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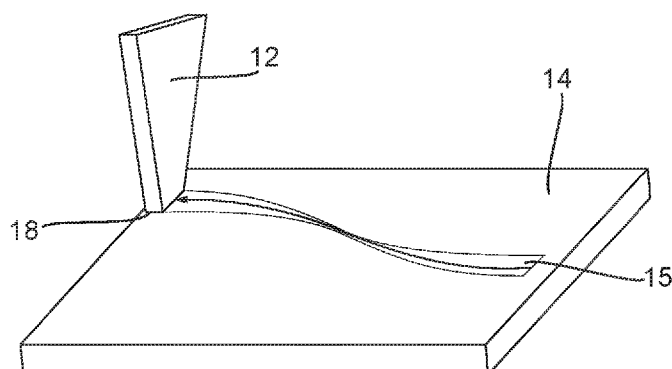
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Fig. 2



(57) Abstract: A probe (12) for scanning probe lithography includes a tip (18) for forming patterns (15) on a surface (14) and a mount on which the tip is mounted for controlling one or more of the position and orientation of the tip. The tip has a first end proximal to the mount and a second end (18) distal to the mount. The cross section of the second end of the tip is non-circular.



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Scanning Probe Lithography

5 This invention relates to a method and a system for scanning probe lithography, in particular for forming variable linewidth lithography patterns with asymmetric probes.

10 Scanning probe lithography is used to form patterns at the microscale and nanoscale, using a probe to create (e.g. scratch) a pattern on the surface of a material. To achieve patterns at scales of less than 100 nm, a probe having a very sharp tip is required. However, while this may allow small scale patterns to be formed, such a sharp tip is not versatile for forming other types of patterns, e.g. variable linewidths, which are often required. A sharp tip may also be damaged or become blunt easily owing to its fragility from being so sharp.

15 A probe with a sharp tip is shown schematically in Figure 1. The probe 1 has a sharp tip 2 that is formed on a cantilever 3. The probe 1 is used to form a variable linewidth pattern 5 on the surface of a material 4. As can be seen, the yield (operational efficiency) resulting from such a tip is low, owing to the time it takes to form patterns using the very small cross sectional area of the tip, particularly when wider linewidth patterns (which have to be raster filled by the tip) are desired to be formed.

25 The versatility and robustness of a probe may be improved by using multiple tips of different sizes, so that larger tips may be used to form the wider linewidth patterns. However, this still results in a low yield owing to needing to interchange different tips when variable linewidth patterns are desired to be formed.

30 The present invention aims to provide improved methods and systems for scanning probe lithography.

When viewed from a first aspect the invention provides a probe for scanning probe lithography, the probe comprising:

a tip for forming patterns on a surface; and

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a mount on which the tip is mounted for controlling one or more of the position and orientation of the tip;

wherein the tip has a first end proximal to the mount and a second end distal to the mount, wherein the cross section of the second end of the tip is non-circular.

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When viewed from a second aspect the invention provides a method of scanning probe lithography, the method comprising controlling a probe for scanning probe lithography, wherein the probe comprises:

a tip for forming patterns on a surface; and

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a mount on which the tip is mounted for controlling one or more of the position and orientation of the tip;

wherein the tip has a first end proximal to the mount and a second end distal to the mount, wherein the cross section of the second end of the tip is non-circular;

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wherein the step of controlling the probe comprises controlling one or more of the position and orientation of the tip to form a variable linewidth pattern on a surface.

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The present invention provides a probe for scanning probe lithography. The probe has a mount and a tip that is mounted on the mount (i.e. at the first, proximal end of the tip). The tip extends from its first end to its second end, in a direction away from the mount. The mount is used to control the position and/or orientation of the tip, so that the tip is able to be used to form lithography patterns on the surface (e.g. transforming a lithographic resist). The tip of the probe has a cross section at its distal end (i.e. the end, remote from the mount, that is used to form a pattern on a surface) that is non-circular. Thus the (e.g. tip of the) probe is rotationally asymmetric (i.e. having a finite order of rotational symmetry). This results, in a controlled angular dependence of a path followed by the tip to a pattern (e.g. linewidth) formed by the tip on the surface.

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The orientation (and thus angular dependence) of the tip may be (e.g. the control and/or variation of) an angle between the normal to the plane of the surface and an axis of the tip (e.g. between the first and second ends of the tip). By varying the angle between the tip and the surface, the surface area of the tip that is in contact with the surface of the material may be varied, which may be desirable in order to achieve different patterns. The orientation (and thus angular dependence) of the tip

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may be (e.g. the control and/or variation of) a degree of rotation of the tip about an axis of the tip (e.g. between the first and second ends of the tip along which the tip extends). (This axis is substantially perpendicular to the plane of the surface when there is no angle between the normal to the plane of the surface and the axis.) It will be appreciated that adjusting this angle relative to the direction of movement of the asymmetric tip allows lines of varying width to be formed.

By providing a tip having a cross section that is not circular (e.g. asymmetric), such that it presents a different projection (e.g. width or shape) on different sides of the tip, allows the same tip to form different shape or width patterns (e.g. from only a single pass of the tip over the surface). This allows variable linewidth lithography patterns to be formed using the tip (e.g. depending on the angle of the tip relative to the material (e.g. between the plane of the surface and the plane of the cross-section, or an angle of rotation of the tip about an axis substantially perpendicular to the plane of the surface, as discussed above)), without having to interchange multiple tips of different sizes. This helps to improve the yield of the probe when performing scanning probe lithography, both because fewer tips are required to form variable linewidth lithography patterns and because the tip may be used to form wider linewidth pattern (e.g. by using the wider profile side of the tip) without having to raster the width of the pattern using a sharp round tip.

The shape of the tip also helps to strengthen the tip because while the tip may be narrow (sharp) in one direction, it is preferably wider in a different direction. The narrow and wider directions may be oriented to each other and to the rest of the probe (e.g. to the mount) in any suitable and desired way. In one embodiment the narrower dimension of the tip is substantially perpendicular to the wider dimension. The wider dimension may be parallel to the direction in which the mount (e.g. the cantilever) extends from the probe. In other embodiments the narrower dimension is parallel to the direction in which the mount (e.g. the cantilever) extends from the probe.

The probe may be used for any suitable and desired type of scanning probe lithography and thus with any suitable and desired type of scanning probe microscope, e.g. a scanning tunnelling microscope or an atomic force microscope. Thus the (e.g. mount of the) probe may be controlled using one of a number of

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suitable techniques for different patterning operations, not limited to, but including, additive (e.g. dip-pen nanolithography, electrochemical deposition), subtractive (e.g. nanomachining, thermal scanning probe lithography) or local surface modification techniques (e.g. local oxidation nanolithography). The probe may further be used
5 for the manipulation (positioning and selective removal) of objects in the micrometre and nanometre scale such as microparticles and nanoparticles.

The tip, which is mounted on the mount and is arranged to form patterns on the surface, may be provided in any suitable and desired way. The tip may have any
10 suitable and desired non-circular cross section at its distal end. The cross section of the distal end of the tip is taken in a plane perpendicular to an axis of the tip that extends from the first end to the second end of the tip (i.e. from the mount to the distal end of the tip). In one set of embodiments, the distal end of the tip has a first dimension (in a direction in the plane of the cross section, i.e. perpendicular to the
15 axis of the tip) which is greater than a second dimension (in a direction also in the plane of the cross section, i.e. perpendicular to the axis of the tip, e.g. which is perpendicular to the first dimension).

This is considered to be novel and inventive in its own right and thus when viewed
20 from a further aspect the invention provides a tip for use in a probe for scanning probe lithography, the tip comprising a distal end for forming patterns on a surface, wherein the distal end is extended along an axis away from a proximal end for attaching to a mount of a probe, wherein the distal end of the tip has a first dimension in a direction perpendicular to the axis of the tip which is greater than a
25 second dimension in a direction perpendicular to the axis of the tip and perpendicular to the first dimension.

It will be appreciated that one or more, e.g. all, of the optional and preferable features outlined herein (e.g. for other aspects of the invention) apply equally to this
30 aspect of the invention.

This “chisel” or “wedge” shaped tip helps to provide a versatile tip that can be moved parallel to the second dimension (thus presenting the wider cross section of the first dimension) to create a wider linewidth pattern, parallel to the first dimension
35 (thus presenting the narrower cross section of the second dimension) to create a

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narrower linewidth pattern or in a direction between the directions of the first and second dimensions to create an intermediate linewidth pattern. Furthermore, the direction in which the tip is moved may be varied between the directions of the first and second dimensions to form a variable linewidth pattern.

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The tip may have any suitable and desired distal shape. In one embodiment the tip comprises a substantially flat distal surface. Preferably the distal tip has a substantially rectangular cross section, in a plane parallel to the axis of the tip and, e.g., to the first dimension. In one embodiment the distal tip has a substantially rectangular cross section, in a plane parallel to the axis of the tip and, e.g., to the second dimension. In another embodiment the distal tip has a substantially wedge-shaped cross section (e.g. substantially having the shape of three sides of a parallelogram), in a plane parallel to the axis of the tip and, e.g., to the second dimension.

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The tip may have only a single apex. However, in one set of embodiments, the tip (for mounting to a single mount) comprises a plurality of (e.g. two) projections (and one or more recesses between the projections). Preferably the plurality of projections are integrally formed (i.e. formed from the same piece of material (monolithic)) as part of the tip. Thus preferably the plurality of projections are provided at (and, e.g., projecting from) the second, distal end of the tip. Preferably the projections share (and, e.g., are integrally formed with) the same first, proximal end of the tip.

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This is considered to be novel and inventive in its own right and thus when viewed from a further aspect the invention provides a tip for use in a probe for scanning probe lithography, the tip comprising a distal end for forming patterns on a surface, wherein the distal end of the tip comprises a plurality of projections and one or more recesses between the projections.

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It will be appreciated that one or more, e.g. all, of the optional and preferable features outlined herein (e.g. for other aspects of the invention) apply equally to this aspect of the invention.

