



US00RE45204E

(19) **United States**
(12) **Reissued Patent**
Miyamoto et al.

(10) **Patent Number:** **US RE45,204 E**
(45) **Date of Reissued Patent:** **Oct. 21, 2014**

(54) **METHOD AND APPARATUS FOR CREATING IMAGING RECIPE**

(75) Inventors: **Atsushi Miyamoto**, Yokohama (JP);
Wataru Nagatomo, Yokohama (JP);
Ryoichi Matsuoka, Yotsukaido (JP);
Hidetoshi Morokuma, Hitachinaka (JP);
Takumichi Sutani, Hitachinaka (JP)

(73) Assignee: **Hitachi High-Technologies Corporation**, Tokyo (JP)

(21) Appl. No.: **12/614,358**

(22) Filed: **Nov. 6, 2009**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **7,559,047**
Issued: **Jul. 7, 2009**
Appl. No.: **11/342,694**
Filed: **Jan. 31, 2006**

(30) Foreign Application Priority Data

Jun. 15, 2005 (JP) 2005-174559

(51) **Int. Cl.**
G06F 17/50 (2006.01)

(52) **U.S. Cl.**
USPC **716/55**; 716/51; 716/53; 382/144

(58) **Field of Classification Search**
USPC 716/50–56; 382/144–145; 352/144–145
See application file for complete search history.

(56) References Cited

U.S. PATENT DOCUMENTS

5,621,653 A 4/1997 Yuzawa
6,016,357 A * 1/2000 Neary et al. 382/144
6,581,193 B1 6/2003 McGhee et al.
6,691,052 B1 2/2004 Maurer

6,868,175 B1 3/2005 Yamamoto
6,886,153 B1 * 4/2005 Bevis 716/19
6,909,930 B2 * 6/2005 Shishido et al. 700/121
7,065,239 B2 6/2006 Maayah
7,123,356 B1 10/2006 Stokowski et al.
7,133,550 B2 * 11/2006 Hiroi et al. 382/145
7,187,796 B1 * 3/2007 Phan et al. 382/144
7,266,235 B2 * 9/2007 Hiroi et al. 382/145
7,269,816 B2 * 9/2007 Bevis 716/19
7,318,214 B1 * 1/2008 Prasad et al. 716/21
2003/0053676 A1 * 3/2003 Shimoda et al. 382/145
2003/0059104 A1 * 3/2003 Mitsui 382/145
2003/0237064 A1 * 12/2003 White et al. 716/5
2004/0081350 A1 4/2004 Kitamura et al.
2004/0181768 A1 * 9/2004 Krukar 716/19

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2000-236007 8/2000
JP 2002-328015 11/2002

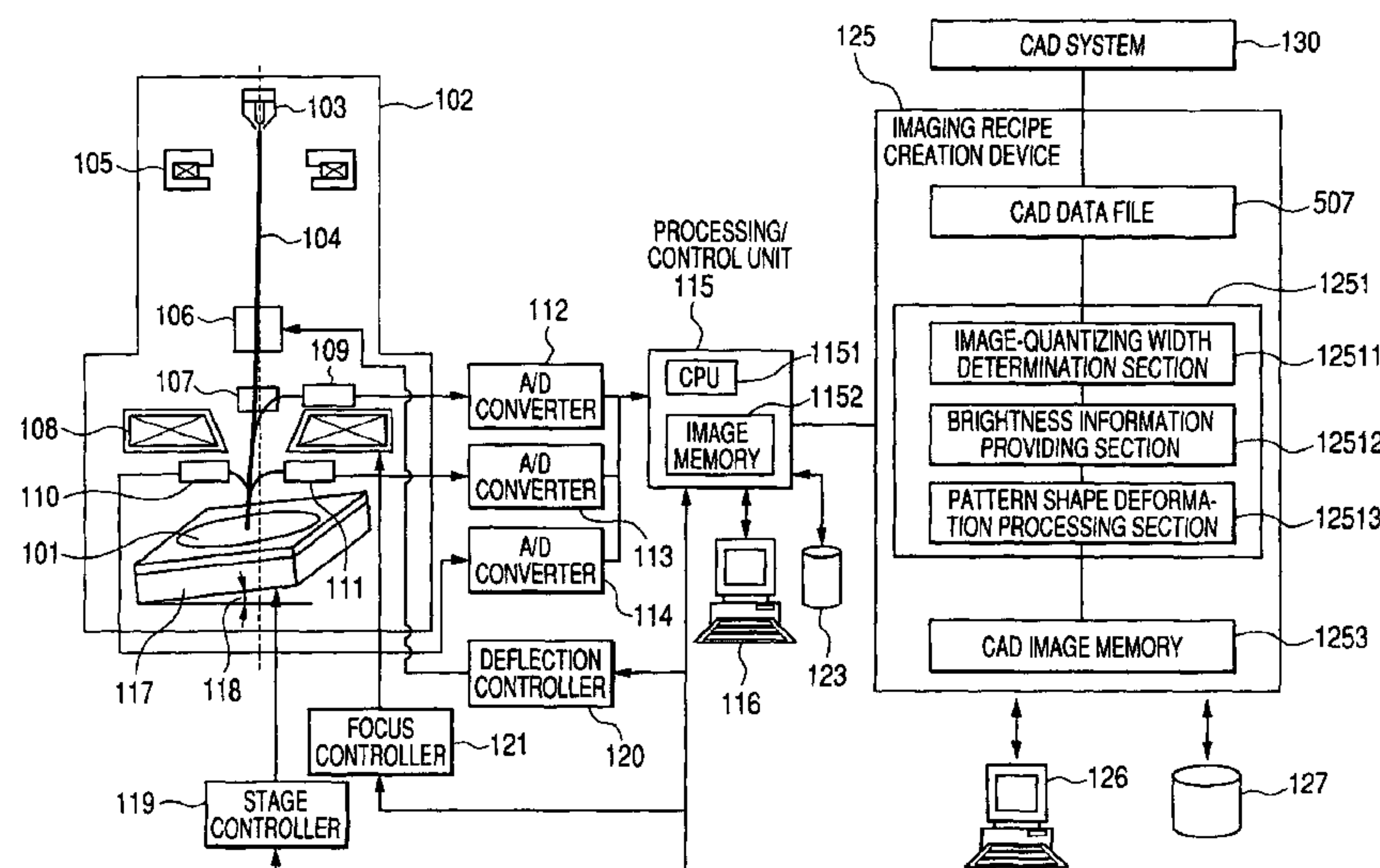
Primary Examiner — Stacy Whitmore

(74) *Attorney, Agent, or Firm* — Antonelli, Terry, Stout & Kraus, LLP.

(57) **ABSTRACT**

In an imaging recipe creating apparatus that uses a scanning electron microscope to create an imaging recipe for SEM observation of a semiconductor pattern, in order that the imaging recipe for measuring the wiring width and other various dimension values of the pattern from an observation image and thus evaluating the shape of the pattern is automatically generated within a minimum time by the analysis using the CAD image obtained by conversion from CAD data, an CAD image creation unit that creates the CAD image by converting the CAD data into an image format includes an image-quantizing width determining section, a brightness information providing section, and a pattern shape deformation processing section; the imaging recipe being created using the CAD image created by the CAD image creation unit.

16 Claims, 24 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

2004/0228515 A1 11/2004 Okabe

2005/0146714 A1 7/2005 Kitamura

2005/0160394 A1 * 7/2005 Bevis 716/19

2005/0226494 A1 10/2005 Yamamoto

2006/0245636 A1 11/2006 Kitamura et al.

2006/0248081 A1 11/2006 Lamy

2006/0284081 A1 * 12/2006 Miyamoto et al. 250/307

2007/0156275 A1 * 7/2007 Piper et al. 700/121

2007/0210252 A1 9/2007 Miyamoto

2008/0002876 A1 1/2008 Hiroi et al.

