(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
9 March 2006 (09.03.2006)

PCT

(10) International Publication Number
WO 2006/025737 A1

(51) International Patent Classification:
H01J 37/31 (2006.01) *B23K 15/08* (2006.01)
B81B 1/00 (2006.01)

(21) International Application Number:
PCT/NL2005/000630

(22) International Filing Date: 31 August 2005 (31.08.2005)

(25) Filing Language: Dutch

(26) Publication Language: English

(30) Priority Data:
1026942 1 September 2004 (01.09.2004) NL

(71) Applicant (*for all designated States except US*): **Technische Universiteit Delft** [NL/NL]; Julianalaan 134, NL-2628 BL Delft (NL).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **ZANDBERGEN, Hendrik Willem** [NL/NL]; De Hoop 11, NL-2223 BZ Katwijk ZH (NL). **TICHELAAR, Frans David** [NL/NL]; Aart van der Leeuwlaan 239, NL-2624 PS Delft (NL). **ALKEMADE, Paulus Franciscus Augustinus** [NL/NL]; Terbregselaan 104, NL-3055 RH Rotterdam (NL).

(74) Agent: **WINCKELS, J.H.F.**; c/o VEREENIGDE, Johan de Wittlaan 7, NL-2417 JR The Hague (NL).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SM, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

WO 2006/025737 A1

(54) **Title:** METHOD AND APPARATUS FOR THE FORMATION OF NANOMETER-SCALE ELECTRODES, AND SUCH ELECTRODES

(57) **Abstract:** A method for the formation of nanometer-scale electrodes, wherein strip of electrically conductive material, in particular metal, is provided with a longitudinal direction, a width direction and a thickness direction and then, with the aid of an electron beam, a groove is provided in a top surface of the strip, in the width direction of the strip, with a nanometer- scale width in the longitudinal direction of the strip.

Title: Method and apparatus for the formation of nanometer-scale electrodes, and such electrodes

The invention relates to a method for the formation of nanometer-scale electrodes. In particular, the invention relates to a method for the formation of electrodes with which nanometer-scale elements can be detected and measured with the aid of conduction.

In the use or detection of very small electrically conductive components, such as active electrical components, making electrical contact is often problematic. Such nanometer-scale components, which may for instance consist of particles with dimensions of one to a few nanometers and may even consist of, for instance, one single molecule, render nanometer-scale electrodes necessary, in particular electrodes with a precision from one to a few nanometers.

It is generally known to manufacture electrodes with the aid of lithographic techniques. Thus, use can be made of metal deposition and lithography with the aid of UV light, followed by etching, with which a precision of about 50 nm can be obtained. A higher precision cannot be obtained because it is limited by the wavelength of the light used. A shorter wavelength cannot be used in this, because all materials are penetrable by light with such a short wavelength.

It is also known to use electron beam lithography in photosensitive or electron-sensitive layers, followed by etching. With this, a precision of about 20 nm can be obtained. While it is true that the electron beam can be focused with a precision of one nanometer or less, yet diffusion of electrons from the beam and/or generated electrons will light the layer sensitive to this also outside the desired areas which are focused on, so that the possible accuracy is limited to the value mentioned of about 20 nm.

The invention contemplates providing a method of the type described in the opening paragraph, in which at least a number of the drawbacks mentioned are avoided, while maintaining the advantages. To this end, the method according to the invention is characterized by the measures according to claim 1.

In a method according to the invention, use is made of an electron beam to directly process an electrically conductive material, without intervention of layers which are sensitive to electrons or light layers. It has been found that, with the aid of an electron beam, atoms can be displaced, so that a groove can be formed in a strip of electrically conductive material, in particular metal, such that the electrical conduction through the strip is influenced, in particular interrupted. Thus, in a simple and particularly accurate manner, nanometer-scale electrodes can be manufactured.

Herein, nanometer scale is at least understood to mean that, at least in a width direction and a thickness direction, the electrodes have dimensions between one nanometer and some tens to hundreds of nanometers, at least near the groove and/or a groove formed between the electrodes has a width which is so small that it can be bridged by elements with outer dimensions on a scale of small and medium-sized molecules, for instance between less than one nanometer and a few nanometers. Herein, a strip is at least understood to mean any type of element manufactured from electrically conductive material which has a minimum length and a minimum width which are considerably larger than the thickness of the material, measured at right angles to this longitudinal and width direction, at least at the height of the location where the at least one groove is provided. Herein, a groove is at least understood to mean a deformation of the surface of the strip which has a depth, viewed from the surface, and a width, while the deformation may have flat as well as singly or doubly curved or irregularly formed side surfaces which at least substantially determine the facing walls of the groove. The groove may have a bottom from the material of the strip but may also extend through the entire thickness of the strip.

In a particular embodiment, the material in which the groove is made is monocrystalline. This offers a greater control of the manufacturing process of the groove.