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By providing the tip with more than one projection creates one or more recesses (gaps) between the two or more projections. Thus, when the tip is used to form a pattern on the surface (being controlled by a single mount), the two or more projections of the tip form a pattern in the surface and, in at least preferred
5 embodiments of the invention, the one or more recesses leave a portion of the surface raised (e.g. untouched) between the pattern formed by the two or more projections. The direction in which the tip is moved across the surface, relative to the orientation of the tip may thus be used to vary the width of the raised portion formed on the surface. It will be appreciated that in this way, the tip may be used to
10 form very narrow linewidths, e.g. narrower than may be possible using a conventional sharp round tip. For example, the tip may be used to form linewidths of less than 10 nm.

In one embodiment (e.g. when the tip comprises two projections) the tip comprises
15 a (e.g. single) recess that extends across the (width of the) tip, perpendicular to the axis of the tip. This allows the tip to form a pattern on a surface which includes a part (corresponding to the recess) which is not modified by the tip (when the tip is oriented appropriately to the direction in which the tip is moved across the surface).

20 The projections and the recess may have any suitable and desired shape. In one embodiment the projections (e.g. each) comprise a substantially flat distal surface. Preferably the projections have a substantially right-angled corner between each projection and the recess. Thus, preferably the projections have a substantially rectangular cross section (in a plane parallel to the axis of the tip and perpendicular
25 to the direction in which the recess extends across the tip). Preferably the recess has substantially rectangular cross section (in a plane parallel to the axis of the tip and perpendicular to the direction in which the recess extends across the tip). Thus preferably the projections are stepped with the recess therebetween. This helps to form a clean pattern in a surface and contrasts with a conventional tapering tip
30 having a single apex.

The projections and the recess may have any suitable and desired size. In one embodiment the projections (e.g. each) have a dimension of between 0.1 μm and 10 μm , e.g. between 0.5 μm and 5 μm , e.g. between 1 μm and 3 μm (e.g.
35 approximately 2 μm) in a direction perpendicular to the axis of the tip and, e.g.,

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perpendicular to the direction in which the recess extends across the tip. In one embodiment the recess has a dimension of between 0.1 μm and 10 μm , e.g. between 0.5 μm and 5 μm , e.g. between 1 μm and 3 μm (e.g. approximately 0.5 or 2 μm) in a direction perpendicular to the axis of the tip and, e.g., perpendicular to the direction in which the recess extends across the tip.

It will be appreciated that owing to the use of a recess (gap) in the tip, rather than a very sharp tip, to form patterns on a surface, the projections of the tip of embodiments of the present invention may be able to have substantially greater dimensions than a conventional, single apex tip and may be able to be relatively blunt, in comparison. The tip of the present invention may therefore, in at least preferred embodiments, be easier to manufacture and less likely to break or be otherwise modified (e.g. owing to wear) during use. The robustness of the tip can also help to increase the speed of scanning.

The tip may be made from any suitable and desired material. In one embodiment the tip is made from silicon nitride (Si_3N_4). In one embodiment the tip is coated with silicon or diamond. In one embodiment the tip is coated with a metal (e.g. gold), a dielectric (e.g. alumina, silicon or diamond) or a polymer. The tip may be functionalised, e.g. with useful molecules such as biomolecules.

The mount, on which the tip is mounted and which is used to control the movement (position and orientation of the tip), may be provided in any suitable and desired way. In one embodiment the mount comprises a cantilever, e.g. for use in an atomic force microscope. In one embodiment the mount comprises a piezoelectric stage, e.g. for use in a scanning tunnelling microscope. Preferably the probe is movable relative to a surface to be patterned. Thus preferably the probe comprises an actuation mechanism (e.g. an xy stage, e.g. an xyz stage) arranged to move the tip relative to (e.g. across) the surface (and, e.g., towards and away from the surface). This enables the position of the tip to be controlled.

As is outlined above, the mount is preferably a single mount (e.g. the probe preferably comprises only one mount) on which a single (e.g. integral (monolithic)) tip is mounted. However, a plurality of mounts (e.g. one or more in accordance with the present invention) may be used together in parallel.

In a preferred set of embodiments the mount is rotatable. Thus preferably the probe comprises an actuation mechanism arranged to rotate the mount. This enables the tip to be rotated relative to a surface (i.e. its orientation to be controlled), so that it is able to form different patterns on the surface owing to its non-circular distal tip. A mount that is capable of being rotated and translated in three dimensions helps to enable the probe to perform high resolution three dimensional patterning. In some embodiments, the material to be patterned may be rotated or tilted relative to the tip.

The mount may be rotatable in any suitable and desired way. In one embodiment the mount is rotatable (e.g. the actuation mechanism is arranged to rotate the mount) about the axis of the tip. This orients the non-circular cross section (e.g. the chisel-shaped tip or the recess between the projections) of the distal tip at a particular orientation relative to the surface such that the tip may be used to form a particular (e.g. linewidth) pattern on the surface. Thus, for example, the orientation of the distal tip may be controlled to control the linewidth of the pattern formed on the surface.

In one embodiment the mount is rotatable (e.g. the actuation mechanism is arranged to rotate the mount) about an axis perpendicular to the axis of the tip. This changes the orientation of the axis of the tip relative to the surface. For example, the default orientation of the axis may be perpendicular to the (e.g. plane of the) surface, thus rotating the axis of the tip forms an angle with the surface normal.

This may help to form different types of patterns on the surface, e.g. depending on the shape of the tip being used, owing to the angle of approach of the tip relative to the surface. For example, a tip whose axis is angled towards the direction in which the tip is being moved across a surface may act to clear away (e.g. "plough") the material of the surface, while a tip whose axis is angled away from the direction in which the tip is being moved across a surface may act to spread the material of the surface. Such techniques may aid the subsequent processes (e.g. of metallisation or etching) that are used with the patterns that have been formed in the surface of the material.

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The probe may be used in any suitable and desired way to form a pattern on a surface, e.g. by scratching or otherwise altering a lithographic resist (thus preferably the surface comprises a lithographic resist). For example, the probe may be used in one or more of a variety of different (nano)lithography techniques, such as dip-pen
5 (nano)lithography, thermal scanning probe (nano)lithography, local oxidation (nano)lithography, electrochemical deposition and conductive or current writing (nano)lithography. The pattern formed on the surface (e.g. lithographic resist) may be used to form a pattern on any suitable and desired material, e.g. a semiconductor, a metal or a biological material such as a protein or DNA. Thus the
10 probe may be used in any suitable and desired (nano)fabrication, e.g. patterning of biological materials, semiconductor device fabrication or conventional nanofabrication. In one embodiment the material on which the pattern is to be formed comprises graphene and/or two-dimensional transition metal dichalcogenides (TMDCs), e.g. comprising layers of tungsten disulfide (WS_2) and/or molybdenum
15 disulfide (MoS_2) (or other two-dimensional materials). Such materials are difficult to pattern using conventional techniques.

In one embodiment the probe is used to form a pattern in a (e.g. polymer) resist layer (e.g. formed on a substrate), i.e. preferably the surface to be patterned
20 comprises a (e.g. polymer) resist layer. The pattern in the resist may then be used to form a (nano)structure using any suitable and desired technique, e.g. metallisation or etching. It will be appreciated that when using a tip having multiple projections, such that the pattern is created by leaving a portion of material using the recess(es) between the protections, for example, it may be necessary to use a
25 negative resist to form the desired (nano)structure.

The apparatus and method of the present invention may be used in conjunction with other techniques, particularly other lithographic techniques, in any suitable and desired way. In particular, any one (or more) of these other lithographic techniques,
30 such as those disclosed herein (e.g. photolithography or electron beam lithography), may be used before and/or after the technique of the present invention, to form patterns on the surface (e.g. a lithographic resist) or on a subsequent material. The advantage of this is that particular aspects of the scanning probe patterning could be retained or dispensed of based on the overlap
35 of the two forms of lithography. For example, embodiments of the present invention

are compatible with photosensitive resists (photoresists) and electron sensitive resists (electron beam lithography resists). Of particular interest is that this technique could be done with the same resist and could even have the probe co-located in the same chamber.

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The probe (e.g. the position and/or orientation of the tip) may be controlled in any suitable and desired way, e.g. depending on the type of scanning probe lithography technique and/or microscope being used for the lithography. In a preferred set of embodiments the distal tip of the probe is arranged to remove or displace material from the surface of a material to be patterned, e.g. by scratching the surface of the material using the probe.

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Preferably the probe is used to scan (e.g. previously formed pattern(s) on) the surface to register (align) the tip of the probe for a pattern to be formed. The tip of the probe may be oriented such that a narrow (e.g. narrowest) part of the tip is directed towards (closest to) the surface, when registering the tip of the probe. Preferably the shape of the tip is characterised (e.g. using a pattern of a known shape) such that the scanning response of the tip may be determined. This helps to register the tip of the probe before starting forming a new pattern because the characterisation of the tip helps to know the location of the tip based on the scanning response. In one embodiment, the relative position of the probe to the surface is registered. This may be performed by scanning registration marks on the surface to be patterned that are in a known position relative to where a pattern is to be formed on the surface.

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Preferably the tip of the probe is calibrated prior to being used to form a pattern on a surface. Preferably the calibration of the tip comprises orienting the tip such that the distal end of the tip is parallel to the surface to be patterned, e.g. the tip may be oriented flat to the surface and then scraped along the surface (like a blade).

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Preferably the calibration of the tip comprises characterising the tip (e.g. using a pattern of a known shape) and using the characterisation of the tip to orient the tip appropriately. The tip, when manufactured, may have a distal end that is angled or may have projections that are not the same length. Calibrating (and, when necessary, orienting) the tip helps to provide, for example, a flat, parallel distal end of the tip to the surface or projections that are the same distance from the surface.

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Calibrating the tip also helps to determine the precise geometry of the tip so that the precise movements of the tip relative to the surface in order to form the desired line or pattern may be determined.

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In operation, preferably the probe comprises a control unit for controlling the position and/or orientation of the tip of the probe to form a pattern in a surface of a material. In one embodiment the control unit (e.g. comprising processing circuitry for executing processing instructions (e.g. software code)) is arranged to determine the pattern that will be formed when the tip of the probe follows a particular path. Preferably the control unit is arranged to act in reverse, e.g. the control unit is arranged to determine the particular path that should be followed by the tip of the probe in order to form a particular pattern with the tip of the probe. Preferably the control unit is arranged to control the tip of the probe to follow a particular path, e.g. to form a particular pattern. Preferably the particular path has been predetermined by the control unit.

