Hence, in order to reproduce the characteristic curve of the femtodiode with reasonable consistency the resolution of the etching process of document D1 would have had to have been about 10 times smaller in the region of 0.2 nm. Moreover, the basic principle of the femtodiode, i.e. the transfer of the total energy quantum of an incident photon to the kinetic energy of a single electron in the free electron Fermi gas of the metal, does not correspond to the fundamental law of the conservation of momentum, which requires the additional interaction of a phonon.

Documents:

D2: A. Sudberry: "Quantum mechanics and the particles of nature", Cambridge University Press 1976, pages 20 and 21, and

D3: J. Kittel: "Introduction to Solid State Physics" 5th edition, John Wiley, New York, 1976, pages 155 and 156

cited by the Appellant, were not regarded to remove the doubts concerning the theory underlying the femtodiode. Document D2 states that only **part** of the absorbed photon energy appears in the form of kinetic energy of an electron emitted from a metal surface. Document D3 concerns the free electron Fermi gas, which in view of the necessary simultaneous conservation of energy and momentum can never absorb a photon. The doubts concerning the theoretical derivation of the working principle of the femtodiode could have been overcome by specifying experimental measurements of a practical device. The Applicant failed to produce such results and thereby failed to demonstrate the feasibility of his invention. Decision T 226/85, OJ EPO 1988, 336, allowing a reasonable amount of trial and error in the case of random experiments, states at the same time that adequate instructions in the specification have to lead the skilled person necessarily and directly towards success and thus supports the refusal of the present application.

IV. The Appellant filed an appeal against this decision, mainly arguing that patentability cannot be made dependent on the fact whether an invention has already been realised or on a proof of the Applicant's ability to realise the structure claimed, as long as this does not contravene the laws and experiences of natural science. The spatial resolution of 2.79 to 3.2 nm in the gap between the femtodiode elements does not form a feature of Claim 1 and is required only for a precise wavelength resolution, which is needed merely for certain particular applications. Energy losses of free moving electrons in metal do not appear in practice in view of the negligible collision cross section and a phonon energy loss of only 0.01 eV per electron impact. The photon energy hv would contribute totally to the electron velocity within the absorbing metal volume since the retarding field responsible for the work function only exists at the faces of the metal.

V. In a communication preparing oral proceedings the Board drew the Appellant's attention to the following:

(a) The claimed "semipermeable tunnelling barrier to an energetic electron" is disclosed to be **realisable** for an absorption of photons in the visible range with a thickness of 2.8 to 3.8 nm **on the basis** of a theoretical model wherein each absorbed photon excites one electron to a state within the conduction band of the first metal lying over the Fermi level in the height of the **total** quantum energy of the photon. The claimed "means for introducing an energetic electron travelling along the axis of said (metal) strip" are embodied according to the description, page 19, lines 12 to 14 by the fact that: "In a femtodiode, a single electron approaches the barrier travelling over sub-micron distances with an energy $\zeta = h.\nu = V.e$". Such an excitation represents a forbidden transition and thus contradicts well established physical laws as set out in detail in documents:

D4: Finkelnburg: "Einführung in die Atomphysik" Springer-Verlag 1958, page 461, and

D5: Bergmann-Schäfer: "Lehrbuch der Experimentalphysik", Walter de Gruyter, Berlin-New York 1992, Vol. 6, pages 78 and 79.

(b) In the Board's preliminary view the technical disclosure in the description concerning the fabrication of the femtodiode, in particular page 18, paragraph 3 would be insufficient to realise a metal - insulator - metal structure, having the claimed functional properties.