2008/0022876 A1 * 1/2008 Yokoyama et al. 101/477

2008/0056559 A1 * 3/2008 Hiroi et al. 382/145

2010/0246933 A9 * 9/2010 Hiroi et al. 382/145

* cited by examiner

FIG. 1

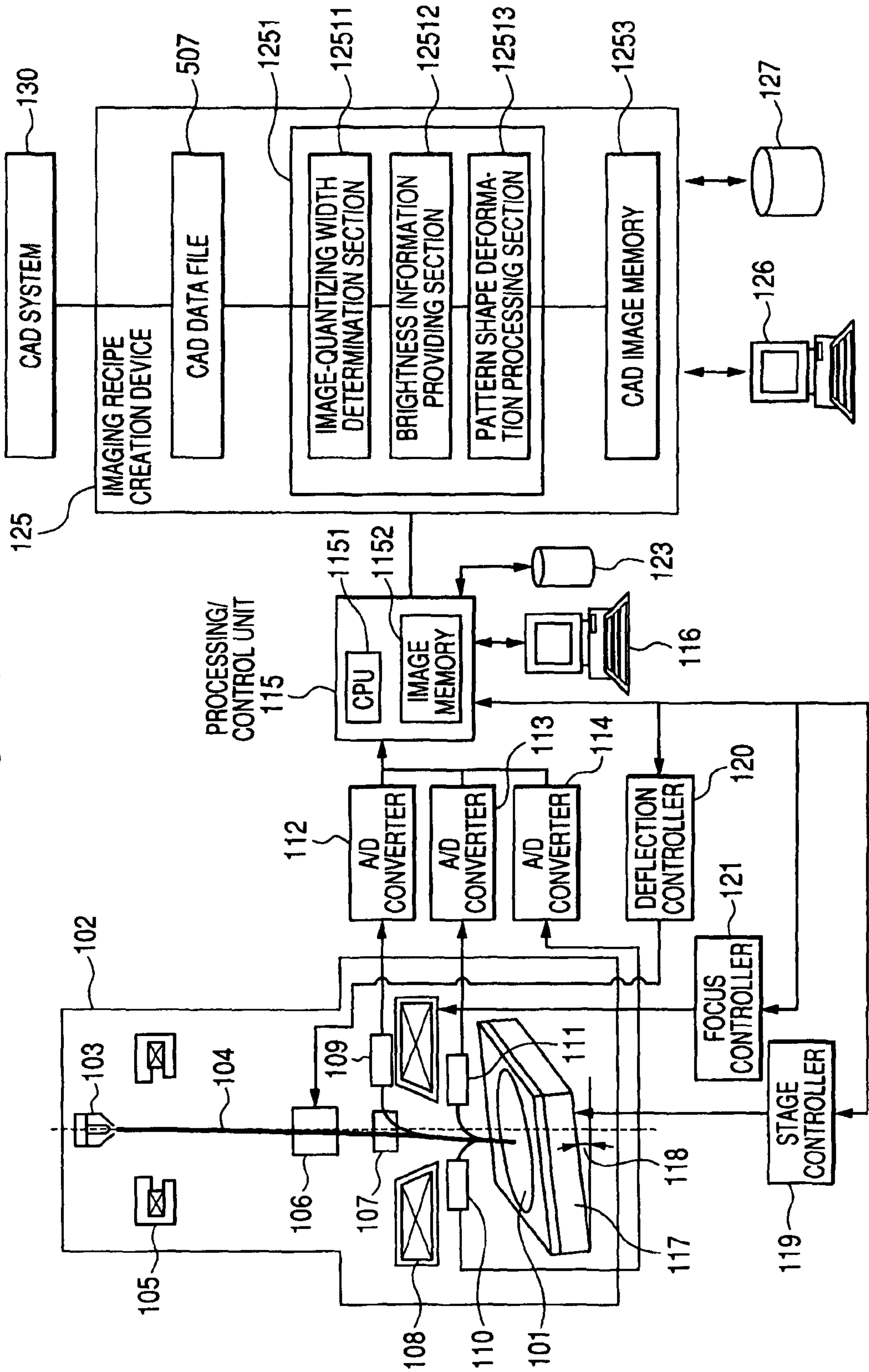


FIG. 2A

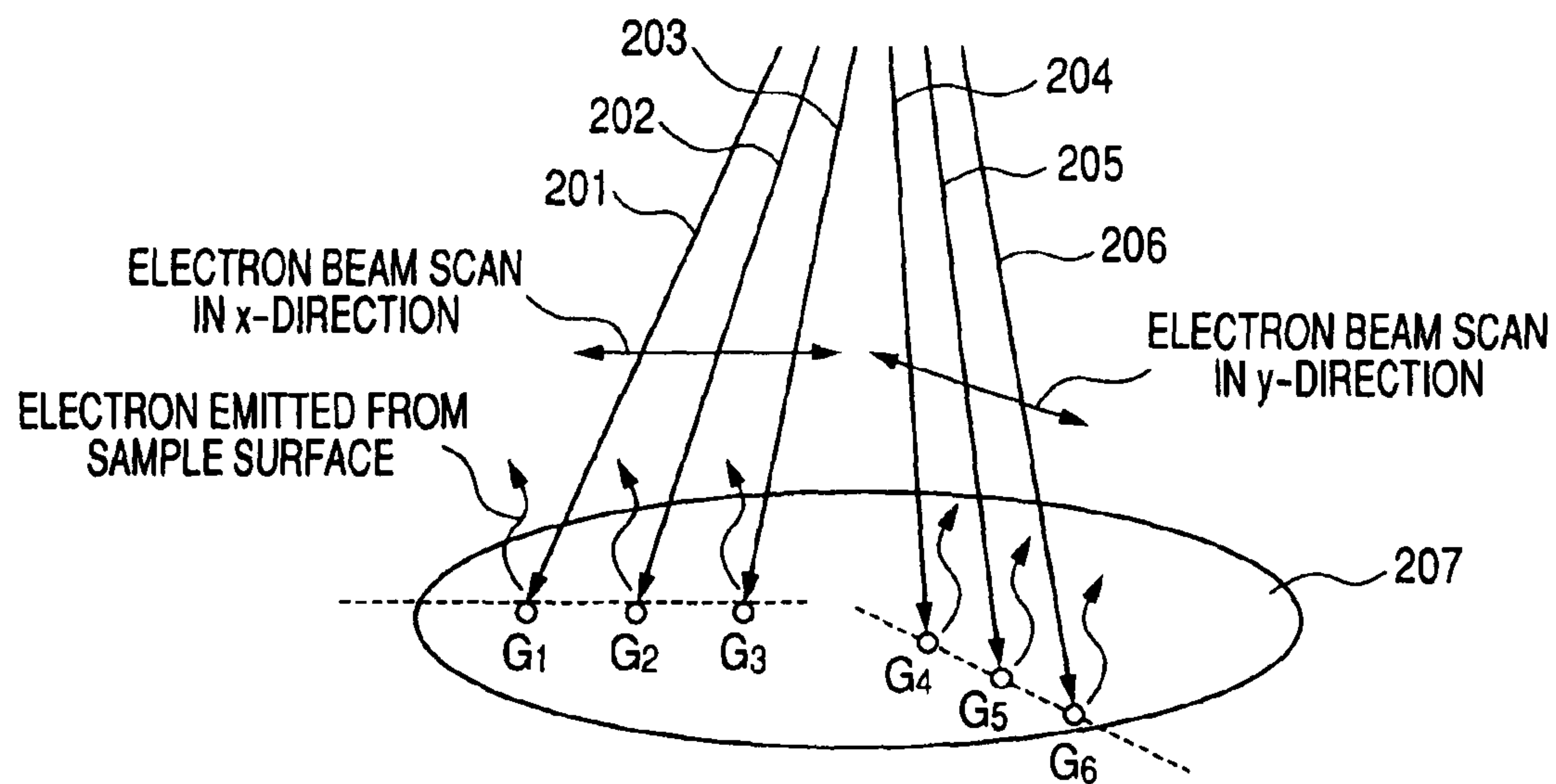


FIG. 2B

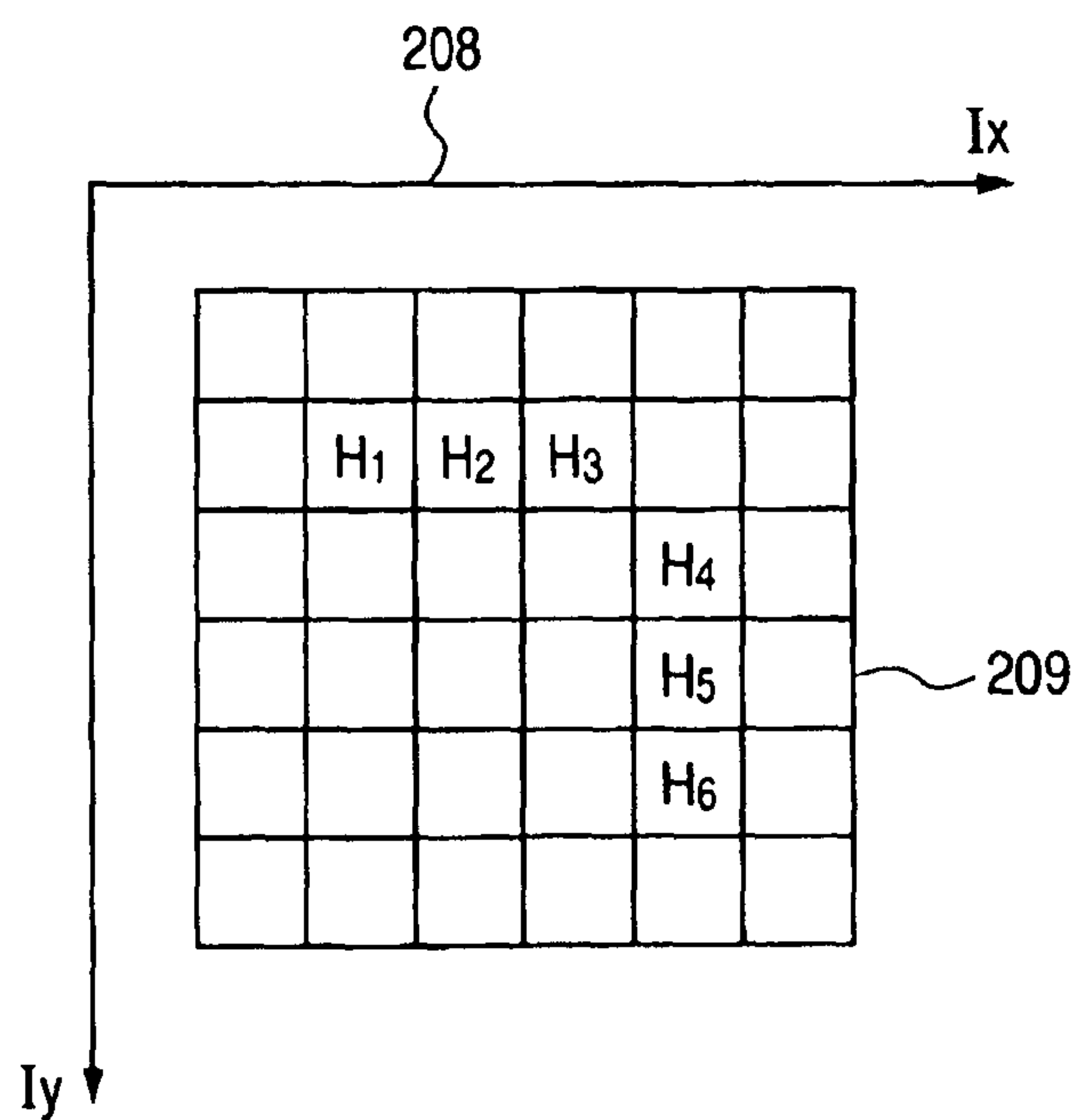


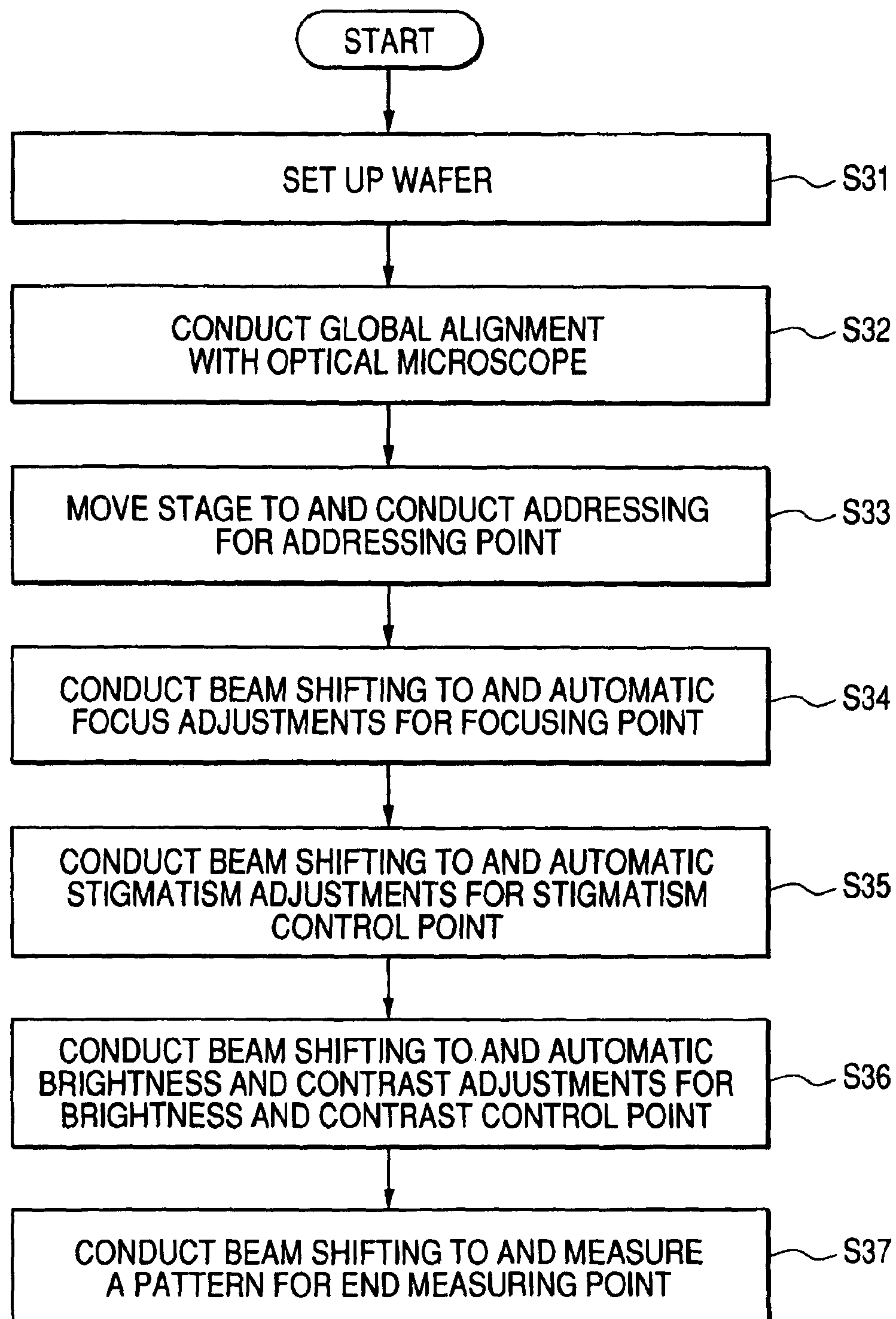
FIG. 3

FIG. 4

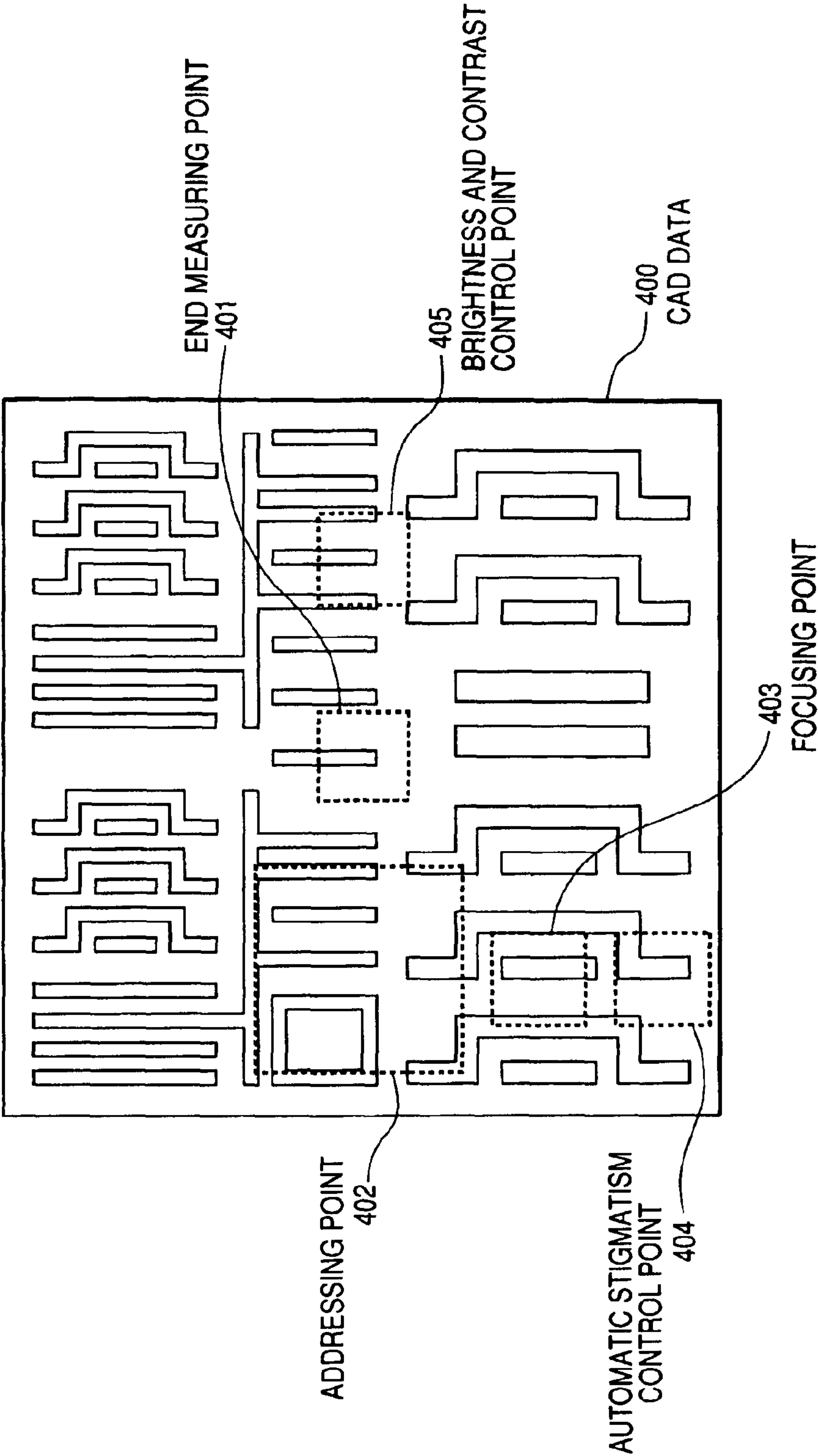


FIG. 5A

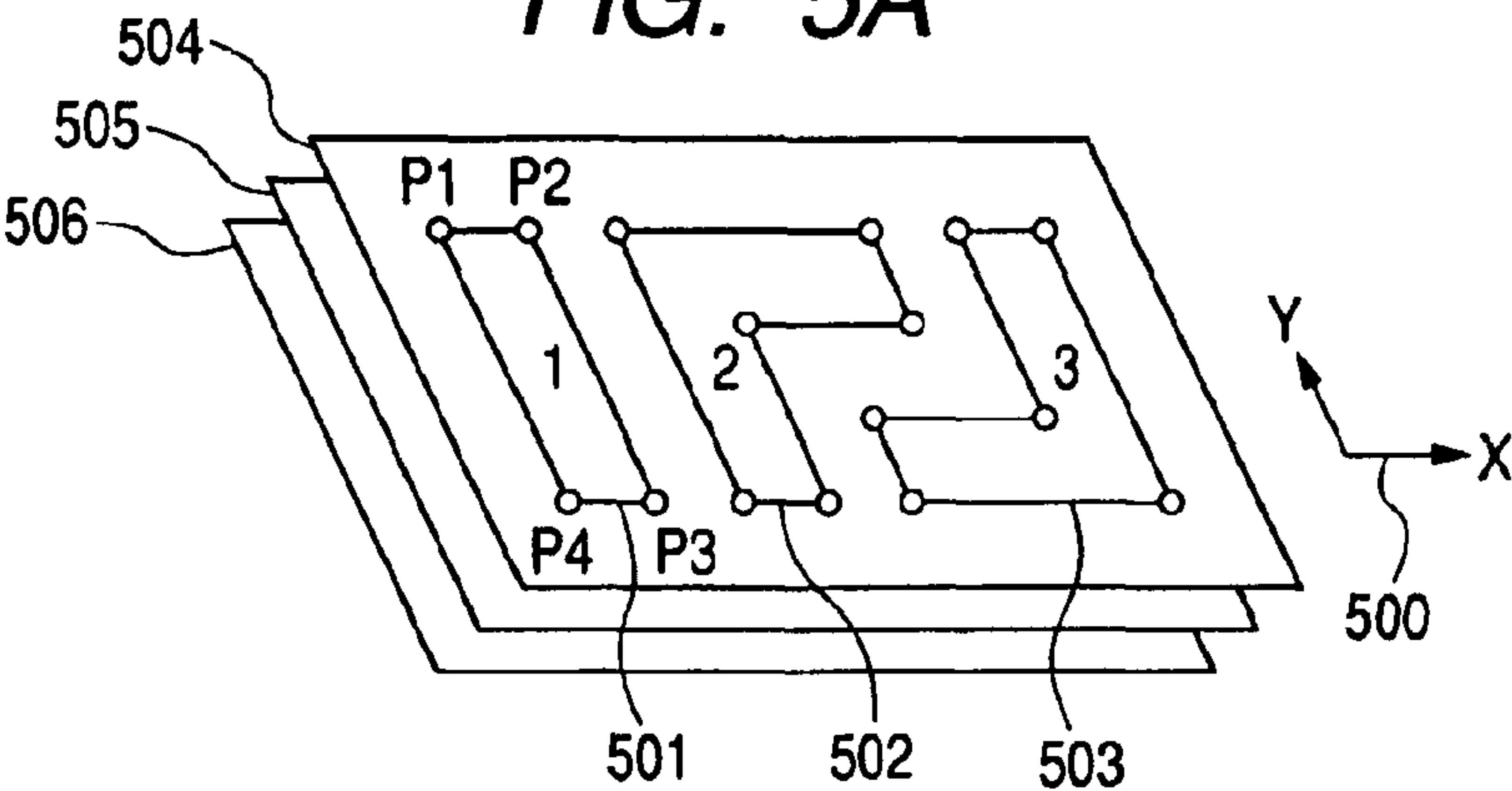


FIG. 5B

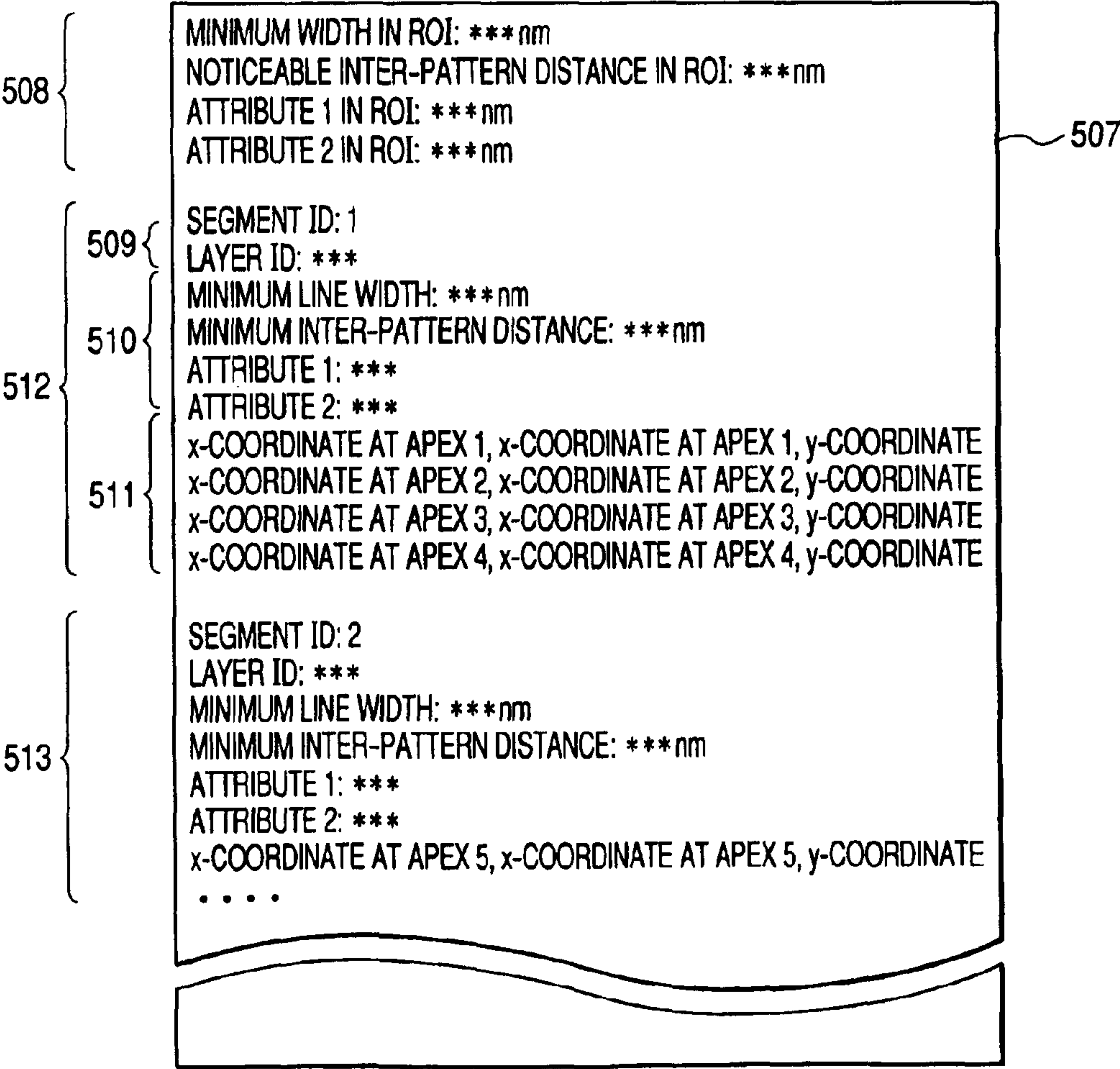


FIG. 6

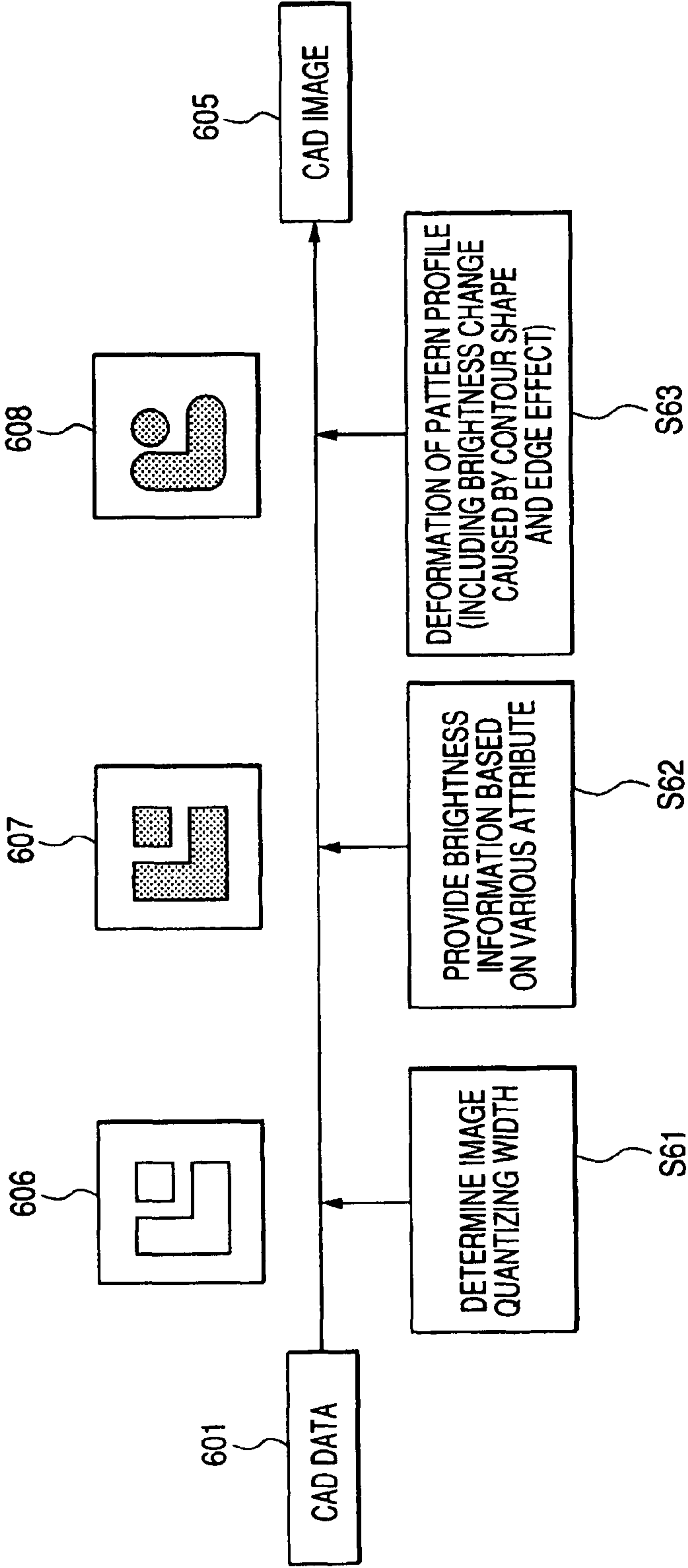


FIG. 7A

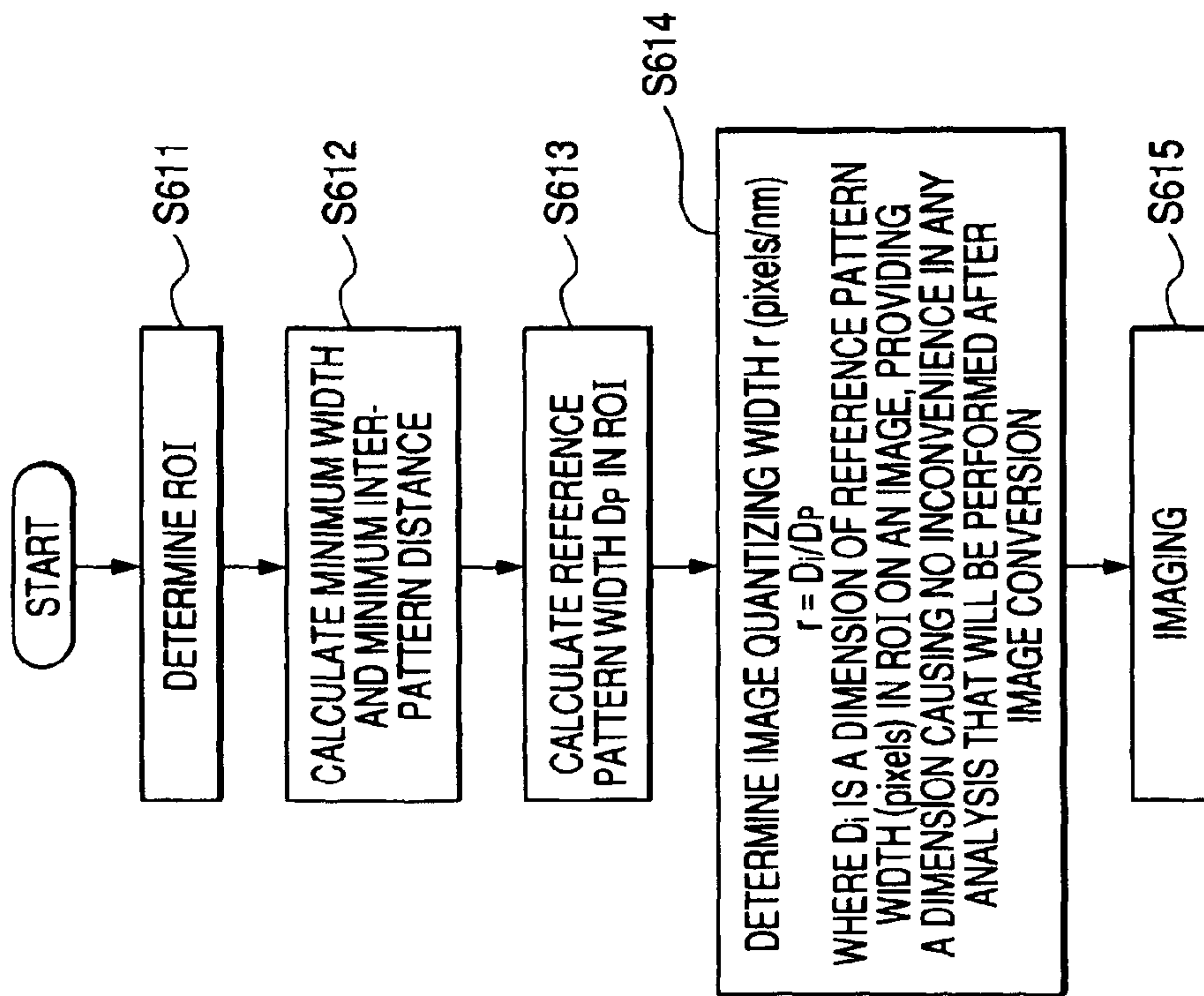


FIG. 7B

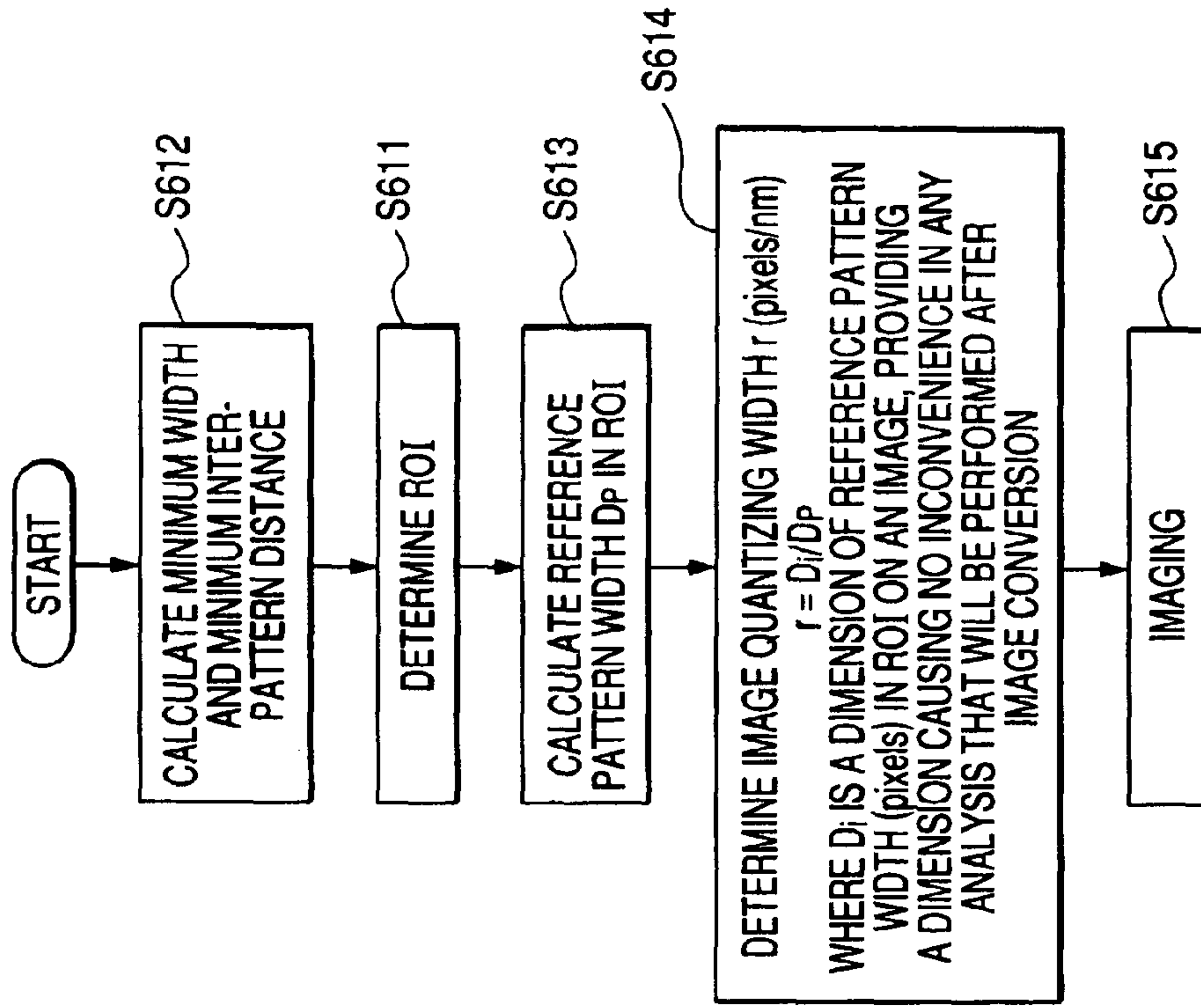


FIG. 8A

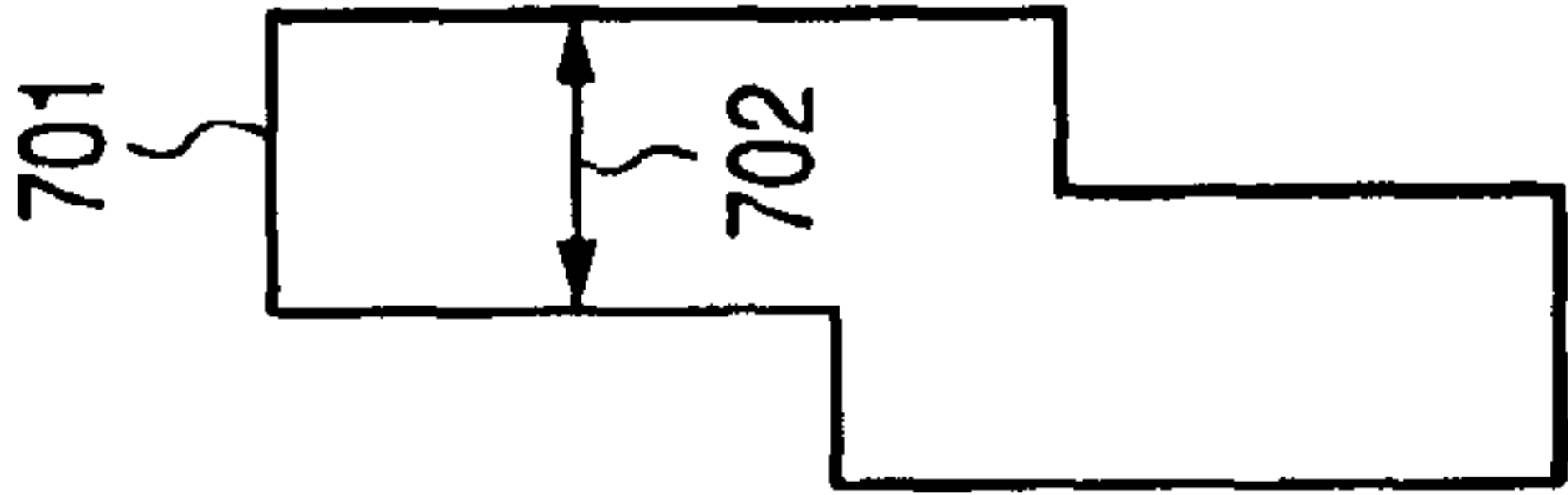


FIG. 8B