When viewed from a further aspect, the present invention provides a method of scanning probe lithography, the method comprising:

- 20 characterising a geometry of a tip of a probe;
- receiving an indication of a line to be formed on a substantially planar surface, wherein the width of the line varies along the length of the line;
- mapping the geometry of the tip to a geometry of the line to determine a set of instructions for forming the line on the planar surface; and
- 25 controlling the probe to form the line on the surface according to the set of instructions, wherein controlling the probe comprises controlling the orientation of the probe about an axis substantially perpendicular to the plane of the surface.

It will be appreciated that one or more, e.g. all, of the optional and preferable features outlined herein (e.g. for other aspects of the invention) apply equally to this aspect of the invention. Thus, for example, the probe to be used may (and preferably does) comprise the probe as outlined in the aspects and embodiments described herein. Preferably the tip of the probe is non-circular, e.g. asymmetric.

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Directly measuring the geometry of a nano- or micro-structure can be expensive, time consuming and inaccurate. However, ignorance of the precise shape of a probe tip can be a significant obstacle to the precise forming of complex patterns in scanning probe lithography. It will be appreciated that a pattern to be formed using the methods, systems and probes of the present invention may be formed using a series of variable linewidth lines.

This aspect of the present invention provides a simple and effective solution that enables the precise and efficient forming of complex patterns. By determining the geometry of the probe tip, it is possible to predict the range of line geometries that may be formed by the probe. When a particular line or pattern is desired to be formed on a surface, such a characterisation allows a set of instructions for controlling the tip to be determined. As a result of the characterisation process, it can be relied upon that the set of instructions, when followed, will cause the probe to form the desired line or pattern.

Furthermore, this characterisation of the probe and the control of its orientation (e.g. as it is moved relative to the surface) allows the probe to be used to form complex patterns involving variable linewidth features on a surface. This may allow a line having a variable linewidth along its length to be formed in a single pass. In embodiments of the present invention, the width of the line formed can be substantially narrower than can be achieved with conventional lithography systems (e.g. as narrow as approximately 10nm).

The probe may comprise a mount on which the tip is mounted. In some embodiments, the tip has a first end proximal to the mount and a second end distal to the mount, wherein the cross-section of the second end of the tip is non-circular.

The distal end of the tip may have a first dimension in direction in the plane of the cross-section which is greater than a second dimension in a direction in the plane of the cross-section perpendicular to the first dimension. The tip may be (e.g. rotationally) asymmetric.

The tip may comprise a plurality of projections. The plurality of projections may be integrally formed. The tip may comprise a recess that extends across the tip. The recess may have a substantially rectangular cross section.

5 In some embodiments, characterising the geometry of the tip of the probe comprises:

scanning the tip in a first direction over a particular surface topography and measuring the deflection of the tip;

10 scanning the tip in a second direction, different from the first direction, over the particular surface topography and measuring the deflection of the tip; and determining, from the deflection measurements, a geometry of the tip of the probe.

15 By measuring the deflection when the probe is moved in two different directions, the geometry of the probe tip in three dimensions may be determined. In some embodiments, the first direction and the second direction are perpendicular. This can help the three-dimensional geometry to be determined efficiently.

20 In some embodiments, characterising the geometry of the tip of the probe may comprise selecting a particular (e.g. predetermined, known) surface topography (e.g. for scanning by the tip). Different surface topographies may be more or less suitable for a particular type of tip. Different surface topographies may allow the geometry of different tips to be determined with greater accuracy or precision. Therefore, selecting an appropriate surface topography can improve the
25 characterisation of the tip, and consequently the accuracy of the formed line.

Characterising the geometry of the tip may comprise manually providing information about the tip. The manually provided information may be used in conjunction with the deflection measurements to determine the geometry of the tip of the probe.
30 Determining the geometry of the tip of the probe may comprise generating a (e.g. 3D) image of the probe tip.

Characterising the geometry of the tip may further comprise using the determined geometry of the tip of the probe to determine an expected topography of a line to be

formed by a particular (e.g. predetermined, known) movement of the probe relative to the planar surface.

5 Receiving an indication of the line to be formed may comprise determining the line to be formed, e.g. from other information received about the line to be formed. This may comprise determining a start point and/or an end point for the tip of the probe (e.g. on the surface). The indication of the line may be a visual indication, e.g. an image or pattern. The line may be one of a plurality of lines to be formed, e.g. together defining a pattern. Thus the method may comprise receiving an indication
10 of a pattern (comprising a line having a variable linewidth) to be formed on a substantially planar surface. The method may comprise analysing the pattern to determine a plurality of component lines (comprising a line having a variable linewidth). The method may comprise determining when a line does not have a variable linewidth.

15 The method may comprise re-characterising the tip of the probe once the probe has been controlled to form the line. This means that the effects of wear or other modification to the geometry of the tip during the forming of the line can be taken into account before proceeding to form subsequent lines, thus helping to improve
20 the quality of the lines formed.

The method may further comprise determining a geometry of the line to be formed according to the received indication of the line. This may comprise analysing the line to determine one or more of a vector, a location, a start point, an end point, a
25 line width, a line length and a line depth.

Mapping the geometry of the tip to a geometry of the line to determine a set of instructions for forming the line on the planar surface may comprise using the geometry of the tip and the geometry of the line to identify a movement (e.g.
30 comprising control of the orientation) of the probe tip relative to the planar surface that will cause the probe tip to form the line.

Mapping the geometry of the tip to the geometry of the line may comprise comparing the geometry of the line with a geometry of a known topographical
35 feature or pattern (e.g. a circle having a variable line width circumference). The

comparison may be used to determine a movement of the probe tip for forming the geometry of the line.

5 The set of instructions may define a path for the probe to follow. The set of instructions may comprise a direction instruction defining one or more vectors along which the probe is to be moved. The set of instructions may comprise an orientation into (or an angle through) which the probe is rotated.

10 As discussed above, the width of a line formed by a non-circular (e.g. asymmetric) tip, or by a recess between a plurality of projections on a tip, can be varied by rotating the tip about an axis substantially perpendicular to the direction in which the tip is moved (and to the plane of the surface). It will be appreciated that the same effect can be achieved by rotating the surface, rather than, or as well as, the tip. Thus, one or more desired line widths may be mapped to a corresponding direction and/or orientation (e.g. relative to the direction) for the probe tip to be moved in.

Mapping the geometry of the tip to the geometry of the line may comprise selecting a parameter to optimise when determining the set of instructions. The set of instructions may be determined in order to optimise one or more of the speed of the process of forming the line, a minimum feature size and a continuous feature variation.

25 It will be appreciated that, when it is desired to form a pattern comprising a plurality of lines (e.g. having widths of varying orders of magnitude), it may be necessary to use a plurality of tips of different geometries. Thus, in some embodiments, the method comprises mapping the geometries of one or more further tips to the geometries of one or more further lines. The method may comprise determining a particular geometry of tip to use in order to form a line of a particular geometry. This determination may be made in consideration of a parameter to be optimised (e.g. the speed of the process of forming the line, a minimum feature size and a continuous feature variation).

35 Controlling the probe to form the line may comprise displacing the probe relative to the surface. The probe may be displaced in a direction substantially perpendicular to the plane of the surface (e.g. towards or away from the surface). In some

embodiments, the probe is displaced in a direction substantially parallel to the plane of the surface (i.e. across the surface).

5 The line may be formed by the removal (or addition) of material from (or to) the planar surface. Controlling the probe to form the line on the surface may comprise moving the probe relative to the surface such that material is removed (e.g. scratched) from the surface by the tip. Controlling the probe to form the line may comprise moving the probe relative to the surface while material is deposited onto the surface from the tip. It may further comprise directing a flow of fluid (e.g. liquid)
10 from a nozzle in the tip to the surface.

In some embodiments, controlling the probe to form the line comprises moving the probe tip over the planar surface in a single pass (e.g. without moving the probe tip over a portion of the planar surface on which the line is to be formed more than
15 once) to form the variable linewidth line. This can greatly improve the efficiency of the scanning probe lithography process in comparison with the previously discussed conventional methods, in which it is required for the probe to move back and forth in order to form lines of variable width.

20 In some embodiments, the method further comprises scanning the surface to determine a topography of the surface. This may comprise moving the probe relative to the surface. A deflection of the probe tip may be measured and used to determine the topography of the surface. This step may be performed after characterising the geometry of the tip. Knowing the precise geometry of the tip
25 allows the topography of the surface to be more accurately determined.

The method may further comprise identifying, from the determined topography of the surface, the location of an alignment feature on the surface. The alignment feature may comprise a protrusion or a recess. A desired location of the pattern to
30 be formed may be a particular distance from the alignment feature. Therefore, identifying the location of the alignment feature allows the pattern to be formed in the desired location (e.g. by controlling the probe to align the tip with the alignment feature).

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When viewed from a further aspect, the present invention provides a system for scanning probe lithography, the system comprising:

a probe, comprising:

a tip for forming lines on a substantially planar surface; and

5 a mount on which the tip is mounted for controlling the orientation of the tip;

wherein the tip has a first end proximal to the mount and a second end distal to the mount, wherein the cross section of the second end of the tip is non-circular; and

10 a processor, configured to:

characterise the geometry of the tip of the probe;

receive an indication of a line to be formed on the, wherein the width of the line varies along the length of the line;

15 map the geometry of the tip to a geometry of the line to determine a set of instructions for forming the line on the planar surface;

control the probe to form the line on the surface according to the set of instructions, wherein controlling the probe comprises controlling the orientation of the probe about an axis substantially perpendicular to the plane of the surface.

20

It will be appreciated that one or more, e.g. all, of the optional and preferable features outlined herein (e.g. for other aspects and embodiments of the invention) apply equally to this aspect of the invention.

25 The processor may comprise a control unit for controlling the position and/or orientation of the tip of the probe to form a line or pattern in a surface of a material, as discussed above.

30 The processor may comprise a memory for storing information about a known surface topography. The processor may be configured to use the information to characterise the geometry of the tip of the probe and/or to map the geometry of the tip to the geometry of the line to be formed. The memory may be configured to store the indication of the line to be formed.

The system may comprise a sensor for measuring the deflection of the probe. The processor may be configured to characterise the geometry of the tip of the probe using the deflection measurements from the sensor. The processor may comprise an input for receiving the indication of the line to be formed.