VI. Oral proceedings were duly held on 12 October 1994. During these oral proceedings and in his preparatory letters dated 9 September 1994 and 5 October 1994 the Appellant relied on the following documents:

D6: Science, Vol. 254, 29 November 1994, pages 1326 to 1328;

D7: John Griffiths: "Colour and Constitution of Organic Molecules", Academic Press 1976, pages 240 to 243;

D8: IBM Technical Disclosure Bulletin, Vol. 10, No. 4; September 1967, pages 494 and 495;

D9: Journal of the Electrochemical Society Vol. 116, No. 7, July 1969, pages 1033 to 1037;

D10: Nature, Vol. 127, 11 June 1987, pages 462 to 464;

D11: Research Report of the Texas A & M Research Foundation: "Resonance Light Absorption and Rectification", November 1993, pages 1 to 16 and Figures 1 to 10; and

D12: Technical Report by Mr Marks, 940413R5, page 10.

VII. At the end of the oral proceedings the Appellant requested that the decision under appeal be set aside and that a patent be granted on the basis of the claims filed on 3 June 1991 and underlying the appealed decision.

VIII. In support of his request the Appellant argued essentially as follows:

(a) A skilled person would have sufficient information to realise a femtodiode via the following measures; Starting from a glass substrate as disclosed in the description, page 18, lines 13 to 15, a NaCl resist is deposited thereon and evaporated by an electron beam in order to produce thus according to the "Isaacson method" disclosed in document D1, the femtodiode pattern in the NaCl resist. In view of the resolution limit of 1.5 nm derivable from Figure 5 of document D1, a NaCl-bar with a 3 nm thickness is easily etchable. As follows from document D1, page 1118, left column, last paragraph, NaCl is an appropriate lift-off-resist for structuring metals. Copper or aluminium metal vapour is deposited into the trenches defined in the resist. Then, washing with water removes the excess material, leaving the femtodiode structure on the glass substrate. Documents D8 and D9 are clear evidence that the lift-off-technique is applicable in the high-resolution deposition of metals for sub-micron devices. After drying, monolayers of different material are deposited in the gap by ion beams at an angle to the surface as disclosed in the description page 13, lines 13 to 22. These monolayers form the different material on adjacent faces of the gap. Hence, only one metal, with different work functions on adjacent monolayers, is used.

(b) The photon penetrates the metal to a depth of 7.5 nm and directly converts its energy into the kinetic energy of the electron according to equation $E = h\nu = \frac{1}{2} mV^2$. The strip of the femtodiode forms a quantum well of a one-dimensional antenna, so that after the absorption of the photon a free electron appears in an allowed energy state of the quantum well. Such allowed energy states are given by the quantum well formula in document D6, pages 1328, left column, paragraph 3. The absorption process in the Femtodiode corresponds to that of a linear polymer molecule acting as a quantum well and described in document D7, or to that in photosynthesis and described in document D10. As shown in document D12, the kinetic energy of the electron is largely conserved until it tunnels, because the energy lost due to lattice impacts will be small.

(c) Experimental evidence for electron excitation by photon absorption in metal bars which have a dimensional similarity with a strip of a femtodiode, is given by the measured short circuit currents in Figures 6 to 8 of document D11 concerning the resonance light absorption and rectification of polarised photons with a wavelength of 632.8 nm in an antenna array.

Reasons for the Decision

1. The present application discloses for the "means for introducing an energetic electron travelling along the axis of the metal strip" claimed in Claim 1 exclusively a light photon. It defines an "energetic electron" as an electron which has absorbed a quantum of light energy

(1.8 to 3.1 eV); see page 2, paragraph 6. The description states that a basic principle of the femtodiode is the transfer of the energy quantum of a photon to a single electron (page 23, paragraphs 1 and 2) so that in a femtodiode a single electron approaches the barrier - i.e. the "unidirectional semipermeable tunnelling barrier to an energetic electron in said first metal strip" claimed in Claim 1 - travelling over sub-micron distances with an energy of V.e = h**ν**; see page 19, lines 12 to 14. Such energetic electron with a kinetic energy of 1.8 to 3.1 eV - on the basis of a theoretical calculation on pages 29 to 34 of the description - shall be able to pass through the tunnelling barrier for the claimed "total transmission of the tunnel junction according to the laws of quantum mechanics" at barrier thickness between 2.8 to 3.8 nm; see page 20, lines 17. This value is approximated for a "combination" of insulating means between the adjacent ends of the strips and work functions on the faces of the strips in form of an asymmetric tunnel junction with a work function ratio $\varnothing_1/\varnothing_2 = 0.6$ (page 34, line 17).