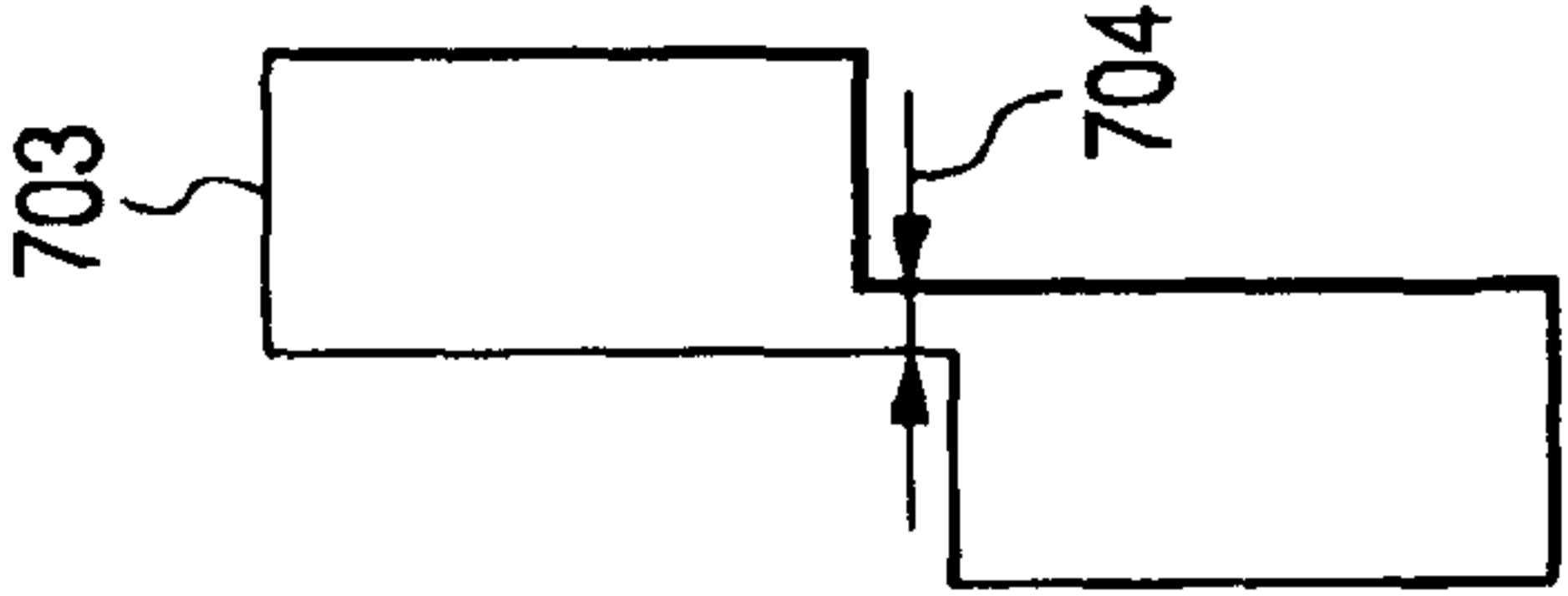


FIG. 8C

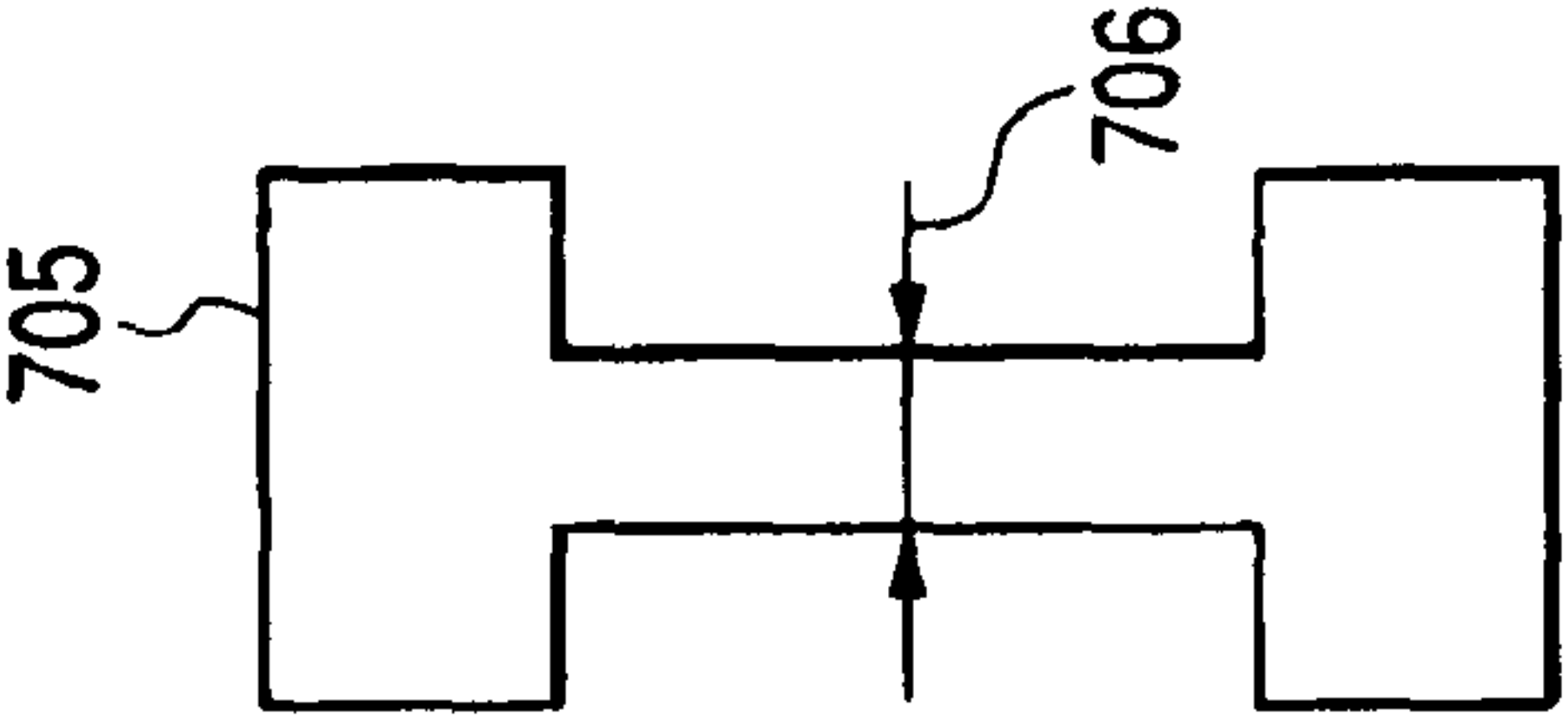


FIG. 8D

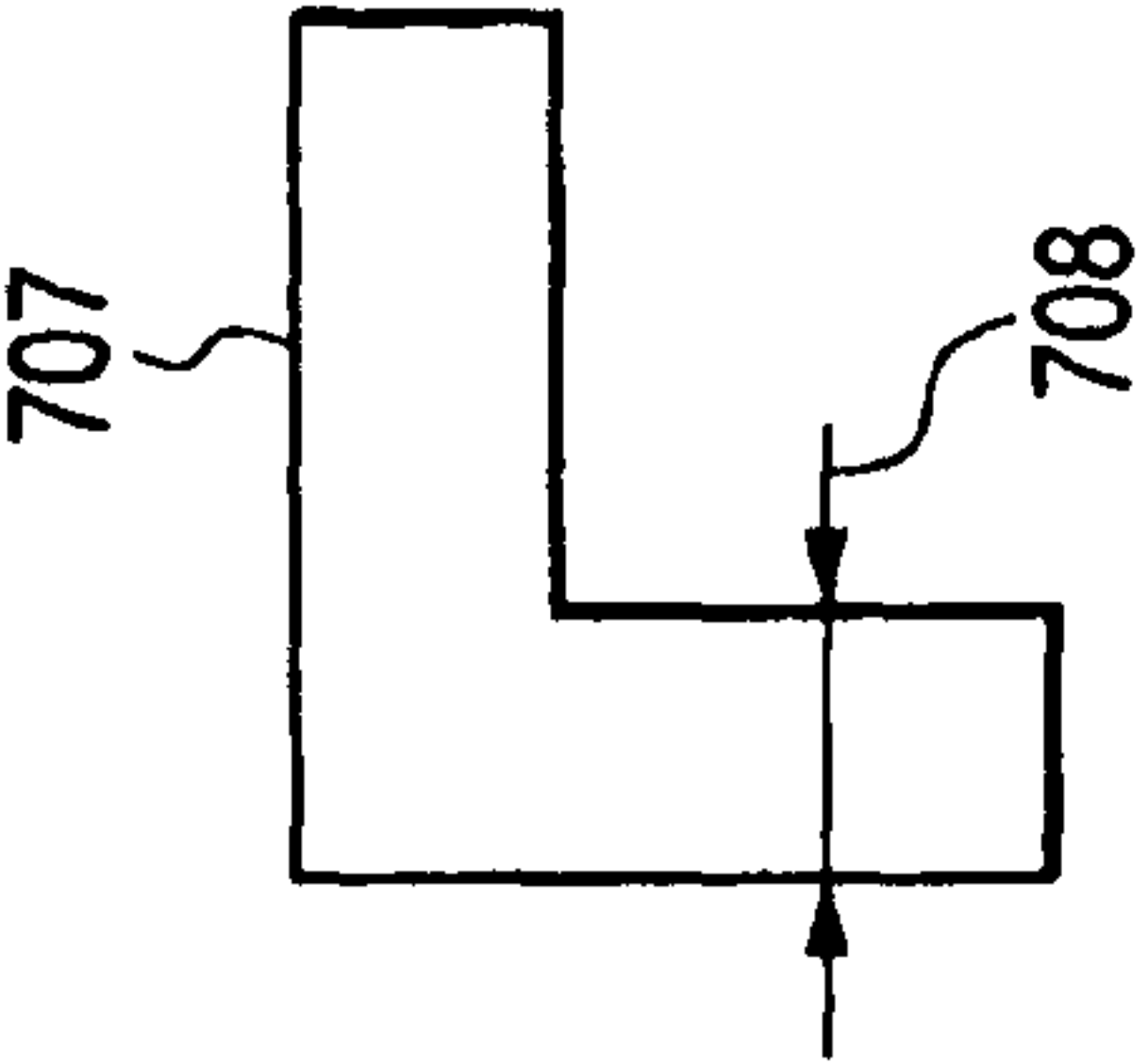


FIG. 8E

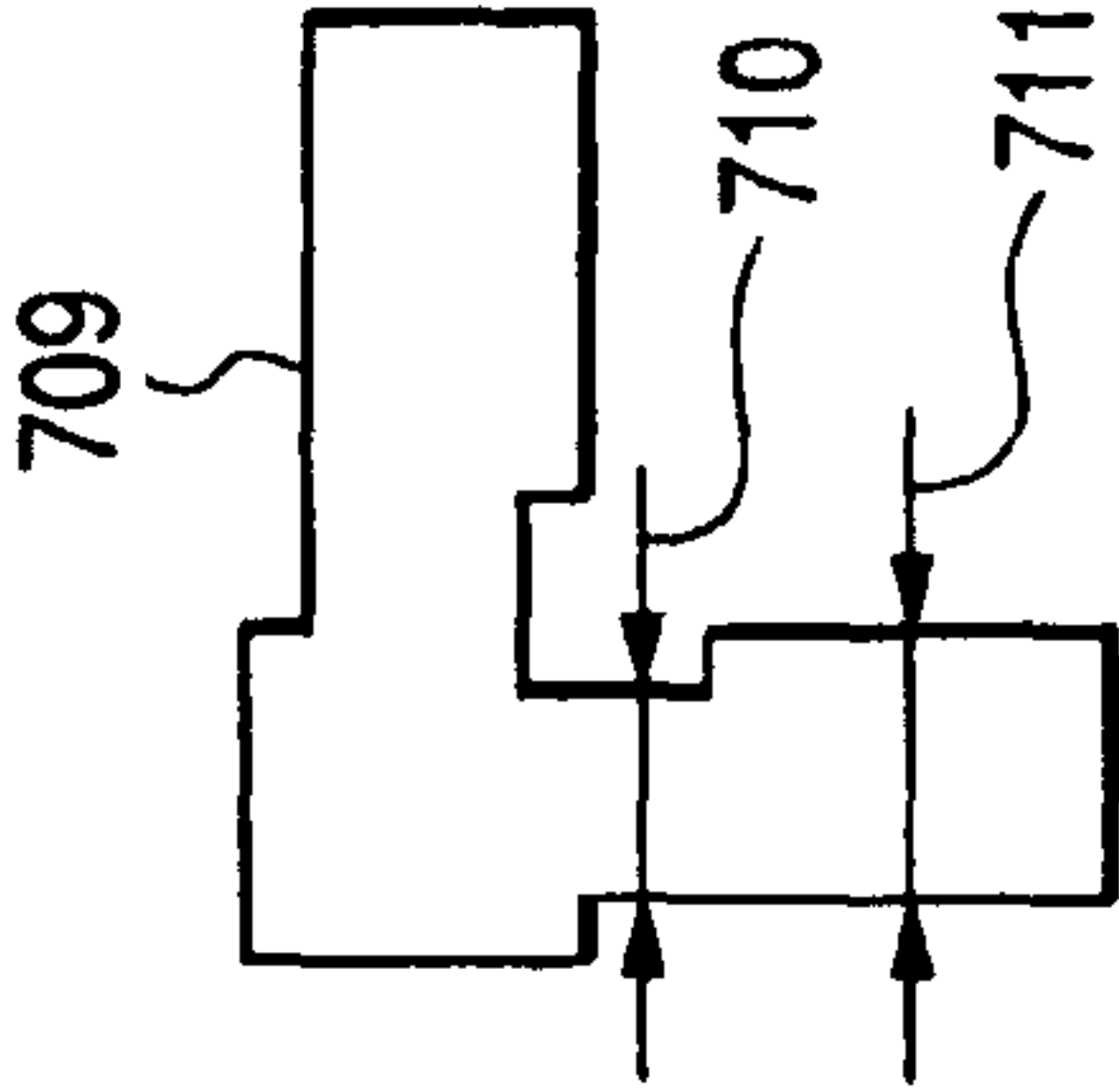


FIG. 9A

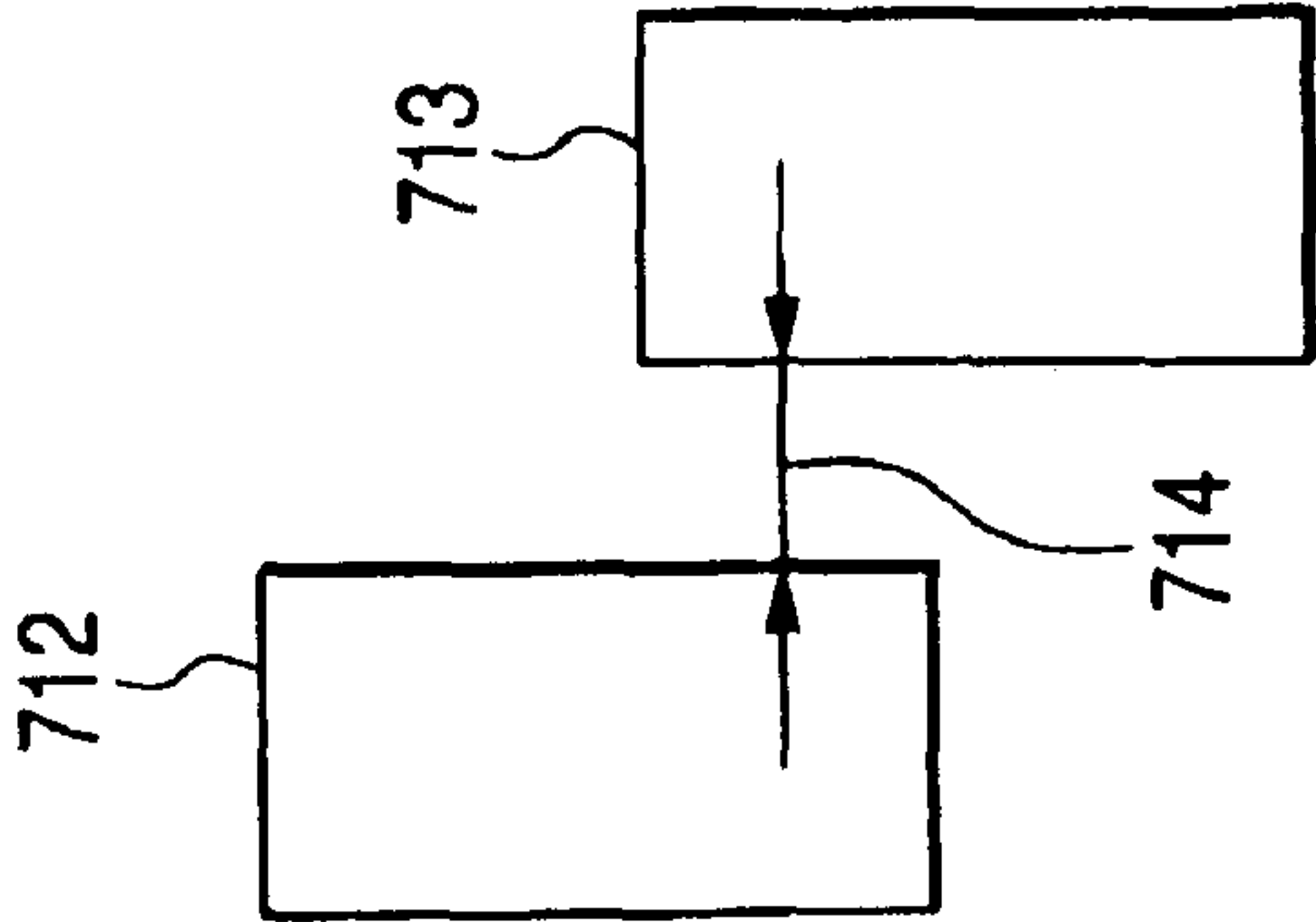


FIG. 9B

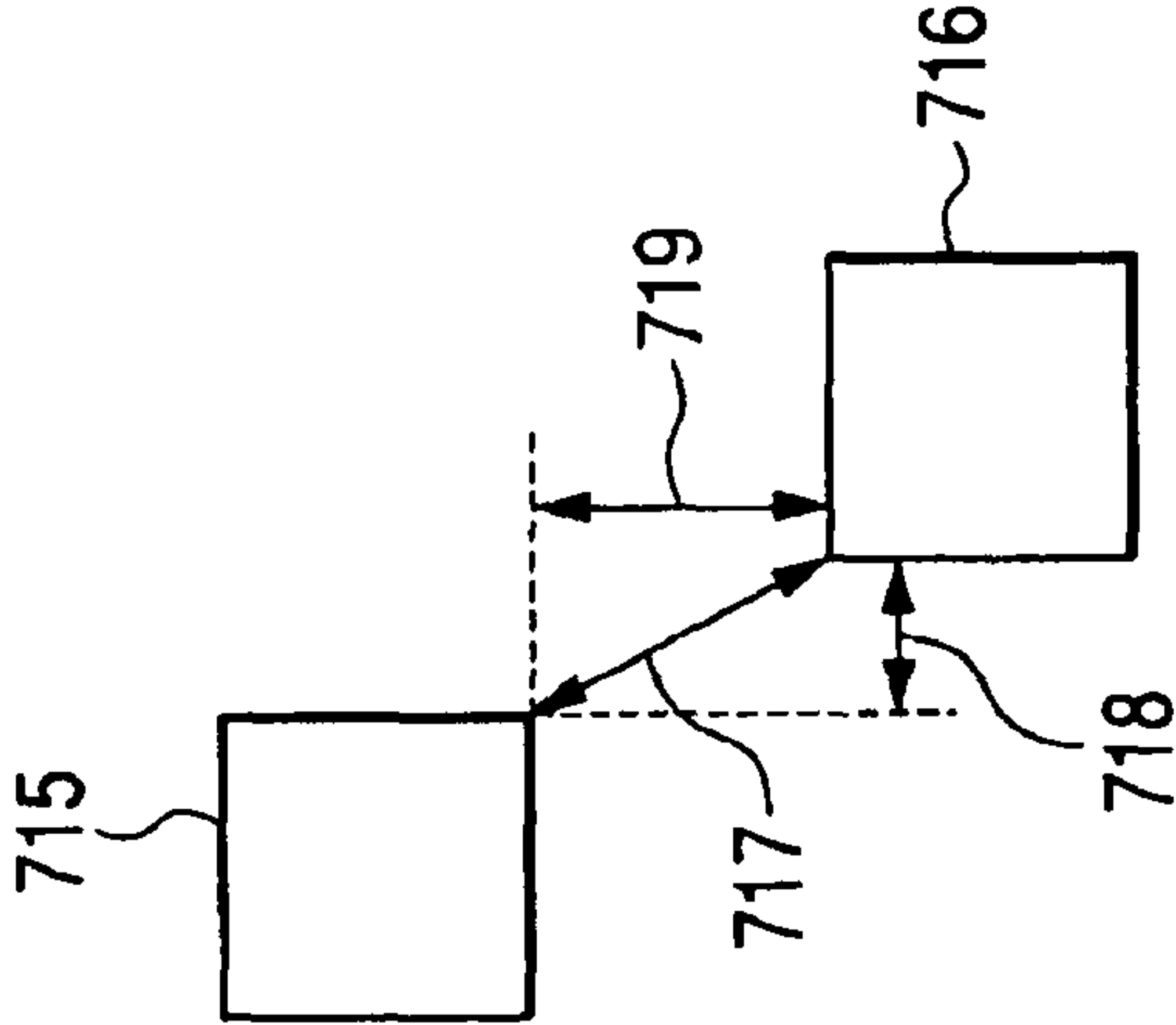


FIG. 9C

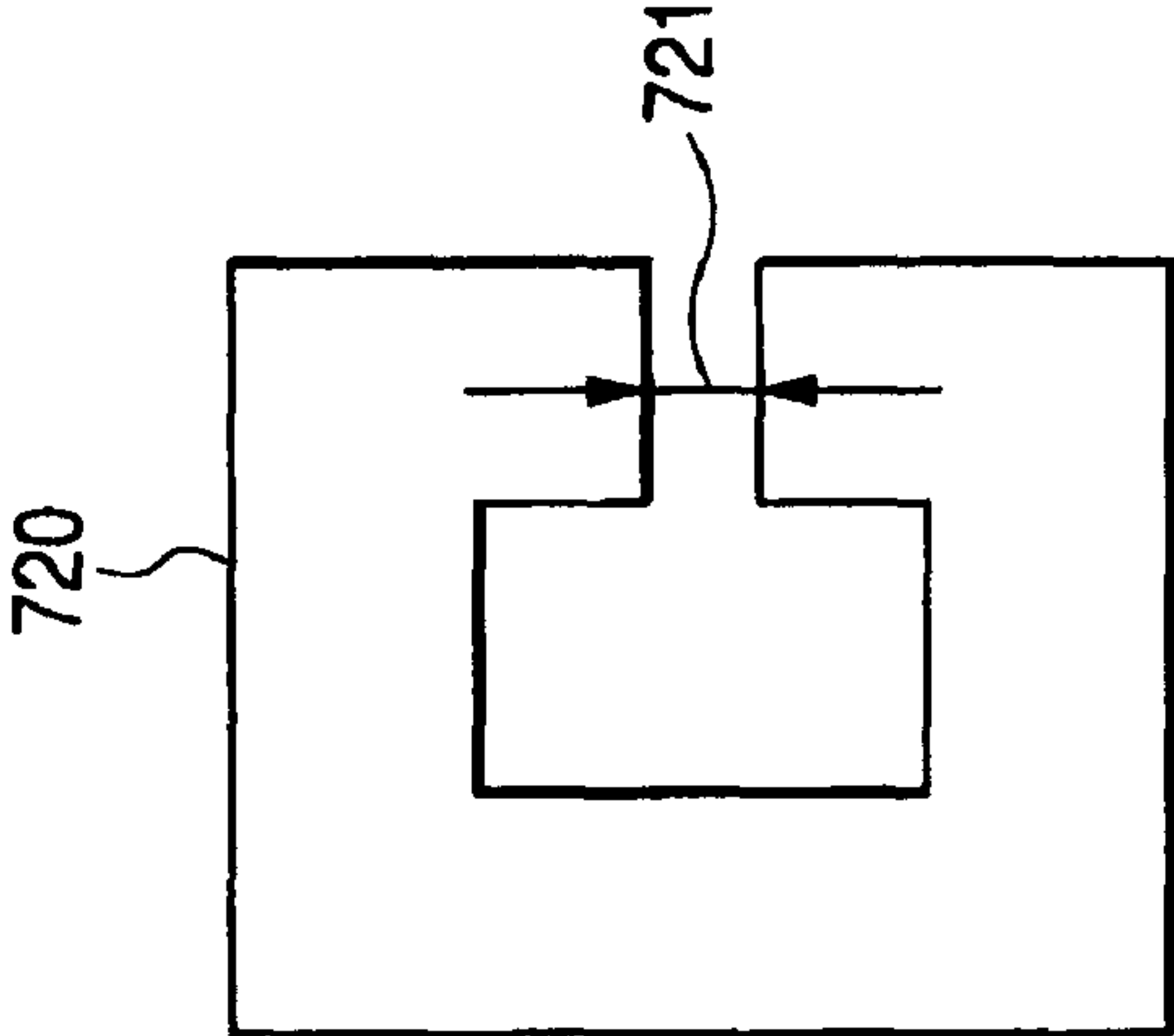


FIG. 10

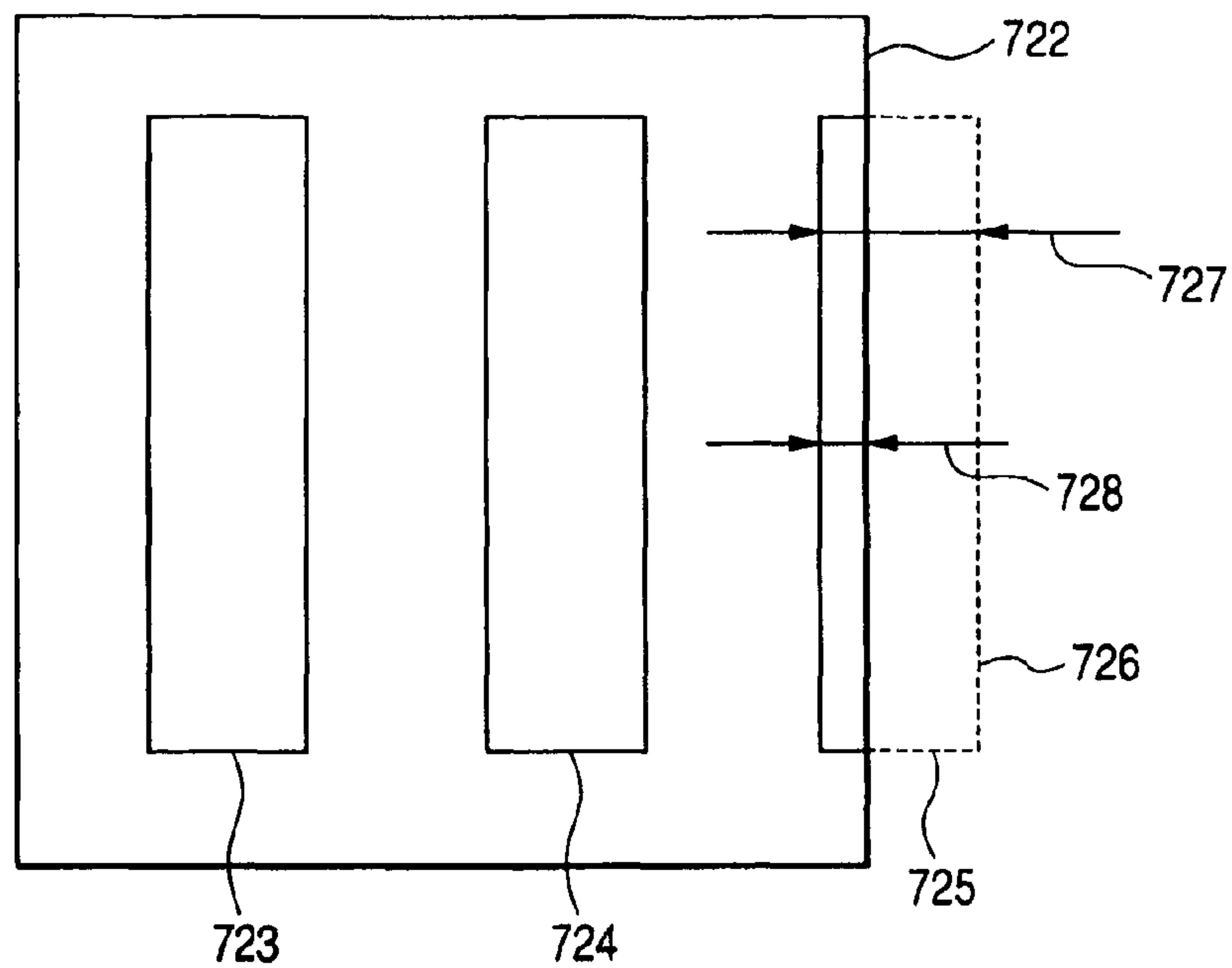


FIG. 11A

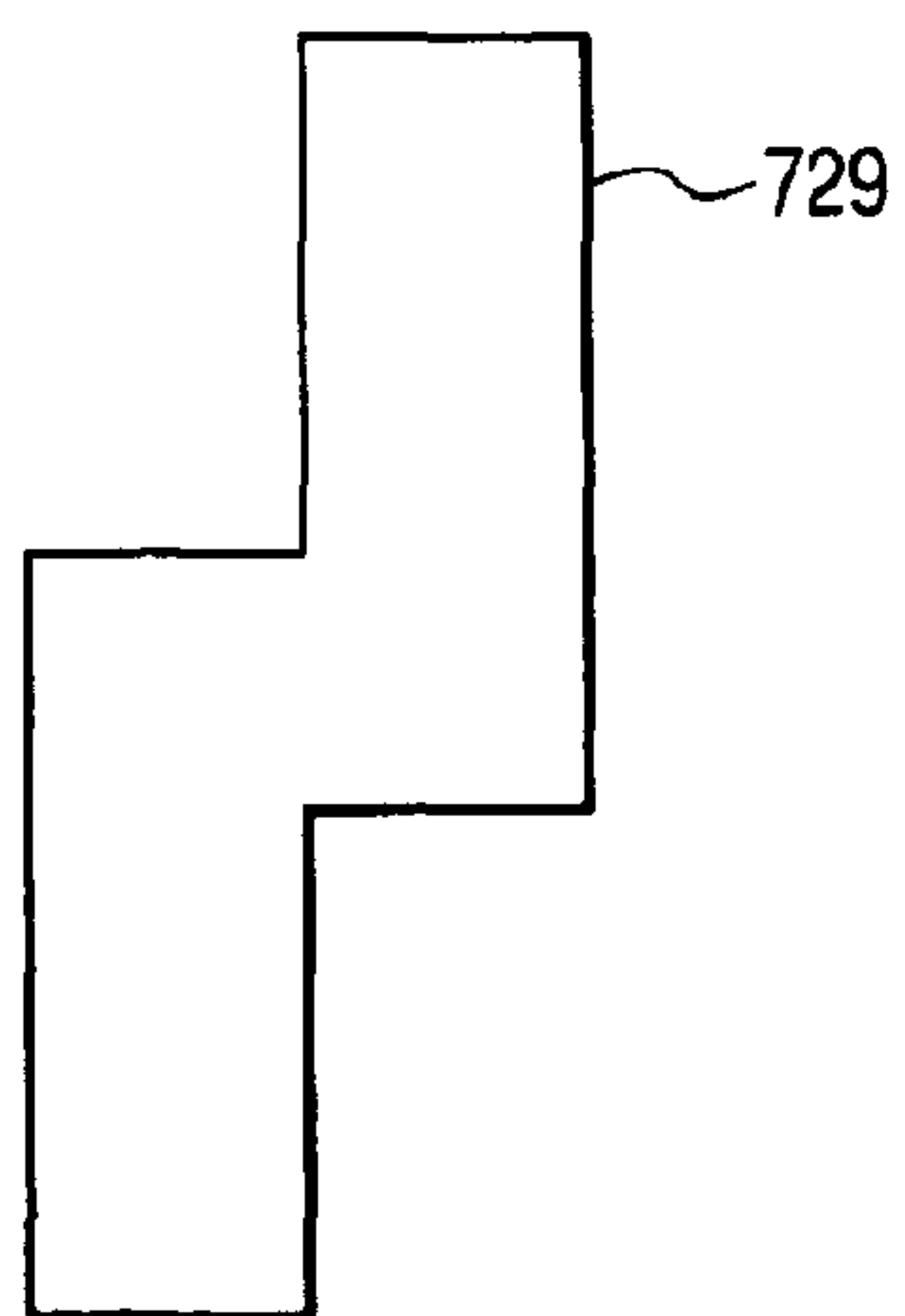


FIG. 11B

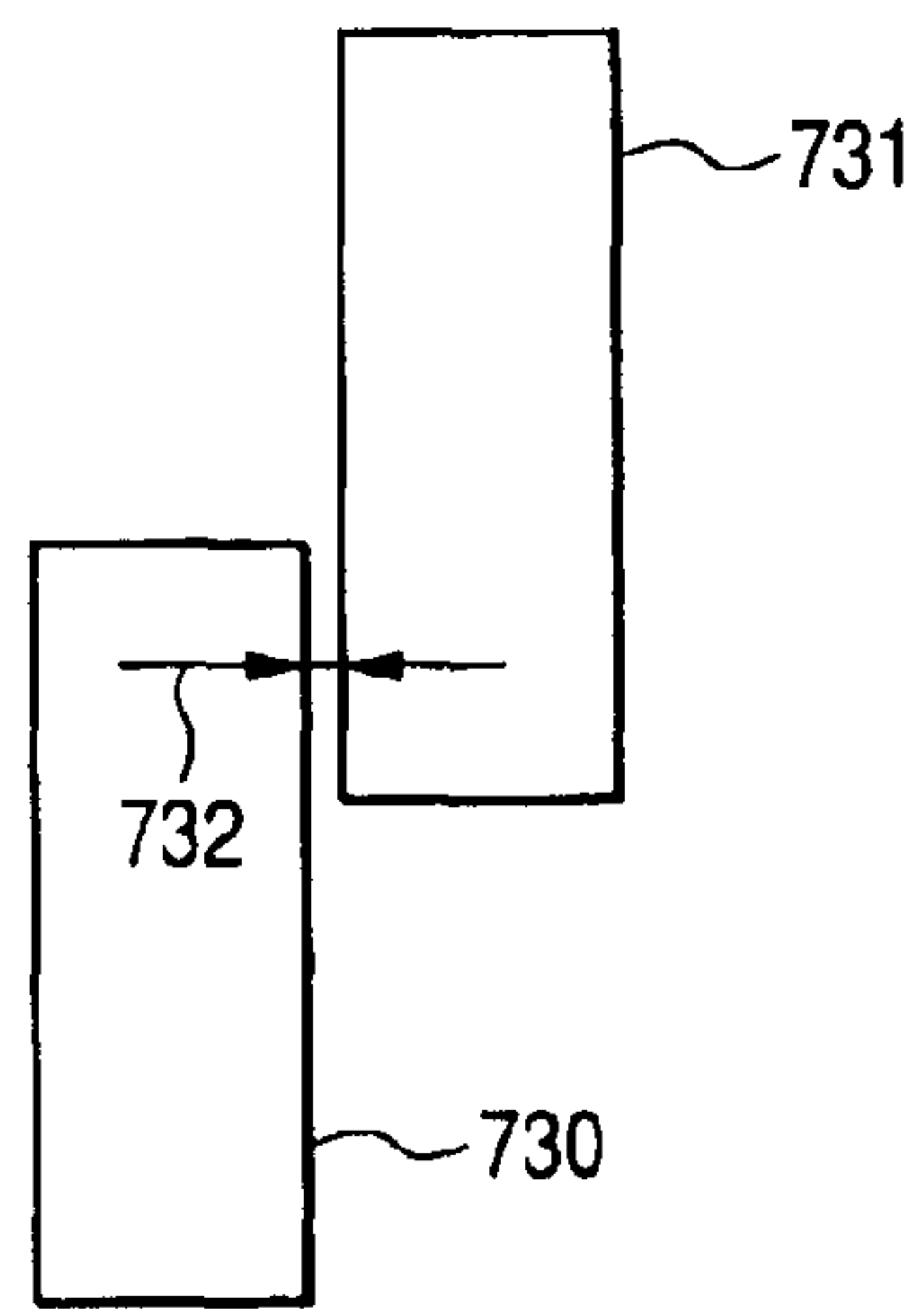


FIG. 12

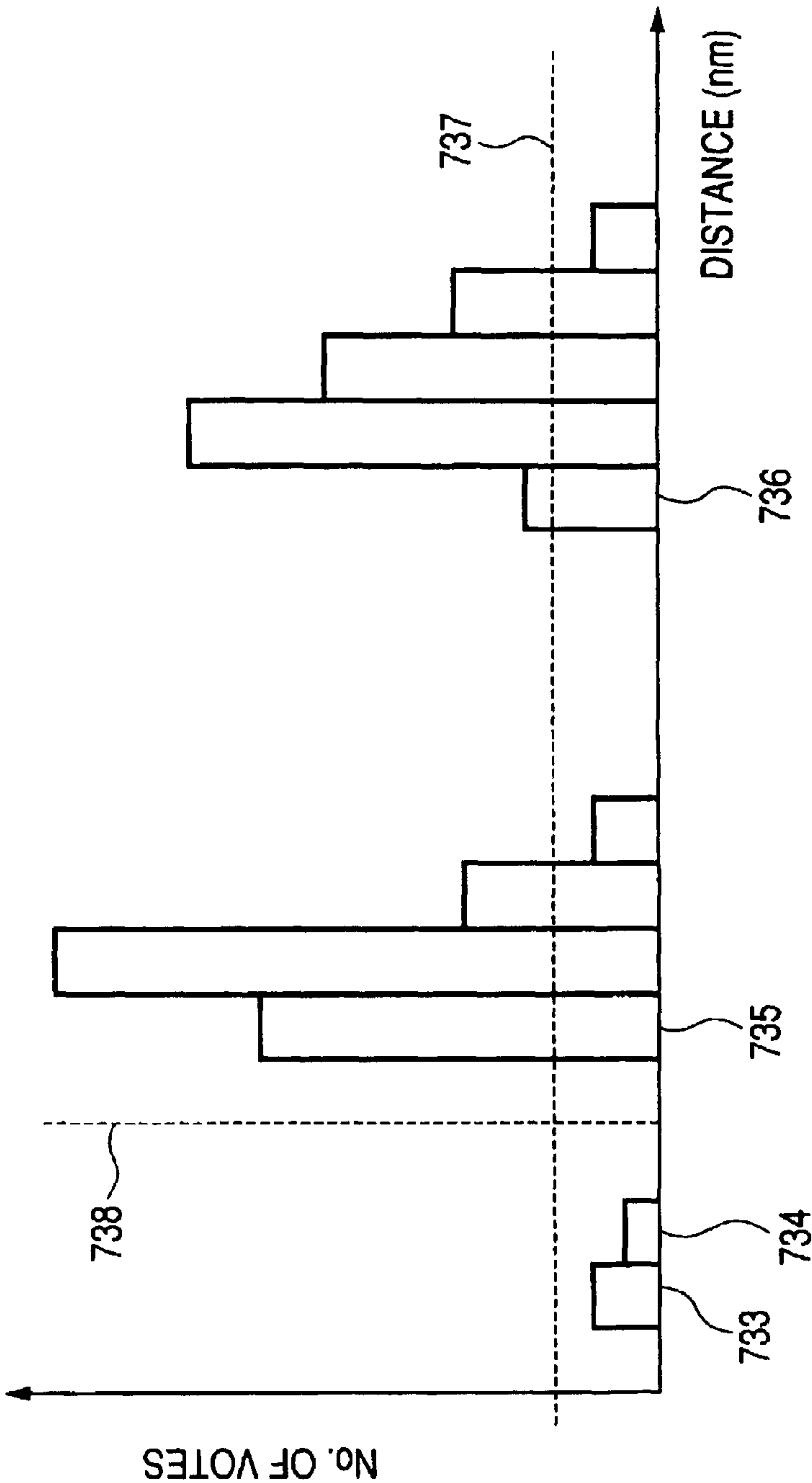


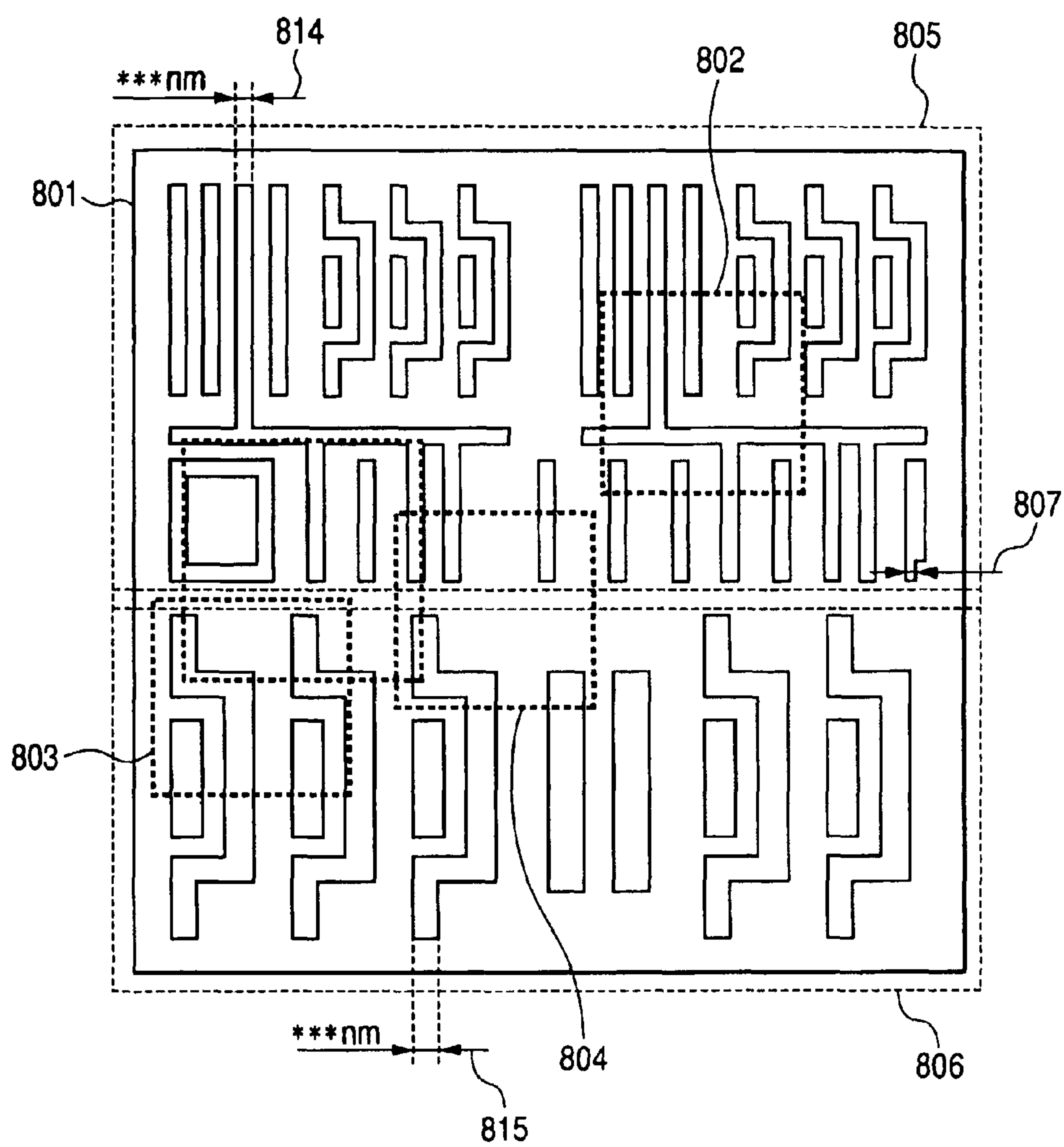
FIG. 13A

FIG. 13B

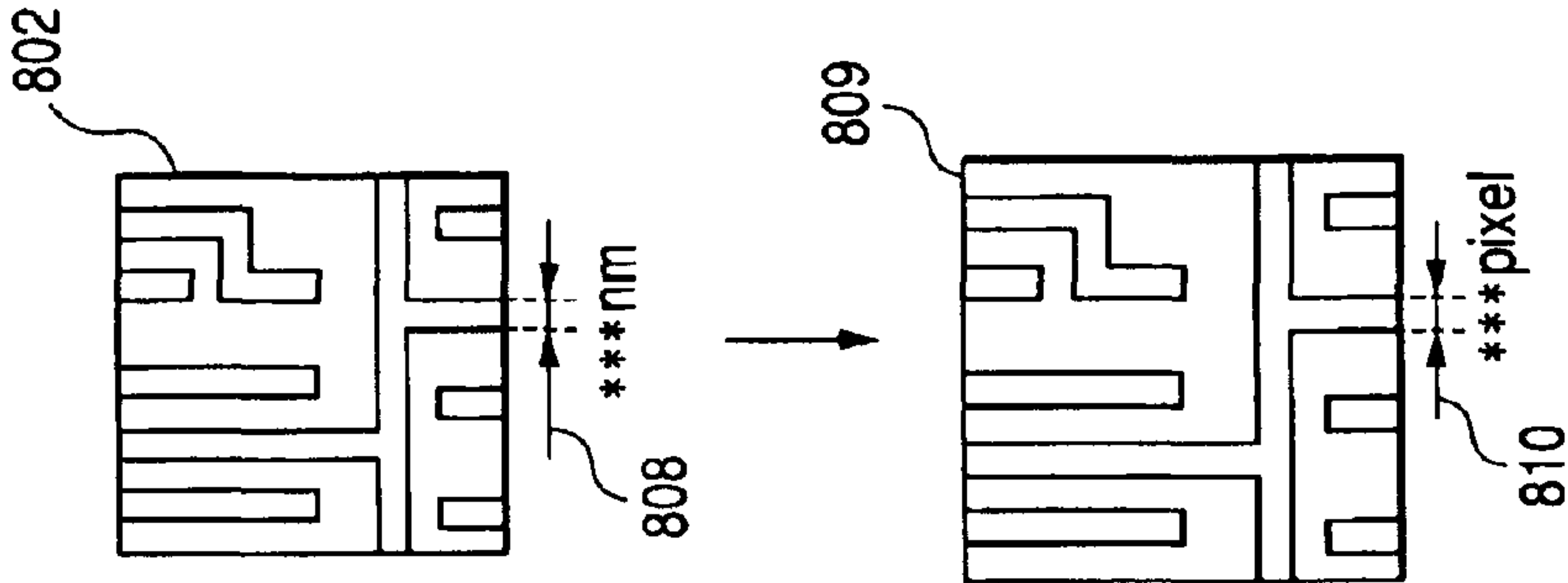


FIG. 13C

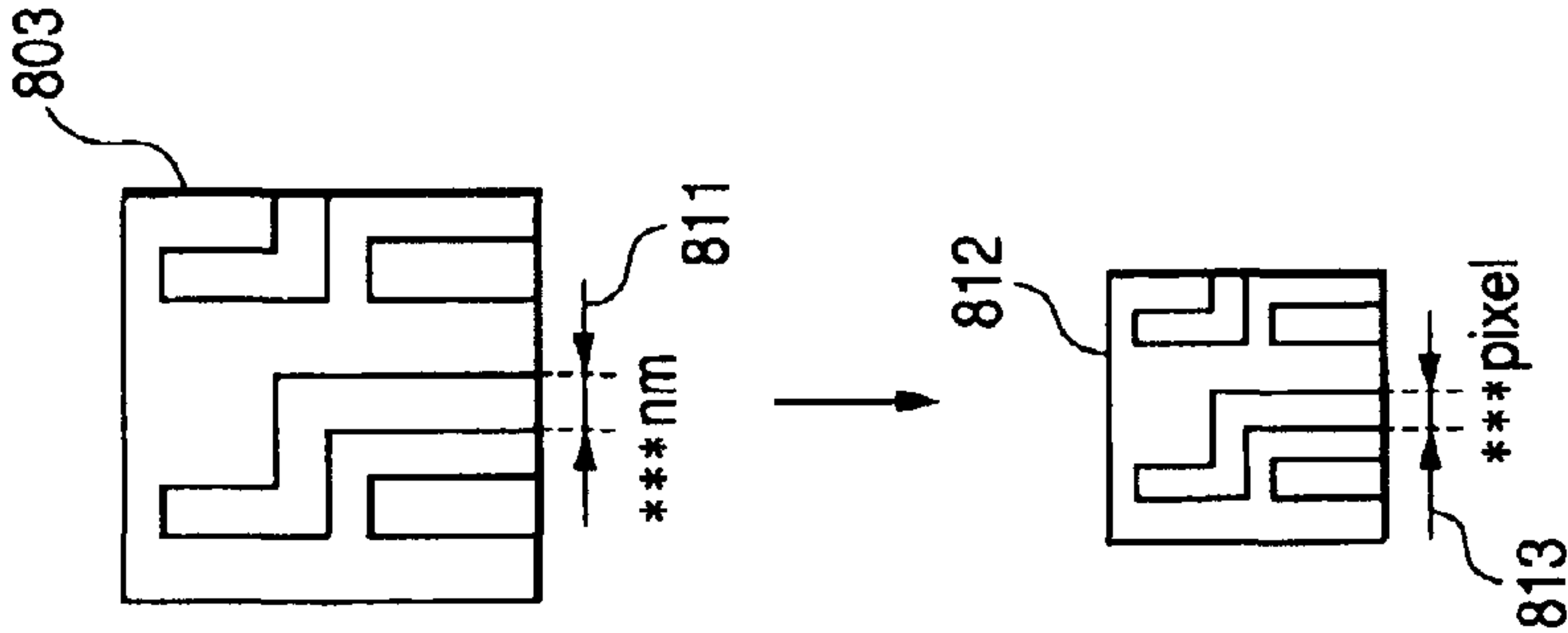


FIG. 13D