In a method according to the invention, the groove is preferably provided in a top surface of the strip, with a depth, calculated approximately at right angles to this top surface, which is at least equal to the thickness of the strip at the location of the groove, such that the strip is divided into at least two parts electrically separated from each other, which parts form the electrodes.

In a particularly advantageous embodiment, the strip is provided on a support, prior to the provision of the at least one groove. This further simplifies processing. In the support, under at least a part of the groove, an opening can be provided, through which changes in the strip can be observed during the formation of the groove, at least the processing of the strip.

Preferably, in a method according to the invention, use is made of an electron microscope, in particular of a transmission electron microscope. With an electron microscope, an electron beam can accurately be generated and monitored, which electron beam can be focused to a spot size of, for instance, about one nanometer. Particularly small surfaces can thus be processed particularly accurately and atoms can be displaced for forming particularly narrow grooves, at least surface changes. Moreover, use of an electron microscope offers the advantage that, during the deformation of the strip, at least the formation of the at least one groove, the changes obtained can be observed accurately and in real time, on the basis of which the electron beam can be monitored and controlled, for instance in direction, size, intensity.

The strip may, for instance, have been or be manufactured from precious metal such as silver, gold, platinum, or from a metallic oxide.

In an advantageous embodiment, the material in which the groove is provided is additionally heated or cooled via an external temperature control. This can influence the formation of groove in a positive manner.

In an advantageous further embodiment, in a method according to the invention, the support is manufactured from a silicon-based material, for instance silicon nitride or silicon oxide. The strip is preferably manufactured by use of conventional techniques, in particular lithography, more in particular photolithography. Thus, relatively narrow, thin strips can be provided accurately and relatively simply, in a desired shape and dimension.

The invention further relates to a set of electrodes, characterized by the measures according to claim 13.

Such a set of electrodes offers the advantage that nanometer-scale elements can thereby be detected, controlled, influenced, investigated or manipulated otherwise with the aid of electric current or charge or quantities derived or to be derived therefrom. The first ends preferably have a slightly tapering design, such that they approach each other at a small distance only across a small width. The strips may, for instance, be formed from a relatively pure metal or from a metal alloy. With use of an alloy, during processing, the first ends can be enriched with one of the components from the alloy, so that the conduction can be influenced positively or negatively.

Prior to the provision of the groove, the strip preferably has a relatively small thickness and width, for instance a thickness between 2 and 20 nm and a width between 20 and 100 nm. Particularly the width may, in principle, be larger, but this causes the processing time to be relatively long. In particular, a strip can be used which on average has a first width and which locally has a smaller width, while the groove is provided in the part with the smaller width. As a result, relatively little time and energy is required for providing the groove, while the electrodes can be relatively wide at a distance from the groove, and consequently easy to approach for, for instance, making electrical contact with peripheral equipment.

The invention moreover relates to the use of an electron beam for the formation of electrodes by migration of atoms and to the use of an electron microscope for the formation of electrodes from a metal strip.

The invention further relates to an apparatus for the formation of at least two electrically conductive strip parts electrically insulated from each other from a strip, in particular electrodes, characterized by the measures according to claim 18.

With such an apparatus, in a particularly accurate and relatively simple manner, conductive strips, in particular electrodes, can be manufactured on a nanometer scale.

In the further subclaims, further advantageous embodiments of a method, electrodes and use are set forth.

In explanation of the invention, exemplary embodiments of a method and apparatuses according to the invention will be elucidated in more detail with reference to the drawing, in which:

Fig. 1 schematically shows an apparatus according to the invention for the manufacture of electrically conductive strips;

Fig. 2 schematically shows, in side elevational view, a set of electrodes manufactured with a method and apparatus according to the present invention, in use;

Fig. 3A schematically shows, in perspective, partially cross-sectional view, a step in a method according to the present invention;

Figs. 3B-H show images, produced with an electron microscope, of a strip during a method according to the present invention; and

Figs. 4A-F show six recordings during the manufacture of an electrode set with a method according to the present invention.

In this description, same or corresponding parts have same or corresponding reference numerals. The exemplary embodiments shown are only shown and described by way of illustration of the present invention and should not be taken as being limitative in any way.

Fig. 1 schematically shows, in a very simplified manner, an electron microscope 1 with focusing means 2, coupled with a camera 3 via a control device 4. Of course, the camera 3 and/or the control device 4 may also be an integral part of the electron microscope 1. In addition, other means can be used for generating and monitoring an electron beam. With the aid of the focusing means 2, a highly focused electron beam can be obtained with a nanometer-scale spot size on a workpiece 5, for instance of a diameter of 2 to 10 nm or less. Fig. 1 schematically shows a workpiece 5, as will be described in more detail, on a very greatly magnified scale. This workpiece 5 comprises a support 6, comprising a base 7 and a membrane 8, on which membrane 8 a strip 9 is supported, from which, with a method according to the present invention, with the aid of an electron beam, an electrode set according to the invention will be formed, as schematically shown in more detail in Fig. 2. The strip 9 has a thickness D which is relatively small, for instance between 2 and 20 nm, more in particular between 5 and 15 nm and a width, at right angles with the plane of the drawing, which can be slightly larger, for instance more than 10 nm, more in particular more than 50 nm and for instance 100 to 150 nm. This will be discussed in more detail.