5 Certain preferred embodiments for the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 shows a conventional probe being used in scanning probe lithography;

10 Figures 2 and 3 show a probe, according to an embodiment of the present invention, being used in scanning probe lithography;

Figures 4 and 5 show a probe, according to another embodiment of the present invention, being used in scanning probe lithography;

Figures 6 and 7 show techniques for using the probe shown in Figures 4 and 5;

15 Figure 8 shows a flowchart illustrating a technique of using the probe according to an embodiment of the present invention;

Figure 9 shows the characterisation of differently shaped probe tips according to an embodiment of the present invention;

20 Figure 10 shows a flowchart illustrating a further technique of using the probe according to an embodiment of the present invention;

Figure 11 shows a flowchart illustrating a technique of patterning using multiple probes comprising different tip geometries, according to an embodiment of the present invention;

25 Figure 12 shows a flowchart illustrating a further technique of patterning using multiple probes comprising different tip geometries, according to an embodiment of the present invention; and

Figure 13 shows a flowchart illustrating a further technique of patterning using multiple probes including determining an accurate topography of a material surface, according to an embodiment of the present invention.

30

Scanning probe lithography is used to form patterns at the nanoscale, using a probe to create (e.g. scratch) a pattern on the surface of a material. Embodiments of the invention that provide a probe for use in scanning probe lithography will now be described.

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Figures 2 and 3 show schematically a probe 11, according to an embodiment of the present invention, being used in scanning probe lithography. The probe 11 comprises a tip 12 that is mounted on a cantilever 13. The cantilever 13, as part of an atomic force microscope, is controlled to manipulate the position and orientation of the tip 12 of the probe 11, so that it can be used to form a pattern 15 on the surface of a material 14. As shown in Figure 3, the pattern is formed by scratching a resist layer 16 (formed from polymethyl methacrylate (PMMA)) that is on a substrate 17 (formed from silicon mononitride (SiN)).

As shown in Figure 2, the tip 12 of the probe 11 has a flat distal end 18. The cross section of the distal end 18 (in a plane that is perpendicular to the main axis of the tip 12 which extends from the cantilever 13 to the distal end 18) of the tip 12 is substantially rectangular. The rectangular cross section has one dimension that is greater than the other (perpendicular) dimension.

As can be seen from the pattern 15 that is formed using the tip 12, as shown in Figure 2, the rectangular cross section of the distal end 18 of the tip 12 enables the probe 11 to form a variable linewidth pattern 15 in the surface of the material 14. This variable linewidth pattern 15 is formed in a single pass, simply by varying the direction in which the tip 12 of the probe 11 is scratched across the surface of the material 14. When the tip 12 of the probe 11 is moved across the surface of the material 14 in a direction perpendicular to the wider dimension of the distal end 18 of the tip 12 a wider linewidth pattern is formed. When the tip 12 of the probe 11 is moved across the surface of the material 14 in a direction perpendicular to the narrower dimension of the distal end 18 of the tip 12 a narrower linewidth pattern is formed.

Figure 3 shows a different method of using the tip 12 shown in Figures 2 and 3. As can be seen in Figure 3, the cantilever 13 of the probe 11 is controlled to orient the tip 12 at an angle with respect to the surface of the material 14, i.e. such that the axis of the tip 12 is angled away from the normal to the plane of the surface of the material 14. This causes the flat distal end 18 of the tip 12 to be angled relative to the surface of the material 14, such that it presents a triangular cross section to the material 14 (in a plane that is perpendicular to the surface of the material 14 and parallel to the direction in which the cantilever 31 extends). In this orientation, when

- 20 -

the tip 12 is scratched across the resist 16 of the material 14, a triangular groove is formed in the resist 16.

Figure 4 shows schematically a tip 32 of a probe, according to another embodiment of the present invention, being used in scanning probe lithography. As with the tip shown in Figures 2 and 3, the monolithic tip 32 shown in Figure 4 is for use in a scanning lithograph probe and so is mounted on a cantilever for an atomic force microscope or on a stage for a scanning tunnelling microscope. The probe is controlled to manipulate the position and orientation of the tip 32 of the probe, so that it can be used to form a pattern 35 on the surface of a material 34.

The tip 32 of the probe shown in Figure 4 has two projections 38, each having a flat distal end with a rectangular cross section, thus forming a rectangular recess (gap) between the two projections 38. The cross section of each of the distal ends 38 (in a plane that is perpendicular to the main axis of the tip 32 which extends from the cantilever to the distal ends 38) of the tip 32 is substantially rectangular.

Figure 5 shows a cantilever mount 33 on which a tip 32 having two projections 38 (e.g. as shown in Figure 4) is mounted. The two projections 38 are spaced from each other in a direction that is perpendicular to the direction in which the cantilever 33 extends.

As can be seen from the pattern 35 that is formed using the tip 32, as shown in Figures 4 and 5, the recess between the two projections 38 of the tip 32 enables the probe to form a raised variable linewidth pattern 36 in the surface of the material 34, owing to the two projections 38 scratching two linewidths 35 of variable spacing in the surface of the material 34. This raised variable linewidth pattern 36 is formed in a single pass, simply by varying the direction in which the tip 32 of the probe is scratched across the surface of the material 34.

The technique used to form the raised linewidth pattern 36 is shown in Figures 6 and 7. Figure 6 shows that, for a probe having a tip 32 with two projections 38 that are spaced from each other by a distance, D , and moved across a surface at an angle θ° , this causes a raised linewidth pattern having a width, W , to be formed.

Figure 7 shows that by using this technique, moving the two projections 38 of the tip 32 across a surface at different angles, enables raised linewidth patterns 36 having different linewidths to be formed or a scratched linewidth pattern 36 to be formed.

First, when the two projections 38 of the tip 32 are scratched across a surface at an angle that is perpendicular to the distance, D, between the two projections 38 of the tip 32, a raised linewidth pattern 36 having a width, D, is formed.

Second, when the two projections 38 of the tip 32 are scratched across a surface at an angle, θ° , that is between 0° and 90° to the distance, D, between the two projections 38 of the tip 32, a raised linewidth pattern 36, having a width that is less than the distance, D, between the projections 38 of the tip 32, is formed. It will be appreciated that when the angle θ° is small, the width of the raised linewidth pattern 36 becomes very narrow.

Third, when the two projections 38 of the tip 32 are scratched across a surface at an angle that is parallel to the distance, D, between the two projections 38 of the tip 32, a scratched (depressed) linewidth pattern 36 (i.e. groove) having a width that is equal to the width of the two projections 38 is formed. Thus, in this mode of operation, the tip 32 may be used similar to the manner of a conventional probe.

It will be appreciated that the probe may be used to create a variety of complex patterns in a single pass, simply by varying the orientation of the tip and the direction in which the tip is scratched across the surface.

Figure 8 shows a flowchart illustrating a technique of using the probe of Figure 4 according to an embodiment of the present invention. Figure 9 shows schematically the characterisation of differently shaped probe tips according to an embodiment of the present invention.

In step S1, the probe is moved in a first direction (along the x-axis) over a known surface topography. This may be a sharp protrusion 44 on the surface of the material 34, as shown in Figure 9. As the probe is moved, a sensor is arranged to measure the displacement of the probe in a direction perpendicular to the plane of the surface of the material 34.

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In step S2, the probe is moved in a second direction (along the y-axis) over the same known surface topography 44 and the displacement of the probe is measured once again.

- 5 In step S3, a processor is configured to analyse the displacement measurements obtained in steps S1 and S2 in order to determine a 3D geometry of the probe tip 32.

10 In step S4, an image of a pattern 35 (e.g. as shown in Figure 4) to be formed on the surface of the material is received by the processor. In step S5, the processor is configured to analyse the image and to determine the geometry of the pattern 35. The determined geometry of the probe tip 32 is mapped to the geometry of the pattern 35 to determine a set of actuation instructions. The set of actuation instructions define a series of paths for the probe to follow relative to the surface of
15 the material 34 and a series of orientations for the probe tip 32 to adopt in order to form the desired pattern 35,

In step S6, the probe is moved relative to the surface of the material 34 according to the determined set of instructions, thus forming the desired pattern 35.

20

Figure 9 shows schematically the characterisation of a flat probe tip 32 and a tilted probe tip 42 according to an embodiment of the present invention.

The flat probe tip 32 has two projections 38 of equal length. The tilted probe tip 42
25 has a first projection 48a and a second projection 48b. The second projection 48b is shorter than the first projection 48.

The surface of a material 34 is also shown in Figure 10. The surface of the material 34 comprises a sharp feature 44 that extends in a direction perpendicular to the
30 plane of the surface by a known distance.

In order to characterise the flat probe tip 32 and the tilted probe tip 42, the flat probe tip 32 and the tilted probe tip 42 are scanned over the feature 44 in the x direction. A deflection sensor (not shown) is configured to measure the deflection of the probe
35 tips 32, 42 relative to the surface of the material 34.

Figure 9 shows the deflection measurements 46a, 46b for the flat probe tip 32 and the tilted probe tip 42 respectively. It can be seen that two deflection peaks of equal height are detected for the flat probe tip 32, whereas, for the tilted probe tip 42, two deflection peaks of different heights are detected. It will be appreciated that the shorter of the two deflection peaks corresponds to the shorter projection 48b of the tilted probe tip.

By measuring the magnitude of the deflection for each probe tip 32, 42, the topography of the probe tips 32, 42 along the x-axis may be determined. It will be appreciated that this process may be repeated and the probe tips 32, 42 moved along multiple axes in order to more precisely determine the geometry of the probe tips 32, 42.

Figure 10 shows a flowchart illustrating a further technique of using the probe of Figure 4 according to an embodiment of the present invention.

In step S101, a tip 32 of a particular geometry, is mounted on a mount of a probe. In step S102, a suitable calibration feature (i.e. a particular topography of the surface of a material 34 such as a sharp protrusion) is selected to be scanned by the tip 32. In step S103, a processor is configured to characterise the geometry of the tip 32 according to the process described in Figures 8 and 9.

In step S104, information relating to the tip 34 may be provided to the processor by a user. In step S105, the processor is configured to generate a 3D image of the tip 32 using deflection measurements obtained during step S103 and the information provided by the user in step S104.