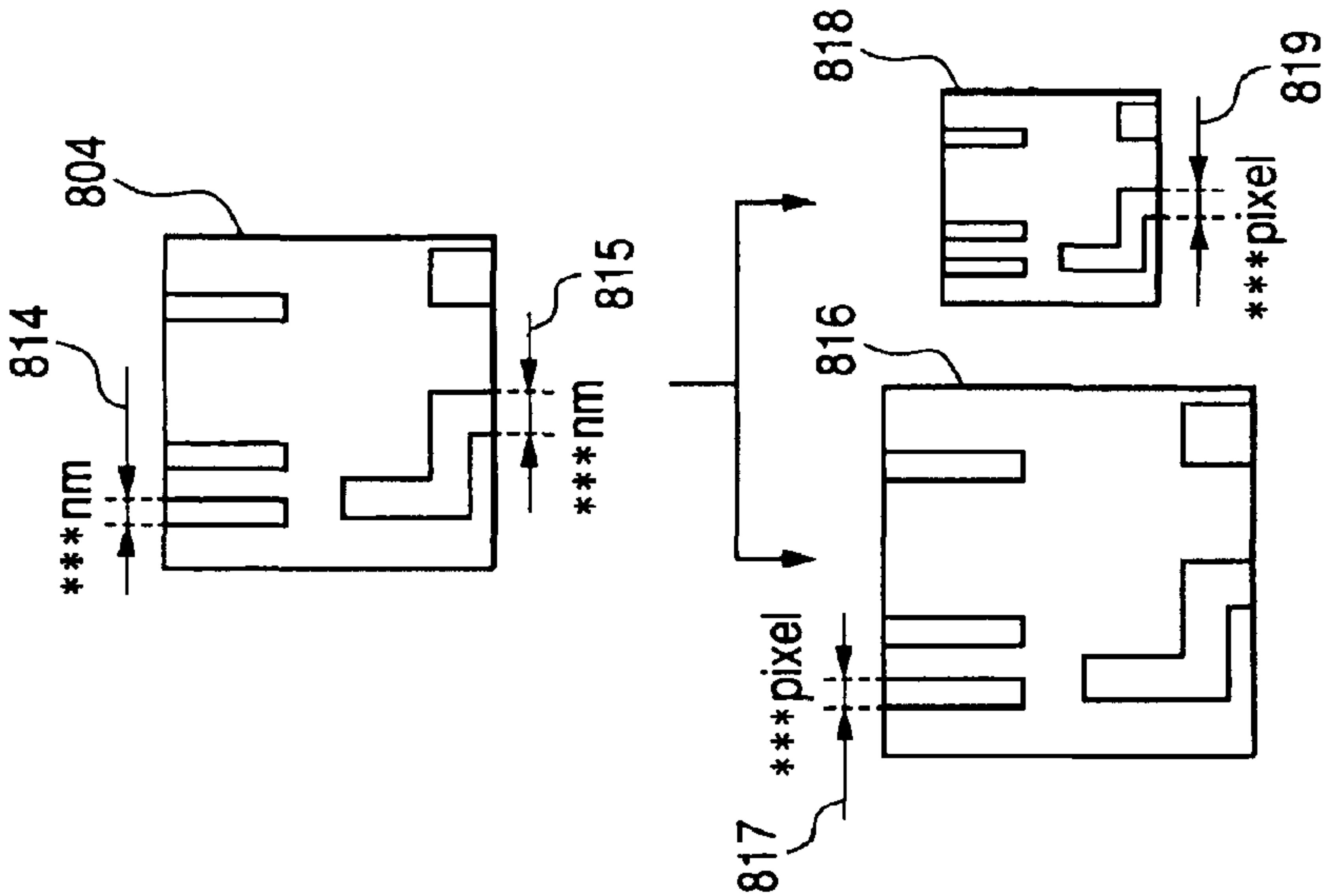


FIG. 14A

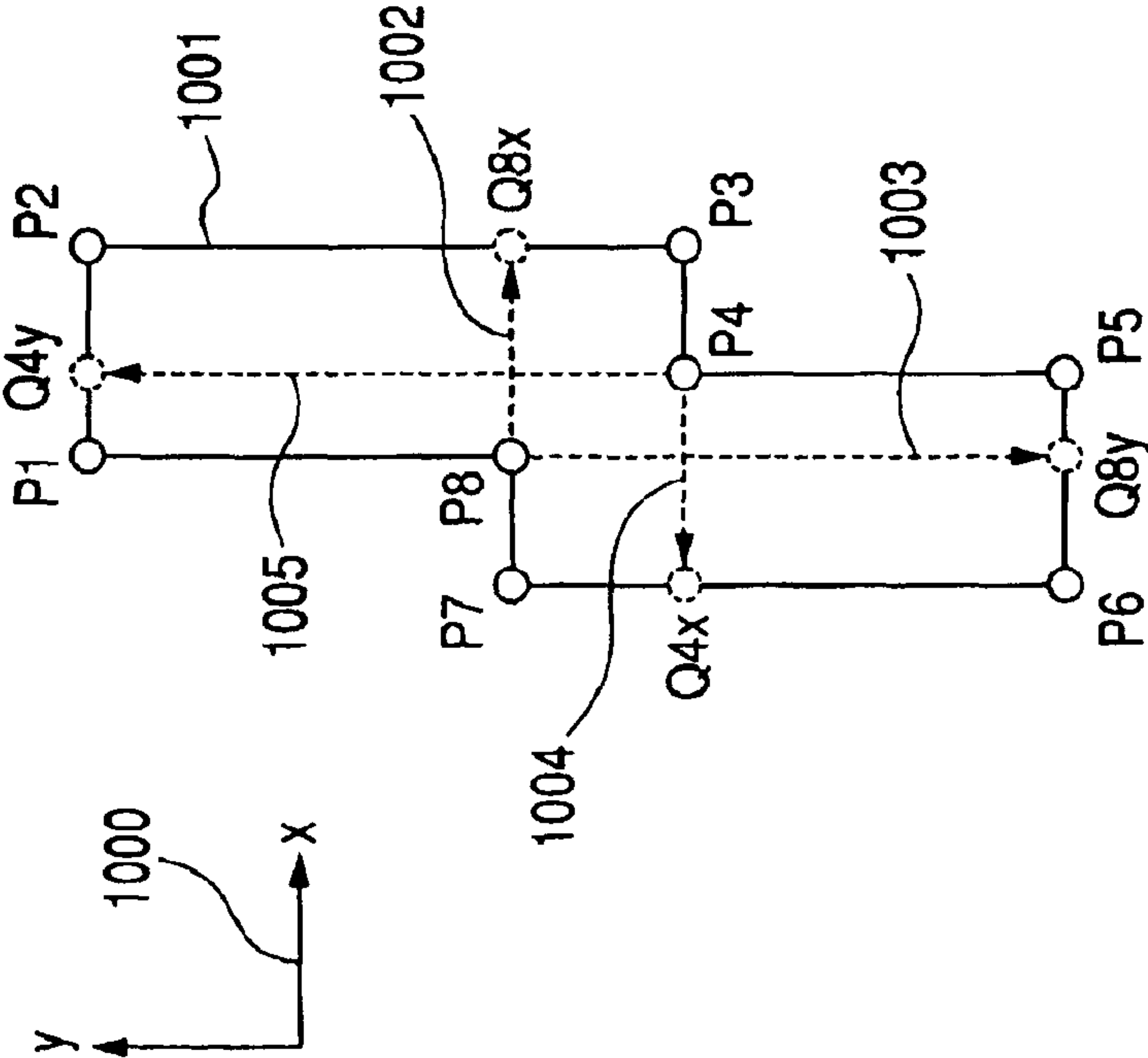


FIG. 14B

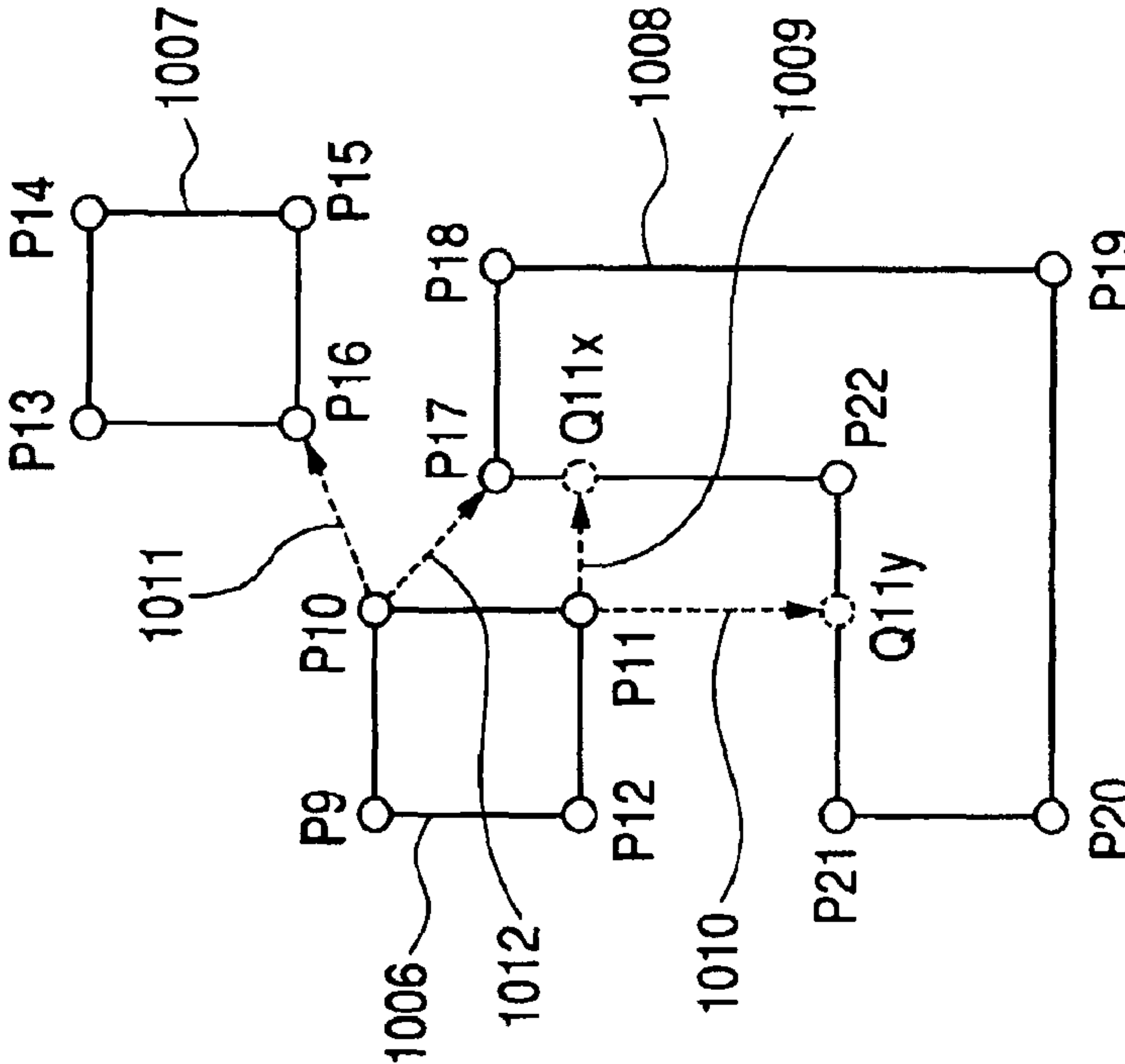


FIG. 15A

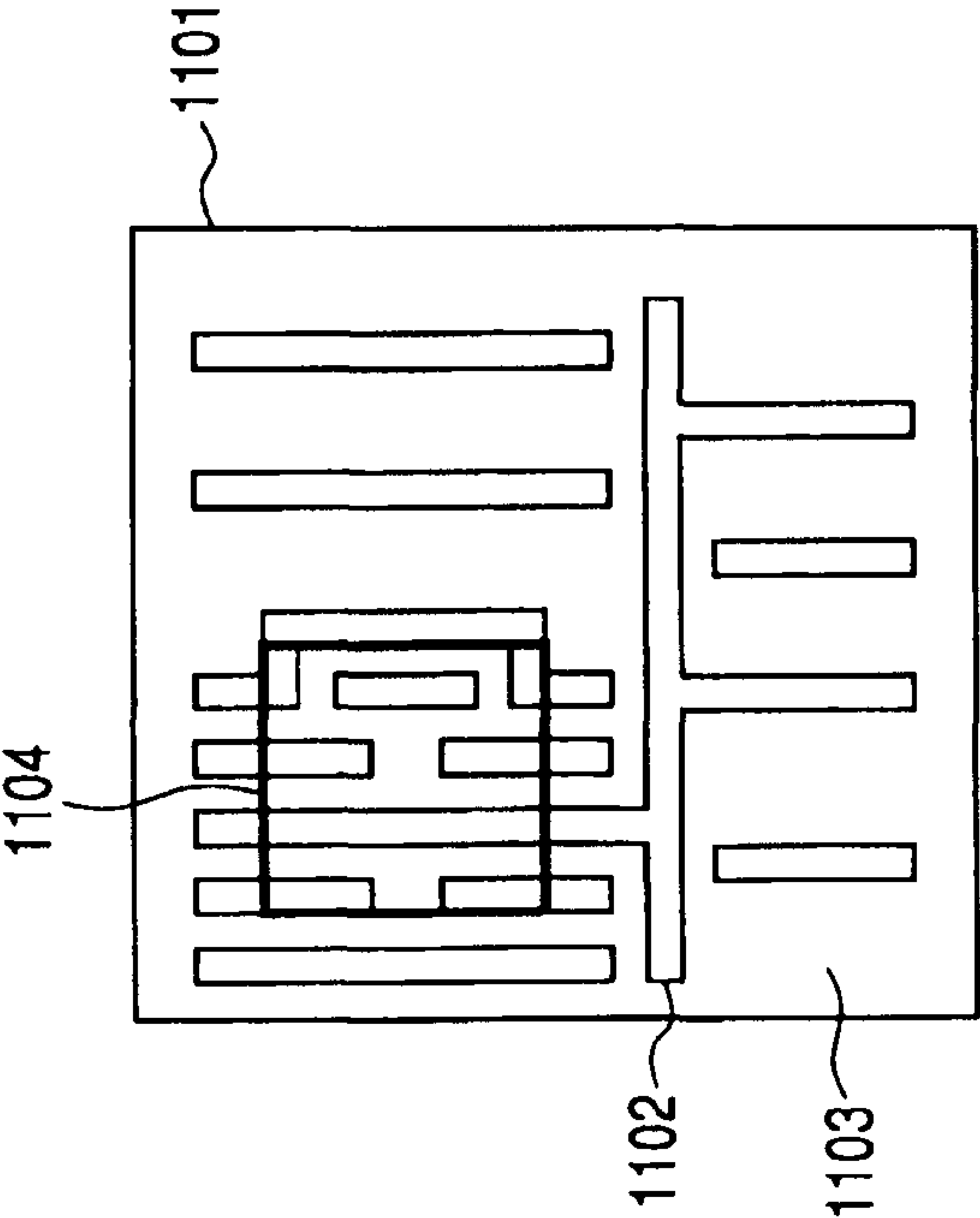


FIG. 15B

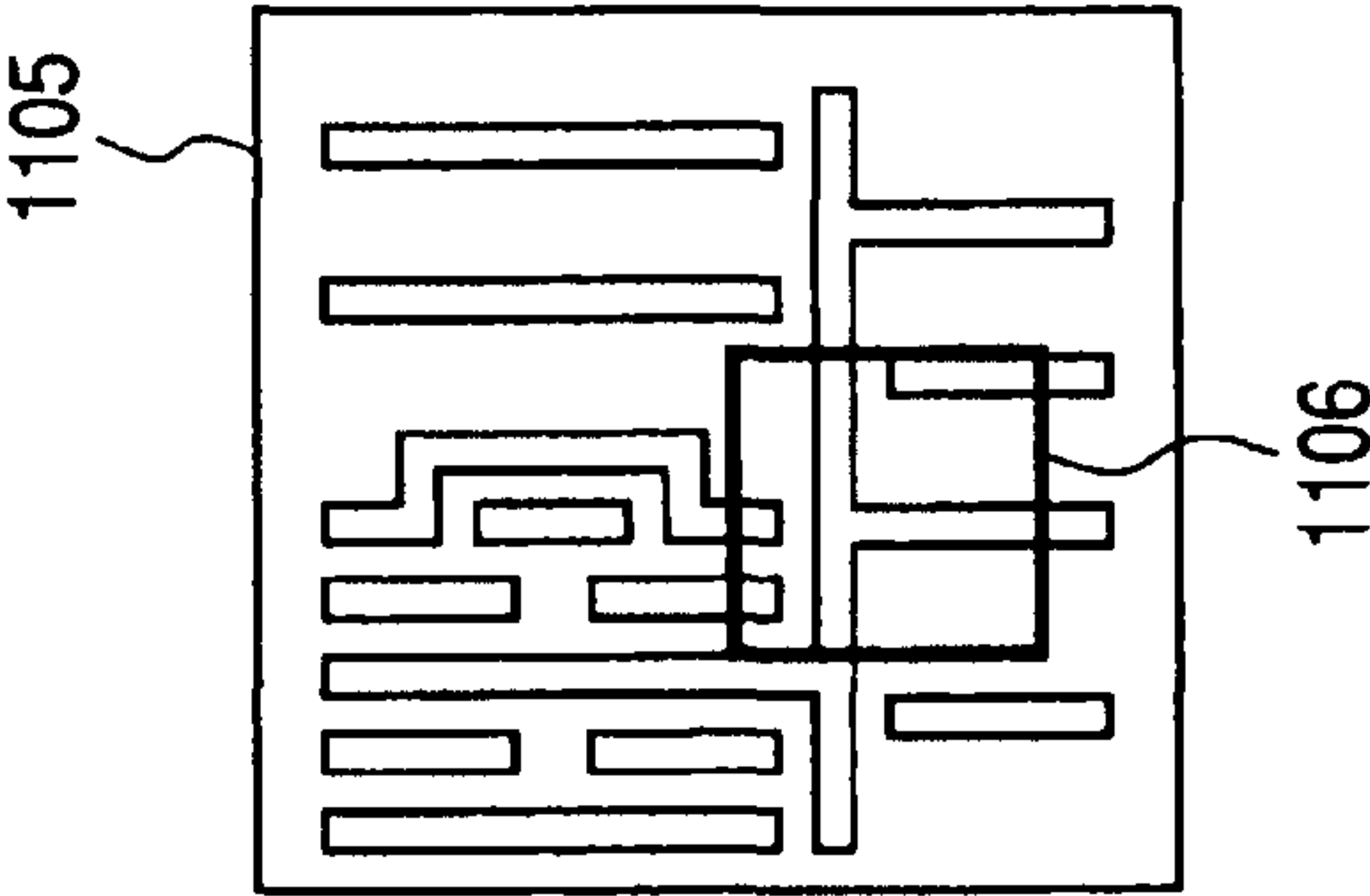


FIG. 15C

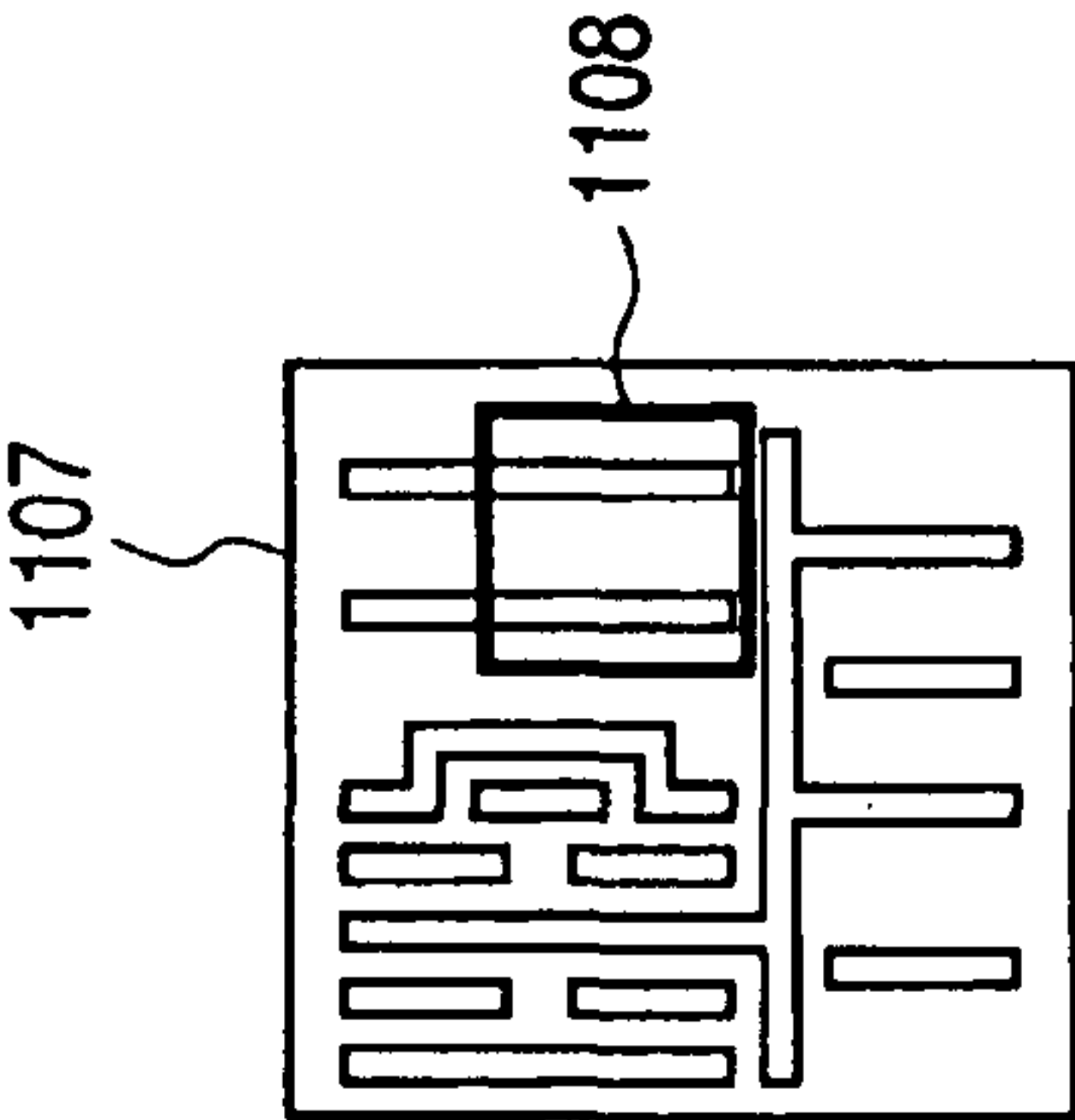


FIG. 16A

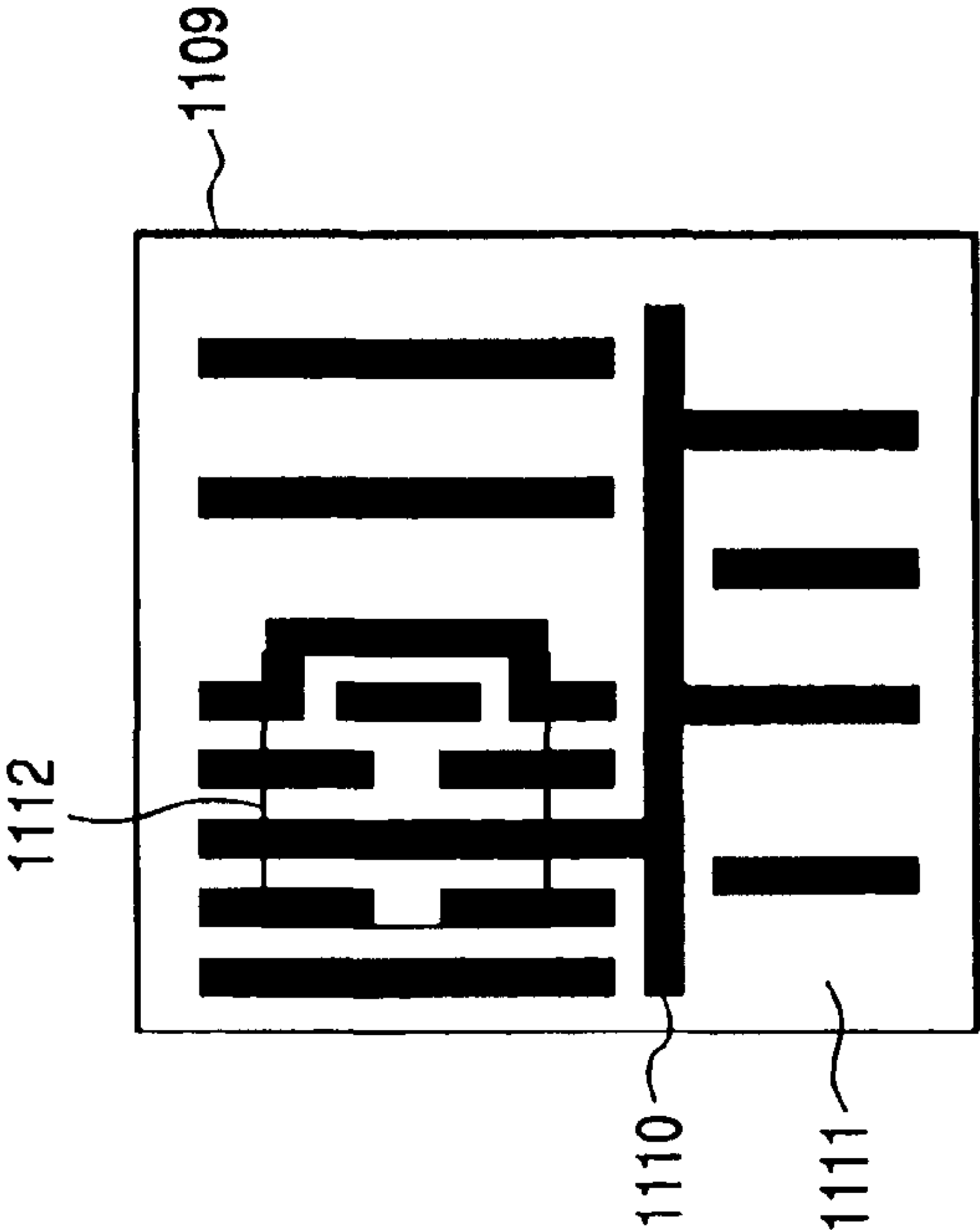


FIG. 16B

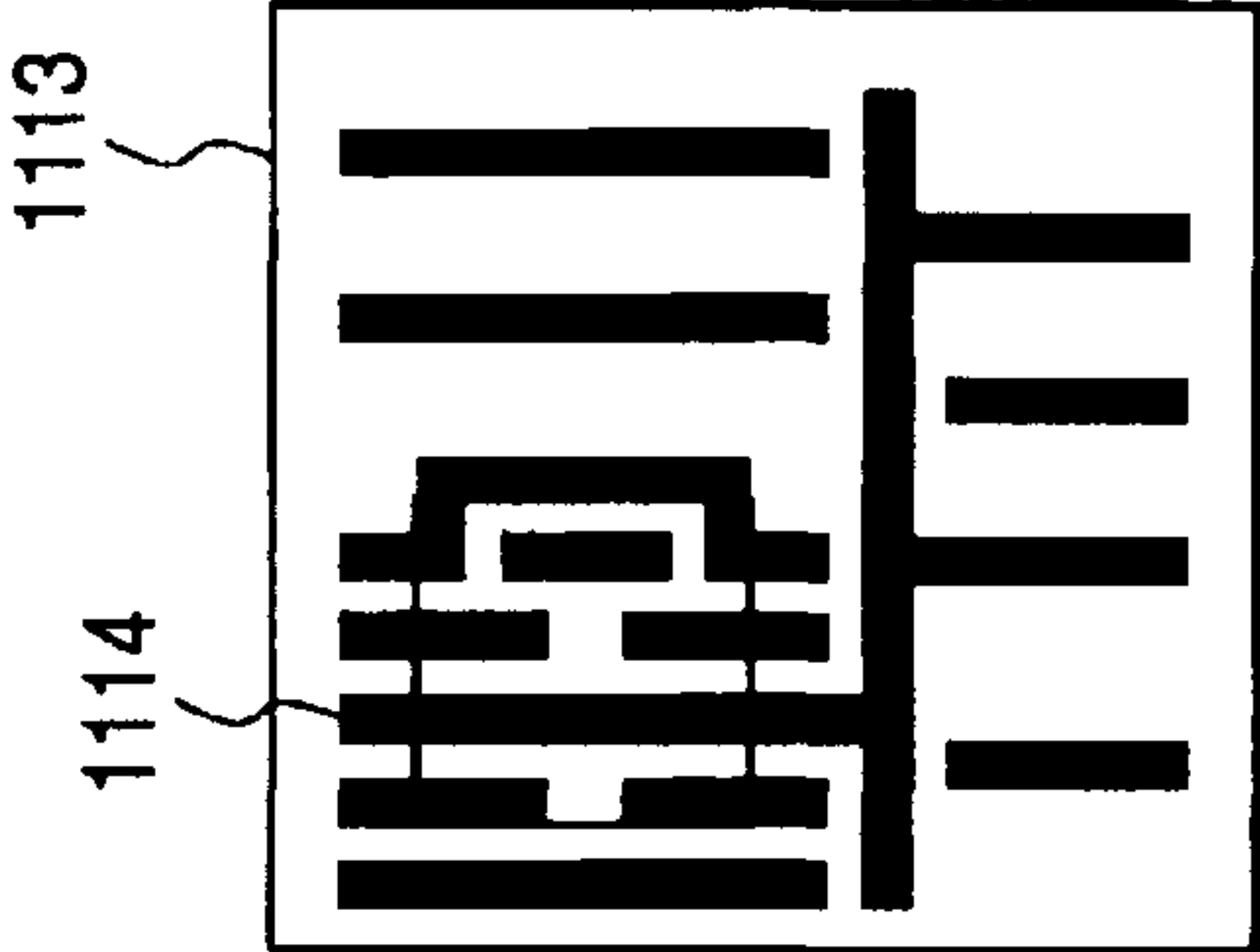


FIG. 16C

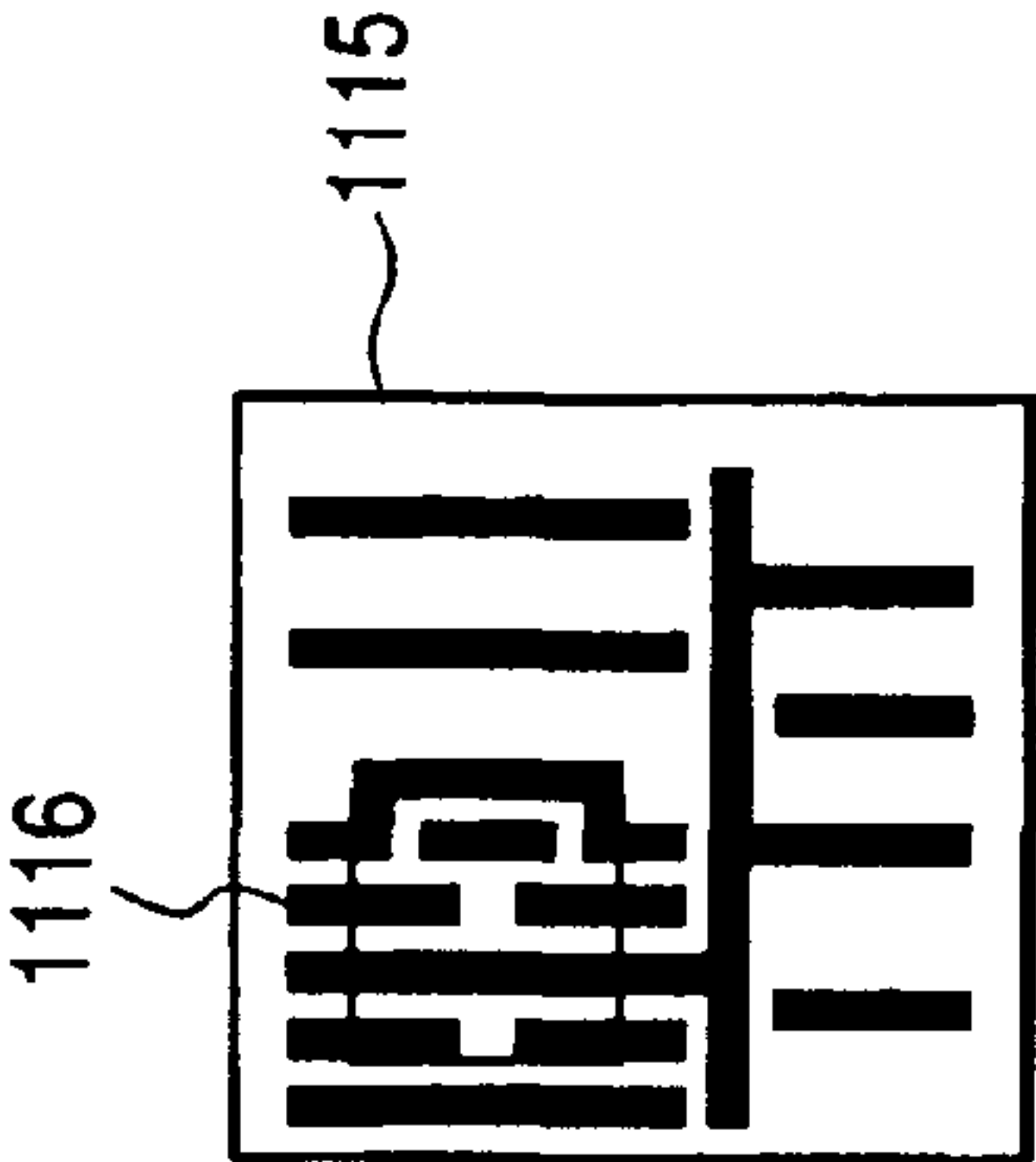


FIG. 17A

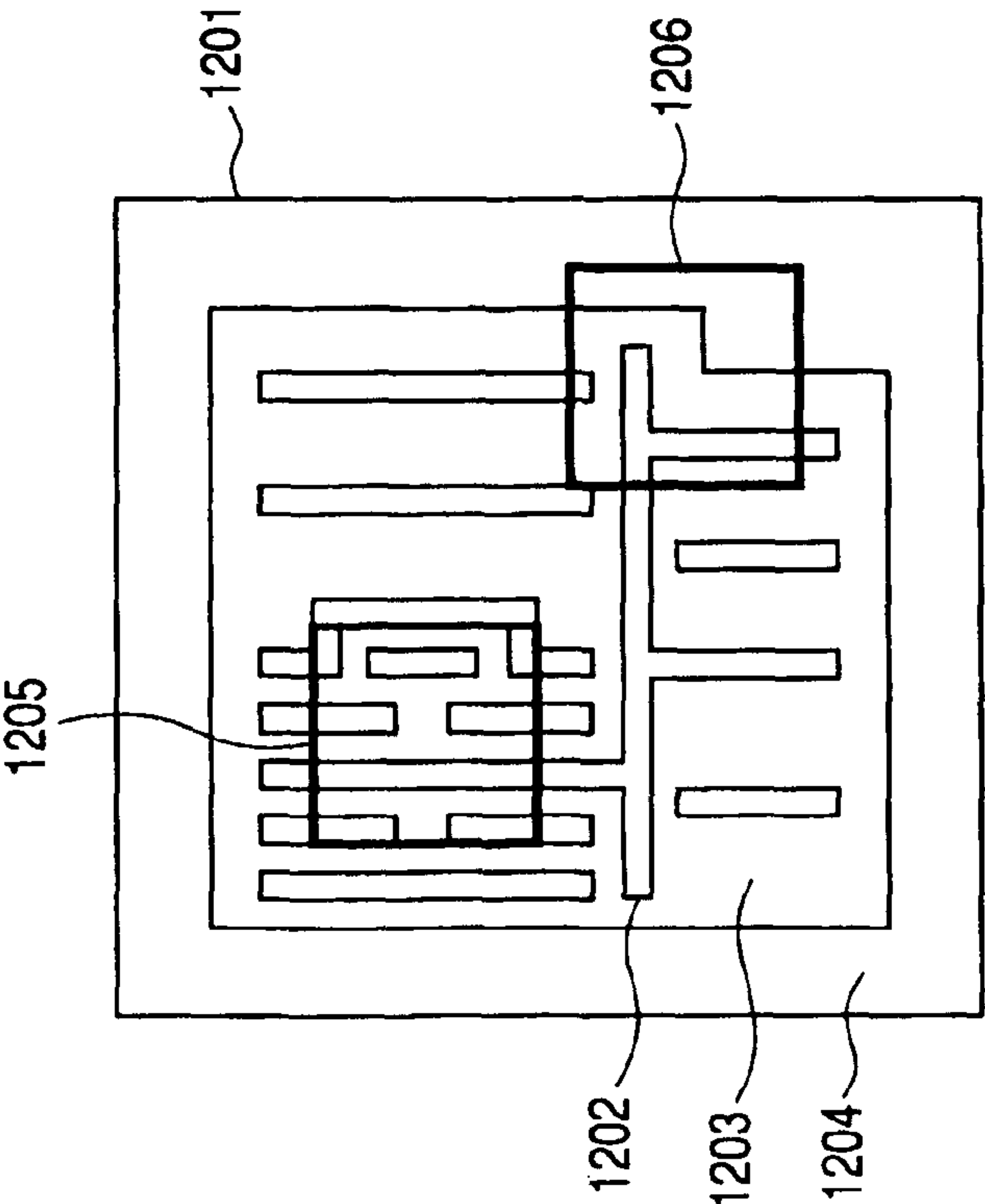


FIG. 17B

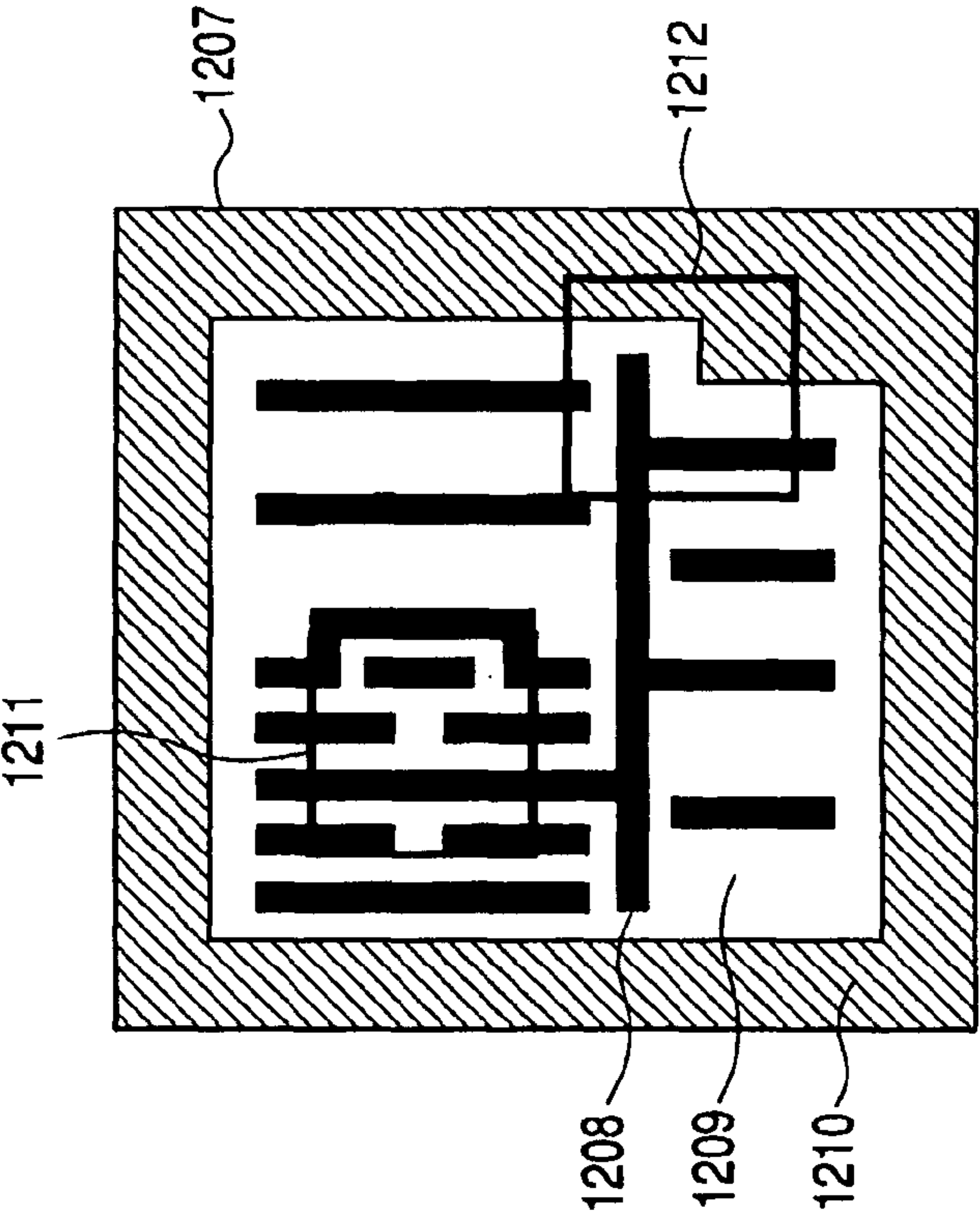


FIG. 18A

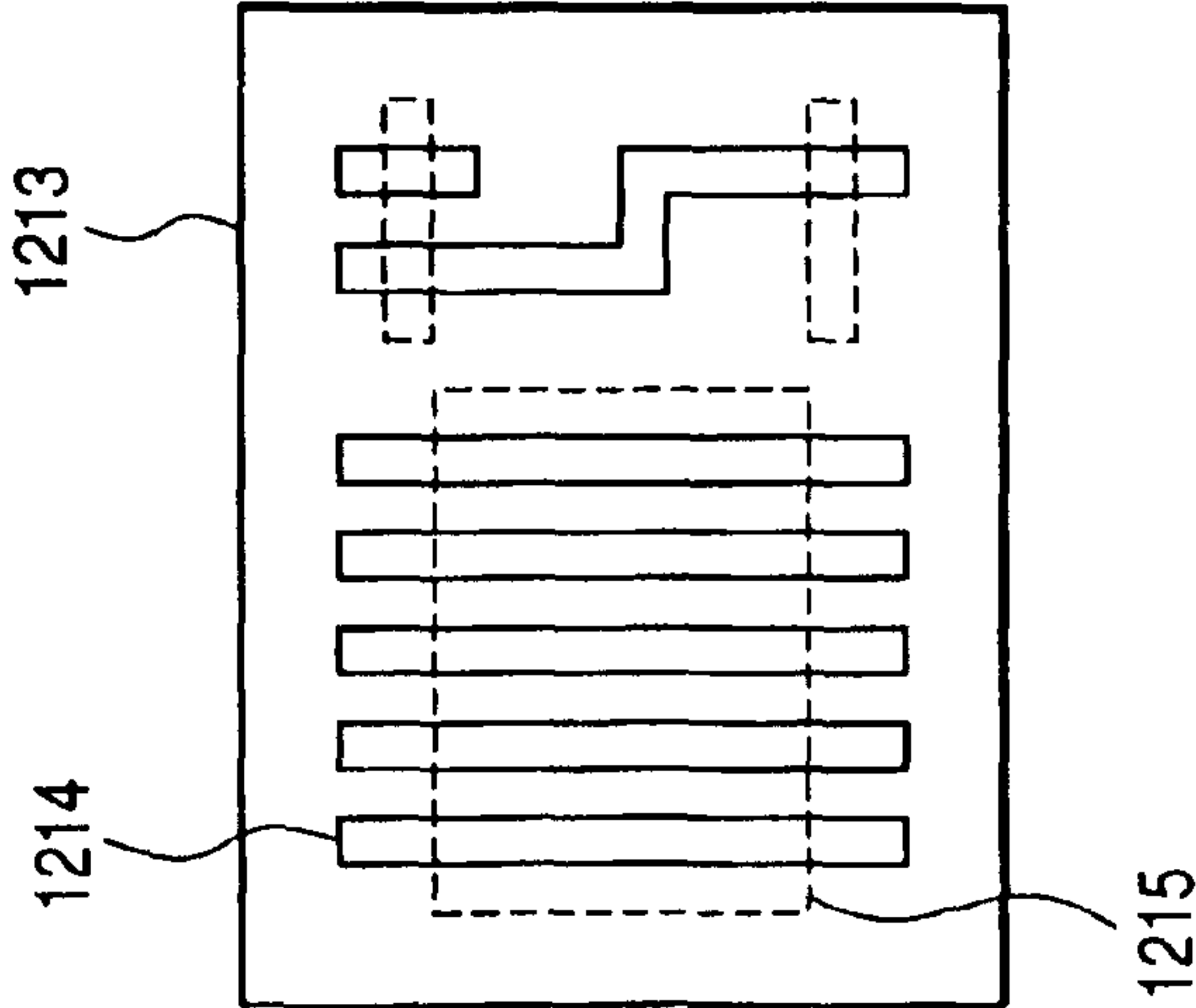


FIG. 18B

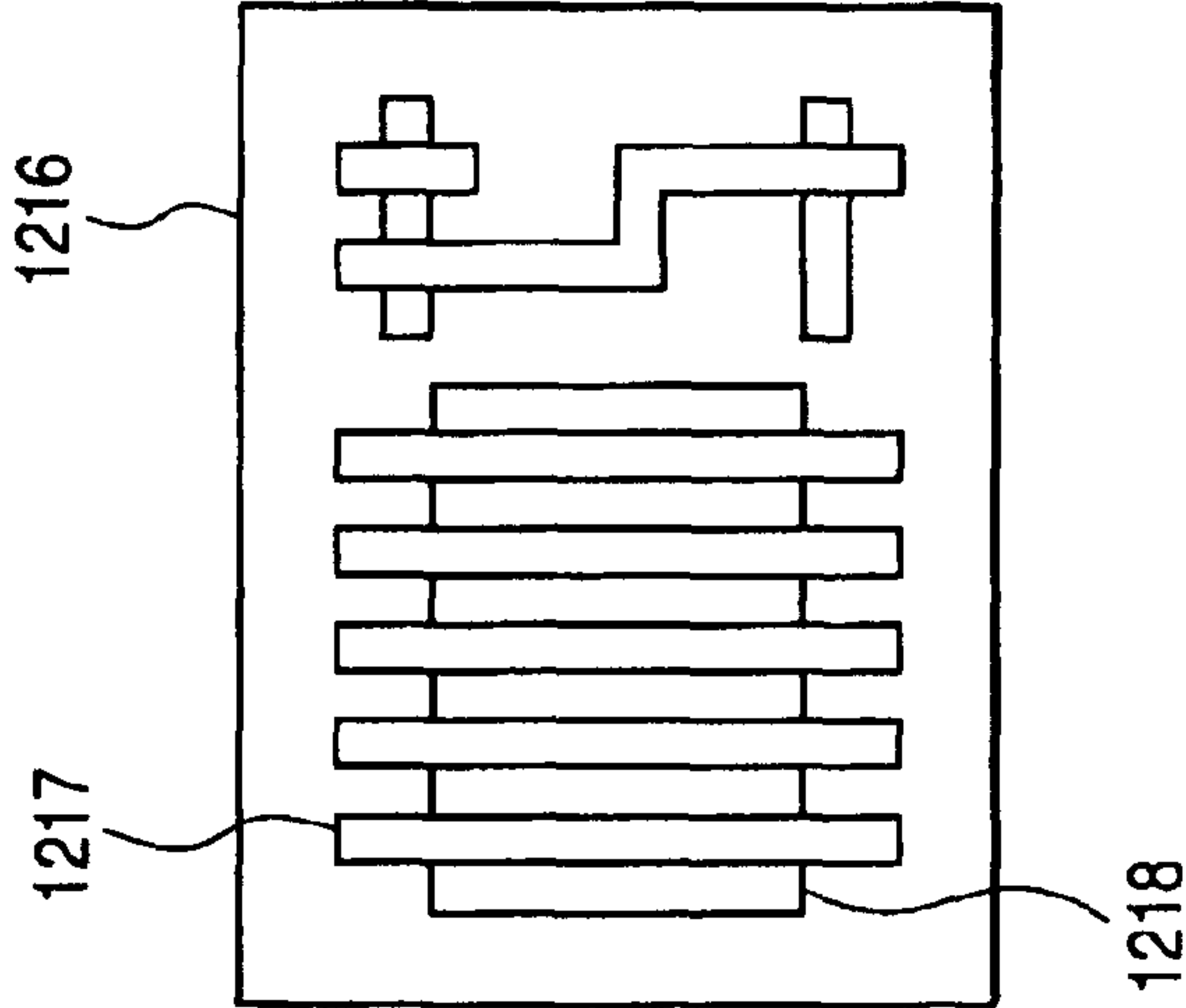


FIG. 18C

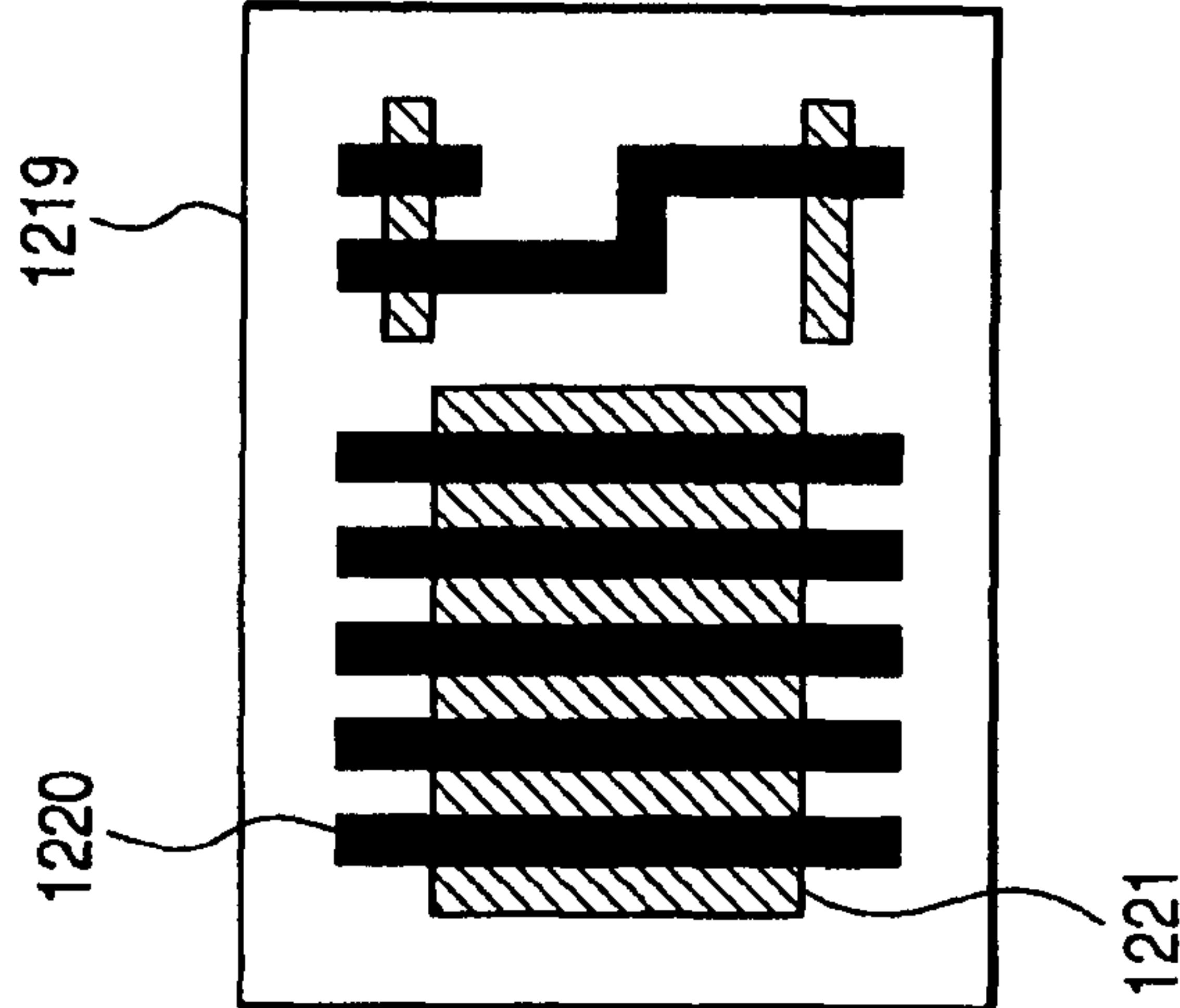


FIG. 19A(a)