2. The complete transfer of an energy quantum of a photon into the kinetic energy of an electron in the conduction band of a metal represents according to well-established physical laws an intra band transition which is forbidden without the participation of a phonon. This means that in nature, not the excitation mechanism underlying the working principle of the femtodiode according to paragraph 1 is expected by a skilled person, but a transition of an electron into a state above Fermi level wherein only part of the photon energy contributes to the kinetic energy of the "energetic" electron and part of the photon energy is transformed into lattice oscillations (phonons). Hence, in an elementary process **creating** an "energetic" electron, its kinetic energy remains below the photon energy and has no clearly

predictable value. Even if after introducing the kinetic electron energy losses by lattice interactions might be negligible (see paragraph VIII-(b) above), a skilled person does not know the actual kinetic energy of the electron travelling along the axis of the metal strip when it approaches the tunnel junction. Thus, there appears to be no reliable basis allowing to approximate theoretically a barrier thickness which allows the penetration of a detectable tunnel current formed by photon-excited Fermi electrons.

3. For the above reasons, the Board is not satisfied that already at a thickness of the insulating means between first and second strip in the order of magnitude of 3 nm, an experimentally detectable tunnel current is realisable. Lower kinetic electron energies might lead to smaller thicknesses of the insulating means even below the 2 nm resolution limit of the Isaacson method disclosed in document D1, so that already for this reason the feasibility of the claimed tunnel junction transmission remains speculative.

4. In the theoretical description of the photosynthesis of document D10, the excitation mechanism of the local electronic excitation of the donor chromophore by photon absorption is not further explained. The free electron treatment for the energy values of the absorption bands in a cyanine molecule in document D7 allows to theoretically describe the wavelength of the absorption spectra of cyanine. However, the excitation processes described therein concern the promotion of an electron from one molecular orbital to another one (see D7, page 240, last paragraph) which corresponds to an optically allowed band-band transition. Document D6 concerns the theoretical description of quantised electron energy states in a potential well and is totally silent about transition probabilities between

such quantised states permitting photon absorption. Hence, documents D10, D7 and D6 provide no evidence that for a free electron Fermi gas which is included into a potential well, the total photon energy is converted into the kinetic energy of one electron.

5. The kinetic electrons formed by photon absorption in the metal bar of the antenna array of document D11 contributed to an experimentally detectable short circuit current after penetrating a semiconductor p-n junction of **unknown** barrier height, so that no conclusions can be drawn from the experimental existence of the current to the kinetic energy of the travelling electrons.

6. The disclosure of the measures for fabricating the metal **structure** of the femtodiode in the description is limited to page 18, lines 17 to 22 reading:

"Electron beams may be employed to produce the extremely small structures required. X-ray or electron beam lithography may be employed to produce the masks. Ion beams or molecular beam epitaxy may be used to lay down the appropriate metal and insulating areas in a manner known to the art of producing sub-micron electronic devices."

7. In order to arrive from such an unspecified enumeration of generally known skills and measures, disclosed in the description as the fabrication method according to the Appellant's submission in paragraph VIII-(a), a skilled person has to pass the following sequence of development steps: First, he has to select among the conventionally known masking techniques a conventional lift-off process. According to documents D8 and D9 these lift-off processes use organic polymer resins, mostly polymethylmethacrylate. Document D9 reports a resolution

of 500 nm (see D9, paragraph 1034, right column, paragraph 5) and thus teaches that with a normally used organic lift-off resin the desired resolution of 2 nm cannot be achieved.