In step S106, the user provides an image of a pattern 35 that is desired to be formed on the surface of the material 34. In step S107, the user may provide a parameter that is to be optimised when determining the path for the tip 32 to follow when forming the pattern 35. In step S108, the image is analysed by the processor and divided into a plurality of lines which together define the pattern 35. In step S109a, the processor determines which of these lines have a variable linewidth and generates a set of instructions for forming these lines. In step S109b, the processor

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determines which of the lines do not have a variable line width and generates a set of instructions for moving the probe tip 32 to form these lines.

5 In step S110, the sets of instructions are combined to form a full set of instructions for controlling the probe to form the desired pattern 35.

10 In step S111, the processor is configured to actuate the probe to move the tip 32 relative to the surface of the material 34 according to the full set of instructions determined in step S110. The set of instructions are interpreted by the processor to displace the probe tip 32 relative to the surface of the material 34 and to rotate the probe tip 32 in such a way as to form the geometries of the lines. Thus, each of the lines that together make up the pattern 35 are formed on the surface of the material 34 in order to form the desired pattern 35.

15 Figure 11 shows a flowchart illustrating a technique of patterning using multiple probes comprising different tip geometries, according to an embodiment of the present invention.

20 In step S201, a user provides a processor with an image of a pattern 35 which is desired to be formed on the surface of a material 34. In step S202, the user may provide an indication of a parameter which is to be optimised when generating the set of instructions for forming the pattern 35. In step S203, the image is analysed by the processor and divided into a plurality of lines which together define the pattern 35.

25 In step S204, the processor is configured to determine, for each of the plurality of lines that define the pattern 35, a suitable tip geometry for forming the line and a set of instructions for the controlling the probe in order to form the line. Thus, a different tip 32 may be chosen in order to form each of the lines. In steps S205a-n, the processor is configured to control each of the selected probe tips 32 in turn in order to form the desired pattern 35.

35 Figure 12 shows a flowchart illustrating a further technique of patterning using multiple probes comprising different tip geometries, according to an embodiment of the present invention.

- 25 -

Steps S301, S302, S303 and S304 are essentially the same as steps S201, S202, S203 and S204 of Figure 11 respectively.

5 In step S305a and S306a, the geometry of a first tip 32 is characterised in the same way as steps S103 and S105 of Figure 10. The same process is repeated for a second tip in steps S305b and S306b. It will be appreciated that the same process may be applied to any number of tips. However, for the sake of simplicity, only two are shown in Figure 12.

10

In step S307, the sets of instructions for each tip 32 are updated according to the accurate tip geometry calculated in steps S306a and S306b.

15 In steps S308a and S308b the combined set of instructions for each tip 32 are compiled. In step S309, the full set of instructions for forming the desired pattern are compiled. In step S310, the processor is configured to control the probe according full set of instructions in order to form the desired pattern 35.

20 As can be seen in Figure 12, once the patterning has occurred, the processor is configured to repeat characterisation of each tip 32 in order to account for wear or modification to the tip geometry during patterning.

Figure 13 shows a flowchart illustrating a further technique of patterning using multiple probes including determining an accurate topography of a material surface, according to an embodiment of the present invention.

25

In step S401, a tip 32 of a particular geometry, is mounted on a mount of a probe. In step S402, a suitable calibration feature (i.e. a particular topography of the surface of a material 34, such as a sharp protrusion) is selected to be scanned by the tip 32. In step S403a, a processor is configured to characterise the geometry of the tip 32 according to the process described in Figures 8 and 9.

30

As can be seen from steps S403a-n in Figure 13, step S403a may be repeated for n different tip geometries. In step S404, a 3D image of the characterised tip(s) 32 is generated by the processor.

35

In step S405, the tip 32 is scanned over the surface of the material 34. As the precise geometry of the tip 32 has been determined in steps S403a-n, this allows an accurate reconstruction of the topography of the surface of the material 34 to be generated in step S406. This accurate reconstruction allows the desired pattern 35 to be formed on the surface of the material 34 with greater accuracy. Characterising the tip 32 before imaging the surface of the material 34 means that asymmetric tips 32 (whose precise geometry would otherwise be unknown) can be used to form more accurate patterns 35.

In step S407, the processor is configured to analyse the reconstruction of the topography of the surface of the material 34 generated in step S406 to determine the location of alignment features. Alignment features may be protrusions or recesses on the surface of the material 34 used to align the tip 32 of the probe with a particular location on the surface of the material 34 so that the pattern 35 is formed in the desired location when the probe is controlled to form the pattern 35.

In step S408, the processor is configured to manoeuvre the tip 32 of the probe to the location of an alignment feature and begin commence forming of the desired pattern 35 on the surface of the material 34.

It will be seen from the above that, in at least preferred embodiments, the present invention provides a probe, methods and systems for scanning probe lithography with a tip with a non-circular (e.g. asymmetric) cross section. Such a tip provides a different width profile when forming a pattern in a surface, thus enabling variable linewidth patterns to be formed in a single pass. Such a tip may also help to provide an improved yield and a stronger tip. The methods and systems of the present invention help to exploit such an asymmetric tip, e.g. through calibration of the tip, in order to use the probe to form variable linewidth patterns.

Claims

1. A method of scanning probe lithography, the method comprising:
5 characterising a geometry of a tip of a probe;
receiving an indication of a line to be formed on a substantially planar surface, wherein the width of the line varies along the length of the line;
mapping the geometry of the tip to a geometry of the line to determine a set of instructions for forming the line on the planar surface; and
10 controlling the probe to form the line on the surface according to the set of instructions, wherein controlling the probe comprises controlling the orientation of the probe about an axis substantially perpendicular to the plane of the surface.
2. The method as claimed in claim 1, wherein characterising the geometry of the tip of the probe comprises:
15 scanning the tip in a first direction over a known surface topography and measuring the deflection of the tip;
scanning the tip in a second direction, different from the first direction, over the known surface topography and measuring the deflection of the tip; and
20 determining, from the deflection measurements, a geometry of the tip of the probe.
3. The method as claimed in claim 2, wherein the first direction and the second direction are perpendicular.
- 25 4. The method as claimed in any preceding claim, wherein the method further comprises determining the geometry of the line to be formed according to the received indication of the line.
- 30 5. The method as claimed in any preceding claim, wherein mapping the geometry of the tip to the geometry of the line comprises comparing the geometry of the line with a geometry of a particular topographical feature or pattern.
- 35 6. The method as claimed in claim 5, further comprising using the comparison to determine a movement of the probe tip for forming the geometry of the line.

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7. The method as claimed in any preceding claim, wherein the set of instructions define a path for the probe to follow.
- 5 8. The method as claimed in any preceding claim, wherein controlling the probe to form the line comprises moving the probe tip over the planar surface in a single pass to form the line.
- 9 10 The method as claimed in any preceding claim, wherein controlling the probe to form the line comprises moving the probe relative to the surface such that material is removed from the surface by the tip.
- 10 15 10. The method as claimed in any of claims 1 to 8, wherein controlling the probe to form the line comprises moving the probe relative to the surface while material is deposited into the surface from the tip.
11. The method as claimed in any preceding claim wherein the probe comprises a mount on which the tip is mounted, and the tip has a first end proximal to the mount and a second end distal to the mount, wherein the cross-section of the
20 second end of the tip is asymmetric.
12. The method as claimed in any claim 11, wherein the distal end of the tip has a first dimension in the direction in the plane of the cross-section which is greater than a second dimension in a direction in the plane of the cross-section
25 perpendicular to the first dimension.
13. The method as claimed in any preceding claim, wherein the tip comprises a plurality of projections.
- 30 14. The method as claimed in claim 13, wherein the plurality of projections are integrally formed.
15. The method as claimed in any preceding claim, wherein the tip comprises one or more recesses that extend across the tip.

35

16. The method as claimed in claim 15, wherein the recess has a substantially rectangular cross-section.
17. A system for scanning probe lithography, the system comprising:
5 a probe, comprising:
a tip for forming lines on a substantially planar surface; and
a mount on which the tip is mounted for controlling the orientation of the tip;
wherein the tip has a first end proximal to the mount and a second end distal
10 to the mount, wherein the cross section of the second end of the tip is non-circular;
and
a processor, configured to:
characterise the geometry of the tip of the probe;
receive an indication of a line to be formed on the, wherein the width of the
15 line varies along the length of the line;
map the geometry of the tip to a geometry of the line to determine a set of instructions for forming the line on the planar surface;
control the probe to form the line on the surface according to the set of instructions, wherein controlling the probe comprises controlling the orientation of
20 the probe about an axis substantially perpendicular to the plane of the surface.
18. The system as claimed in claim 17, wherein the processor comprises a control unit for controlling the position and/or orientation of the tip of the probe.
- 25 19. The system as claimed in claim 17 or 18, wherein the system comprises a sensor configured to measure the deflection of the probe.
20. The system as claimed in claim 19, wherein the processor is configured to characterise the geometry of the tip of the probe using deflection measurements
30 from the sensor.