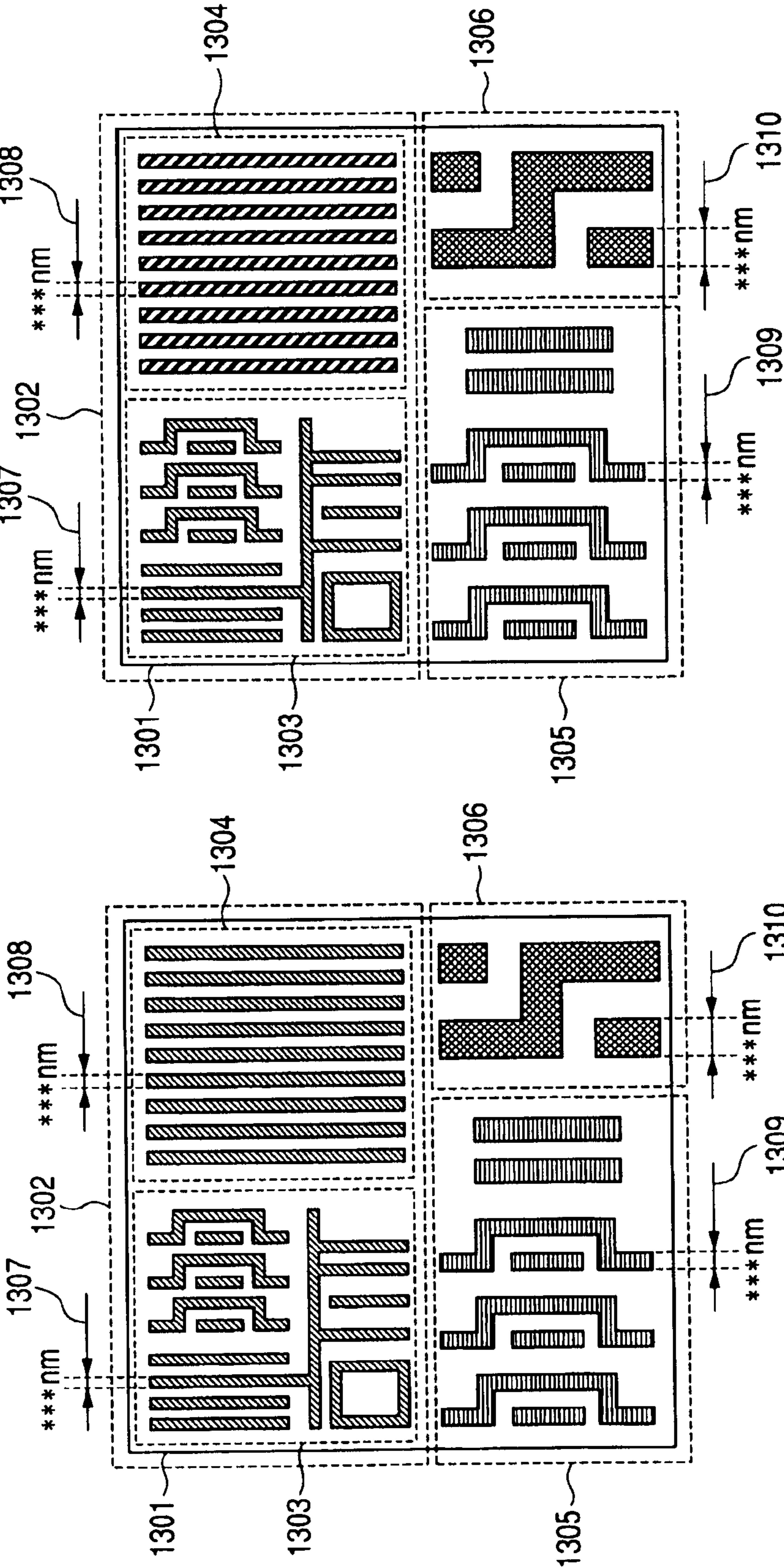


FIG. 19A(b)