8. According to the established case law of the Boards of Appeal a skilled person is assumed to be able to develop a technical object on the basis of his common general knowledge which is derivable for instance from a textbook and thus easily at hand in his daily work. However, since document D1 is a scientific periodical which reports on very recent technical development, it has to be concluded that NaCl as lift-off mask material was not a commonly used means which a skilled person was able to apply routinely. There is no reference to document D1 in the description of the present application. Thus, only after an intensive systematic overall search within the documentation concerning the complete state of the art of manufacturing sub-micron structures, would a skilled person have been able to make use of the teaching disclosed in document D1. Such a search is regarded to be an undue burden in carrying out an invention on the basis of its technical disclosure in a patent application. Therefore, in the Board's view, it must be excluded that the skilled person would have made use of the teaching of document D1 and applied on its own NaCl as mask material in realising the invention claimed in Claim 1.

9. Moreover, the Appellant's submission in paragraph VIII-(a) above is based on the fact that only **one** metal layer needs to be structured by the lift-off-technique with a NaCl resist, making an alignment of a second patterning step superfluous. In the Board's view, a skilled person derives exclusively from the description that the first metal strip is formed by a metal 1 and the second metal strip by a metal 2. He will interpret such a teaching in

view of the necessary magnitude of the work function difference in between metal 1 and metal 2. Thus, within the frame of the integral information about the basic principles of the femtodiode disclosed in the present application, the skilled person is guided to assume that a successful functioning of the femtodiode is dependent on the fact that metal 1 and metal 2 have to be realised by **two different** chemical substances, see in particular the description page 11, lines 18 to 20; pages 12, line 15; page 23, line 21 and page 41, line 18. The text on page 13, lines 13 to 22 on which the appellant relies in paragraph VIII-(a) above, concerns quite generally the possibility of changing the work function of a metal by an ion adsorbate on its surface. Practical use of this teaching is made in order to match the work function difference to a specific wavelength of the photons. Table IV on page 16 teaches to realise the wavelength match by modifying one work function i.e. by covering **one** metal with an adsorbate and leaving the second diverging metal of the other face **without** adsorbate; see the lists in the left and right column of Table IV. Thus, the examples disclcsed in Table IV all exclude a femtodiode structure wherein the faces of the metal strips are formed by two **different** adsorbates which cover one and the same metal. Such a structure lies on a development direction which is opposite to the one recommended in the description of the application. In the Board's view, a skilled person's normal abilities in putting a functioning femtodiode into practice are surpassed by such an intellectual reorganisation of the disclosed particular structures of an advantageous embodiment of a femtodiode. Moreover, the disclosed impurity implantation into a metal surface does not hint that the ion deposited substance as such has to be understood as the strip metal appearing in the systematic drawings which shall explain the potential well structure within the femtodiode structure. On the basis of the integral teaching of the description, in the Board's view a skilled person would never think of giving the strip volume a mere substrate function and shifting the electrical well properties of the disclosed asymmetric metal 1 - insulator - metal 2 configuration which forms the claimed tunnel junction to a monolayer in the surface. There is no disclosure in the application of the actual values of a work function shift by a monolayer. Therefore, it remains speculative whether a combination of different adsorbate monolayers can be found, which combination of the same metal is able to create a work function difference high enough to make the tunnelling barrier unidirectional as claimed.

10. As set out in detail above, the Appellant's submissions have not been able to remove the Board's objection that a skilled person - when using only his common general knowledge - can realise with undue burden a functioning femtodiode on the basis of the technical information he is able to derive from the original application documents. Therefore the Board maintains its finding that the present European patent application does not disclose the invention in a manner sufficiently clear and complete for it to be carried out by a person skilled in the art. Hence, the originally filed application documents do not satisfy the requirements of Article 83 EPC.

Order

For these reasons it is decided that:

The appeal is dismissed.

The Registrar: The Chairman:

M. Beer G. D. Paterson