In use, preferably prior to the processing of the strip 9 in the membrane 8, if this is present, at least one opening is provided next to and/or under the strip 9, at the height of the position where the strip 9 will be processed with the aid of the electron beam 2. The purpose of such an opening is that, with the aid of the camera 3, deformations of the strip 9 and/or of the membrane 8 can be observed, for instance in real time, with the aid of the camera 3, so that, with the aid of the control device 4, the electron microscope 1, in particular the focusing means 2, and/or displacements of the electron beam can be controlled for obtaining the desired deformation of the strip 9 by displacement of atoms, in particular diffusion of atoms in the strip 9, such that, as schematically shown in Fig. 2, in the strip 9 above the opening 10, a groove 11 is formed which completely cuts through the strip 9 across its width B, i.e. at right angles to the plane of the drawing in Figs. 1 and 2, at least up to the membrane 8, so that, on both sides of the groove 11, an electrode 12A, 12B is formed, which electrodes are electrically separated from each other by the groove. Each electrode 12A, 12B has a first end 13A, 13B. The first ends 13A, 13B bound the groove 11 and have a mutual distance W, the width of the groove 11, on a nanometer scale. This width W may, for instance, be 1-2 nm, but may also be made smaller or larger, depending on, for instance, the spot size, the intensity of the electron beam, the processing time and the like. As shown in Fig. 4, on or between the first ends 13A, 13B, an element 14 can be positioned, after which, with the aid of a circuit 15 connected to the two electrodes 12A, 12B, for instance the presence of the element 14 can be established or electrical properties thereof can be determined, the element 14 can be electrically excited or be electrically influenced or manipulated in another manner, or the presence thereof can be determined. It will be clear that, when an element 14 with a width Q which is of the same order as the width W of the groove 11 rests on or against the first ends 13A, 13B, the circuit 15 will be closed. As a result of the use of a method according to the present invention, for instance nanoclusters, nanotubes or even single molecules can be used as element 14. These can be characterized on the basis of electrical measurements with the aid of the circuit 15.

Fig. 3A shows in perspective, partly cross-sectional view, a workpiece 5 during the carrying out of a method according to the present invention, where an electron beam 16 is schematically drawn in as an hourglass shape, while a focusing point 17 is located at the height of the membrane 8, at least the strip 9.

The workpiece 5 comprises a strip 9 supported on a support 6. This support 6 comprises a base 7, an intermediate layer 18 and a membrane 8. In the example shown in Fig. 3A, the membrane is, for instance, an approximately 40 nm thick SiN membrane, while the intermediate layer is a silicon oxide layer, supported by a relatively thick layer of silicon. In the basis 7 and the intermediate layer 18, an opening 10 has been provided in a manner known per se, which widens in the direction away from the membrane 8. This opening 10 is, for instance, approximately rectangular and is, for instance, 400 by 400 nm.

In Fig. 3A, the strip 9 is, for instance, manufactured from a 10 nm thick exposed gold film with a bicrystalline orientation or a platinum film with an approximately equal thickness and a width B of about 150 nm. In a part 19 extending above the opening 10, the width B_1 of the strip 9 has been reduced considerably, for instance to a width of about 20 or 50 nm, in order to reduce the processing time.

Fig. 3A shows, as described hereinabove, an apparatus according to the invention, while Figs. 3B-H show images of a strip 9 according to the invention during processing with a method according to the present invention. These are TEM images. Figs. 3B-D show three images of an unsuccessful manufacturing attempt, and Figs. 3E-H show a successful attempt. In Figs. 3B, C, D, E and H, in the top right-hand corner, cross sections of the workpiece are schematically shown, during the respective step.

Fig. 3B shows a polycrystalline metal strip 9 manufactured from platinum with a width of 50 nm, in which a bridge 19 has been provided, with a width of about 50 nm. This has been obtained with the aid of an ion beam (ion beam milling). Then, as shown in Fig. 3B, with a short lighting, a small opening has been provided in the Si_3N_4 membrane, as indicated by arrow K. Then, as shown in Fig. 3C, parts of the bridge have locally been removed by local radiation by the electron beam, so that the width of the bridge 19 has been reduced considerably, to about 1.5 nm, as shown in Fig. 3C in the bottom right-hand corner. Then, as shown in Fig. 3D, the electron beam has intentionally been widened in order to be able to record the formation of the groove 11 in real time with a fast CCD camera (fast-scan CCD). However, this change in the electron flux resulted in a strong increase of the width of the bridge, which greatly complicated a good control of the groove formation.