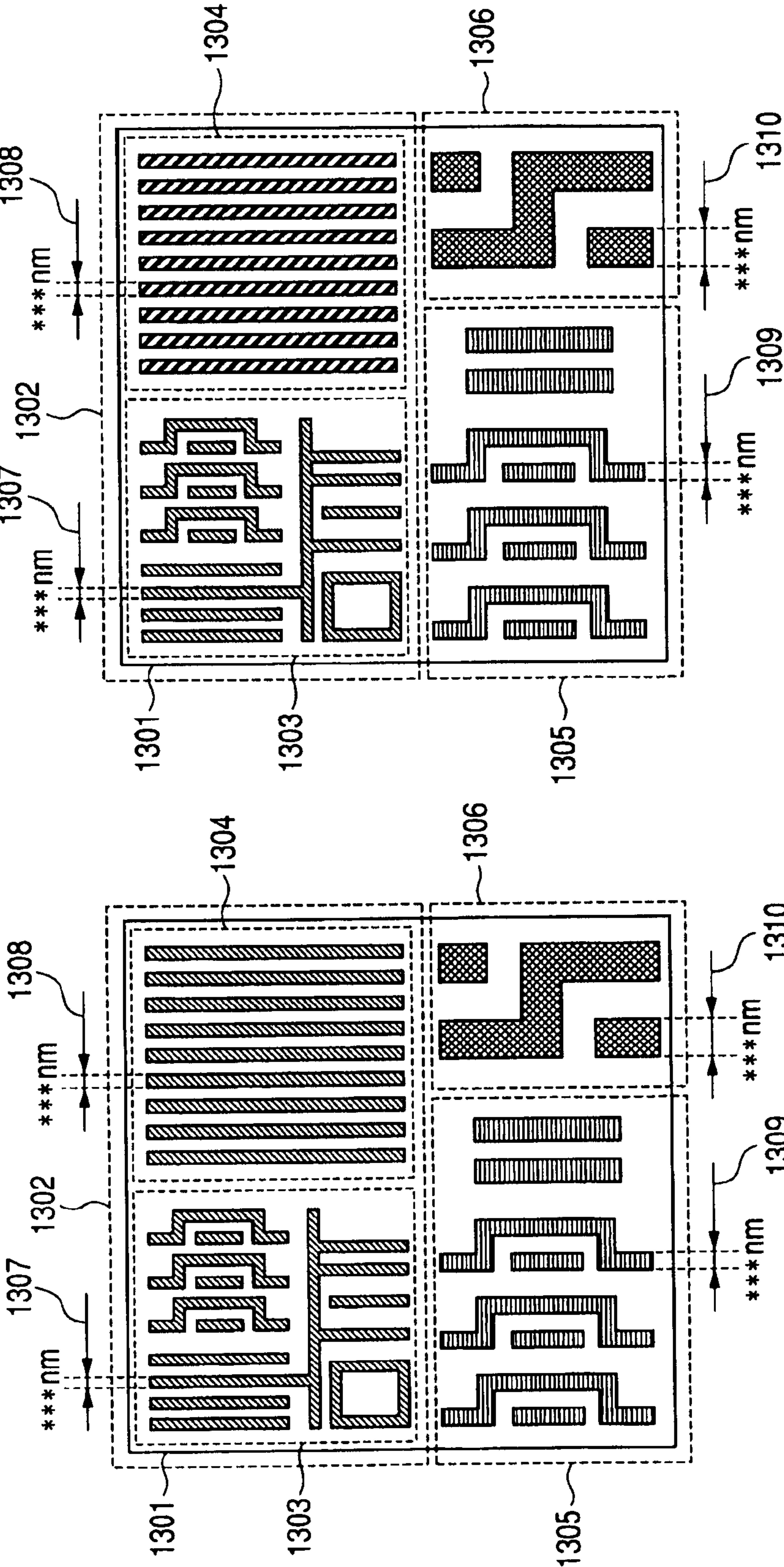


FIG. 20

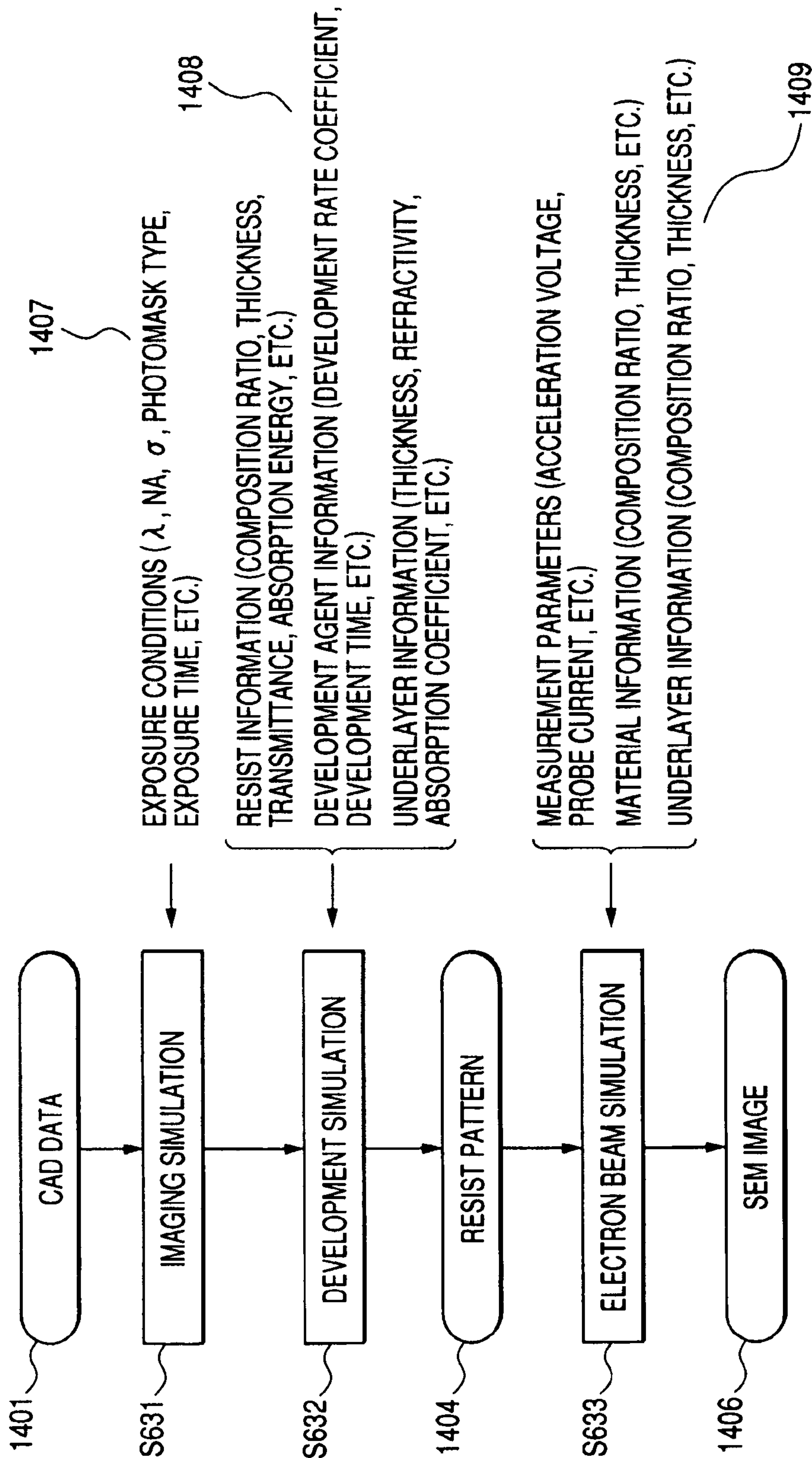


FIG. 21A

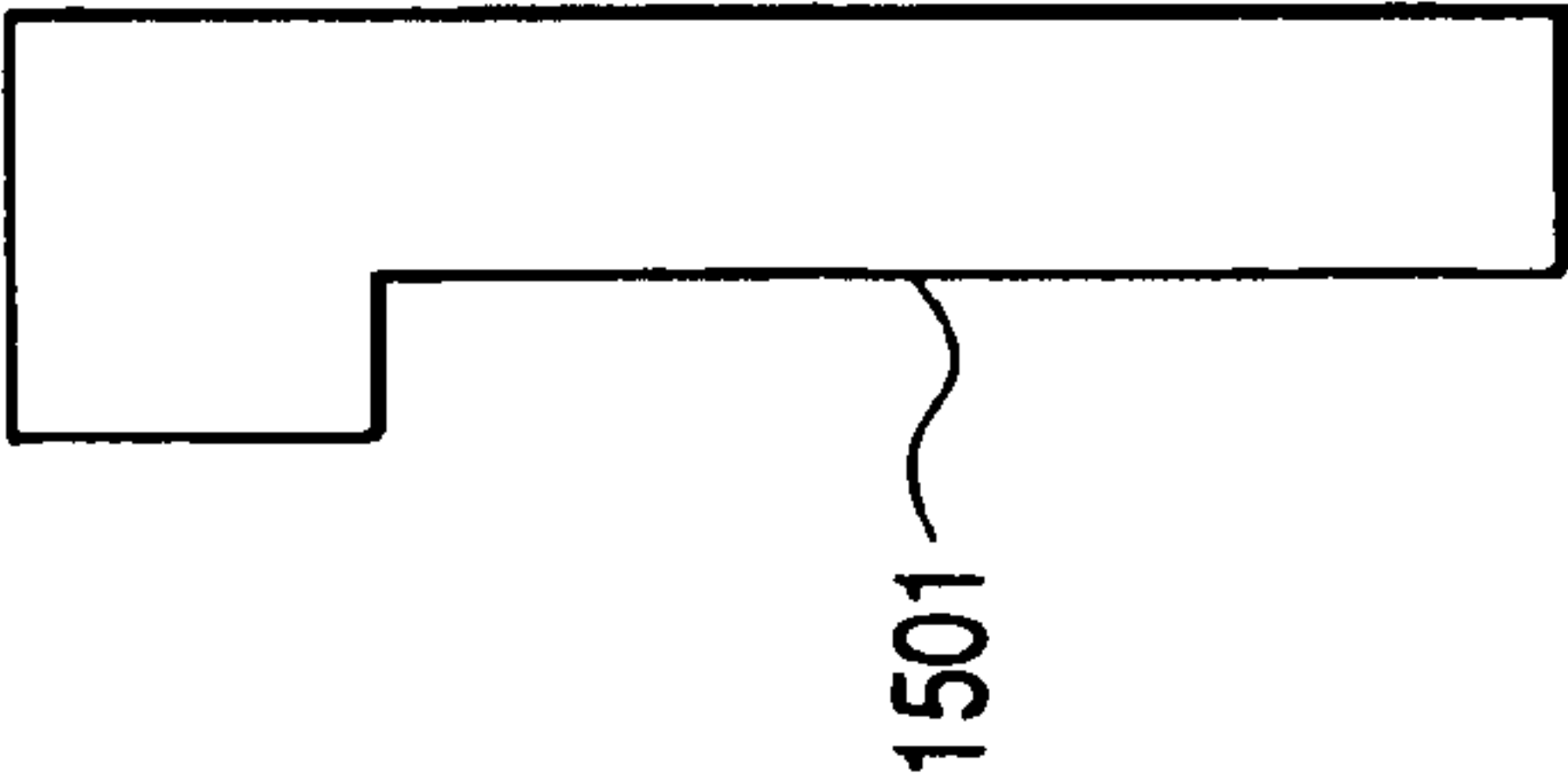


FIG. 21B

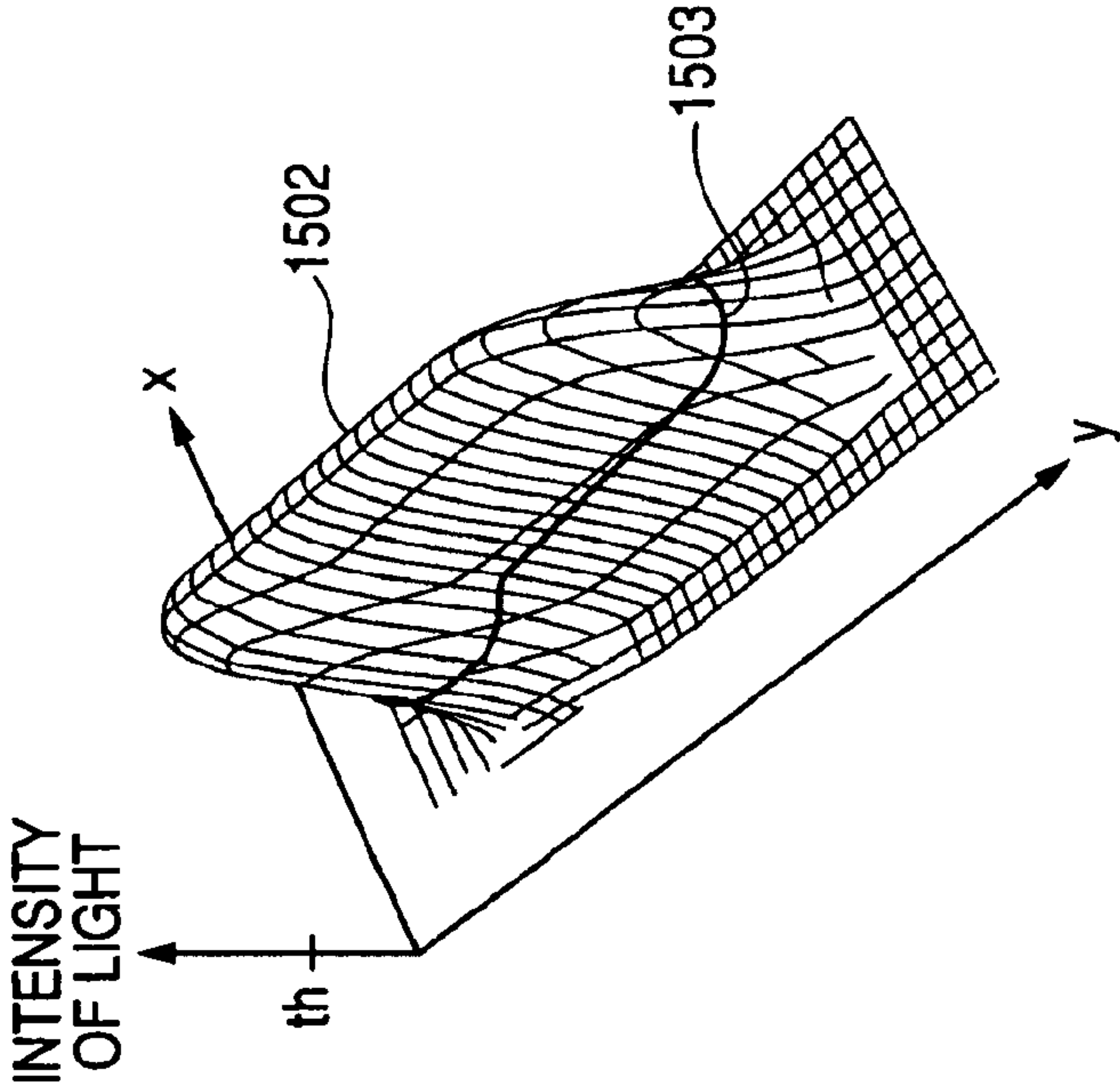


FIG. 21C

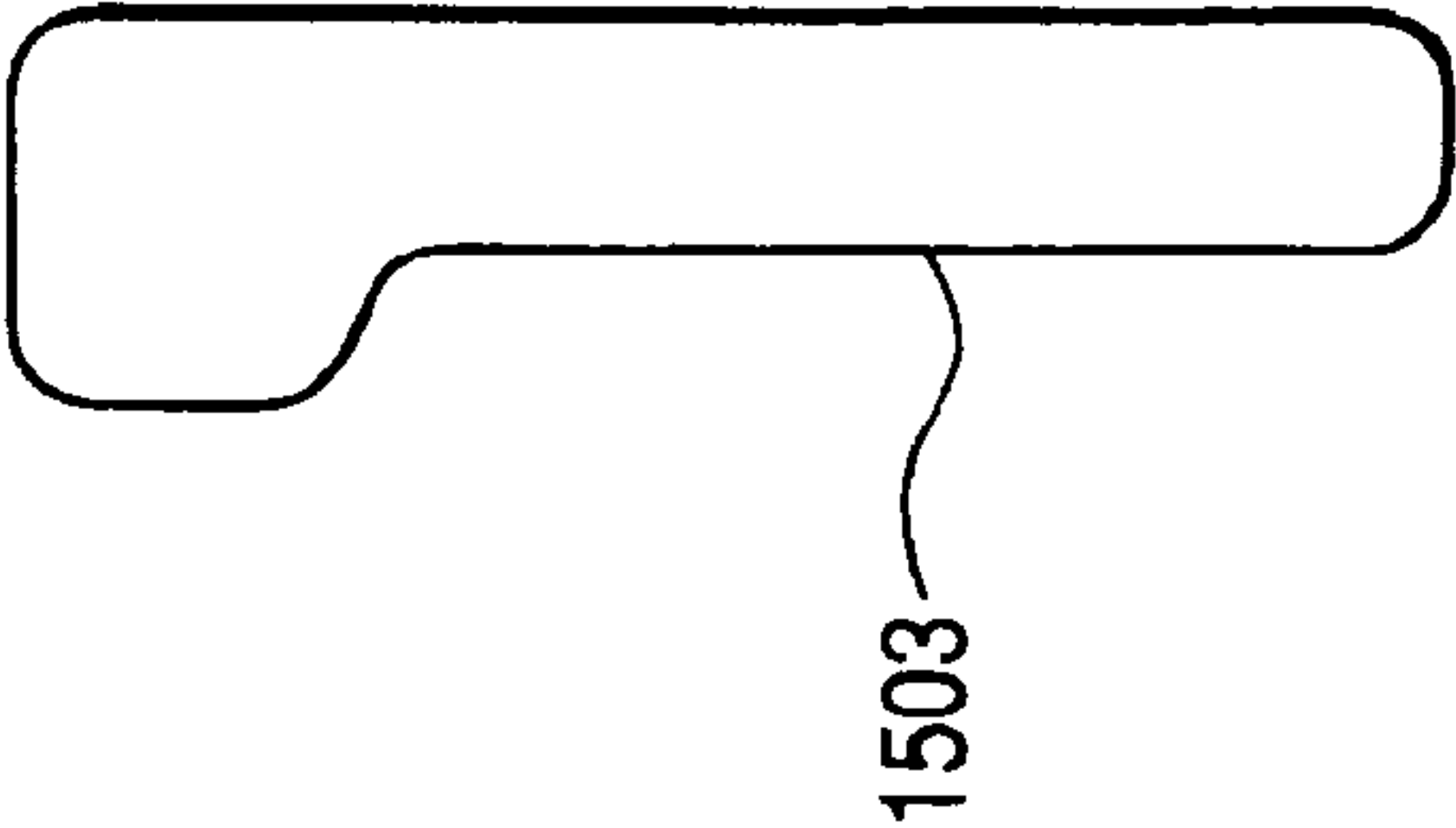


FIG. 22A

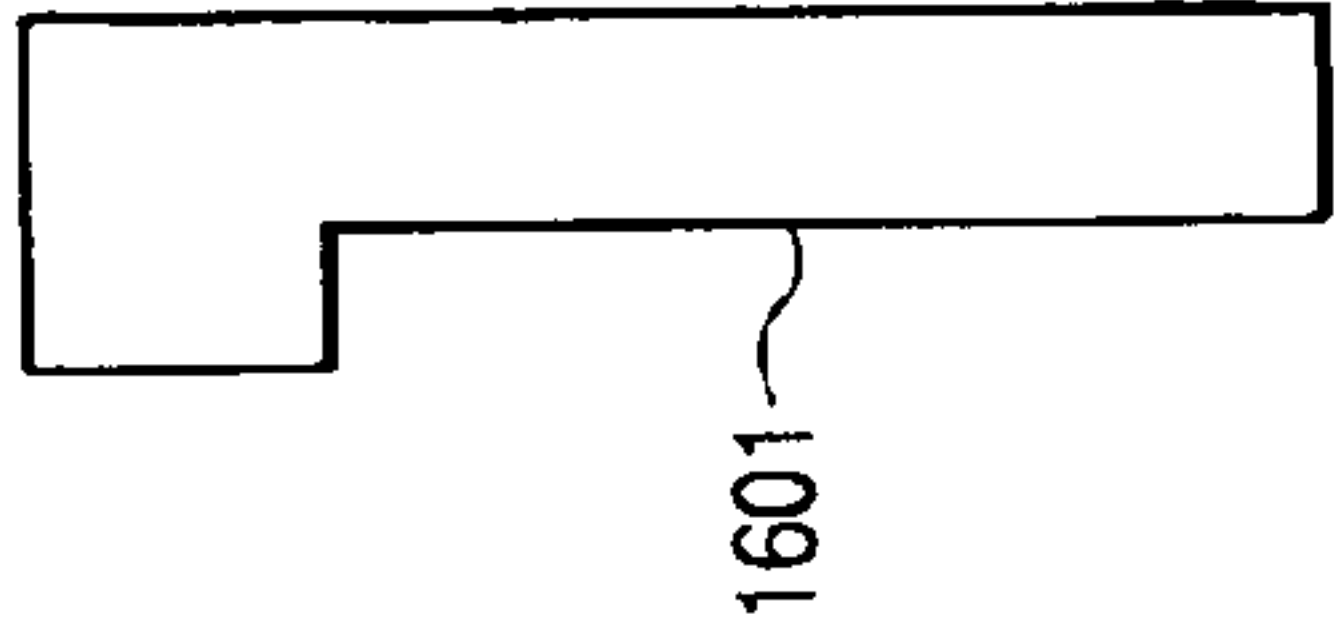


FIG. 22B

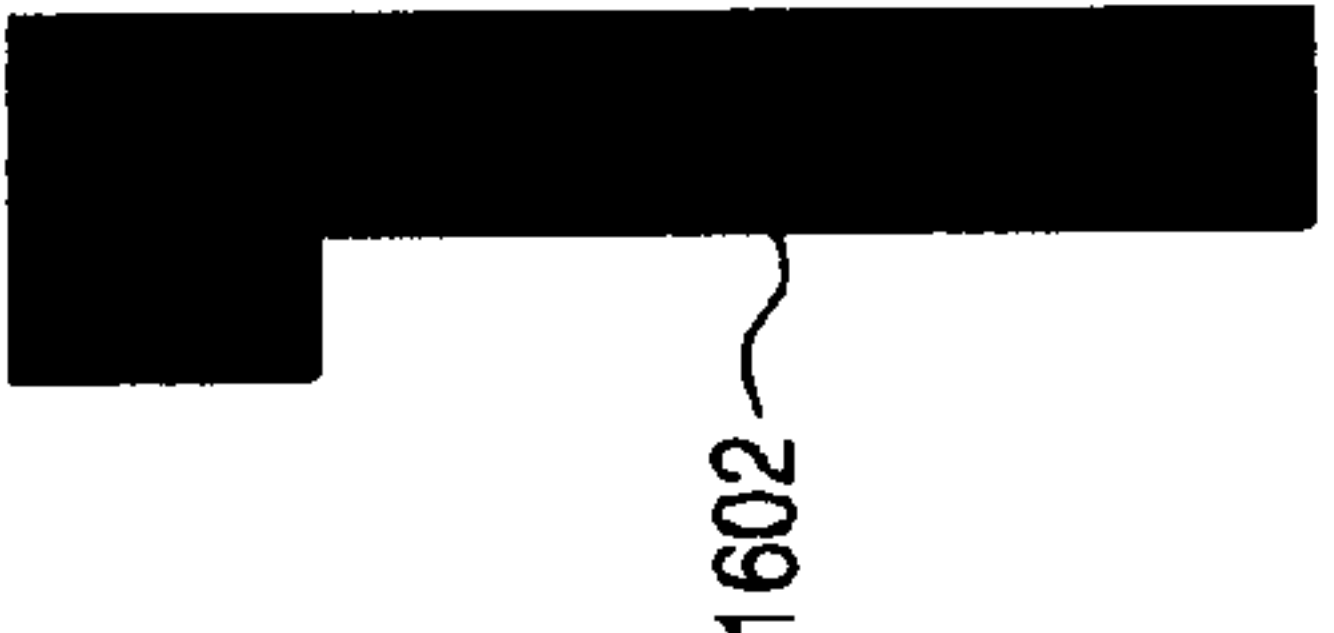


FIG. 22C

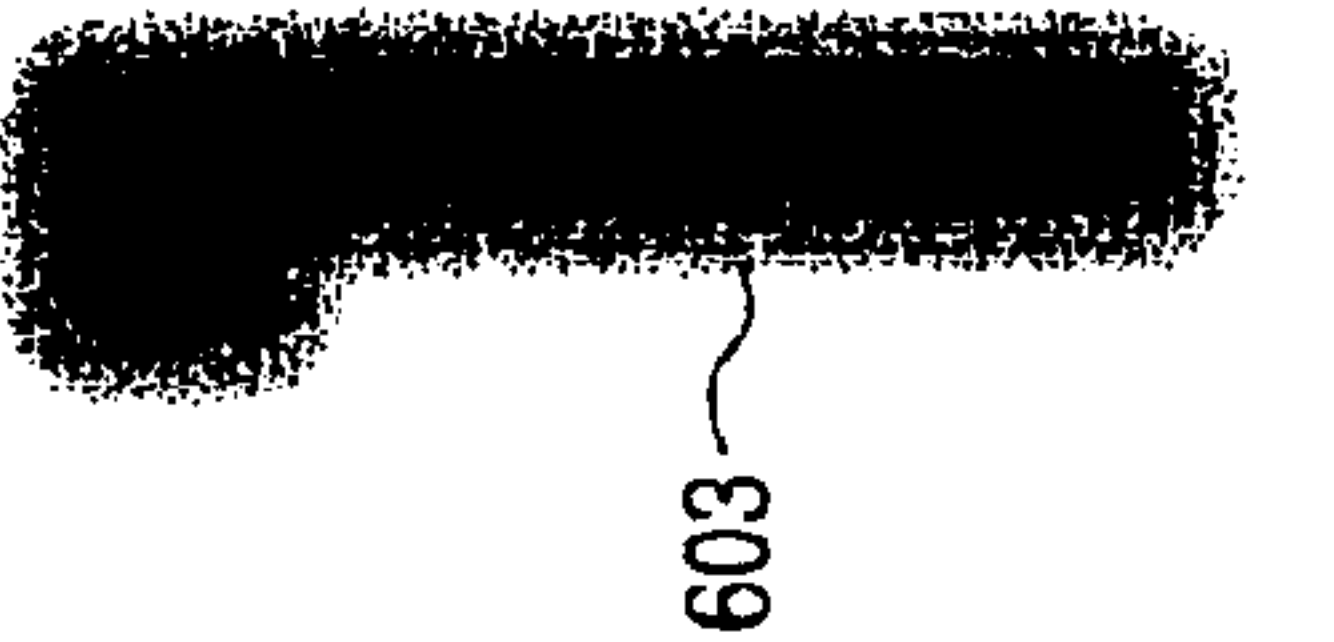


FIG. 22D

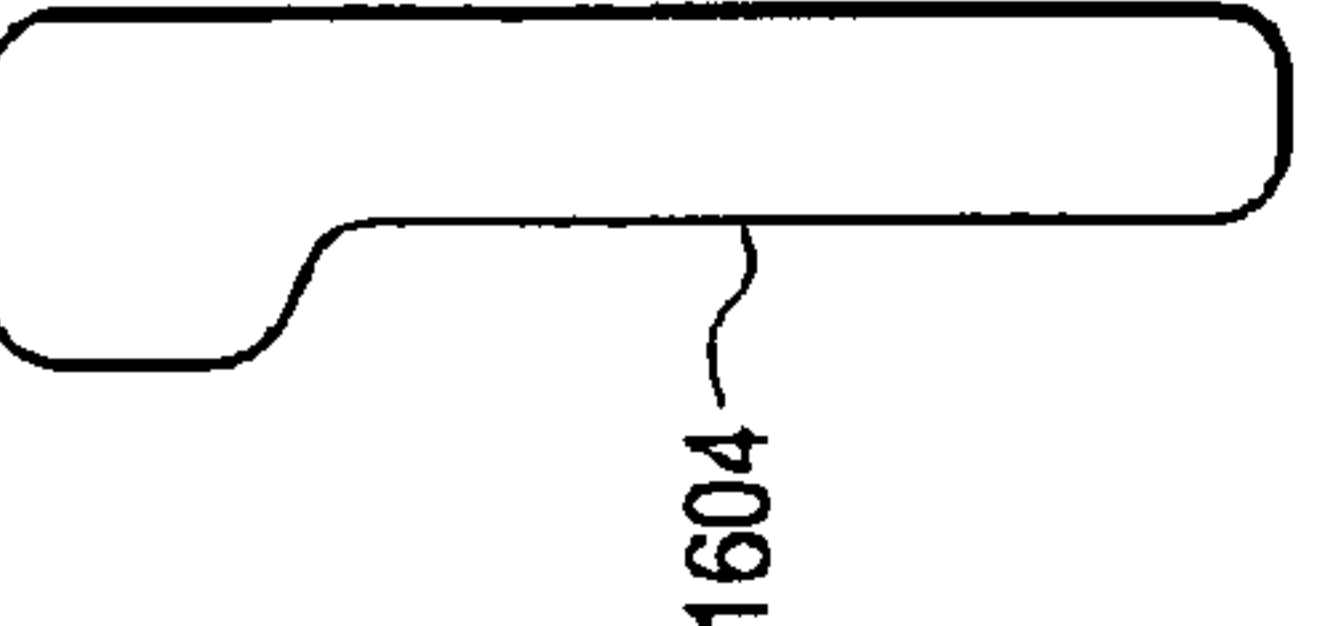


FIG. 23A

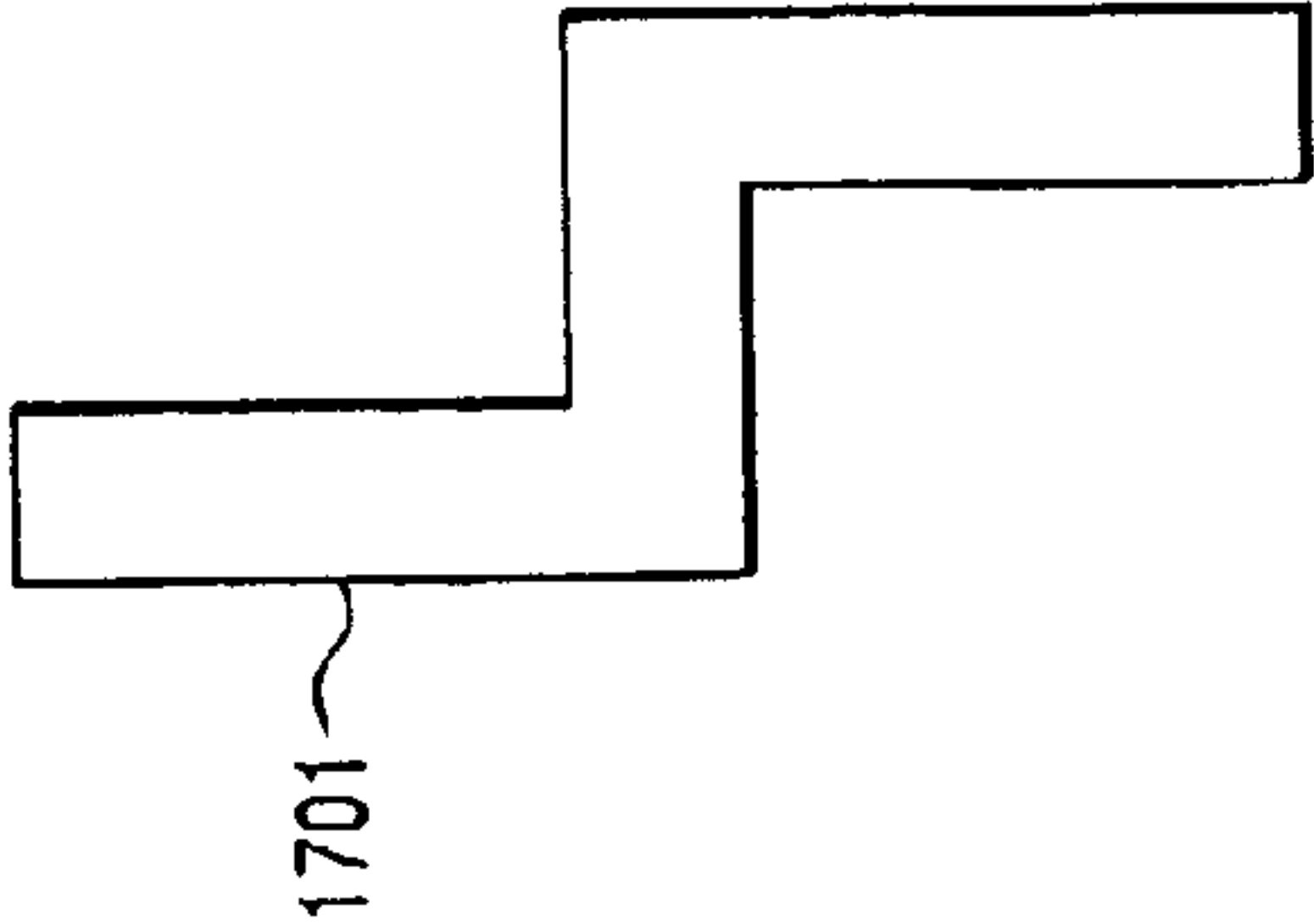


FIG. 23B

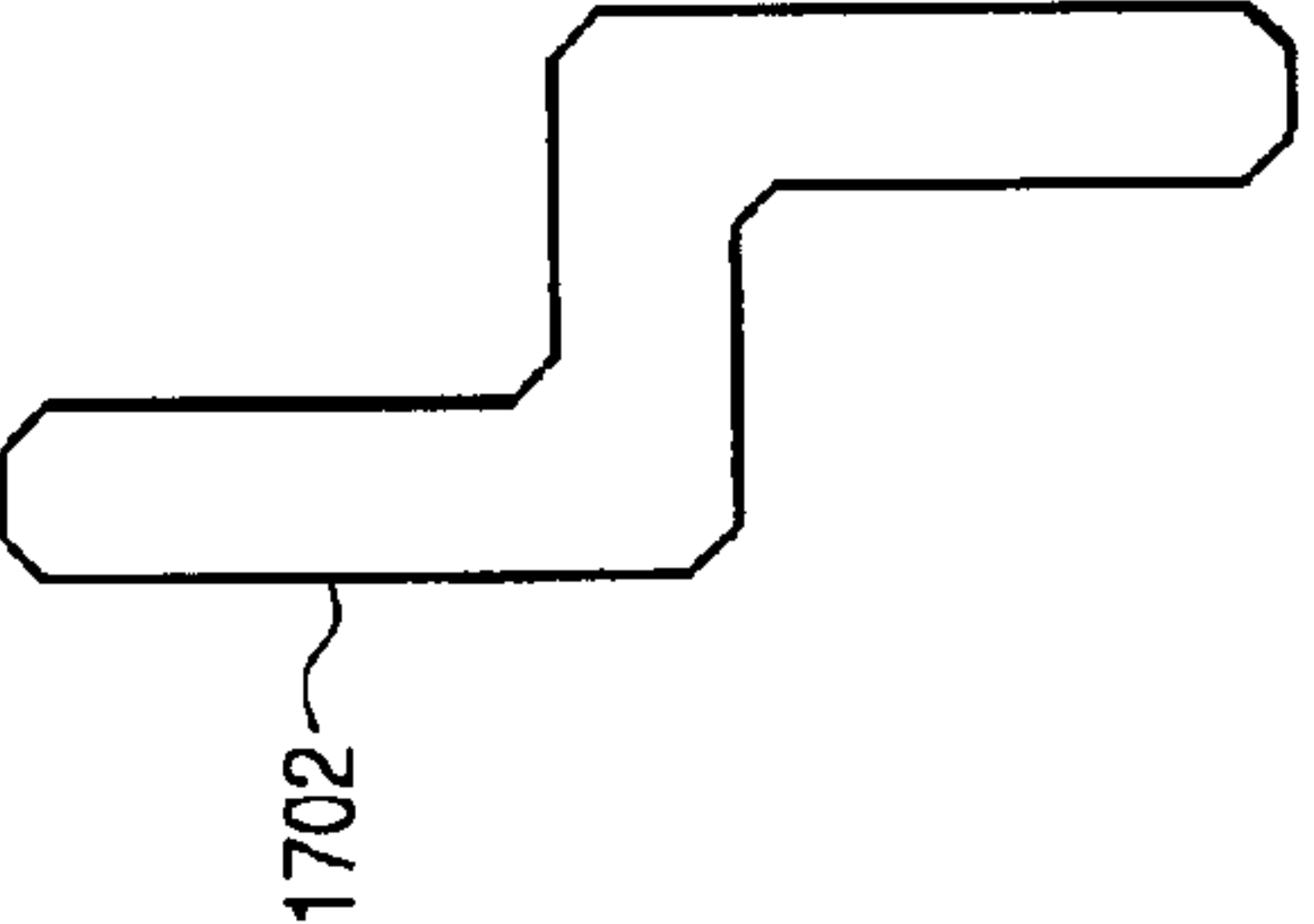


FIG. 23C

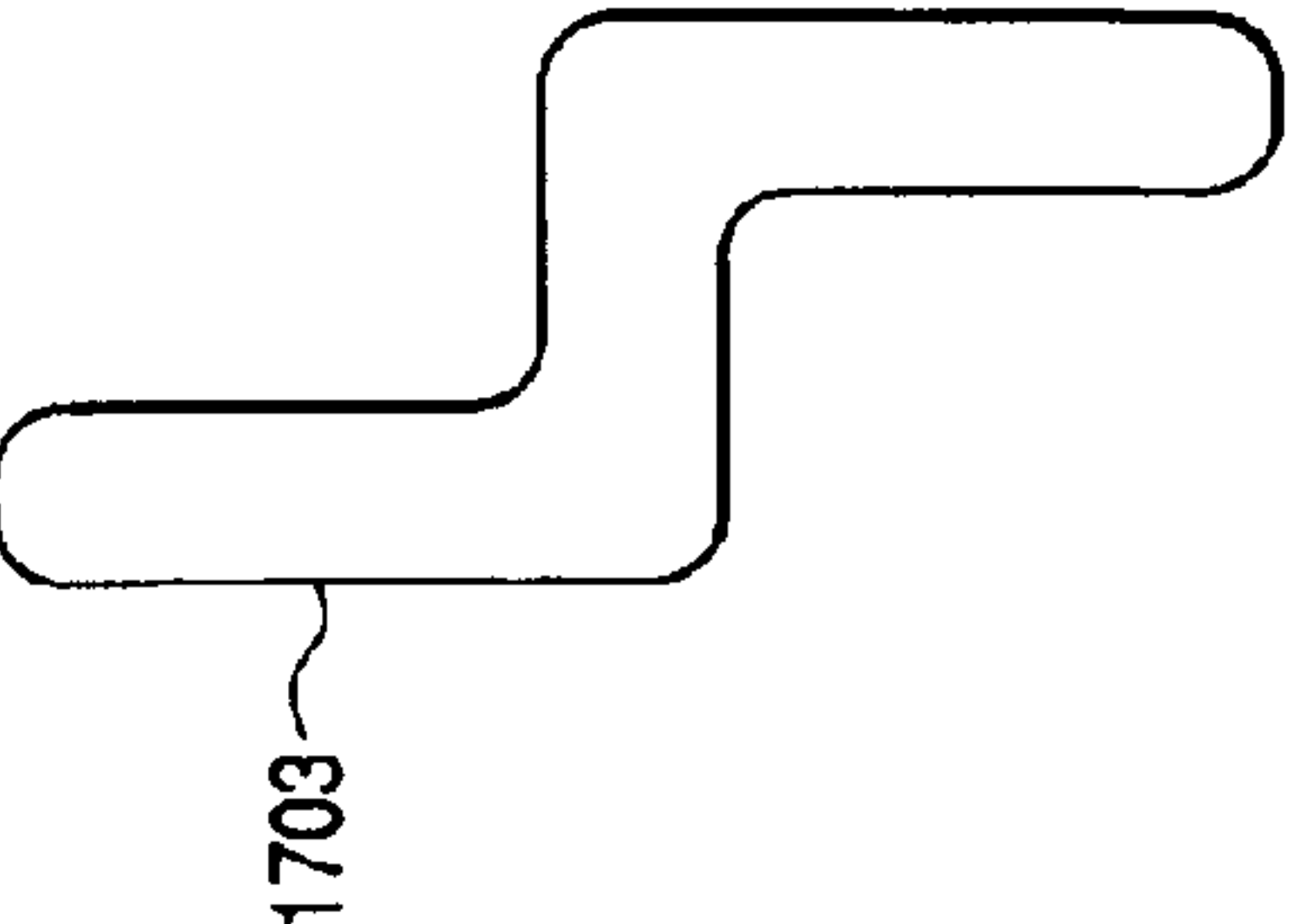


FIG. 24A

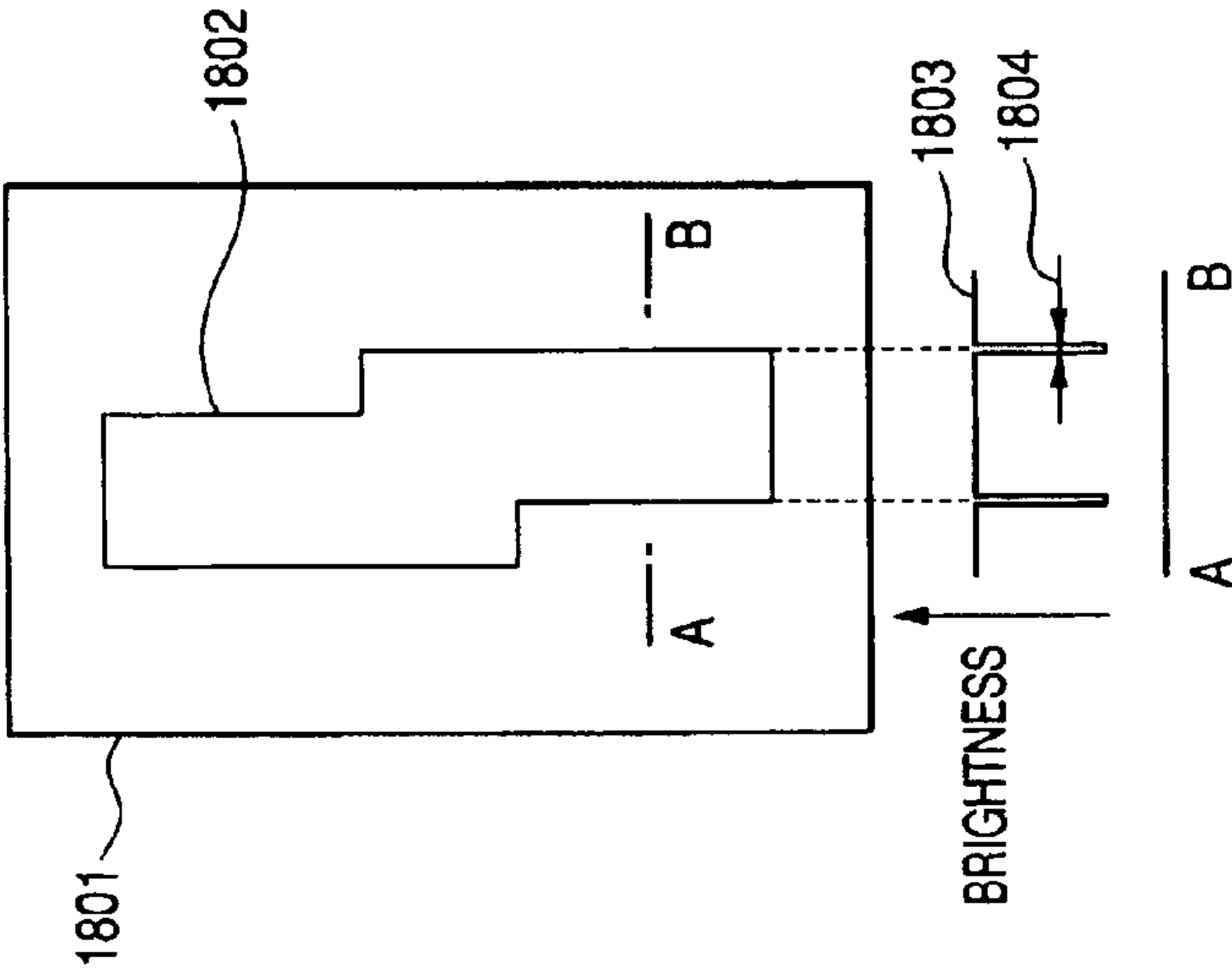


FIG. 24B

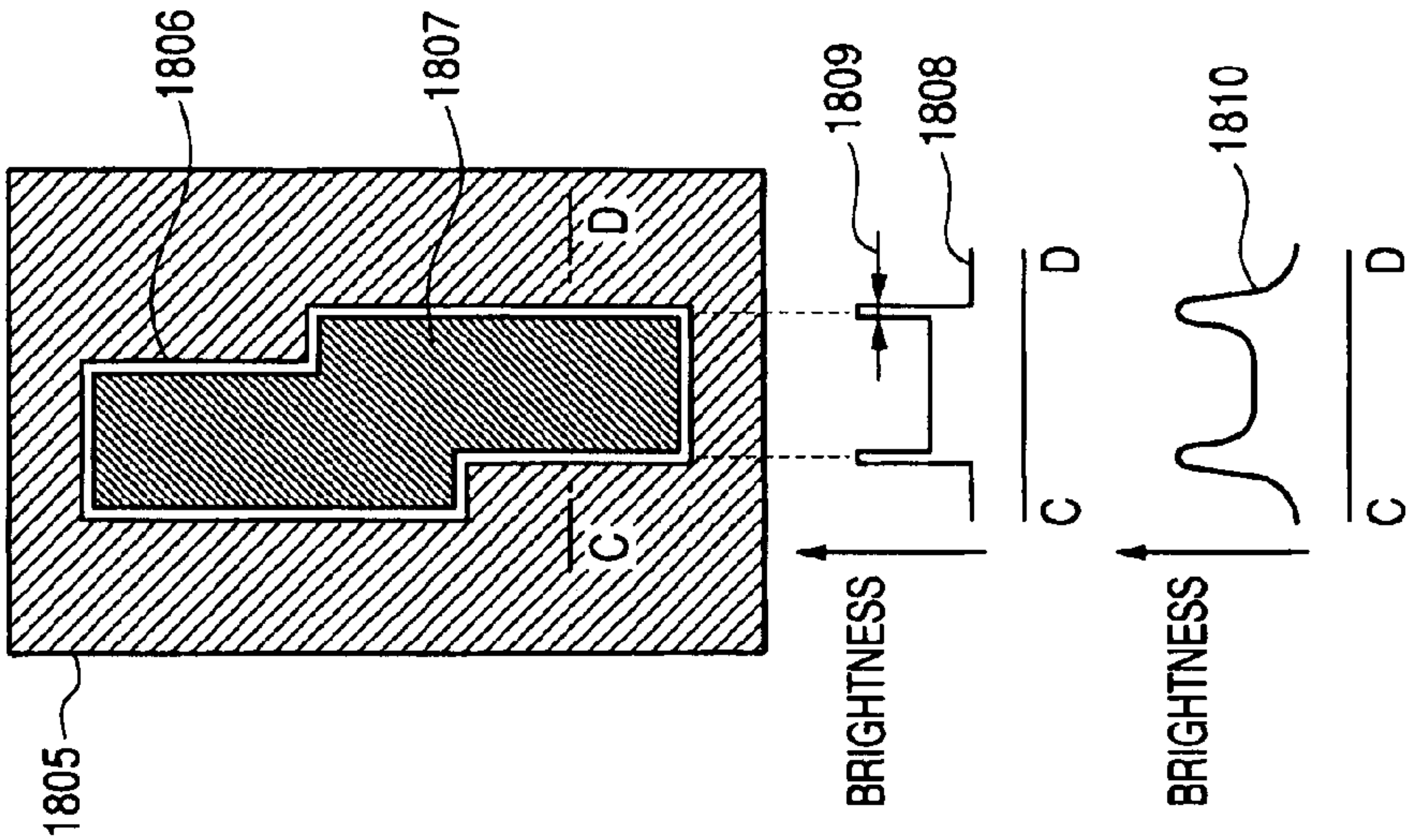


FIG. 25A

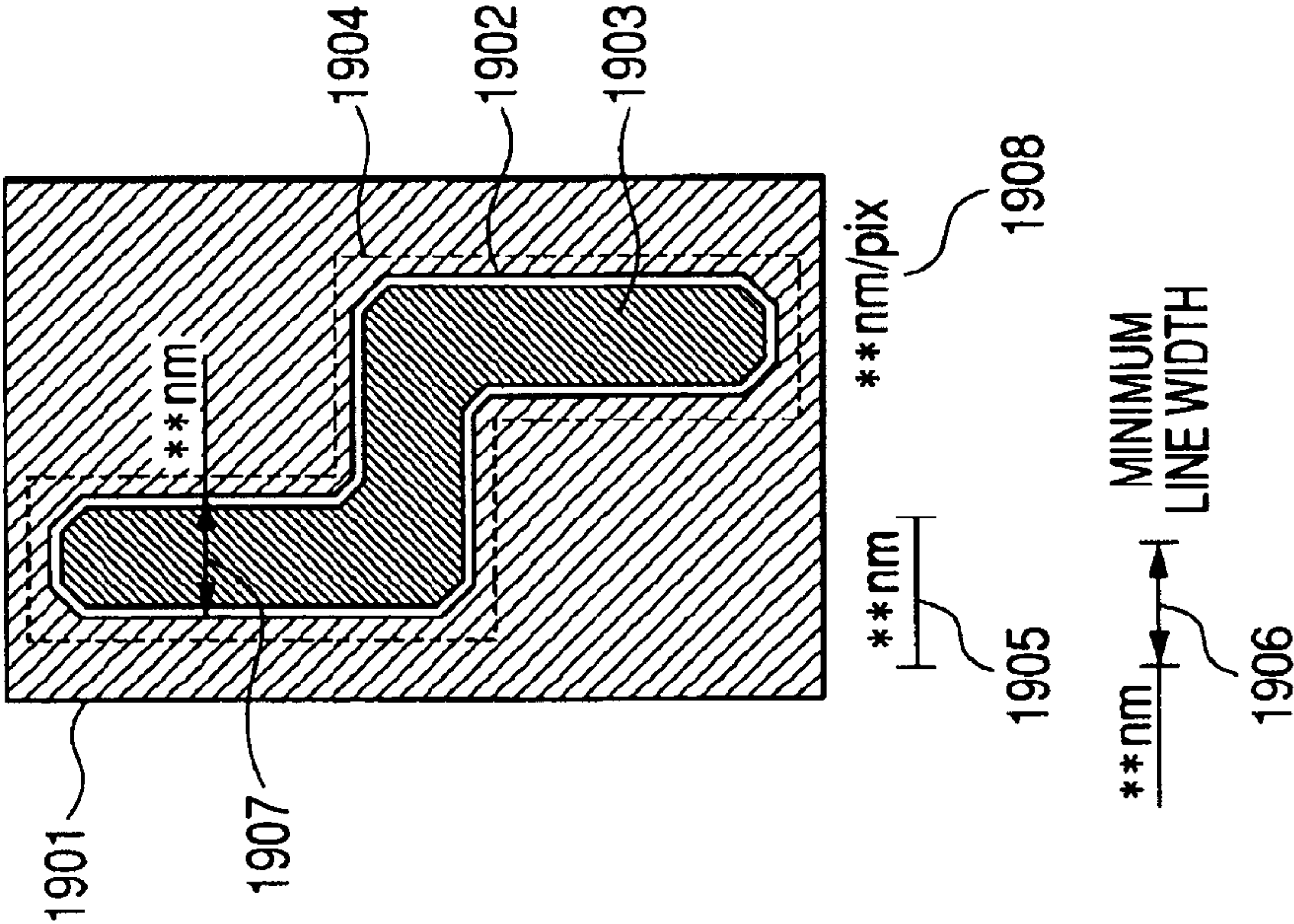
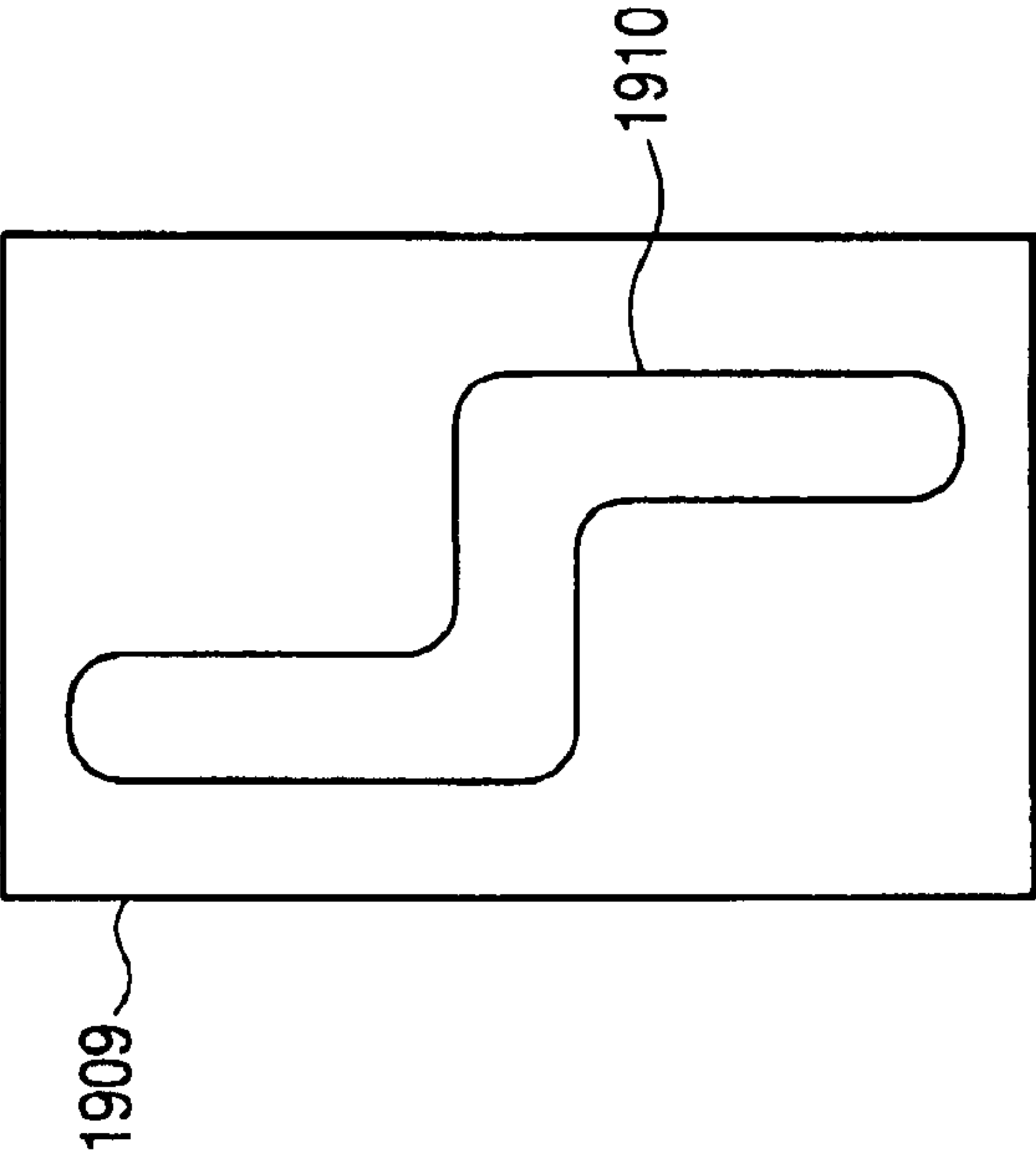


FIG. 25B



METHOD AND APPARATUS FOR CREATING IMAGING RECIPE

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS REFERENCE TO RELATED APPLICATION

Notice: More than one reissue application has been filed for Reissue Pat. No. 7,559,047. The reissue applications numbers are Ser. No. 12/614,358, filed Nov. 6, 2009 (the present application) and Ser. No. 12/621,307, filed Nov. 6, 2009 (a continuation of Ser. No. 12/614,358), the contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for creating imaging recipe used to acquire images at any position on a sample with a critical-dimension scanning electron microscope (CD-SEM) or the like. The imaging recipe defines not only coordinates of imaging points of addressing point and evaluation point (end measuring point), but also the image templates or imaging conditions (or the like) that are associated with the above coordinates. The invention is also concerned with an apparatus (SEM apparatus) for evaluating shapes of patterns formed on semiconductor wafers.

Traditionally, CD-SEMs and the like are most commonly used to inspect the workmanship of the highly accurate wiring patterns formed on semiconductor wafers. In SEM apparatuses such as the CD-SEMS, dimensionally critical points on the semiconductor patterns to be inspected are observed as measuring points through the SEM, then various dimensional data on the patterns, such as wiring widths, are measured from the images acquired during the observation process, and the dimensional data is monitored to detect changes in process parameters.

To perform these inspections, it is necessary to create the imaging recipe that defines the coordinates of imaging points, imaging conditions, image templates of each imaging point, and other data.

Japanese Patent Laid-Open Nos. 2002-328015 and 2000-236007 disclose examples of a known technique for creating imaging recipe used with such a SEM apparatus.

Japanese Patent Laid-Open No. 2002-328015 describes a semiconductor inspection system constituted by two sub-systems. One is a navigation system that stores CAD data and other design information on a semiconductor wafer and uses the stored design information to set the imaging/inspection conditions including the regions of the semiconductor wafer that are to be inspected. The other is a scanning electron microscopic system that acquires images of the semiconductor wafer in accordance with the set imaging/inspection conditions and is executed inspection of patterns. According to Japanese Patent Laid-Open No. 2002-328015, this semiconductor inspection system also has a function that detects the position of an addressing point (AP) from the CAD data and registers the CAD data of this detected position as a template. In addition, this system has a function that acquires a SEM image associated with the AP, then matches between the acquired SEM image and the registered CAD template at the AP, and after re-registering as another template the SEM image associated with the position of the CAD template, uses the re-registered SEM template subsequently.

Also, Japanese Patent Laid-Open No. 2000-236007 describes a method of creating sequence files for automatic detection with a scanning electron microscope. This file-creating method includes five process steps: acquiring design data from CAD data; acquiring pattern data of any region from the design data; extracting pattern contour edge data on the basis of the pattern data; specifying from the pattern outline edge data the sections to be measured; and setting template edge data from the pattern outline edge data associated with the specified sections.

For the semiconductor inspection system described in Japanese Patent Laid-Open No. 2002-328015, however, a linear image created from the CAD data (for example, an image on which only the boundary of a mask for forming pattern on a resist is represented as edges) is used to determine imaging points manually or automatically. Therefore, there has been the problem that appropriate imaging points cannot be selected because of a significant difference in visual or apparent position between the above linear image and an actual SEM image.

Also, using the method based on optical simulation or resist shape simulation, described in Japanese Patent Laid-Open No. 2000-236007, requires setting resist information (atomic composition ratio, film thickness, negative/positive attribute, light transmittance, light absorption energy, and others), the optical constants (wavelength, numerical aperture, s, the kind of mask, and others) of the light exposure apparatus used, developing agent information (composition, developing rate coefficient, developing time, and others), and other various simulation parameters. In addition, these simulation parameters are not easy to set. Furthermore, the simulation parameters could include those which vary according to the particular position on the wafer surface or a particular time.

SUMMARY OF THE INVENTION

The present invention relates to an apparatus and method designed to create an imaging recipe (including: coordinates of imaging points, imaging conditions, and image template information) for evaluating shapes of patterns by measuring electrical wiring widths and other various dimension values of the patterns from observation images. In the above apparatus and method, analysis using CAD images converted from CAD data can create (generate) the imaging recipe automatically and within a minimum time.

The present invention relates to an apparatus and method for evaluating shapes of patterns formed on semiconductor wafers. In the apparatus and method, a SEM apparatus (or the like) with an imaging recipe creation device can be used to measure at high speed and accurately a large number of sections to be inspected, estimate semiconductor device characteristics and manufacturing process states, and feed back measurement and estimation results into various manufacturing processes.

More specifically, an aspect of the present invention is an imaging recipe creation apparatus and method for creating an imaging recipe for SEM-based observation of semiconductor patterns by use of a scanning electron microscope. The above apparatus and method comprise a CAD data file which obtains by receiving and storing CAD data that contains layout information of the above semiconductor patterns, and a CAD image creation unit which creates CAD images by converting the stored CAD data within the CAD data file into image form. The apparatus and method are designed so as to create the imaging recipe by using the CAD images that have been created by the CAD image creation unit.

In addition, the CAD image creation unit in the above aspect of the present invention includes an image-quantizing width determination section which creates the above CAD images by converting the above CAD data into image form by use of the image-quantizing width determined from the CAD data on the basis of reference pattern width to be noted. In the image-quantizing width determination section, the reference pattern width to be noted includes a minimum line width or minimum inter-pattern distance of the semiconductor patterns to be noted. Furthermore, the CAD image-creation unit in the above aspect of the present invention is constructed so that the minimum line width or minimum inter-pattern distance of the semiconductor patterns is either calculated from the CAD data automatically, assigned by a user, or calculated from the CAD data automatically on the basis of user-set parameters (conditions). Besides, the above reference pattern width has its value specified in a header (or the like) of the CAD data or displayed in GUI (Graphic User Interface) screen mode. Moreover, if the reference pattern width differs between the CAD data regions extracted, the CAD data is converted into image form with image-quantizing widths different for each of the extracted CAD data regions. Determining image-quantizing widths in this way prevents an image size from becoming redundant and makes it possible to generate the CAD images that have held a pattern structure to be noted.

Another aspect of the present invention is a semiconductor pattern shape evaluation apparatus that conducts SEM-based observations on a semiconductor pattern formed on a semiconductor wafer in accordance with an imaging recipe by using a scanning electron microscope and evaluates a shape and dimensions of the semiconductor pattern on the basis of the SEM-based observations. The semiconductor pattern shape evaluation apparatus includes an imaging recipe creation device that creates the imaging recipe for the SEM-based observations mentioned above.

According to the present invention, automatic determination of imaging points (including a part or all of an addressing point, focusing point, stigmatism control point, brightness and contrast control point, or end measuring point) or the like from the CAD image is possible by using a CAD image that has been created based on image-quantizing width, assigned brightness, geometrical deformation, and/or the like, for which reason, the imaging creation that has conventionally been manually conducted can be implemented more easily and at higher speed.

According to the present invention, during actual observation of imaging points through a SEM, it is also possible to match a CAD image (template) whose coordinates are known and a SEM image very accurately, and consequently to evaluate a shape and dimensions of a pattern very accurately.

These and other objects, features, and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic block diagram showing an embodiment of a SEM apparatus according to the present invention;

FIG. 2A is a perspective view schematically showing a state of the electrons emitted from the surface of a semiconductor wafer when the wafer surface is scanned with focused electron beams in the SEM apparatus, and FIG. 2B is a diagram showing a method of converting into image form the signal quantities obtained by detecting the electrons emitted from the semiconductor wafer surface;

FIG. 3 is a diagram showing an example of an imaging sequence in the SEM apparatus according to the present invention;

FIG. 4 is a diagram of the CAD data showing various imaging positions in a low-magnification image according to the present invention;

FIG. 5A is a diagram that shows layout data of design patterns according to the present invention, and FIG. 5B is a diagram showing an example of a file format of the layout data;

FIG. 6 is a diagram showing an example of a total process flow in a CAD image-creating unit according to the present invention;

FIG. 7A is a diagram showing a process flow for determining a quantizing width of an image after extracting a ROI, and FIG. 7B is a diagram showing a process flow for calculating reference pattern width and determining a quantizing width of an image before extracting a ROI;

FIG. 8A is a diagram showing a semiconductor pattern shape, FIG. 8B is a diagram showing another semiconductor pattern shape, FIG. 8C is a diagram showing yet another semiconductor pattern shape, FIG. 8D is a diagram showing a shape of a pattern to be formed on a wafer, and FIG. 8E is a diagram showing the pattern shape derived by optical proximity correction of CAD data;

FIG. 9A is a diagram showing a semiconductor pattern shape in which a minimum inter-pattern distance is given as 714, FIG. 9B is a diagram showing a semiconductor pattern shape in which a minimum inter-pattern distance is given as 717, and FIG. 9C is a diagram showing a semiconductor pattern shape in which a minimum inter-pattern distance is given by 721;

FIG. 10 is a diagram showing a case in which an original minimum line width cannot be determined because of one pattern being split by a boundary of an extraction region;

FIG. 11A is a diagram showing a resist pattern formed on a wafer, and FIG. 11B is a diagram showing two exposure masks for forming the resist pattern of FIG. 11A;

FIG. 12 is a diagram explaining an example of determining minimum line width by the number of votes;

FIG. 13A is a diagram showing a CAD image created from CAD data, FIG. 13B is a diagram showing a CAD image of a ROI created from CAD data, FIG. 13C is a diagram showing a case in which a width 811 of a reference pattern on a CAD image of a ROI created from CAD data is greater than a width 808 of the reference pattern in FIG. 13B, and FIG. 13D is a diagram showing a CAD image formed so that a width of a reference pattern becomes a pixel size;

FIG. 14A is a diagram showing an example of a calculation method for minimum line width, and FIG. 14B is a diagram showing an example of a calculation method for a minimum inter-pattern distance;

FIG. 15A is a diagram showing a CAD image of a mask pattern, FIG. 15B is a diagram showing a CAD image of the same mask pattern as that of FIG. 15A, but different in image-quantizing width, and FIG. 15C is a diagram showing a CAD image of the same mask pattern as that of FIG. 15A, but different from the CAD images of FIGS. 15A and 15B in terms of image-quantizing width;

FIG. 16A is a diagram showing an example of CAD image generation in which information on partial mask removal is used as attribute information, the diagram representing a binary image of a pattern color-coded in accordance with the partial mask removal information, FIG. 16B is a diagram showing a binary image of the same mask pattern as that of FIG. 16A, but different in image-quantizing width, and FIG. 16C is a diagram showing a binary image of the same mask

5

pattern as that of FIG. 16A, but different from the binary images of FIGS. 16A and 16B in terms of image-quantizing width;

FIG. 17A is a diagram showing a CAD image that includes a plurality of patterns and two kinds of underlayers, and FIG. 17B is a diagram showing a CAD image that incorporates differences in brightness values of a SEM image;

FIG. 18A is a diagram showing a CAD image with two layers displayed in overlapped form, FIG. 18B is a diagram showing a case in which a boundary of the patterns observed on a SEM image is extracted from a positional relationship between the upper and lower layers on the CAD image, and FIG. 18C is a diagram showing a CAD image on which patterns present on layers are color-coded for each layer;

FIG. 19A (a) is a diagram showing a CAD image with a plurality of mixed patterns each having a different line width, FIG. 19A (b) is a diagram showing a CAD image with changes in color-coding brightness value between a logic block and a memory block in the plurality of mixed patterns of different line widths, FIG. 19B (a) is a diagram showing a CAD image with an entire region color-coded in the mixed state of the plural patterns each having a different line width, and FIG. 19B (b) is a diagram showing a CAD image having a region color-coded by combining the color-coding methods of FIGS. 19A (b) and 19B (a) in the mixed state of the plural patterns each having a different line width;

FIG. 20 is a diagram showing an example of a process flow for simulating a pattern shape actually generated from CAD data (mask data) in a pattern shape-deforming unit according to the present invention;

FIG. 21A is a diagram showing a mask pattern, FIG. 21B is a diagram that shows simulation results on an on-wafer luminous intensity distribution obtained during the light exposure that uses the mask pattern of FIG. 21A, and FIG. 21C is a diagram showing a contour shape of a luminous intensity distribution of a sliced surface obtained by slicing the luminous intensity distribution of FIG. 21B at a luminous intensity level "th";

FIG. 22A is a diagram that shows CAD data of a mask, FIG. 22B is a diagram of a photomask pattern to which partial mask removal (unmasking) information is appended, FIG. 22C is a diagram showing a multivalued image obtained by smoothing the photomask pattern of FIG. 22B, and FIG. 22D is a diagram that shows binarization results on the multivalued image of FIG. 22C;

FIG. 23A is a diagram that shows CAD data, FIG. 23B is a diagram showing a shape obtained by cutting several tens of percent of line width at corners of the pattern of FIG. 23A, and FIG. 23C is a diagram showing a shape obtained by replacing the corner section of the pattern of FIG. 23A with sectors;

FIG. 24A shows a CAD image with a pattern depicted by line drawing, and FIG. 24B shows a CAD image drawn allowing for an edge effect of a boundary of a pattern;

FIG. 25A is a diagram showing an example of a GUI for displaying a CAD image, the diagram being an overlapped representation of design data and a CAD image drawn allowing for an edge effect of a boundary of a pattern, and FIG. 25B is a diagram showing another example of a GUI for displaying a CAD image, the diagram being a representation of a SEM image disposed next to the CAD image and design data of FIG. 25A.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of a SEM apparatus with an imaging recipe creation function according to the present invention, namely,

6

a semiconductor pattern shape evaluation apparatus using a scanning electron microscope such as a critical-dimension scanning electron microscope (CD-SEM), will be described hereunder using FIGS. 1 to 25.