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Fig. 1

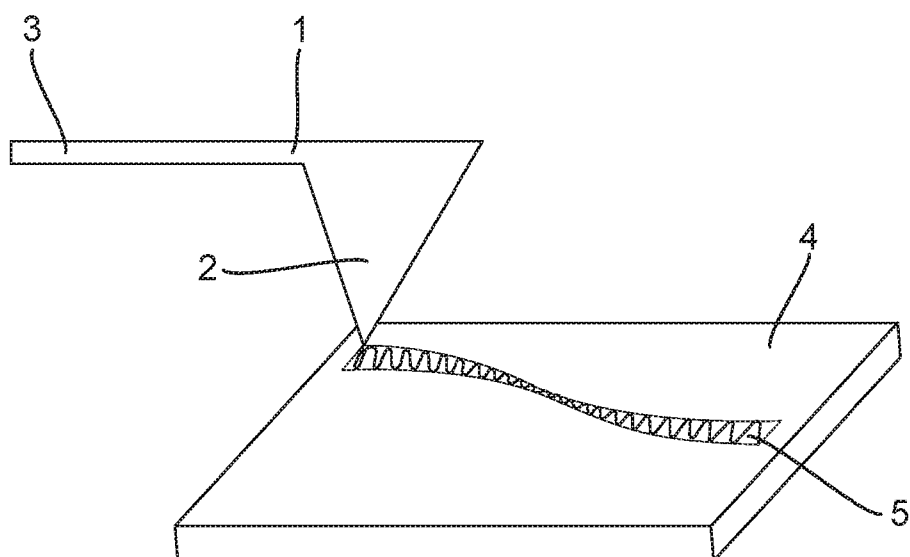
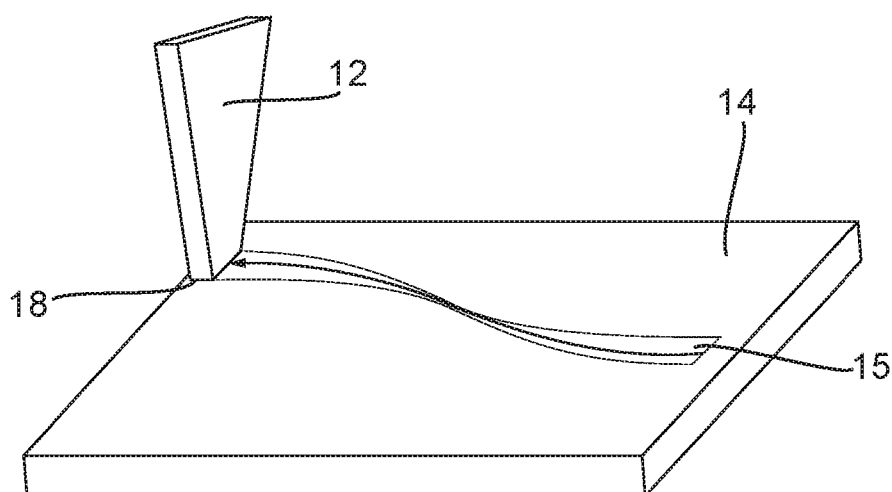


Fig. 2



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Fig. 3

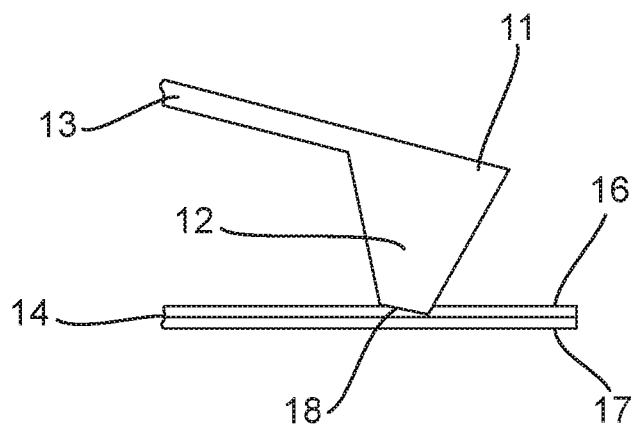
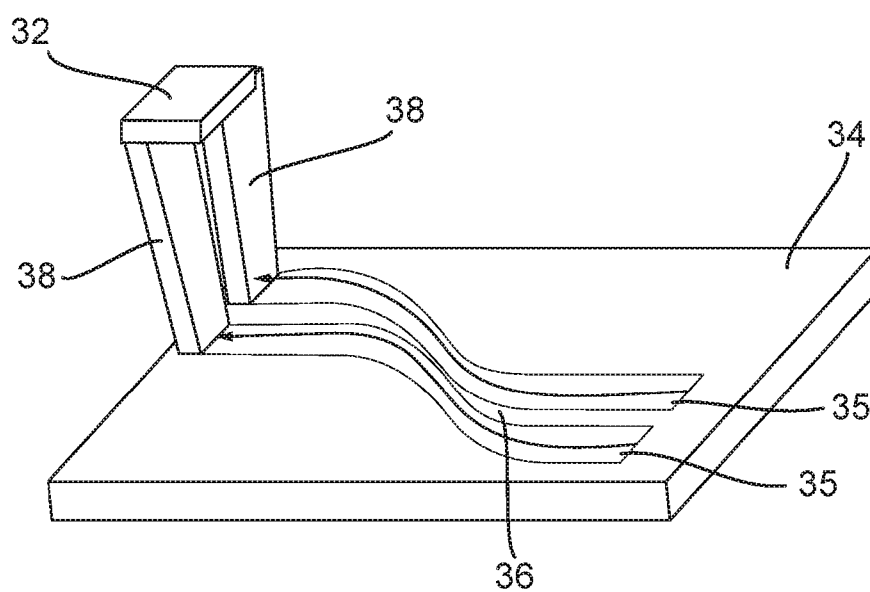
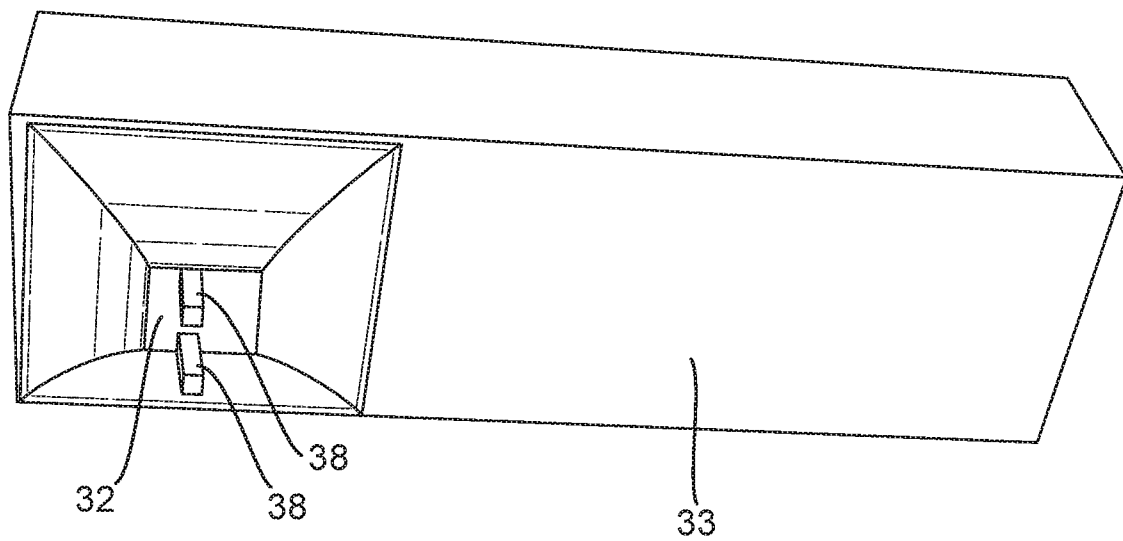


Fig. 4



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Fig. 5



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Fig. 6

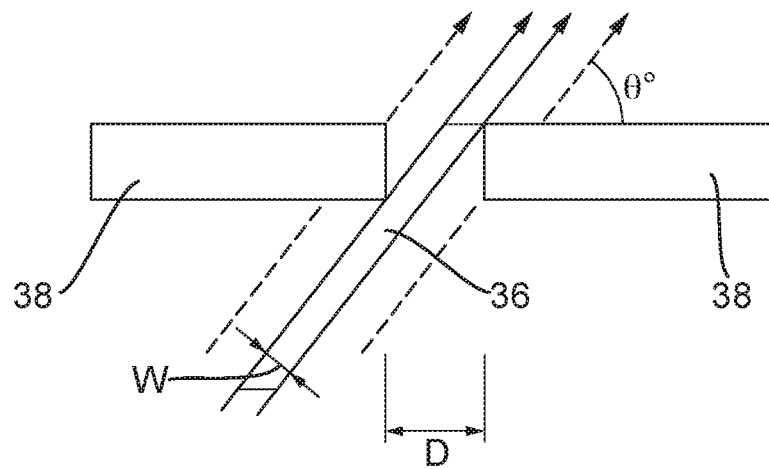
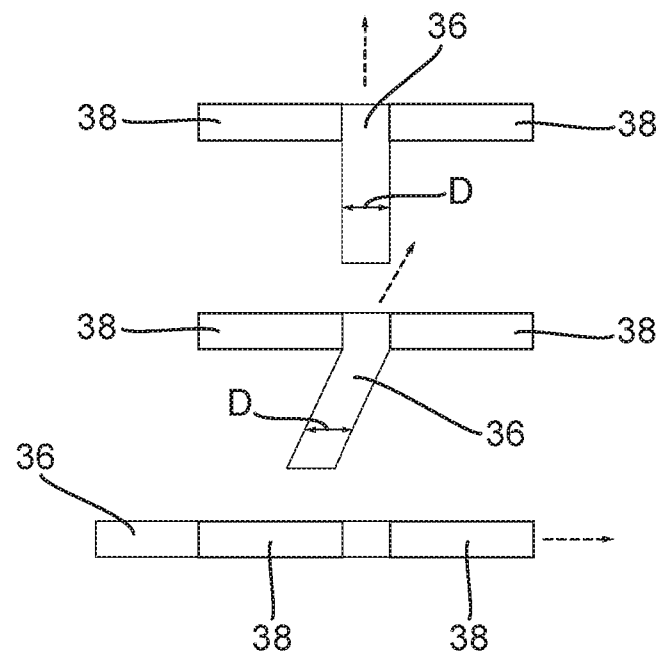