In Fig. 3E, an image is shown, approximately halfway a manufacturing method in a second attempt. First, a cut is made in an upper part of the bridge (Fig. 3E), after which, from the bottom side (bottom side and top side are herein understood to mean the top and bottom in the different images of Figs. 3A-H and 4A-F, which means both sides of the strip 9 at the height of the bridge 19 when viewed approximately at right angles to the surface of the membrane 8), so that the width of the bridge 19 is reduced further and further. In Fig. 3E, in the top left-hand corner, the changed shape of the bridge is shown in more detail, being slightly magnified.

As Figs. 3F-H clearly show, further processing with the electron beam, which has been moved in a direction approximately at right angles to the longitudinal direction of the strip 9, relative to this strip, at least bridge 19, results in a groove 11 formed between two first ends 13A, B of two electrodes 12 formed on both sides of the groove 11. The narrowest groove which has thus been formed in the given embodiment has a minimum width of 0.6 nm and electrically separates the two electrodes 12 from each other. As shown in Fig. 3H, further processing with an electron beam leads to a further widening of the groove 11, in the example shown to a width of about 1.4 nm.

Particularly advantageously, the material in which the groove is provided can be monocrystalline. Of the material, moreover, the temperature can be controlled, for instance by cooling or heating.

In Figs. 4A-4F, six images are shown, which were taken from a film made during processing of a 10 nm thick, exposed gold film with bicrystalline orientation for the formation of a set of electrodes 12. First, a hole was made with the aid of the electron beam for the formation of an approximately 20 nm wide bridge 19. Then, the width of the bridge 19 was slowly reduced during the continuous observation thereof with a fast camera. As appears from Figs. 4A-E, the width of the bridge gradually decreased until a moment between 97 and 101 seconds from the outset, when the bridge 19 broke (between images 4E and 4F), after which the two first ends 13A, 13B of the two electrodes 12A, 12B withdrew relatively fast (within about 0.1 second), thereby forming a groove having a width of about 2 nm. This width could be increased by continued electron beam lighting. From the contrast obtained of the strip, it can be concluded that the height of the two first ends 13A, 13B was approximately equal above the membrane 8.

As the case may be, the height of the electrodes 12A, 12B may not be equal after the formation, which could be the result of, for instance, non-isotropic, lighting-induced mechanical stress which could lead to curling up of the electrode ends 13A, 13B. By use of polycrystalline metal strips, such as gold, provided on a membrane, for instance a 40 nm SiN membrane, which membrane was also locally removed during processing with the electron beam, this effect can be reduced or even be prevented. This local removal of the membrane has the additional advantage that, unintentionally, metal parts extending in the environment of the groove 11 were removed. In addition, the opening in the substrate under and around the groove offers high-resolution TEM inspection of molecules captured in the groove. The best control of the manufacture and processing of the electrodes 12 is obtained when the metal strip is located on the side facing the electron beam. Grooves with a width of about 1 and 5 nm were obtained, with minimal deformation.

The processing of platinum, as shown in Fig. 3, requires considerably more time than the processing of the gold. This seems to be the result of the fact that platinum atoms have a considerably lower mobility than those of gold. It has been found that control of radiation-induced recrystallization and atom transport plays a role in the control of the formation of the nanoelectrodes. Single crystal grains can be formed, which can be extended in the direction of the electron beam. It has been found that particularly platinum grains, thus formed with the aid of the electron beam, can be displaced by a gradual displacement of the electron beam as if it were a show shovel. It has been found that an electron beam with a relatively small spot size (for instance about 2 nm) resulted in less undesired recrystallization than an electron beam with a larger spot size.

Electron beam-induced changes in the strip are related to atom diffusion along surfaces and grain boundaries. Lateral atom displacements were clearly visible in the film from which the images were taken. The simplest cuts through polycrystalline strips 9 were made when the dimensions of any single crystalline grains were relatively small (preferably smaller than about 5 nm). However, for preserving the shape of the electrodes after processing, relatively large grains proved to be advantageous.

Within the present invention, use can be made of monocrystalline instead of polycrystalline strips, preferably through epitaxial growth on a monocrystalline silicon membrane and subsequent oxidation of the silicon. An advantage of this method is that a grain orientation can be chosen for which the surfaces of the electrodes are relatively stable. In addition, an increase of the temperature during radiation could accelerate the deformation of the metal, in particular platinum. Preferably, the electron beam is controlled, for instance in diameter, shape and intensity of the electron beam, depending on the observed changes in the material. It is, for instance, possible, when the groove 11 is formed, to reduce the intensity in order to prevent too fast a widening of the groove 11. Of course, with a method according to the present invention, more complex shapes than the straight grooves 11 shown can be manufactured as well, and also other elements than the electrodes mentioned. A method according to the present invention can excellently be combined with optical lithography and focused ion beam processing known per se.

A set of electrodes according to the present invention may, for instance, be used, together with an opening therewith, for detecting, for instance, molecules which go through this opening, such as for instance use as a nanosensor, comprising a pore with electrodes therewith for being able to quickly electrically detect, for instance, DNA strands (single DNA strands).