Factors such as decreases in design margins, coupled with further fineness and high density of LSI patterns, are substantially increasing the number of sections to be inspected to dimensionally manage semiconductor patterns. These tendencies are bringing about a strong demand for the improvement of the throughputs and automation ratios of the SEM apparatuses and other apparatuses used as dimensional management tools.

To use a SEM apparatus (or the like) to observe measuring points as dimensionally critical points on the semiconductor patterns to be inspected, and evaluate the shapes of these patterns by measuring the wiring widths and other various dimensions of the patterns from associated observation images, it is necessary to determine the coordinates of the imaging points including a part or all of an addressing point (AP), a focusing point (FP), a stigmatism control point (a stigmatic point) (SP), a brightness/contrast control point (BP), and an evaluation point (an end measuring point) (EP). It is also necessary to determine imaging conditions (an imaging magnification coefficient and other factors related to image quality, such as an electron beam dose rate, focus, and stigmatism). In addition, image templates at each imaging point must be registered. Information of the coordinates of each imaging point, information of the imaging conditions, and information of image template are collectively called an imaging recipe.

In order to effectively utilize the semiconductor pattern design data managed as CAD data, the present invention creates an imaging recipe automatically or within a minimum time by appropriately converting the CAD data into image data and conducting analyses using the CAD images obtained by the conversion. Consequently, the use of the SEM apparatus or the like makes that it possible to measure at high speed and accurately a large number of sections to be inspected, estimate semiconductor device characteristics and manufacturing process states, and feed back measurement and estimation results into various process data.

1: SEM Apparatus (Semiconductor Pattern Shape Evaluation Apparatus Using a Scanning Electron Microscope)

1.1: SEM Apparatus Configuration

FIG. 1 is a schematic block diagram of a scanning electron microscope (SEM) which acquires a secondary electron image (SE image) or backscattered electron image (BSE image) of a sample in the present invention. The SE image and the BSE image are collectively called a SEM image. Also, the image acquired here includes a part or all of either a top-down image of an object-under-measurement when the object is observed from a vertical direction, or a tilt image of the object when observed from any oblique direction.

An electron optical system 102 includes an electron gun 103 that generates an electron beam (primary electron) 104, a condenser lens 105 that converges the electron beam 104 generated from the electron gun 103, a deflector 106 that deflects the converged electron beam 104, an ExB deflector 107 that detects a secondary electron, and an objective lens 108 that forms an image of the sample (semiconductor wafer) 101 on the surface thereof by acquiring the converged electron beam. Sample 101 is rested on an XY stage 117. The deflector 106 and the objective lens 108 then work together to control an irradiation position and aperture stop of the electron beam such that any position on the sample 101 rested on the stage 117 will be irradiated with the electron beam in a focused condition thereof. The XY stage 117 moves the

sample **101** and enables an image of the sample at any position thereon to be acquired. Changing an observing position by moving the XY stage **117** is called "stage shifting", and changing the observing position by deflecting the electron beam via the deflector **106** is called "beam shifting."

In the meantime, a secondary electron and backscattered electrons are emitted from the sample **101** that has been irradiated with an electron beam. The secondary electron is detected by a secondary electron detector **109**, whereas the backscattered electrons are detected by backscattered electron detectors **110**, **111**. The backscattered electron detectors **110** and **111** are installed to face in directions different from each other. The secondary electron and backscattered electrons that have been detected by the secondary electron detector **109** and the backscattered electron detectors **110**, **111**, respectively, are each converted into digital signal form by A/D converters **112**, **113**, **114**. These digital signals, after being input to a processing/control unit **115** and stored into an image memory **1152**, are sent to a CPU **1151** to undergo image processing appropriate for particular needs. The CPU **1151** executes processing shown in FIG. 3, for example, to measure various dimension values of a pattern, such as wiring width, and monitor these dimension values to detect changes in process parameters. Geometry of the semiconductor pattern, including the above dimensions, is thus evaluated.

To acquire (image) AP, FP, SP, BP, or EP based on imaging recipes created by an imaging recipe creation device **125**, the processing/control unit (computer system) **115** sends a control signal to a stage controller **119** and/or a deflection controller **120** and evaluates the geometry of the semiconductor pattern by conducting various types of image processing and control operations on an observation image of the sample **101**. Also, the processing/control unit **115** is connected to the stage controller **119** that observes a global alignment mark on the wafer **101** via an optical microscope (not shown) and controls a position and movement of the stage **117**. The control of the stage position and movement includes the global alignment control conducted to compensate for any deviations of the wafer **101** from a home position thereof and for any rotational errors of the wafer. The processing/control unit **115** is also connected to the deflection controller **120** that controls electron beam shifting (beam deflection) by controlling the deflector **106**, and to a focus controller **121** that controls focus by controlling the objective lens **108**. Additionally, the processing/control unit **115** is connected to a display unit **116** having an input device, and thus has functions such as a graphic user interface (GUI) to display images and others to a user.

Although an example of a SEM apparatus configuration with two backscattered electron image detectors is shown in FIG. 1, this number of backscattered electron image detectors can be either reduced or increased. Also, part or all of the above-mentioned processing and control functions of the computer system **115** can be allocated to a plurality of different processing terminals to provide required processing and control.

Several methods are usable to obtain a tilt image of an object to be measured, namely, an image of the object when observed from any oblique direction, by using the apparatus shown in FIG. 1. Examples of these methods include the following:

(1) Scheme for forming an inclined image by deflecting an irradiated electron beam via an electron optical system and inclining an irradiation angle of the electron beam, as described in, for example, Japanese Patent Laid-Open No. 2000-348658

(2) Scheme by inclining the stage **117** itself that moves a semiconductor wafer **101** (in FIG. 1, the stage is inclined at a tilt angle **118**)

(3) Scheme by mechanically inclining the electron optical system itself.

The processing/control unit **115** is further connected to an imaging recipe creation device **125** via a network, a bus, or the like. The imaging recipe creation device **125** creates imaging recipes, each of which defines coordinates of the imaging points including either an addressing point (AP), a focusing point (FP), a stigmatism control point (SP), a brightness/contrast control point (BP), or an evaluation point (an end measuring point) (EP), or a plurality or all thereof. Each imaging recipe also includes imaging templates of the above coordinates, imaging conditions (an imaging magnification coefficient and other factors related to image quality), and other information. The imaging recipe creation device **125** is connected to a CAD system **130** via the network or the like in order to acquire CAD data.

The imaging recipe creation device **125** includes a CAD data file **507** for storing CAD data, a CPU (CAD image creation unit) **1251** having an image-quantizing width determination section **12511**, a brightness information providing section **12512**, and a pattern shape deformation processing section **12513**, and a CAD image memory **1253** for storing the CAD images created by the CPU **1251**. The image-quantizing width determination section **12511**, the brightness information providing section **12512**, and the pattern shape deformation processing section **12513** may use programs to execute respective processing. The imaging recipe creation device **125** includes an imaging recipe creation unit which creates an imaging recipe by using a CAD image created by the CAD image creation unit **1251**. Additionally, the imaging recipe creation device **125** is connected to a display unit **126** having an input device, and thus has functions such as a GUI to display images and others to the user. Furthermore, the imaging recipe creation device **125** is connected to a storage device **127** for storing various data.

Next, a method in which, when the surface of the semiconductor wafer is scanned with electron beams and irradiated therewith, signal quantities of the electrons emitted from the semiconductor wafer surface are converted into image form, will be described using FIGS. 2A and 2B. For example, the electron beams are, as shown in FIG. 2A, irradiated as beams **201-203** or **204-206** to conduct scans in x- and y-directions. Changing a deflecting direction of the electron beams enables a scanning direction to be changed. Three locations on the semiconductor wafer that has been irradiated with the electron beams **201-203** in the x-direction are denoted as G_1 to G_3 , respectively. Similarly, three locations on the semiconductor wafer that has been irradiated with the electron beams **204-206** in the y-direction are denoted as G_4 to G_6 , respectively. The signal quantities of the emitted electrons at the locations G_1 to G_6 are expressed as brightness values of pixels H_1 to H_6 within the image **209** shown in FIG. 2B. Subscripts 1 to 6 at lower right portions of the locations G are associated with subscripts 1 to 6, respectively, assigned to the locations G , H . Reference number **208** is a coordinate system (I_x , I_y) that denotes the x- and y-directions on image I .

1.2: SEM Imaging Sequence

Next, an imaging sequence for observing any evaluation point (end measuring point) (EP) will be described using FIG. 3. A section to be imaged in the imaging sequence, and imaging conditions to be used therein (i.e., an imaging magnification coefficient and other data related to image quality), and evaluation conditions at EP are created as an imaging recipe by the imaging recipe creation device **125**. After being

created, the imaging recipe is stored into, for example, a storage device **123** and managed properly.

First, sample **101** is set up on the stage **117** of the SEM apparatus in step **S31**. Next, in step **S32**, the processing/control unit **115** calculates a deviation of the sample from a home position thereof and a rotational deviation of the sample by observing the global alignment mark on the wafer through an optical microscope (not shown), and conducts corrections by controlling the stage **117** via the stage controller **119** on the basis of those deviations. In step **S33**, the processing/control unit **115** moves the imaging position to an addressing point (AP) in accordance with the imaging conditions and coordinates of the imaging point, created by the imaging recipe creation device **125**, by moving the stage **117**, and acquires an image using lower-magnification imaging conditions than those of EP (end measuring point).

A supplementary description of AP is given here. For direct observation of EP, in order to solve the problem that the associated section to be observed may become disturbed for reasons of stage-positioning accuracy and the like, the processing/control unit **115** first observes AP whose coordinates created by the imaging recipe creation device **125** beforehand for pre-positioning and registered in the storage device **123**, for example, are known. Next, the processing/control unit **115** conducts position matching between an image template at the AP previously created by the imaging recipe creation device **125** and stored into, for example, the storage device **123**, and a SEM image at the above-observed AP. The processing/control unit **115** thus detects the vector denoting a deviation between central coordinates of the image template and those of the AP when this point is actually observed. Next, the processing/control unit **115** subtracts the above-detected deviation vector from a relative vector between the coordinates of the image template and those of EP, and then controls the deflector **106** via the deflection controller **120** according to the difference vector subtracted. This control operation moves the imaging position by beam shifting (beam incident direction is tilted to change an irradiation position) to enable the observation of EP, whereby EP can be imaged with high coordinate accuracy (in general, positioning accuracy by beam shifting is higher than the positioning accuracy of the stage).

Therefore, the AP created by the imaging recipe creation device **125** and stored into, for example, the storage device **123**, should desirably satisfy conditions such as ease of matching between the registered image template and the observed SEM image. There are three reasons for that. A first reason is that since the AP is a pattern present at a distance through which the imaging position can be moved from EP by beam shifting, and since contamination at EP is to be suppressed, a field of view (FOV) for EP imaging may not need to be included in FOV of AP imaging. A second reason is that since the pattern needs to allow for the positioning accuracy of the stage, it is necessary for the AP to be correspondingly lower than EP in terms of imaging magnification. A third reason is that the pattern for the AP needs to be characteristic in terms of shape or brightness (the pattern for the AP is of a shape convenient for matching or has brightness).

As described later herein, according to the present invention, a CAD image that incorporates features of a more practicable SEM image can be generated as an image template while considering the above-described conditions during selection of a point as AP in the imaging recipe creation device **125**. Moreover, automatic selection of an appropriate imaging point for purposes such as evaluating the image in terms of specificity, complexity, and the like, also becomes possible. In addition, during manual selection of the imaging

point, a CAD that incorporates features of an actual SEM image can be displayed in, for example, a GUI screen mode of the display unit **126** in order to provide an operator with more judgment criteria.

In order to avoid image acquisition intended only to register a CAD image or a SEM image or, as disclosed in Japanese Patent Laid-Open No. 2002-328015, an image template, one possible variation of an AP image template registration method is by first registering an image template as a CAD template in the storage device **123**, for example, and then re-registering the SEM image actually acquired at AP, as the image template. As described later herein, according to the present invention, since the CAD image that incorporates features of a more practicable SEM image can be generated as an image template, it becomes possible to match the CAD image to an observed SEM image more appropriately than by registering the CAD image as a template.

Next, in step **S34**, beam shifting based on the control and processing of the processing/control unit **115** is conducted to move the imaging position to a focusing point (FP), at which an image is then acquired and automatic focusing parameters are calculated. Automatic focusing based on the calculated automatic focusing parameters is thus conducted. A supplementary description of FP is given here. During imaging at EP, automatic focusing is conducted to acquire a clearer image. Extended irradiation of the sample **101** with electron beams, however, causes contamination to stick to the sample.

For minimum sticking of contamination at EP, therefore, before observing EP on the basis of automatic focusing parameters, the processing/control unit **115** observes a coordinate point present near EP, as FP, and calculates the automatic focusing parameters. For these reasons, the FP registered in the storage device **123** should desirably satisfy several conditions. A first condition to be satisfied is that the FP is a pattern present at a distance through which the imaging position can be moved from the AP and EP by beam shifting and the field of views (FOV) for the AP and EP imaging must not be included in the FOV of FP imaging. A second condition to be satisfied is that the imaging magnification at the FP must be of much the same level as that of EP. A third condition to be satisfied is that the FP needs to have a pattern shape convenient for execution of automatic focusing (image blurring due to an out-of-focus event must be easy to detect). During the selection of FP, it is effective for the processing/control unit **115** to use the CAD image created by the imaging recipe creation device **125**, as in the selection of AP. During FP selection, therefore, it is possible to provide operator support by conducting automatic FP selection that uses the above CAD image, or by making a GUI-based display of the above CAD image on the display unit **116**.

Next, in step **S35**, beam shifting based on the control and processing of the processing/control unit **115** is conducted to move the imaging position to a stigmatic point (a stigmatism control point) (SP), at which an image is then acquired and stigmatism correction parameters are calculated. Automatic stigmatism correction based on the calculated parameters is thus conducted.

A supplementary description of SP is given here. During imaging at EP, stigmatism correction is conducted to acquire a distortionless image. Similarly to AP and FP, however, extended irradiation of the sample **101** with electron beams causes contamination to stick to the sample. For minimum sticking of contamination at EP, therefore, before observing EP on the basis of stigmatism correction parameters, the processing/control unit **115** observes a coordinate point present near EP, as SP, and calculates the stigmatism correction parameters. For these reasons, the SP registered in the

11

storage device **123** should desirably satisfy several conditions. A first condition to be satisfied is that since the SP is a pattern present at a distance through which the imaging position can be moved from AP and EP by beam shifting, the field of view (FOV) for AP and EP imaging must not be included in FOV of SP imaging. A second condition to be satisfied is that the imaging magnification at the SP must be of much the same level as that of EP. A third condition to be satisfied is that the SP needs to have a pattern shape convenient for execution of stigmatism correction (image blurring due to stigmatism must be easy to detect). During the selection of the SP, it is effective for the processing/control unit **115** to use the CAD image created by the imaging recipe creation device **125**, as in the selection of AP. During SP selection, therefore, it is possible to provide operator support by conducting automatic SP selection that uses the above CAD image, or by making a GUI-based display of the above CAD image on the display unit **116**.

Next, in step **S36**, beam shifting based on the control and processing of the processing/control unit **115** is conducted to move the imaging position to a brightness and contrast control point (BP), at which an image is then acquired and brightness and contrast correction parameters are calculated. Automatic brightness and contrast correction based on the calculated parameters is thus conducted.

A supplementary description of BP is given here. During imaging, in order to acquire a clearer image having an appropriate brightness value and contrast, a voltage value and other parameters of a photomultiplier in the secondary electron detector **109**, for example, are adjusted so that, for example, the highest level portion of an image signal and the lowest level portion are set to obtain full contrast or a contrast level close thereto. Similarly to AP and FP, however, extended irradiation of the sample with electron beams causes contamination to stick to the sample. For minimum sticking of contamination at EP, therefore, before observing EP on the basis of brightness and contrast correction parameters, the processing/control unit **115** observes a coordinate point present near EP, as BP, and calculates the brightness and contrast correction parameters. For these reasons, the BP registered in the processing/control unit **115** should desirably satisfy several conditions. A first condition to be satisfied is that since the BP is a pattern present at a distance through which the imaging position can be moved from AP and EP by beam shifting, the FOV for AP and EP imaging must not be included in the FOV of SP imaging. A second condition to be satisfied is that the imaging magnification at the BP must be of much the same level as that of EP. A third condition to be satisfied is that to obtain appropriate brightness and contrast of the image that will be acquired at an end measuring point (an evaluation point) using the parameters adjusted at the BP, the BP needs to have a pattern shape similar to that of the end measuring point (the evaluation point). During the selection of the BP, it is effective for the processing/control unit **115** to use the CAD image created by the imaging recipe creation device **125**, as in the selection of AP. During BP selection, therefore, it is possible to provide operator support by conducting automatic BP selection that uses the above CAD image, or by making a GUI-based display of the above CAD image on the display unit **116**.

There is a variation in which, for example, as the case may be, part or all of the automatic focusing, automatic stigmatism correction (control), and automatic brightness and contrast correction (control) processes described above in steps **S34**, **S35**, and **S36**, respectively, are omitted or execution order of these steps is arbitrarily changed or the coordinates of FP, SP,

12

and/or BP overlap (e.g., automatic focusing and automatic stigmatism correction are conducted in the same place).

Finally, in step **S37**, beam shifting based on the control and processing of the processing/control unit **115** is conducted to move the imaging position to an evaluation point (EP), at which an image is then acquired and pattern dimensions are measured using assigned evaluation conditions to evaluate the shape of the semiconductor pattern.

An example of template positioning of imaging points AP **401**, FP **402**, SP **403**, BP **405**, and EP **404** on lower-magnification CAD data **400** than for EP is shown with dotted-line frames in FIG. **4**.

An image template at AP being registered in the storage device **123** is one possible variation of a CAD image or a SEM image or a method of for example first registering the image template as a CAD template and then re-registering the SEM image actually acquired at AP, as the image template, in order to avoid image acquisition intended only to register an image template as disclosed in Japanese Patent Laid-Open No. 2002-328015.

2: Image Generation

The following describes an embodiment of a method of using the imaging recipe creation device **125** to convert CAD data **601** into image form and view or process the image data in order to conduct the foregoing CAD data-based imaging-point determining operations or image template registering operations on the storage device **123**. Information of the CAD data **601** written in a CAD data file **507** is first described. Design information on the semiconductor patterns shown in FIG. **5A** is assumed as an example in the description. In the figure, three layers, **504** to **506**, are schematically shown and three patterns, **501** to **503**, are shown on top layer **504**. The pattern **501** includes four apexes, P1 to P4. CAD data generally contains segment information that denotes a contour or profile of a pattern shape, represented by x- and y-coordinates of the apexes P1-P4, and layer information of the layers **504-506**. The x- and y-coordinates are expressed in an arbitrary reference coordinate system **500**, each having a unit of nanometers or the like.

The three process steps required for, or becoming effective during processing subsequent to, the conversion of the CAD data **601** into a CAD image **605** by the CPU (CAD image creation unit) **1251** of the imaging recipe creation device **125**, will be next described. The three process steps are, as shown in FIG. **6**, an image-quantizing width determination step **S61**, a brightness information providing step **S62** based on various attributes, and a pattern shape deformation step **S63**. Reference number **606** denotes a CAD image created with an arbitrary image-quantizing width in step **S61**, **607** denotes a CAD image provided with brightness information in step **S62** on the basis of arbitrary attribute information, and **608** denotes a CAD image to which a change in SEM signal quantity, associated with pattern shape (profile) deformation or an edge effect or the like, is provided as a change in brightness value in step **S63**.

2.1: Image-Quantizing Width Determination Step

An example of executing image-quantizing width determination step **S61** using the image-quantizing width determination section **12511** will be described using FIGS. **7** to **14**. The ROI (Region Of Interest) data determined by, the minimum line width/minimum inter-pattern distance data calculated by, reference width "Dp" data within the calculated ROI, the image-quantizing width "r" (=Di/Dp) data and other data determined by the image-quantizing width determination section **12511** using the CAD data **601** are stored into the storage device **127**, for example. The CAD image **606** (**605**) that has been formed by converting the CAD data including

the template position coordinates of observation points (AP, FP, SP, BP, EP) is stored into the CAD image memory **1253**.
2.1.1: Example of Reference Pattern Width “Dp” (Minimum Line Width, Minimum Inter-Pattern Distance)

First, in step **S611**, a region is extracted from the written CAD data within the CAD data file **507** and determined as an imaging region in order to convert the CAD data **601** into image form. Hereinafter, this region is called a ROI (Region Of Interest). Next, the number of pixels equivalent to the image-quantizing width (the unit pattern dimension, say, 1 nm, written in the CAD data file **507**) on the image is determined. Determination of the image-quantizing width itself, however, is an important factor. That is to say, inadvertent reduction of the image-quantizing width will result in an image size redundant for complexity of the shape of the pattern drawn. Thus, more image memory space than necessary will be used and a greater deal of calculation time will be spent in various image processing. Conversely, increasing the image-quantizing width too much will result in the patterns being concatenated or disappearing during quantization or in some other inconvenience of the on-image pattern shape significantly differing from the pattern shape actually required.

In the present invention, therefore, during the conversion of the extracted CAD data into image data, since a pattern structure needs to have been saved during subsequent CAD image processing, the image-quantizing width is determined with the pattern width to be noted, as a reference (hereinafter, this reference is called the reference pattern width). A minimum dimension (minimum line width of the pattern or the minimum inter-pattern distance) is used as an example of the reference pattern width.

The minimum line width is a minimum dimension of the pattern width used in semiconductor circuit design, and this dimension is typically given as gate length (or the like) of a transistor. In the present invention, the minimum line width also contains the minimum pattern width of all patterns or any pattern within the ROI. When the semiconductor pattern shapes **701**, **703**, **705** shown in FIGS. **8A** to **8C** by way of example are viewed alone, the minimum line width is given as distances **702**, **704**, **706**, respectively. Also, as shown in FIGS. **8D**, **8E**, when a pattern shape (e.g., **709**) of the CAD data provided with optical proximity correction (OPC) performed to prevent deformation of a resist pattern due to a diffraction phenomenon of light during exposure is taken as an input with respect to a pattern shape to be created on the wafer (e.g., for the pattern **707**, the minimum line width is given as the distance **708**), it is possible to select a dimension of the narrowest section **711** of the pattern existing before OPC is conducted, as the minimum line width, or to select a dimension of the narrowest section **710** of the pattern existing after OPC has been conducted, as the minimum line width.

The minimum inter-pattern distance is the minimum inter-pattern dimension used in semiconductor circuit design. When the semiconductor pattern shapes **712-713** or **715-716** shown in FIGS. **9A**, **9B** by way of example are viewed alone, the minimum line width is given as distances **714**, **717**, respectively. However, in perspective of the measure of the potential hazard that thickness of the patterns may cause short-circuiting therebetween, when the distance **717** is broken down in x- and y-directions and a distance **718** in the x-direction and a distance **719** in the y-direction are taken as Dy and Dx, respectively, the minimum inter-pattern distance between the pattern shapes **715-716** is given as the greater of the two distances, that is, in FIG. **9B**, as Dy (Dy>Dx). As the case may be, the minimum inter-pattern distance includes such a distance **721** between sections in one pattern as given by the pattern shape **720** of FIG. **9C**.

If the ROI contains a plurality of patterns and the above minimum line width or minimum inter-pattern distance differs between the plurality of patterns, respective minimum values can be defined as a minimum line width or minimum inter-pattern distance within the ROI.

An increase or decrease in the pattern thickness with respect to a dimensional design value could cause a device defect such as a short circuit or an open state. The minimum line width or minimum inter-pattern distance within the ROI has connection with circuit design margins against the above device defect such as a short circuit or an open state. It is therefore effective to determine the image-quantizing width on the basis of the minimum line width or minimum inter-pattern distance within the ROI, and to determine a to-be-monitored EP for an original design pattern on the basis of image data concerning a design pattern free of pattern disappearance, concatenation, and the like. The image data concerning a design pattern free of pattern disappearance, concatenation, and the like, is also effective for determining AP, FP, BP, SP.

A more specific example of converting a ROI **802** from CAD data **801** of FIG. **13A** into image data will be considered next. FIG. **7A** shows a process flow of the image-quantizing width determination step **S61**. First, a region to be extracted from the CAD data in order to conduct the conversion into image data is determined as a ROI in step **S611**. Next, during definition of the reference pattern width as the minimum line width within the ROI (there can be a variation of using the minimum line width or the minimum inter-pattern distance as the reference pattern width, or using the minimum line width or the minimum inter-pattern distance, whichever is the smaller, as the reference pattern width), the minimum line width is calculated for each pattern within the ROI in step **S612**. In step **S613**, reference pattern width “Dp” (expressed in nanometers, for example) within the ROI is calculated as, for example, the minimum line width of each pattern mentioned above. That is to say, as shown in FIG. **13B**, minimum line width **808** (=Dp) within the ROI is calculated from the ROI **802**.

Next, image-quantizing width “r” (pixels/nm) is determined on the basis of reference pattern width “Dp” in step **S614**. Image-quantizing width “r” is given as “ $r = Di/Dp$ ” using the dimension “Di” (pixels) on the image of the reference pattern width “Dp”. As shown in FIG. **13B**, the reference pattern width “Dp” **808** (nm) on the CAD image **809** created from the CAD data **802** becomes “Di” **810** (pixels). The dimension “Di” on the image is assigned the value that does not cause inconvenience during the arbitrary analysis (data viewing, image processing) conducted after image conversion, and the “Di” value can be changed according to particular details/kind of analysis, or for each manufacturing process for the semiconductor, or for each position on the wafer, or for each set of SEM imaging conditions (including an imaging magnification, image quality data, and others).

Conversely, for similar analysis, as shown in FIGS. **13B**, **13C** as an example, the image-quantizing width differs according to the ROI actually set up, and even if the above-mentioned ROI is of the same region size (actual size), the CAD image that has been obtained by the conversion can differ in region size (image size). That is to say, the reference pattern width “Dp” within ROI **803**, denoted as **811** in FIG. **13C**, is greater than the reference pattern width “Dp” within ROI **802**, denoted as **808** in FIG. **13B**, in other words, the pattern line width included in ROI **803** is greater than the pattern line width included in ROI **802**. Accordingly, if such image quantizing is conducted that causes the respective reference pattern widths “Dp” **808**, **811** of ROIs **802**, **803** to

become the same value on the image, the CAD images **809**, **812** created from the ROIs differ in image size. The reference pattern widths “Di” **810**, **813** on the CAD images **809**, **812**, however, are equal and when the line widths is noted, similar analytical results will be obtained between both images.

2.1.2: Problem-Causing Variation in Reference Pattern Width Determination (Image Edges, Pattern Splitting, and an Example of Minority in Votes)

Next, a supplementary description will be given of a variation of an image-quantizing width determining method.

First, the following problem occurs when minimum line width within a ROI is to be calculated in relation with a method of determining reference pattern width “Dp”. That is to say, for example, when as shown in FIG. **10**, respective minimum line widths of patterns **723**, **724**, **725** within a ROI are calculated and the smallest of the calculated values is defined as the minimum line width within the ROI, as with the pattern **725**, one pattern originally formed by combining the pattern **725** of a solid line and the pattern **726** of a dotted line is split by a boundary of an extraction region **722**. In that case, an after-extraction minimum line width **728**, not an original minimum line width **727**, will be obtained, even if the pattern **725** of a solid line is processed.

Calculation of the line width that originally does not exist could occur, depending on a particular manner of setting up such an extraction region. The calculation can be avoided using any one of five methods. A first method is by setting up an extraction region ROI so that the ROI does not span over one pattern. A second method is by extruding the minimum line width that has been calculated from the pattern positioned at an end/edge of an extraction region, from the use intended for processing during calculation of desired pattern width. A third method is by calculating minimum line width from before-extraction pattern shape information. A fourth method is by acquiring as preliminary input information the line width that can exist as minimum line width, and if line width values smaller than the preliminary input information are calculated, not using those values. A fifth method is by creating a histogram from the minimum line width that has been calculated from each pattern within a ROI, and calculating the reference pattern width existing in the ROI, from the distribution obtained.

A supplementary description is given below of the above third method of calculating the minimum line width from the before-extraction pattern shape information. To know the line width existing before extraction, it is effective, after determining the extraction region ROI, to identify the pattern positioned at the boundary of the region, and examine the contour shape existing before the extraction. Alternatively, it is effective to calculate line widths of each pattern before the extraction, and manage these line widths as a set of pattern attributes. For example, it is effective to calculate minimum width information for each pattern, as denoted by **510** in FIG. **5B**, and write the information into a data file or the like. Since the minimum width information is shared before and after the extraction, actual minimum width information is not lost by the extraction. When the minimum inter-pattern distance and other pattern-dependent attributes described later are calculated before or after ROI extraction, managing the above distance and attributes by use of the file **507** or displaying the distance and attributes in the GUI screen mode of the display unit **126** is likewise effective in arbitrary analysis.

FIG. **7B** shows a process flow of converting CAD data into image data by, before starting the ROI extraction, calculating reference pattern width from obtained attributes such as the minimum line width. First, in order to determine reference pattern width in the step **S613**, the minimum line width and

other information to be used as reference is calculated for each pattern in step **S612**. Next, the ROI is determined in step **S611**. Subsequent steps are the same as those described in FIG. **7A**.

Also, the following problem occurs when the minimum distance between patterns within the ROI is to be calculated in relation with a method of determining reference pattern width “Dp”. That is to say, the two exposure masks **730**, **731** shown in FIG. **7 11B** may be used to create on the wafer the resist pattern **729** shown in FIG. **11A**, for example. If a distance **732** between the exposure masks **730**, **731** is very short, the patterns created will also be concatenated by concatenating between these exposure masks **730**, **731** on the luminous intensity distribution obtained during exposure, so the exposure masks themselves will not be affected. However, for example, if calculating the minimum inter-pattern distance from the exposure masks **730**, **731** is attempted, the distance **732** that originally does not exist could be calculated as the minimum inter-pattern distance. This can be avoided using either of two methods. A first method is by acquiring as preliminary input information the distance that can exist as the minimum inter-pattern distance (>the distance between the patterns concatenated during exposure), and if line width values smaller than the preliminary input information are calculated, not using those values. A second method is by creating a histogram from the minimum inter-pattern distance that has been calculated from each pattern within a ROI, and calculating the reference pattern width existing in the ROI, from the distribution obtained.

The above method “by creating a histogram from the minimum line width or minimum inter-pattern distance that has been calculated from each pattern within a ROI, and calculating the reference pattern width existing in the ROI, from the distribution obtained” will be described in further detail using FIG. **12**. A method of calculating the reference pattern width from the minimum line width within the ROI is described below as an example. First, the minimum line width is calculated for each pattern within the ROI and then as shown in FIG. **12**, votes are conducted on the histogram, wherein a horizontal axis denotes a distance (in this example, the minimum line width) and a vertical axis denotes the number of votes). The shortest distance that has been voted for in this example is a distance **733**, but the number of votes for patterns associated with the distance **733** is very small. It is therefore possible to incorporate processing in which the distances whose number of votes is less than a threshold value **737** of the number of votes arbitrarily given (in FIG. **12**, distances **733**, **734**) will be excluded from calculation of the minimum line width within the ROI. It is also possible to incorporate processing in which the line width (e.g., **738**) that can exist as minimum line width will be acquired as preliminary input information, and if the line width values (in FIG. **12**, line widths **733**, **7344**) that are smaller than the preliminary input information are calculated, those values will not be used as the minimum line widths. Such processing will make it possible to prevent minor line widths and other line widths not important in device characteristics, as with the line width **807** shown in FIG. **13**, from being selected as typical minimum line widths within the ROI.

2.13: More Specific Methods of Calculating the Minimum Line Width and the Minimum Inter-Pattern Distance

Direct calculation from CAD data (numeric data of the apex coordinates of the pattern) and calculation from the CAD image obtained by converting CAD data with a suitable image-quantizing width value are available as more specific methods of calculating the minimum line width and the minimum inter-pattern distance in each pattern or the ROI. In the

17

latter of the above two methods, the minimum line width or minimum inter-pattern distance obtained will have a quantizing error of inaccuracy equivalent to the suitable image-quantizing width value.

An example of a calculation method for a minimum line width of a pattern **1001** is shown in FIG. **14A**. The pattern **1001** has eight apexes, P1 to P8. For example, a straight line is drawn from the apex P8, in an x-direction of an x/y coordinate system **1000** and in an internal direction of the pattern, and a position at which the line first intersects with the pattern is determined as a crossing point Q8x. During direct calculation from CAD data, whether crossing points exist between the line **1002** drawn from the apex P8, and each segment constituting a contour of the pattern **1001** (a segment between apexes P1, P2, a segment between apexes P2, P3, and so on up to a segment between apexes P8, P1) is sequentially examined by calculation, as an example of determining the crossing point Q8x.

During calculation from the CAD image obtained by converting CAD data with a suitable image-quantizing width value, the pattern is scanned along a straight line **1002**, from the apex P8, in the internal direction of the pattern, and a coordinate point at which a boundary of the pattern first appears is taken as a crossing point. Similarly, a straight line is drawn from the apex P8, in a y-direction and in the internal direction of the pattern, and a position at which the line first intersects with the pattern is determined as a crossing point Q8y. Distances **1002**, **1003** from the apex P8 to ends of the pattern in the x- and y-directions are thus calculated. The same is also conducted for each of the other apexes (distances from the apex P4 to the ends of the pattern in the x- and y-directions are given as **1004**, **1005** in another example). The shortest of the thus-obtained distances **1002** to **1005** is taken as the minimum line width of the pattern **1001**.

An example of a calculation method for a minimum inter-pattern distance of a pattern **1006** is shown in FIG. **14B**. In this figure, three patterns, **1006** to **1008**, are shown and these patterns have apexes P9-P12, P13-P16, and P17-P22, respectively. First, a straight line is drawn, for example, from the apex P10 to an apex of another pattern (say, P16, P17), and a distance between the apexes is calculated (e.g., distance **1011**, **1012**). The example here assumes that the above line does not pass through an arbitrary pattern inclusive of the own pattern **1006** and another pattern (**1007**, **1008**). If, as with the distance **721** shown in FIG. **9C**, the distance **721** between sections on one pattern is to be included in the minimum inter-pattern distance, the above distance includes both a distance of the segment drawn from the apex P10 to an apex of another pattern, and a distance of the segment drawn from the apex P10 to another apex of the pattern **1006**. The example here assumes that the line, even if drawn between apexes of the same pattern, does not pass through there. In actuality, however, such a line does not exist in the example shown. A similar inter-apex distance calculation is also conducted for other apexes of the pattern **1006**.