Fig. 7



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Fig. 8

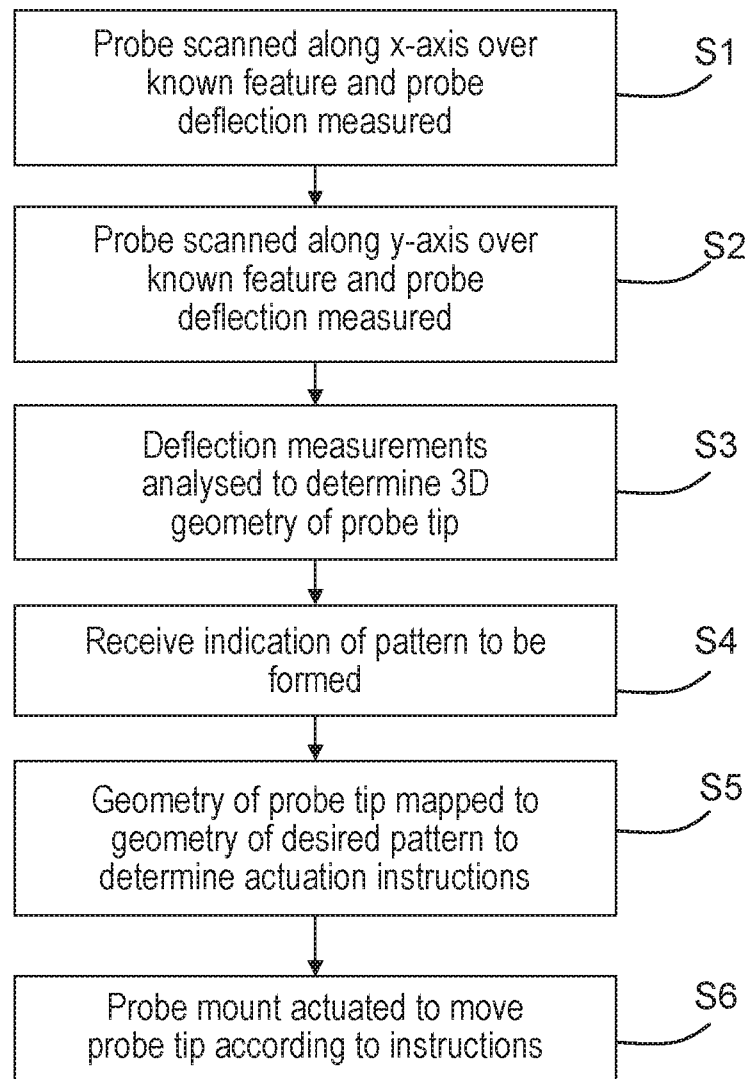


Fig. 9

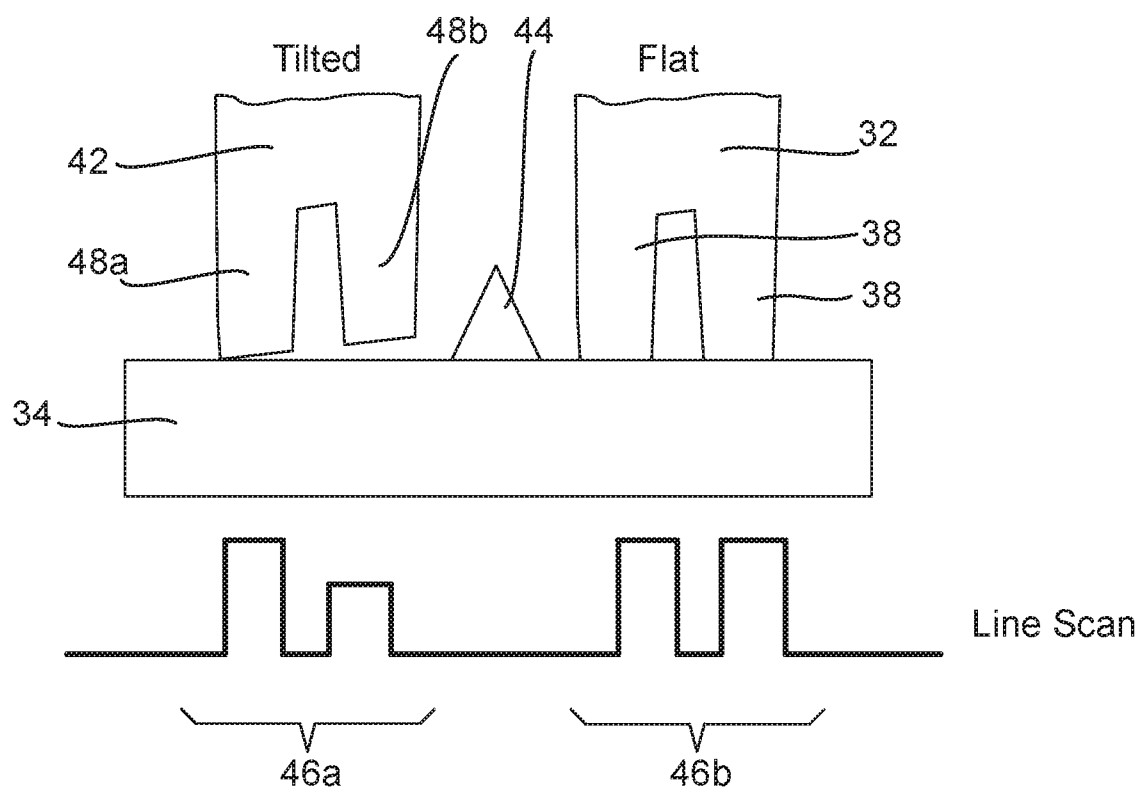


Fig. 10

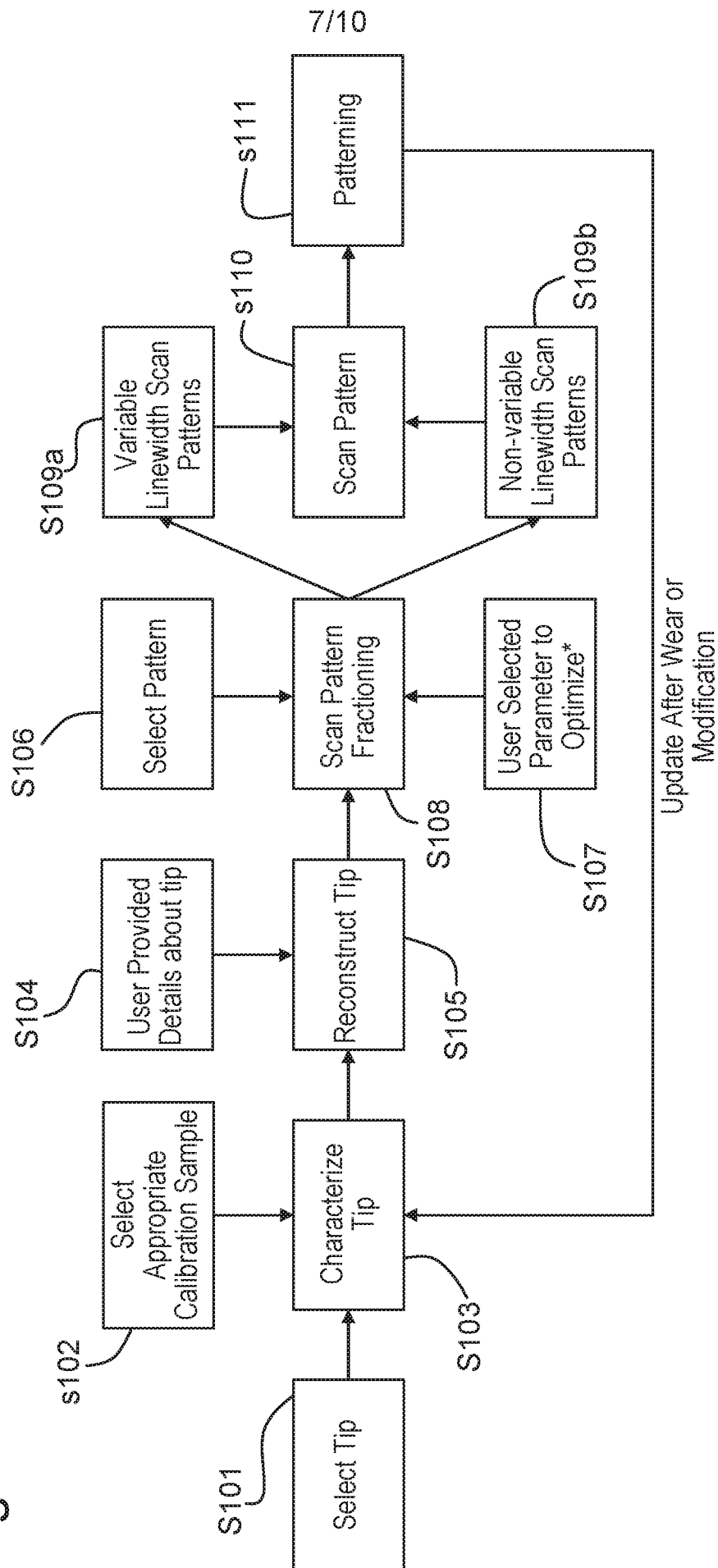


Fig. 11

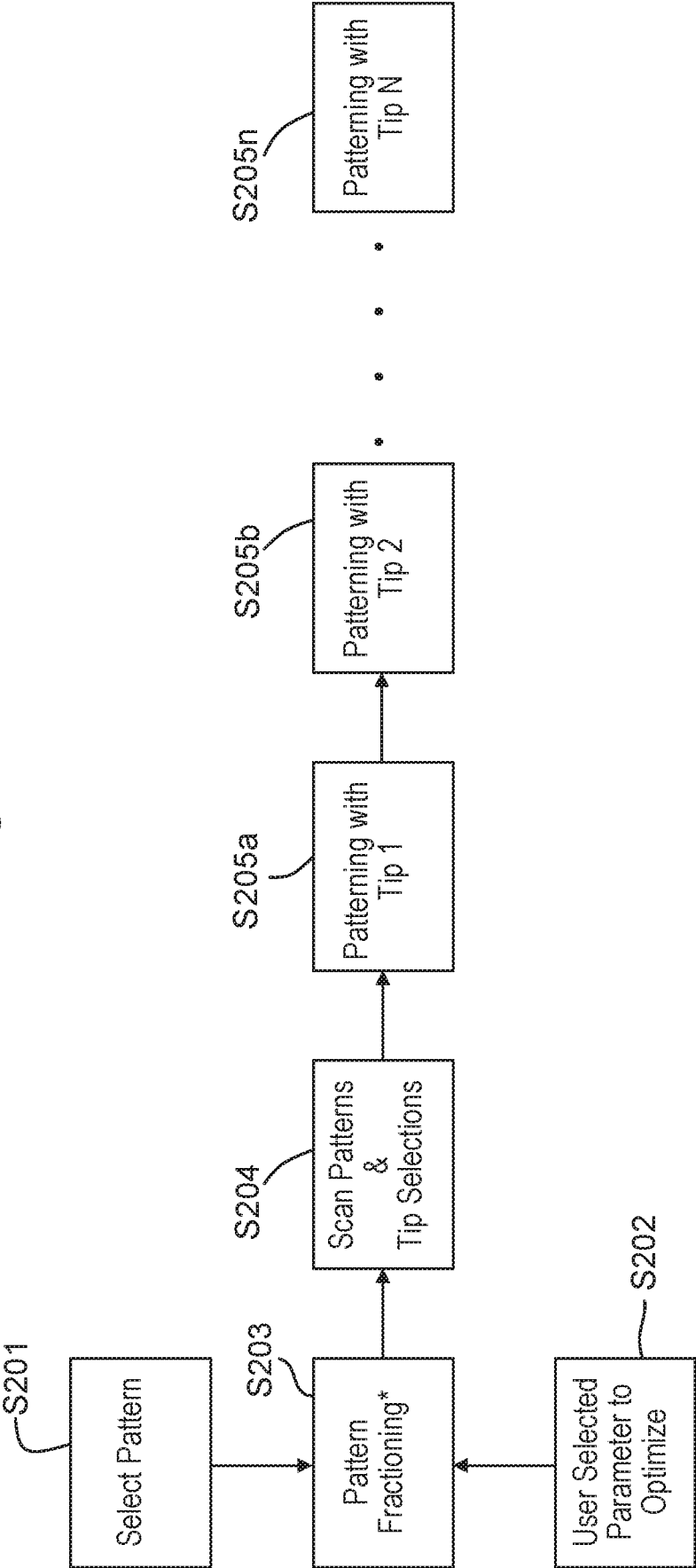


Fig. 12

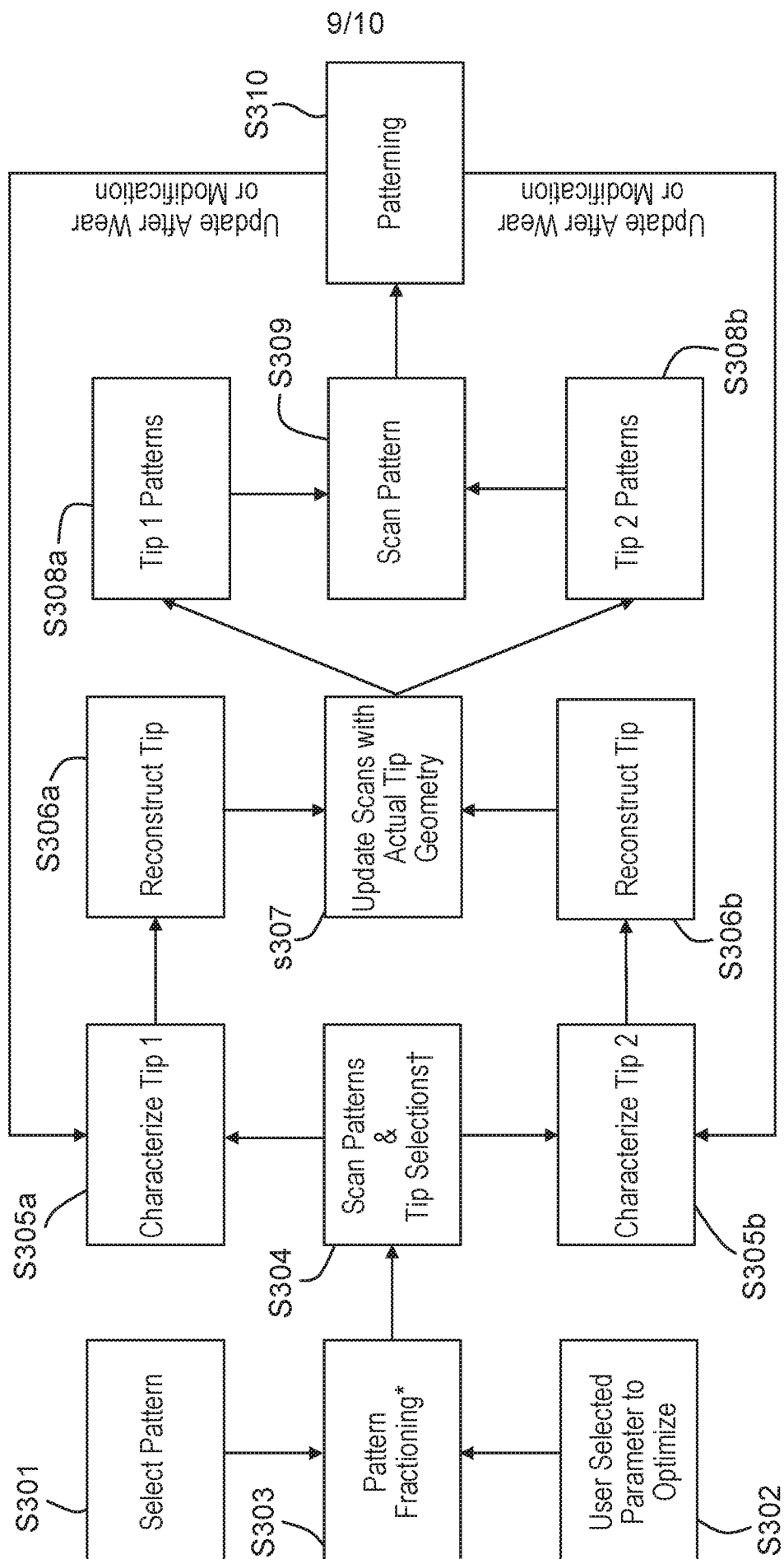
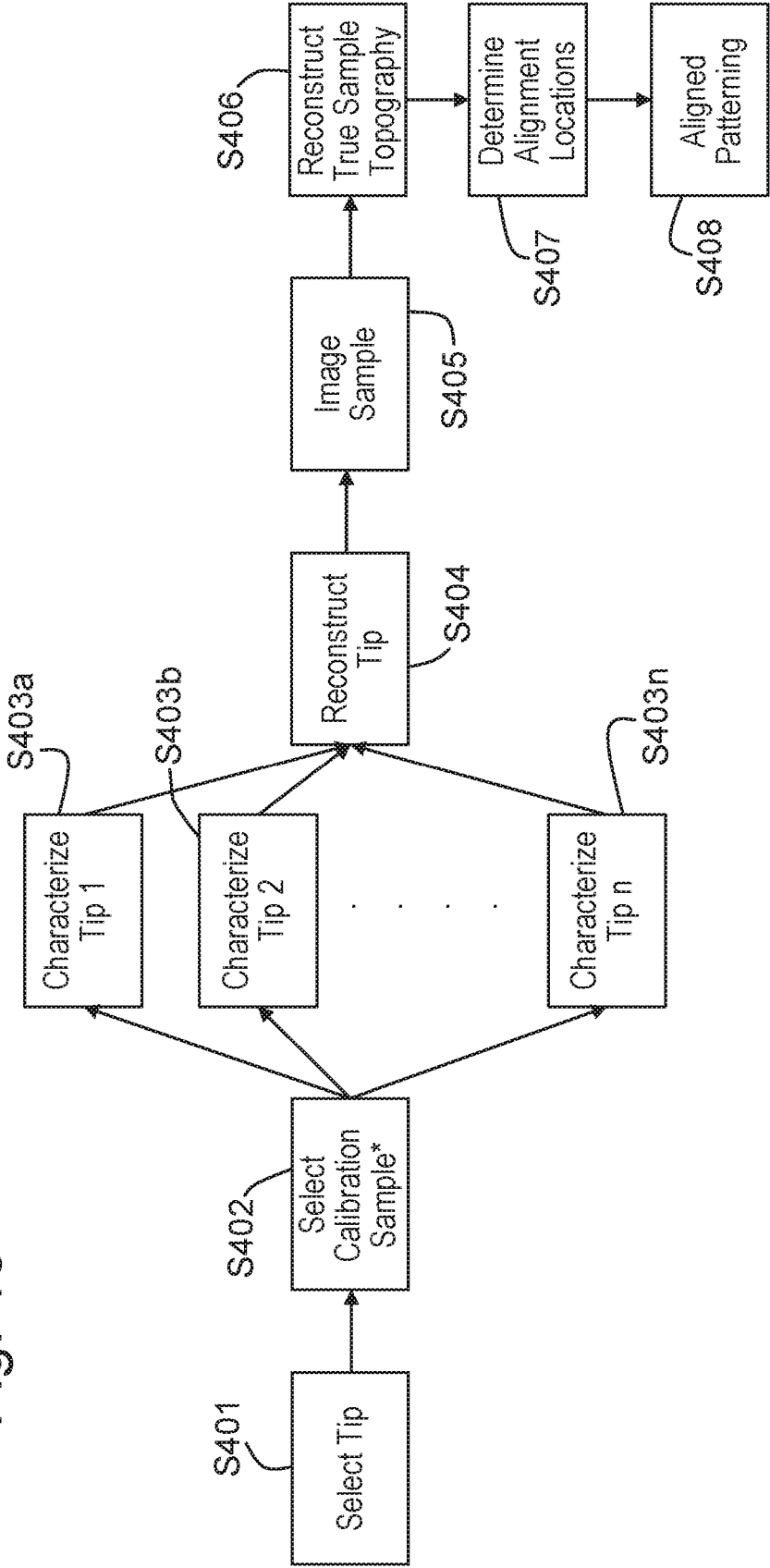


Fig. 13



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/051281

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/00 G01Q70/10
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F G01Q

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

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

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 787 768 B1 (KLEY VICTOR B [US] ET AL) 7 September 2004 (2004-09-07)	1,4, 7-12, 17-20
Y	column 3, line 24 - line 27; figures 1-13	13-16
A	column 6, line 6 - line 26 column 8, line 42 - line 63 column 12, line 34 - line 44	2,3,5,6
Y	EP 2 535 725 A1 (IMEC [BE]) 19 December 2012 (2012-12-19) paragraphs [0024], [0029]; figures 2-4,7 ----- -/--	13-16



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

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Date of mailing of the international search report

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Angioni, Catherine

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2020/051281

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	MURAT KAYA YAPICI ET AL: "A Novel Scanning Probe Array with Multiple Tip Sharpness for Variable-Resolution Scanning Probe Lithography Applications", NANOTECHNOLOGY, 2008. NANO '08. 8TH IEEE CONFERENCE ON, IEEE, PISCATAWAY, NJ, USA, 18 August 2008 (2008-08-18), pages 147-150, XP031315435, ISBN: 978-1-4244-2103-9 page 149 - page 150; figures 1-6 -----	1-20
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