For carrying out a method according to the present invention as described with reference to Figs. 3 and 4, use was made of a Philips CN-300 UT-FEG controlled TEM (transmission electron microscope) with an acceleration voltage of 300 kV. Spot sizes between 2 and 10 nm were used with a current of about 5 nA. This corresponds with a flux of about 10^9 electrons/s nm^2. The metal strips were manufactured with the aid of electron beam lithography, after which, in the case of the platinum strips, a further deformation was obtained with focused ion beams. For this, 1 pA and 30 keV Ga^+ beam of a FEI Strata 238 Dual-Beam instrument was used.

Of course, other settings may be chosen, for instance depending on the metal. Thus, a lower energy can be used, for instance from 150 KeV, and/or a lower current, for instance from 2 nA.

The invention is not limited in any way to the exemplary embodiments shown in the description and drawings. Many variations thereof are possible within the framework of the invention as set forth in the claims.

Thus, other widths and/or thicknesses can be used in strips, as well as other types of supports. In addition, micropores can be manufactured with other applications.

These and similar variations are understood to be within the framework of the invention as set forth in the claims.

CLAIMS

1. A method for the formation of nanometer-scale electrodes, wherein a strip of electrically conductive material, in particular metal, is provided with a longitudinal direction, a width direction and a thickness direction and then, with the aid of an electron beam, a groove is provided in a top surface of the strip, in the width direction of the strip, with a nanometer-scale width in the longitudinal direction of the strip.

2. A method according to claim 1, wherein the top surface is determined by the longitudinal direction and the width direction, wherein the groove is provided with a depth in the thickness direction which is approximately equal to the thickness of the strip.

3. A method according to claim 1 or 2, wherein the groove divides the strip into two separate parts forming the electrodes.

4. A method according to any one of claims 1-3, wherein the strip is provided on a support, such that the thickness direction extends approximately at right angles to the support, wherein the groove is provided such that the strip is completely cut through, at least up to the support, thereby forming said electrodes on both sides of the groove.

5. A method according to claim 4, wherein the support under said groove is at least partly removed, thereby forming an opening under said groove.

6. A method according to any one of the preceding claims, wherein the electron beam is applied with the aid of an electron microscope.

7. A method according to any one of the preceding claims, wherein an electron beam is used with an energy level higher than about 100 keV, more in particular at least 300 keV, an electric current of more than 2 nA, more in particular at least 5 nA, wherein preferably a spot size of at least 2 nm and more in particular at least 10 nm is used.

8. A method according to any one of the preceding claims, wherein a strip is used and/or is manufactured from a pure metal or a metal alloy or a metallic oxide, wherein the material is preferably polycrystalline, bicrystalline or monocrystalline.

9. A method according to any one of the preceding claims, wherein the strip is applied or provided on a semiconductor or insulator, such as a silicon-based support.

10. A method according to any one of the preceding claims, wherein said strip is formed by photolithography or electron beam lithography.

11. A method according to any one of the preceding claims, wherein, during the formation of said groove, deformation of the strip is observed and wherein the electron beam is controlled on the basis of the observed deformation.

12. A method according to claim 11, wherein the electron beam is obtained with the aid of an electron microscope and wherein the deformation is observed with the aid of the same electron microscope.

13. A set of electrodes, substantially manufactured from a strip of metal, wherein the electrodes each comprise a first end, which first ends face each other and are at a mutual distance on a nanometer scale, which first ends have been formed by processing said strip with an electron beam, so that metal atoms have been diffused, at least displaced, thereby forming a groove in said strip.

14. A set of electrodes according to claim 13, wherein, at least prior to the formation of said groove, said strip has a thickness between 0.5 and 100 nm, in particular between 2 and 20 nm, more in particular between 5 and 15 nm and has a width of more than 2 nm, in particular more than 10 nm, more in particular more than 50 nm and preferably at least 100 nm and preferably less than 1000 nm.

15. A set of electrodes according to claim 13 or 14, wherein the strip is supported on a support, wherein the support is preferably provided with an opening under said groove.

16. Use of an electron beam for the formation of electrodes by diffusion of atoms.

17. Use of an electron microscope for the formation of electrodes from a metal strip.

18. An apparatus for the formation of at least two electrically conductive strip parts from a strip, comprising at least an electron microscope and a control device, wherein the control device is arranged for directing an electron beam of said electron microscope on a top surface of the strip and thereby forming, in said strip, a groove across the width of the strip by causing atoms of said strip to diffuse, and for observing the formation of the groove preferably in real time, wherein the control device is further arranged for controlling the electron beam on the basis of said observation.