Next, a straight line is drawn, for example, from the apex P11, in the x-direction of the x/y coordinate system **1000** and in an external direction of the pattern, and a position at which the line first intersects with the pattern is determined as a crossing point Q11x. Similarly, a straight line is drawn from the apex P11, in the y-direction and in the external direction of the pattern, and a position at which the line first intersects with the pattern is determined as a crossing point Q11y. Distances **1009**, **1010** from the apex P11 to ends of the pattern in the x- and y-directions are thus calculated. The same is also conducted for each of the other apexes of the pattern **1006**. Finally, the shortest of the above-mentioned inter-apex dis-

18

tance (e.g., distance **1011**, **1012**) and distances **1009**, **1010** in the x- and y-directions is taken as the minimum inter-pattern distance. In this example, the distance **1009** is taken as the minimum inter-pattern distance. The minimum inter-pattern distance between the pattern shapes **715-716** in FIG. **9B** is determined by calculating the distance **718** in the x-direction and distance **719** in the y-direction, both obtained when the distance **717** is broken down in the x- and y-directions, and taking the distances **718** and **719** as Dx and Dy, respectively. The minimum inter-pattern distance between the pattern shapes **715-716** is there given as Dy (Dy>Dx). Similarly, the larger of the components obtained by breaking down an appropriate distance in the x- and y-directions can be used as the inter-apex distance mentioned above.

2.1.4: Variations of a Reference Pattern Width Determining Method

A method in which the smallest value of the minimum fine widths or minimum inter-pattern distances of each pattern is used as reference pattern width has been described in the foregoing example. Several other variations are also usable as methods of determining reference pattern width. That is, the reference pattern width selected depends on how the CAD image that has been generated from reference pattern width is used.

For example, consider a case in which an AP position is determined from the CAD image that has been created using the CAD data **801** of FIG. **13A** as an example. For the CAD data **801**, patterns whose line widths can be broadly divided into two kinds exist in mixed form. The patterns with the smaller line width (typical line width **814**) are distributed in a region **805**, and the patterns with the greater line width (typical line width **815**) are distributed in a region **806**. Since AP is an addressing point, this imaging region has a characteristic pattern, so for proper detection of a deviation between an actual observing position of AP and an initially set AP position, changes in correlation value between an actual observation image and a registered AP template image desirably have high sensitivity against the deviation. Also, AP is imaged at a magnification lower than that of EP. If the smaller line width **814** distributed in the region **805** is observed in a collapsed or color-coded state or does not form a characteristic pattern shape in the low-magnification SEM image that has been observed for AP use, the pattern shapes of the smaller line width **814** do not always need to have been saved in a CAD image. In that case, image-quantizing width may be determined with the greater line width (typical line width **815**) taken as reference pattern width. As a result, a CAD image **818** can be obtained by converting CAD data into image data such that as shown in, for example, FIG. **13D**, the reference pattern width (nm) **815** becomes to an image size (pixels) **819**.

Also, consider a case in which an EP position is determined. Since EP is an imaging position intended for high-magnification monitoring of such an end measuring point (a dimension-measuring point) that leads to a device defect, there is a need to conduct the above determination allowing for small line width values such as the line width **814**, so image-quantizing width may be determined with the line width **814** taken as reference pattern width. As a result, a CAD image **816** can be obtained by converting CAD data into image data such that as shown in, for example, FIG. **13D**, the reference pattern width (nm) **814** becomes to an image size (pixels) **817**.

In the above-mentioned determination of AP or EP, the reference pattern width and the reference pattern width existing after the image conversion has been made can be arbitrarily given to calculate image-quantizing width suitable for

various image processing, or to calculate the image-quantizing width used to appropriately express the line width that wants to be noted during data viewing. The reference pattern width and the reference pattern width existing after the image conversion can be either managed as defaults for each process by the system used for imaging, or arbitrarily given by a user. In addition, the image-quantizing width at which the magnifications of the SEM image and the CAD image agree can be given for matching between both images.

2.2: Brightness Information Provision Based on Various Attributes

Next, examples of using the brightness information providing section **12512** to execute brightness information providing step **S62** based on various attributes will be described using FIGS. **16** to **18**, **19A**, and **19B**. A CAD image **607** (**605**) to which brightness information based on various attribute information has been assigned to each pixel is stored into the CAD image memory **1253** or temporarily stored into the storage device **127**. That is, a description will be given of a method in which, when CAD data **601** is converted into the CAD image, brightness information convenient for any analysis (data viewing, image processing) with the CAD image is assigned to each pixel of the CAD image **607** on the basis of attribute information. The above attribute information includes part or all of mask pattern partial removal information (i.e., whether a particular location at a resist mask is a resist-photosensitizing location), or the kind of material of the sample surface (semiconductor pattern) at an associated position, or lower layers, or manufacturing processes (process steps), or layers, or pattern shapes, or roughness/fineness levels of the patterns, or design margins.

Effective analysis of an effective CAD image becomes possible by incorporating various attribute information into brightness data as described above. More specifically, explicitly expressing the various attribute information enables the analysis that simultaneously allows for both the various attribute information and a distribution thereof on the wafer. The explicitly expressing the various attribute information is particularly effective in automatic searching for AP, FP, SP, BP, EP during image processing. Depending on the kind of various attribute information allowed for, CAD images having brightness patterns similar to those of an actual SEM image can also be generated, in which case, essentially the same analysis as that which uses the SEM image is possible.

2.2.1: Attribute Example 1 (Differences in Partial Unmasking Information Volume)

Using mask pattern partial removal information as attribute information will be described as an example of CAD image generation based on the foregoing attribute information. FIG. **15A** shows a CAD image of a mask pattern. This figure assumes that a resist material has its polarity inverted according to a positive/negative state. The figure also assumes, for example, that the inside of pattern **1102** is a region optically sensitized to form the pattern, and that a region **1103** is a region formed as an underlayer without being optically sensitized. The image obtained by drawing the pattern **1102** and other elements with contour lines in this way is hereinafter called a contour image. As shown in FIG. **16A**, however, partially unmasked regions may each be color-coded with a different brightness value according to a particular difference in partially removed mask pattern state. A monochrome binary image with patterns color-coded in black, inclusive of a pattern **1110**, is shown in FIG. **16A**. Any brightness values other than black and white can be combined. Hereinafter, the image having the regions color-coded in accordance with the attribute information represented by mask pattern partial removal information is called a color-coded image.

An example of the effect of incorporating the difference in partially removed mask pattern state into brightness data is described below. When image processing is used to determine what position (ROI) is to be registered as AP by use of the CAD image **1101**, whether the AP is an appropriate imaging region may be judged using factors such as an index of whether a selected pattern is characteristic. For example, a ROI **1104** is selected as the AP in FIG. **15A**. When those CAD images **1105**, **1107** of FIGS. **15B**, **15C** that are of the same CAD data as that of respective original CAD images but differ in image-quantizing width are subjected to similar judging processing, the results obtained are likely to significantly differ between both images. For example, ROIs **1106**, **1108** are likely to be selected as APs.

In an image **1109** with the patterns color-coded on the basis of unmasking information, when AP searches are conducted on the CAD images **1113**, **1115** of FIGS. **16B**, **16C** that differ in image-quantizing width, similar results are obtainable and improved stability of the AP searches is anticipated. This is because color-coded images **1109**, **1113**, **1115** are greater than contour images **1101**, **1105**, **1107** in terms of a rate of the number of pixels indicating each pattern within the ROI, and thus because features of these color-coded images are expected to be more readily and more accurately identifiable in terms of pattern shape. Also, the difference in image-quantizing width causes deformation of the pattern shape due to a quantizing error, but a rate of the deformation in the ROI is lower in the color-coded images. For the contour images, however, all pixels indicating the each pattern are basically affected by a quantizing error.

2.2.2: Attribute Example 2 (Differences in the Kind of Material and in Manufacturing Process)

Another example of attribute information will be next described in perspective of differences in the kind of sample's material at an associated position or in manufacturing process. The differences in the kind of sample's material or in the kind of manufacturing process (e.g., surface roughness of the sample differs according to the kind manufacturing process of CMP (chemical mechanical polishing) process etc.) cause a change in the quantity of secondary electrons emitted from the sample surface after electron beam irradiation, and lead to changes in brightness values of SEM images. If these factors changing the brightness values of the SEM images are managed as attribute information and the attribute information is incorporated into brightness values of CAD images, it will be possible to generate a CAD image that incorporates characteristic differences in SEM signal quantity due to the above differences in attributes.

The CAD image **1201** shown in FIG. **17A** includes a plurality of patterns (e.g., **1202**) and two kinds of underlayers **1203**, **1204**. The underlayers **1203**, **1204** have a difference in the kind of material of the sample surface or a difference in the kind of manufacturing process in which, for example, the sample surface differs in surface roughness according to the kind of manufacturing process of the CMP process etc. The underlayers **1203**, **1204** have respective different brightness values in actual SEM images. Accordingly, these differences are expressed as the differences in the brightness values of CAD images. Such a state is shown in FIG. **17B**, for instance. In this figure, a CAD image is generated as a multivalued image (in this example, three-level image) whose pattern section, e.g., **1208**, and underlayers **1209** and **1210** each have a difference brightness value. The fact that results equivalent to more practical SEM imaging results can be obtained during any analysis is anticipated by generating such a CAD image. Although a template with a characteristic brightness pattern is to be selected as AP during AP determination based on a CAD

image, the conventional CAD image **1201** of FIG. **17A** is likely to be judged that since a ROI **1205** has a more complex pattern than a ROI **1206**, the ROI **1205** is appropriate as AP. As a matter of fact, however, the ROI **1206** has a difference in brightness value between the underlayers **1203** and **1204** in a SEM image, and this characteristic contrast level may render the ROI **1206** appropriate as AP. Such information cannot be considered during line drawing only with a pattern contour such as that of the CAD image **1201**. For the CAD image **1207** shown in FIG. **17B**, however, a ROI **1212** can be selected as AP since the above contrast information is incorporated in brightness information of the CAD image.

2.2.3: Attribute Example 3 (Difference in Lower Layer)

Yet another example of attribute information will be next described in perspective of whether a lower layer is present at an associated position. As shown in FIG. **5A**, a plurality of layers (e.g., **504** to **506**) are stacked to form semiconductor patterns. In a SEM image, not only the pattern existing on the uppermost layer but also the patterns existing on lower layers may require observation. FIG. **18A** is an overlapped representation of two layers in a CAD image **1213**, in which representation, a pattern on the upper layer is drawn with a solid line (e.g., upper-layer pattern **1214**) and a pattern on the lower layer is drawn with a broken line (e.g., lower-layer pattern **1215**). In this case, the pattern boundary **1217**, **1218** observed in the SEM image is extracted on the basis of a relationship in position between the layers in a CAD image **1216**, as shown in FIG. **18B**, and the patterns on the layers **1220**, **1221** are color-coded for each layer, as shown in FIG. **18C**. Thus, a CAD image **1219** is generated.

2.2.4: Attribute Example 4 (Differences in Pattern Line Width, in Pattern Roughness/Fineness Level, and in Design Margins)

Still another example of attribute information will be next described in perspective of a difference in pattern shape or in pattern roughness/fineness level. As shown in FIG. **19A** (a), the sample may have a plurality of mixed patterns each having a different line width (e.g., line widths **1307** to **1310**). A CAD image is generated with each pattern color-coded according to the particular line width thereof. More specifically, in a region **1302**, for example, the patterns with the line width **1307** or **1308** (line width similar to the line width **1307**) or with a line width similar thereto are present, and in a CAD image **1301**, these patterns are color-coded with one desired brightness value. Similarly, in a region **1305**, for example, the patterns with the line width **1309** or with a line width similar thereto are present, and in the CAD image **1301**, these patterns are color-coded with one desired brightness value (different from the color-coding brightness value in the region **1302**).

Even in a region with patterns of the same line width, the color-coding brightness value can be changed between a logic block **1303** and a memory block **1304**, as shown in FIG. **19A** (b). Patterns with such changes in the color-coding brightness value are generally called repeated patterns.

Color-coding an underlayer of the pattern, not the inside thereof, or as shown in FIG. **19B** (a), color-coding all regions such as regions **1303** to **1306** are usable as variations of color-coding methods. It is also possible, as shown in FIG. **19B** (b), to combine such a color-coding method as in FIGS. **19A** (a), (b), and such a color-coding method as in FIG. **19B** (b). In this combination of color-coding methods, a region (e.g., **1305**, **1306**) that includes a shape of a desired pattern to be noted can have only the inside of the pattern color-coded, and other regions (e.g., **1303**, **1304**) can each be color-coded in a specific color. In addition, a region range can be definitely

displayed by color-coding an underlayer with a desired brightness value, as in the region **1305**.

A description mainly of line width has been described above as attribute information. However, it is possible to color-code the patterns or underlayers that each include, as attribute information, a minimum inter-pattern distance, or pattern roughness/fineness levels based on the minimum inter-pattern distance or the like, or pattern shapes, or design margins (e.g., shifts in position of, the amounts of deformation of, or other factors of patterns capable of maintaining a connected relationship with respect to contact holes in upper or lower layers), and are based on the above attribute information. Region color-coding by region segmentation based on the above attributes is also possible. In addition, although the color-coding brightness value can be given arbitrarily, it is possible to select a brightness value close to that of an actual SEM image.

2.3: Pattern Shape Deformation

Next, examples concerning the pattern shape deformation step **S63** executed by the pattern shape deformation processor **12513** will be described using FIGS. **20** to **24**. The CAD image **608** (**605**) that has gone through the pattern shape deformation step is stored into the CAD image memory **1253** or temporarily stored into the storage device **127**. CAD data **601** such as design data or resist mask data is likely to result in a pattern shape different from that actually generated on the wafer. Therefore, any differences between the pattern in the CAD image **608** (**605**) that has been generated from the CAD data **601**, and the pattern in the SEM image obtained by imaging the pattern generated on the wafer, may cause inconvenience during matching between both patterns or during CAD image-based processing similar to SEM image processing. Accordingly, a method of approximating the pattern in the CAD image **608** to the pattern in the SEM image will be described below.

2.3.1: Contour Shape Deformation

2.3.1.1: Pattern Deformation Method Using a Photolithographic Simulator

Approximation of the pattern in the CAD image **608** generated from the CAD data **601**, to the pattern in the SEM image obtained by imaging the pattern generated on the wafer, can be accomplished by simulating the pattern formation in a semiconductor process by use of the CAD data **601**.

This method is described below using the process flow chart shown in FIG. **20**. First, in step **S631**, on the basis of CAD data **1401** of the mask stored within the CAD data file **507**, the pattern shape deformation processing section **12513** uses image-forming simulation to consider a diffraction phenomenon and others of light and calculate the luminous intensity distribution optically transferred onto a resist film present on the wafer. Input parameters for the image-forming simulation include the CAD data **1401** and image-forming exposure conditions **1407** (wavelength λ of the light, numerical aperture NA, the kind of photomask, exposure time, and others).

Next, in step **S632**, on the basis of the above-calculated luminous intensity distribution, the pattern shape deformation processing section **12513** conducts developing simulation to compute the process parameters that dissolve the resist film of the wafer, then to calculate the shape of the resist pattern **1404** formed on the wafer, and to store calculation results into the storage device **127**, for example. Input parameters for the developing simulation include the calculated luminous intensity distribution, developing process parameters **1408**, namely, resist information (composition ratio of the material used, thickness, transmittance, absorption energy, and others), developing agent information (develop-

ing rate coefficient, developing time, and others), and under-layer information (thickness, refractivity, absorption coefficient, and others).

Next, in step **S633**, the pattern shape deformation processing section **12513** conducts electron beam simulation to calculate the above-calculated resist pattern CAD image data (data of an image close to the pattern shape in the SEM image obtained by imaging the pattern) and then to store calculation results into the CAD image memory **1253**. During the electron beam simulation, for example, parameters relating to the process of intra-substance electron scattering of the electron incident on the resist pattern are computed using the Monte Carlo method, and strength of the secondary electrons emitted from the substance surface and detected by SEM is calculated. The above two types of arithmetic operations are repeated at various points on the resist pattern, whereby the SEM image data that has been obtained by imaging the resist pattern are calculated. Input parameters **1409** on the electron beam simulation include the above-calculated resist pattern shape, SEM measuring conditions (acceleration voltage, probe current, and others), and material information (composition ratio, thickness, and others). It is possible, by such processing, to simulate the pattern formation in the semiconductor process by use of the CAD data **1401** of the mask, and calculate a shape close to the pattern shape in the SEM image obtained by imaging the pattern generated on the wafer.

In the foregoing process flow shown in FIG. **20**, however, there are problems such as increased process costs and difficulty with process parameter setup. The following describes alternative techniques for solving these problems.

2.3.1.2: Simplified Method of Estimating the Pattern Shape from the Luminous Intensity Distribution

Parameter setup becomes unnecessary by using the technique shown in FIGS. **21A** to **21C**, instead of the above-described developing simulation shown in FIG. **20**. More specifically, the luminous intensity distribution **1502** in FIG. **21B**, obtained from the mask pattern **1501** in FIG. **21A** by the image simulation in step **S631**, is sliced using desired luminous intensity “th”, and as shown in FIG. **21C**, a contour shape **1503** of the luminous intensity distribution on that slice surface is calculated. The luminous intensity “th” for extracting the slice surface (hereinafter, “th” is called the slice level) is determined by changing the slice level “th” so that the contour shape of the luminous intensity distribution on the slice surface will be closest to a contour shape of a pattern present in the actual SEM image obtained by imaging the pattern on the wafer.

In the processing/control unit **115**, during matching between the CAD image created by the CPU (CAD image creation unit) **1251** of the imaging recipe creation device **125**, and the SEM image obtained by pattern imaging, the slice level “th” and the matching position are varied as described above. Matching will be complete when the CAD image that has been generated using the slice level “th”, and the SEM image that has been obtained by pattern imaging best match in position with each other.

During the AP, FP, SP, BP, EP searches and/or other operations using the CAD image generated by the imaging recipe creation device **125**, when the above SEM image is not to be acquired, the processing/control unit **115** can also use a previously learnt slice level “th” (e.g., based on learning with the SEM image acquired by imaging the pattern that has been exposed and developed under the same conditions). Alternatively, the user can give any slice level “th”.

2.3.1.3: Pattern Deformation Method that Uses Smoothing

A simplified method of approximating the pattern in the CAD image **608** generated from the CAD data **601**, to the

pattern in the SEM image obtained by imaging the pattern generated on the wafer, is by providing the former pattern with image processing for reduced high-frequency pattern components. A method that uses Gaussian filtering is shown in FIGS. **22A** to **22D** as one such example. This method includes generating a photomask pattern **1602** with partial mask removal information added thereto, from CAD data **1601** of a mask, then conducting a smoothing process (e.g., Gaussian filtering) on the photomask pattern **1602**, and generating a multivalued image **1603**. Additionally, the generated multivalued image **1603** is binarized with a desired brightness value, and the resulting contour shape **1604** is calculated. The brightness value used for the binarization is determined in the same manner as that of the slice level “th”. This method, unlike a simulator-based one, has advantages that it requires no setup of process parameters or other parameters and calculation costs are low.

2.3.1.4: Pattern Deformation Method that Uses Profile Deformation of Corners

Another simplified method of approximating the pattern in the CAD image **608** generated from the CAD data **601**, to the pattern in the SEM image obtained by imaging the pattern generated on the wafer, is by providing the former pattern with image processing for deformed corners of the pattern. This method deforms a corner shape of a pattern in CAD data **1701** selectively to obtain a shape close to an actual pattern shape in a SEM image, as shown in FIGS. **23A** to **23C**. For example, generating a shape **1702** having several tens of percent of line width cut at corners of a pattern contour shape, or generating a shape **1703** having the above corners replaced with sectors makes it possible to obtain approximately a pattern shape in the SEM image acquired by imaging the pattern generated on the wafer.

The methods of deforming the pattern shape by smoothing or by cutting corners are only examples. Simplified processing with these methods make it possible to obtain an approximated CAD image **608** close to an actual SEM image, with minimum setup of process parameters and at low process costs. Better results can be obtained during processing by the processing/control unit **115**, such as matching between a CAD image and a SEM image.

2.3.2: Edge Effect

For a SEM image, very high brightness values are occasionally detected at, for example, boundary lines of step-shaped sections of the image. This characteristic phenomenon of the SEM image is called the edge effect. The edge effect arises from the fact that the number of secondary electrons excited by electron beam irradiation and jumping outward from the surface layer of the sample differs between the planar sections and step-shaped sections of the SEM image. The characteristic brightness pattern of the SEM image caused by the edge effect is not represented in conventional CAD images. Similarly to the foregoing pattern shape deformation, however, CAD images closer to SEM images can be obtained.

FIG. **24A** shows a CAD image **1801** expressed by line drawing of a pattern **1802**. A brightness profile between sections A and B of the above pattern is shown as reference numeral **1803**. Since contour lines of the pattern are usually drawn in pixel units, a width **1804** of the contour lines drawn in black in the figure is 1 pixel. In contrast to this, FIG. **24B** shows a CAD image **1805** having a boundary drawn with the edge effect taken into account. In this figure, both pattern interior **1807** and underlayers are color-coded at the same time. In the present invention, line width of a boundary section **1806** of the pattern is expanded to a line width **1809** of several pixels, as shown by C-D brightness profile **1808**.

25

Additionally, selectively providing a smoothing filter in the entire CAD image or near a pattern boundary section thereof makes it possible to obtain a profile closer to an actual SEM image profile, as shown by C-D brightness profile **1810**.

2.4: Variation of CAD Image Generation (Arbitrary Combination of the Methods Described in Items 2.1 to 2.3)

Methods of generating a CAD image **605** from CAD data **601** have heretofore been described. When the CAD image **605** is generated, however, it is possible to combine part or all of the image-quantizing width determining step **S61**, the attributes-based brightness information providing step **S62**, or the pattern deformation step **S63**.

In addition, it is desirable that the brightness levels or pattern shapes in an SEM image, obtained dependently on various conditions such as exposure conditions (image-forming exposure conditions and developing process conditions included) and image acquisition conditions (imaging magnification and image quality-related factors included), should differ and that the brightness levels or pattern shapes obtained in an associated CAD image **605** should resemble those of the SEM image. In order to respond to these variations of brightness or shape, appropriate parameters are desirably assigned when such changes in CAD image-generating parameters (image-quantizing width, brightness, and shape deformation) can be predicted in, for example, the imaging recipe creation device **125** beforehand. If the prediction is difficult, a plurality of CAD images should be created by combining arbitrary different parameters. Changes in SEM image state can then be flexibly accommodated by, during, for example, processing such as matching to the SEM image by the processing/control unit **115**, conducting sequential matching operations using the plural CAD images created by the imaging recipe creation device **125**, and adopting the CAD image having the highest correlation.

3: Application Using a CAD Image

EXAMPLE OF UTILIZING A CAD IMAGE

Various kinds of analyses (data viewing, image processing) in the SEM apparatus or equivalent that uses, for example, a CAD image created by the imaging recipe creation device **125**, will be described hereunder.

According to a method of generating a CAD image according to the present invention, an appropriate image size that does not collapse a pattern-of-interest having an arbitrary attribute(s) can be determined during GUI-based display on a display unit or the like, during data viewing, or during arbitrary image processing. Also, the above arbitrary attribute(s) can be made visible in the CAD image, or a process that incorporates the attribute(s) can be conducted during arbitrary image processing. In addition, during data viewing or arbitrary image processing, analyses equivalent to those of the SEM image acquired from an actual pattern can be conducted by, for example, adding exposed-pattern deformation from design data or adding the edge effect or other changes in SEM signal state. Above arbitrary image processing includes a process step such as determining AP, FP, SP, BP, EP coordinates or image sizes (field sizes) and other imaging conditions, or registering a CAD image as an AP, FP, SP, BP, or EP template, or matching the CAD image and the SEM image and measuring any differences in coordinate position offsets between both images or in pattern shape therebetween. Automating a part or all of these process steps improves an automation ratio of the entire process flow from EP setup on the wafer to SEM-based image acquisition, dimension measurement/OPC shape evaluation, and feedback into process data.

26

In addition, the minimum line widths or minimum inter-pattern distances or reference pattern widths in each pattern or in a plurality of in-field patterns are effective not only during generation of a CAD image, but also determination of process parameters in arbitrary image processing that uses the CAD image. In other words, for example, when AP, FP, BP, EP is determined from any CAD image, a smoothing filter size can be determined based on line width in order to blur pattern being not more than the line width that wants to be noted. Furthermore, during such processing as described above, it is considered processing sequences that a desired input CAD image may be generated with the image-quantizing width for saving a reference pattern width that wants to be noted during any analytical operation, or a CAD image is generated with general-purpose image-quantizing width (for example, image-quantizing width at which all patterns will be saved) and then a desired input CAD image may be generated by repeating the quantization for the CAD image with any image-quantizing width according to an analytical content conducted or obtained thereafter, or a desired input CAD image may be generated by processing a CAD image by using appropriate process parameters (such as a smoothing parameter).

4: GUI Display and File Output

4.1: GUI Display

A description will be given of a method in which the CAD image that has been created according to the present invention is displayed in GUI (Graphic User Interface) screen mode of the display unit **116**, **126**. The above CAD image can be displayed in GUI screen mode, at which time, a plurality of images each different in conditions can be simultaneously displayed next to one another or in overlapped form, depending on particular needs. The above conditions include a part or all of a difference in magnification or a difference in image type (SEM image or CAD image) or differences in CAD image generating scheme (differences in the attributes emphasized). An example in which a CAD image **1901** (having a CAD pattern **1903** whose contour shape is approximated to a SEM image shape) and original related design data **1904** (shown with a dotted line) are displayed in overlapped form with a SEM image **1909** further displayed next to the overlapped display is shown in FIG. **25** as an example of the above image display method. The SEM image **1909** can either have its as-acquired SEM image displayed as it is, or have an internal pattern **1910** of the image displayed linearly by processing such as contour extraction. In addition, a scale **1905**, minimum line width **1906** (or **1907**), and an actual size/pixel ratio **1908** can each be displayed as an analog or digital indicator in an overlapped or side-by-side arranged format on the above display. The scale **1905** indicates how long in the CAD image an arbitrary unit dimension in full size is. For example, the scale **1905** makes a scale indication of the length in an image of a 100-nm full size.

The above minimum line width **1906** make a scale indication or a numerical value indication of the minimum line width of a pattern, or patterns (pattern group), within the image, and sections with a line width equivalent to the minimum line width can also be displayed as **1097**. Typical values for each pattern or within a display range can be displayed as the display of the minimum line width **1906** and **1907**, and these typical values can be simultaneously displayed as, for example, typical line widths **1307** to **1310** in FIGS. **19A** and **19B**. In addition, although the above GUI display method has been described taking the minimum line width as an example, the minimum inter-pattern distance or reference pattern width or any attribute value can be displayed as a scale or a bright-

ness value or digitally (a numerical value) on an associated pattern, or at any location, in GUI screen mode.

4.2: File Output

A numerical representation of the minimum line width or minimum inter-pattern distance or various attribute information in the present invention can be written into a CAD data file or other files, for management. A method of integrated management with the CAD data file **507** will be described as an example using FIG. **5B**. FIG. **5B** shows an example of a file format in which the CAD data in FIG. **5A** is written. At the top layer **504** shown therein, three patterns **501** to **503**, are shown and the pattern **501** includes four apexes **P1** to **P4**. Segment information **511** that identifies a contour of a pattern shape represented by x- and y-coordinates of the apexes **P1** to **P4**, and layer information **509** such as **504** to **506** are generally written for each pattern in the CAD data file **507** (the above two kinds of information are listed as **512**, **513**, for each pattern). The x- and y-coordinates are expressed in any reference coordinate system **500** and have a unit such as nanometers.

In the present invention, in addition to the above, part or all of a numerical representation of the minimum line widths or minimum inter-pattern distances or various attribute information for each pattern can be expressed as **510**, for example. Additionally, part or all of typical values or distribution information in any region (including extraction region ROI) of the minimum line widths or minimum inter-pattern distances or desired pattern widths or various attribute information for each pattern can be written into a file header **508**. The above attribute information includes part or all of mask pattern partial removal information (i.e., whether a particular location at a resist mask is a resist-photosensitizing location), or the kind of sample's material at an associated position, or manufacturing processes, or pattern shapes, or roughness/fineness levels of the patterns, or design margins.

In addition, the CAD image generating method, analytical method, display method, or file management method described in the present invention can be utilized not only in SEM apparatuses, but also optical microscope apparatuses, scanning probe microscopes (hereinafter, called SPMs), or the like. That is to say, setup of AP and EP may be required in the above optical microscope apparatuses or SPMs as well, and in an SPM, for instance, the SEM images heretofore described will be the depth information acquired by the SPM, or will be image conversion results on the depth information (depth data will be converted into brightness data of images).

As described above, in embodiments of the apparatus or method for creating an imaging recipe in a SEM apparatus, an optical microscope apparatus, or an SPM apparatus (or the like) according to the present embodiment, at least the following six advantageous effects can be obtained:

(1) It is possible, by determining image-quantizing width based on the pattern width that should be noted determined by the minimum line width or minimum inter-pattern distance of patterns, to determine appropriate image-quantizing width for the complexity of the pattern to be noted and obtain processing results at high speed and accurately in various image-processing.

(2) Any differences in, for example, SEM signal quantity due to the differences in attributes that are detected in, for example, an actual SEM image, can be represented in a CAD image by representing any differences in mask pattern partial removal information, material information of the sample, information on processing states, or other attribute information, as different brightness values, and assigning these values to the CAD image. On the result of assigning these values to the CAD image, in AP template searches etc. it is possible to

conduct AP template searches in consideration of for example, SEM signal quantity that appears in feature due to the above differences in attributes. In addition, there is an advantage that the template searches improve in stability with respect to conventional linear images or that highly accurate relationship can be established during matching between the CAD image and, for example, the SEM image.

(3) Provision of image processing which deforms the pattern profile written in CAD data makes it possible for the deformation of the pattern on, for example, a SEM image, due to any differences in exposure process conditions or image acquisition conditions, or the like, to be represented in a CAD image as well. Improved accuracy in matching between both images is thus anticipated.

(4) Changes in SEM image state, for example, can be flexibly accommodated by creating beforehand a plurality of CAD images each different in part or all of image-quantizing width, a brightness providing method based on attributes, or a shape deformation method and level.

(5) For example, SEM image acquisition only for determining the coordinates of the imaging points including a part of AP, FP, SP, BP, or EP, or all thereof, and for determining image acquisition conditions becomes unnecessary by using the CAD image created according to the above-mentioned image-quantizing width, brightness providing method, or shape deformation method. That is to say, the coordinates of the above imaging points, and image acquisition conditions can be determined from the CAD image, and the CAD image itself can be registered as a template. For example, when using a SEM apparatus to actually observe any one of the above imaging points, it is necessary to match a CAD image (template) whose coordinates are known, and a SEM image, for example, and estimate the imaging position. According to the present embodiment, however, both images can be matched very accurately as described in item (3) above.

(6) Automatic determination of the imaging points and the like from a CAD image is possible, for which reason, the imaging recipe creation that has conventionally been manually conducted can be implemented more easily and at higher speed.

The present invention can be applied to a SEM apparatus such as a CD-SEM.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. An apparatus for creating an imaging recipe to observe, by using a scanning electron microscope, a semiconductor pattern formed on a sample, the apparatus comprising:

a CAD data file within which is input and stored CAD data that contains layout information of the pattern formed on the sample, the CAD data being in the form of segment information represented by X and Y coordinates of apexes of the pattern and layer information;

a CAD image creation unit which creates a CAD image by converting the stored CAD data within the CAD data file into an image format; and

an imaging recipe creation device which creates the imaging recipe by using the CAD image created by the CAD image creation unit.

2. The apparatus according to claim 1, wherein the CAD image creation unit includes an image-quantizing width

29

determining section which creates the CAD image by converting the CAD data into an image using image-quantizing width determined based on a pattern width of a predetermined reference pattern.

3. The apparatus according to claim 2, wherein, in the image-quantizing width determining section, the pattern width of the predetermined reference pattern includes a minimum line width or minimum inter-pattern distance of the predetermined reference pattern.

4. The apparatus according to claim 3, wherein, in the image-quantizing width determining section, the minimum line width or minimum inter-pattern distance of the predetermined reference pattern is calculated from the CAD data.

5. The apparatus according to claim 1, wherein the CAD image creation unit includes a brightness information providing section which creates the CAD image by converting the CAD data into a multivalued image having various attributes assigned as brightness data.

6. The apparatus according to claim 5, wherein, in the brightness information providing section, the attributes include any one of, or a plurality of, or all of, mask pattern partial removal information, material or manufacturing process information, layer information, shape information on the pattern, a roughness/fineness level of the pattern, and design margins.

7. The apparatus according to claim 5, wherein: in the brightness information providing section, the various attributes include mask pattern partial removal information; and the CAD image creation unit includes a pattern shape deformation processing section which creates the CAD image by conducting a deforming process on the pattern shape written in the CAD data.

8. The apparatus according to claim 7, wherein, in the pattern shape deformation processing section, the deforming process includes image processing which is conducted to round the pattern shape at a corner section thereof or/and change the pattern in width.

9. The apparatus according to claim 1, wherein the CAD image creation unit includes:

an image-quantizing width determination section which creates the CAD image by converting the CAD data into an image using the image-quantizing width determined based on a pattern width of a predetermined reference pattern;

a brightness information providing section which creates the CAD image by converting the CAD data into a multivalued image having various attributes assigned as brightness data; and

a pattern shape deformation processing section which creates the CAD image by conducting a deforming process on the pattern shape written in the CAD data.

10. The apparatus according to claim 1, wherein the imaging recipe created by the imaging recipe creation device includes coordinates of an imaging point, and an image template at the coordinates, or imaging conditions for SEM observation.

11. The apparatus according to claim 10, wherein the imaging point includes any one of, or a plurality of, or all of; an addressing point, a focusing point, a stigmatism control point, and a brightness and contrast control point, and an evaluation point.

12. A method for creating an imaging recipe to observe, by using a scanning electron microscope, a semiconductor pattern formed on a sample, the method comprising the steps of: transferring CAD data in which layout information of the semiconductor pattern is written, to a CAD data file, the CAD data being in the form of segment information

30

represented by X and Y coordinates of apexes of the pattern and layer information;

creating a CAD image by conducting an image conversion based on the CAD data transferred to the CAD data file in the transferring step;

creating the imaging recipe by using the CAD image created in the CAD image creating step; and

outputting the imaging [receipt] *recipe* to a display unit through a graphic user interface.

13. The method according to claim 12, wherein the CAD image creating step further includes:

an image-quantizing width determining step that creates the CAD image by converting the CAD data into an image using the image-quantizing width determined based on a reference pattern width;

a brightness information providing step that creates the CAD image by converting the CAD data into a multivalued image having various attributes assigned as brightness data; and

a pattern shape deformation processing step that creates the CAD image by conducting a deforming process on the pattern shape written in the CAD data.

14. The method according to claim 12, wherein the imaging recipe created in the step of creating the imaging recipe includes coordinates of an imaging point, and an image template at the coordinates, or imaging conditions for SEM observation.

15. An apparatus for evaluating a shape of a semiconductor pattern formed on a sample, the apparatus comprising:

an observation device which observes the pattern formed on the sample, through a scanning electron microscope in accordance with an imaging recipe;

an imaging recipe creation device which creates the imaging recipe for imaging with the scanning electron microscope to observe the pattern by use of the observation device; and

an evaluation device which evaluates a shape of the pattern on the basis of the results obtained during the observation by the observation device;

wherein the imaging recipe creation device includes:

a CAD data file within which is input and stored the CAD data that contains layout information of the pattern formed on the sample, the CAD data being in the form of segment information represented by X and Y coordinates of apexes of the pattern and layer information;

a CAD image creation unit which creates a CAD image by converting the stored CAD data within the CAD data file into an image format; and

an imaging recipe creation unit which creates the imaging recipe by using the CAD image created by the CAD image creation unit.

16. *An apparatus for creating an imaging recipe to observe, by using a scanning microscope, a semiconductor pattern formed on a sample, the apparatus comprising:*

a CAD data file within which is input and stored CAD data that contains layout information of the pattern formed on the sample, the CAD data being in the form of segment information represented by X and Y coordinates of apexes of the pattern and layer information;

a CAD image creation unit which creates a CAD image by converting the stored CAD data within the CAD data file into an image format; and

an imaging recipe creation device which creates the imaging recipe by using the CAD image created by the CAD image creation unit,

31

wherein the CAD image creation unit converts template position coordinates of the CAD data to reference X-Y coordinates of apexes of the pattern and layer information.

* * * * *

5

32