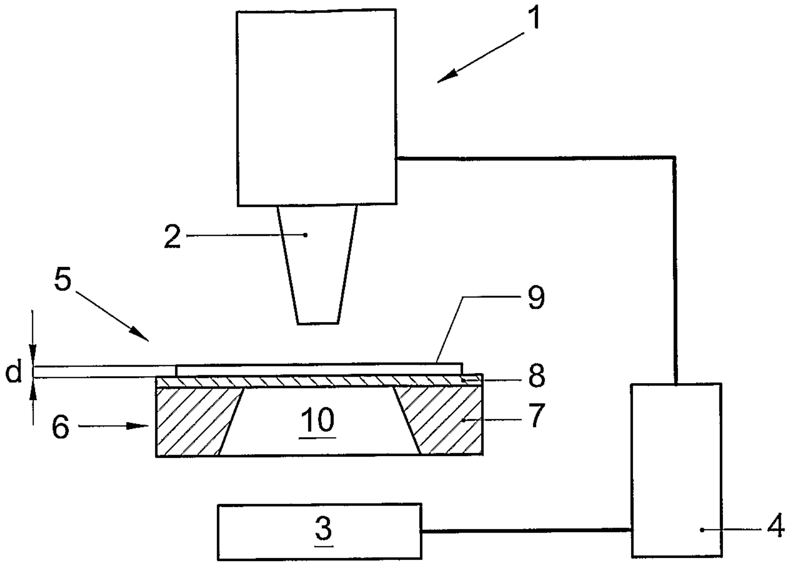


Fig. 1

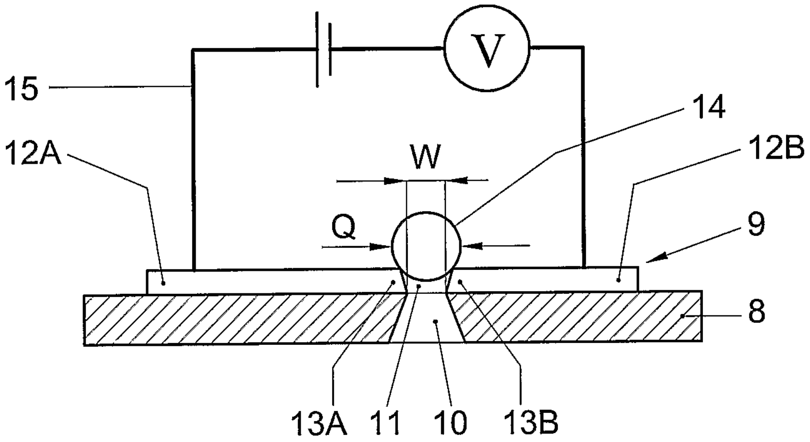


Fig. 2

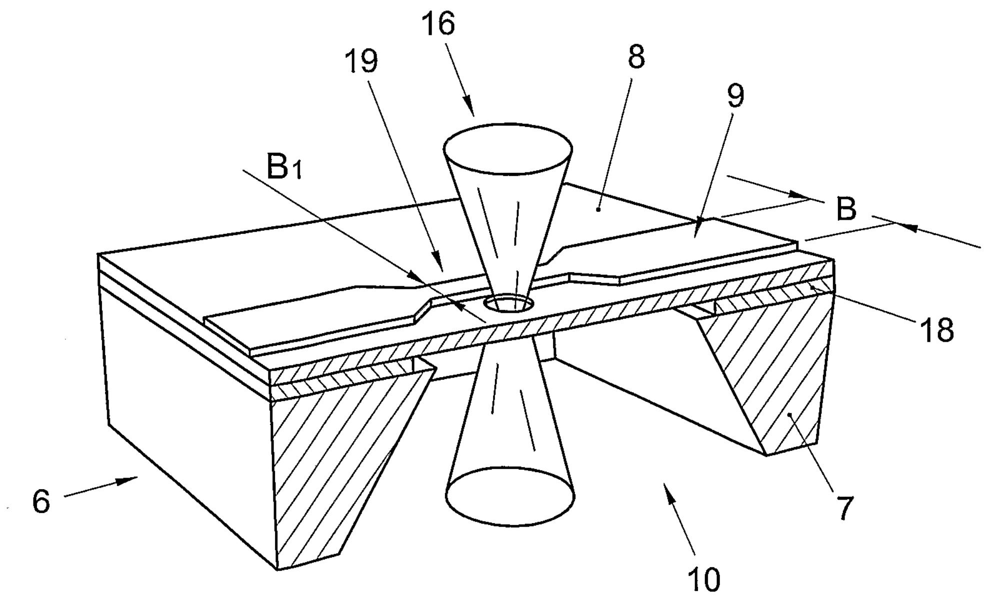


Fig. 3a

Fig. 3

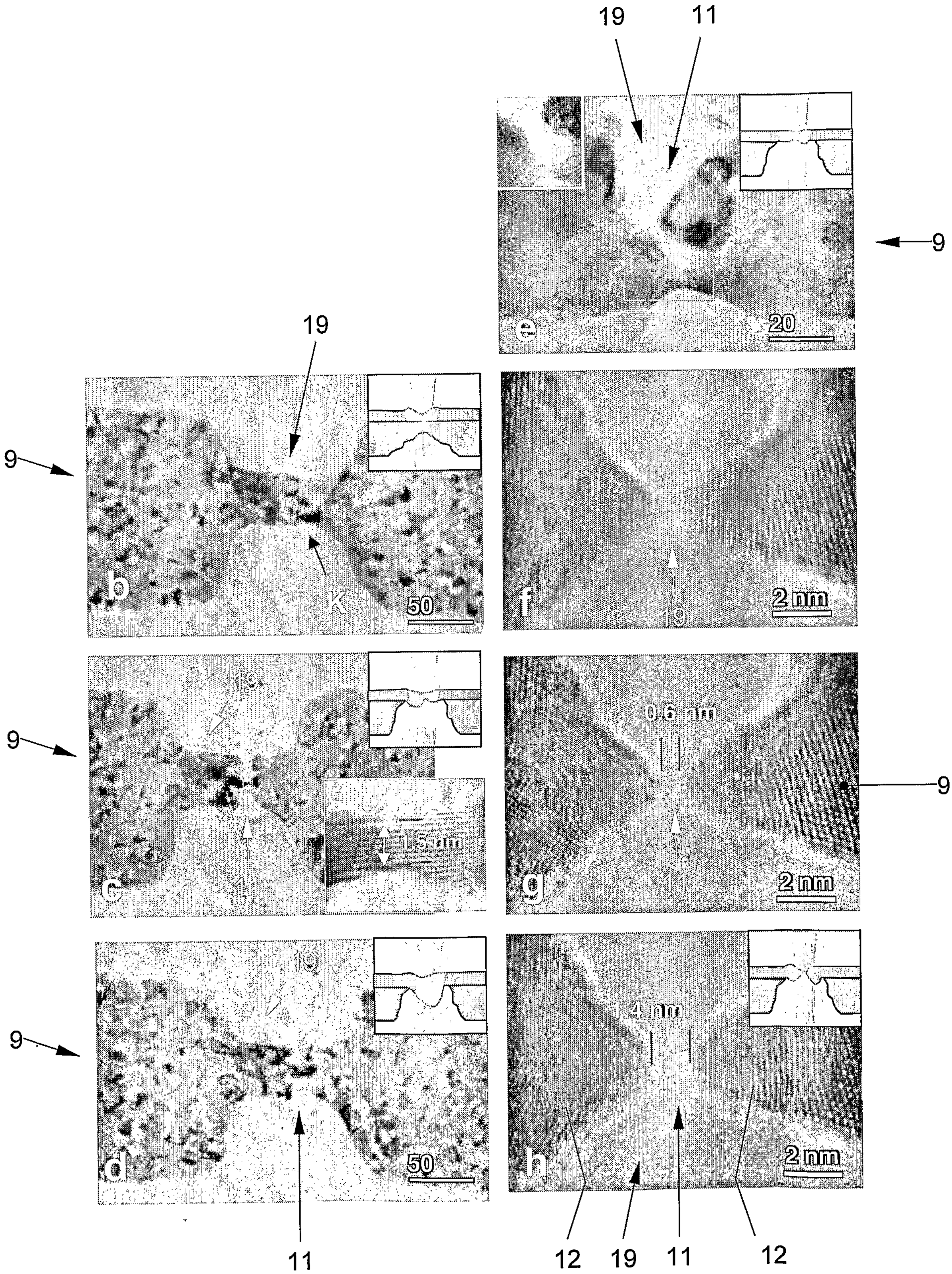
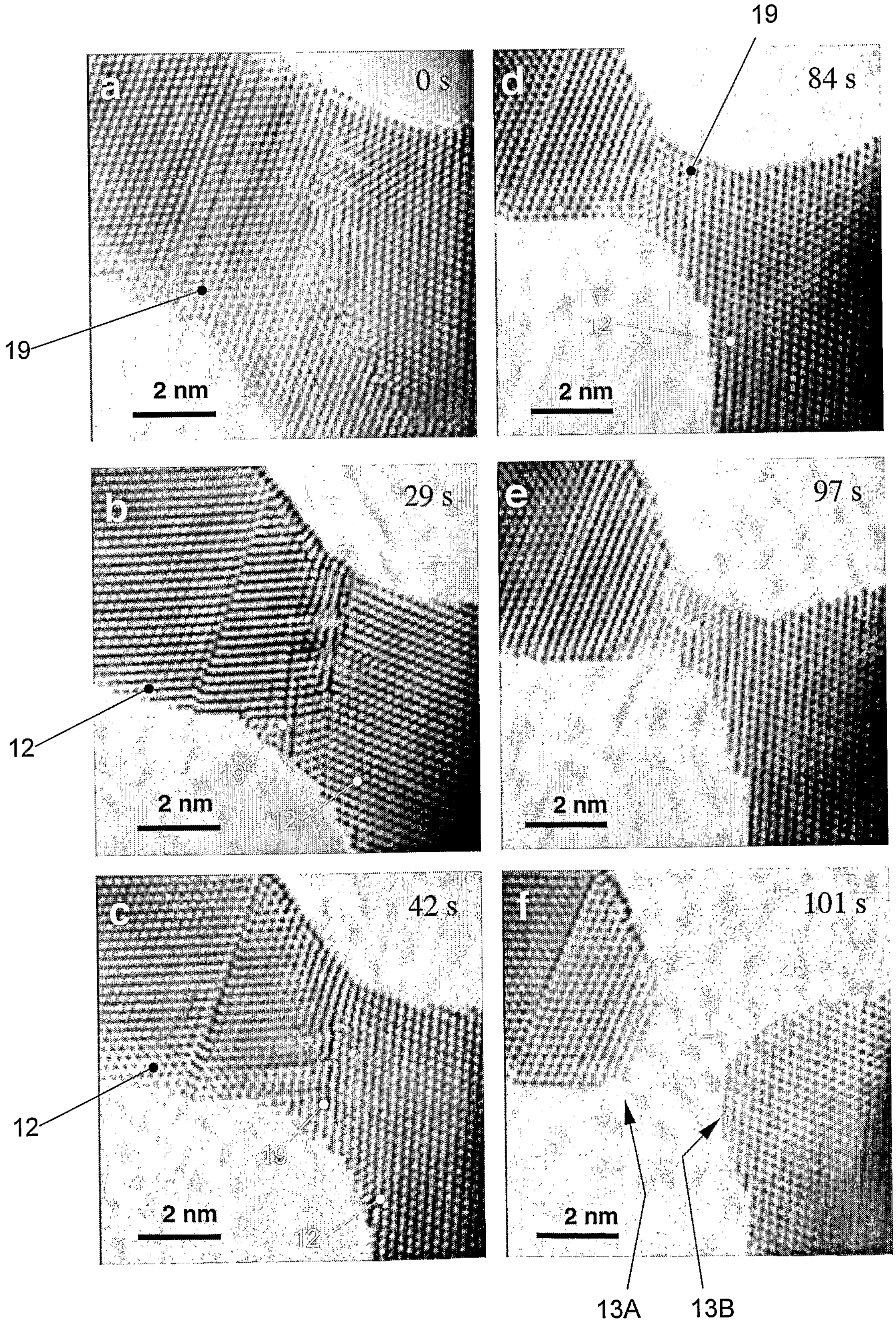

19
11
9
e
20
19
9
b
k
50
f
19
2 nm
19
9
c
1.5 nm
11
0.6 nm
9
g
11
2 nm
19
9
d
50
11
4 nm
h
2 nm
12
19
11
12

Fig. 4



a
0 s
19
2 nm
d
84 s
19
12
2 nm
b
29 s
12
19
12
2 nm
e
97 s
2 nm
c
42 s
12
19
12
2 nm
f
101 s
2 nm
13A
13B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL2005/000630

A. CLASSIFICATION OF SUBJECT MATTER
H01J37/31 B81B1/00 B23K15/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01J B81B B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/146430 A1 (DUGAS MATTHEW P) 29 July 2004 (2004-07-29) paragraphs '0041! - '0050!; figures 2-5 -----	1-18
X	EP 1 433 744 A (AGILENT TECHNOLOGIES, INC) 30 June 2004 (2004-06-30) paragraphs '0038! - '0042!; figure 9 -----	1-6,13, 15-17
A	US 2002/050565 A1 (TOKUDA MITSUO ET AL) 2 May 2002 (2002-05-02) abstract; figures 3,10 -----	1-18
A	US 4 508 952 A (MOCHEL ET AL) 2 April 1985 (1985-04-02) column 1, line 57 - column 2, line 23 ----- -/--	1-18

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 December 2005	21/12/2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Dauw, X

1

INTERNATIONAL SEARCH REPORT

International Application No
PCT/NL2005/000630

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	TURNER P S ET AL: "NANOMETRIC HOLE FORMATION IN MGO USING ELECTRON BEAMS" PHILOSOPHICAL MAGAZINE LETTERS, HAMPSHIRE, GB, vol. 61, no. 4, January 1990 (1990-01), pages 181-193, XP000106639 ISSN: 0950-0839 the whole document -----	1-18
A	BROERS A N ET AL: "Electron beam lithography - Resolution limits" MICROELECTRONIC ENGINEERING, ELSEVIER PUBLISHERS BV., AMSTERDAM, NL, vol. 32, no. 1, September 1996 (1996-09), pages 131-142, XP004013429 ISSN: 0167-9317 the whole document -----	1-18

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/NL2005/000630

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2004146430 A1	29-07-2004	NONE	
EP 1433744 A	30-06-2004	US 2004121525 A1	24-06-2004
US 2002050565 A1	02-05-2002	NONE	
US 4508952 A	02-04-1985	NONE	