

Title: Direct atomic layer deposition and/or etching method

FIELD

5 The invention relates to atomic layer deposition methods and the fabrication of nanostructures therewith.

BACKGROUND

Atomic layer deposition, ALD, is a known technique for
10 manufacturing nanoscale structures by depositing a thin film of a process material onto a substrate. ALD generally involves sequentially exposing a surface material, e.g. the substrate, to precursors and having the precursors react with the surface material.

In area-selective ALD, a thin layer of material is deposited at a
15 selective and predetermined area of the substrate. This can be achieved using a particular deposition head that is arranged to only locally deposit a layer on the substrate. A continuous layer of material can be obtained by moving the depositing head relative to the substrate.

While in a Z-direction, i.e. transverse to a plane of the substrate, an
20 atomic-scale resolution can be obtained, the in-plane resolution in an X-Y plane, i.e. parallel to the plane of the substrate, is limited, e.g. in the order of 50-400 micrometers.

SUMMARY

25 Is it an aim to improve the in-plane resolution of area-selective atomic layer deposition methods.

According to an aspect, an atomic layer deposition and/or atomic layer etching method is provided, particularly an direct atomic layer
deposition and/or atomic layer etching patterning method. The method
30 comprises drawing, using a first precursor fluid, on a substrate a first line extending longitudinally and having, in lateral direction, a first linewidth;

drawing, using a second precursor fluid, on the substrate a second line extending longitudinally and having, in lateral direction, a second linewidth. The first and second lines partly overlap one another laterally by a predetermined amount which is smaller than the first linewidth and the second linewidth; and/or the first and second lines are laterally spaced apart from one another by a predetermined amount which is smaller than the first linewidth and the second linewidth, such that a first protrusion is formed of which a largest width in lateral direction is smaller than the first linewidth and the second linewidth, and/or a first recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth. The drawing of the first and second lines can be used for directly patterning on the substrate. The patterning can include deposition and/or etching. Particularly the overlap and/or gap allows for high resolution patterning. The substrate can be a homogeneous substrate or a substrate already including different material layers and/or structures.

Optionally, the drawing of the first line comprises depositing, using the first precursor fluid, a first layer as the first line, or etching, using the first precursor fluid, a first gully as the first line. Optionally, the drawing of the second line comprises depositing, using the second precursor fluid, a second layer as the second line, or etching, using the second precursor fluid, a second gully as the second line. Each line may hence be formed by either a deposited layer or an etched gully.

The aspect can accordingly provide an atomic layer deposition method, particularly an area-selective atomic layer deposition method, wherein the method comprises depositing, using a first precursor fluid, a first layer, e.g. on a substrate, as a first line extending longitudinally and having, in lateral direction, a first linewidth; and depositing, using a second precursor fluid, a second layer, e.g. on a substrate, as a second line extending longitudinally and having, in lateral direction, a second linewidth, wherein the first and second lines are deposited to partly overlap

one another laterally by a predetermined amount such that, at the overlap, a first protrusion is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth, and wherein the first and second lines are deposited to, at least partly, be laterally spaced
5 apart from one another by a predetermined amount such that, at the spacing, a first recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth.

The aspect can accordingly alternatively or additionally provide an atomic layer etching method, particularly an area-selective atomic layer
10 etching method. The atomic layer etching method may be similar to the atomic layer deposition method described herein, wherein instead of depositing atomic layers, atomic gullies are etched, i.e. a material layer is selectively removed. The atomic layer etching method may comprise etching, using a first precursor fluid, a first gully as a first line extending
15 longitudinally and having, in lateral direction, a first linewidth; and etching, using a second precursor fluid, a second gully as a second line extending longitudinally and having, in lateral direction, a second linewidth, wherein the first and second lines are etched to partly overlap one another laterally by a predetermined amount such that, at the overlap,
20 a first recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth, and wherein the first and second lines are etched to, at least partly, be laterally spaced apart from one another by a predetermined amount such that, at the spacing, a first protrusion is formed of which a largest width, in lateral direction, is
25 smaller than the first linewidth and the second linewidth.

The first line can be drawn, i.e. deposited or etched, using an ALD/ALE head. Herein ALD/ALE head refer to a head configured for atomic layer deposition (ALD) and/or atomic layer etching (ALE). The ALD/ALE head can be configured for depositing and/or etching, using the first
30 precursor fluid, a spot when the ALD/ALE head is immobile relative to the

substrate. Hence, the ALD/ALE head can differ from alternative ALD/ALE heads that are configured to deposit and/or etch, using the first precursor fluid, a line when the ALD/ALE head is immobile relative to the substrate. The ALD/ALE heads depositing and/or etching the line, using the first precursor fluid, when immobile relative to the substrate generally have an elongate deposition/etching slit and are used for blanket deposition/etching with the first precursor fluid when moving relative to the substrate. The ALD/ALE head depositing and/or etching, using the first precursor fluid, a spot when immobile relative to the substrate can have a deposition/etching nozzle having comparable dimensions in all directions in a plane parallel to the substrate. The nozzle can e.g. be circular. The ALD/ALE head drawing, with the first precursor fluid, a spot when not moving relative to the substrate can be used for depositing/etching the first layer as a line by moving the ALD/ALE head along the substrate, such as in a longitudinal direction of the first line. It will be appreciated that the line width of the first layer can be determined by the dimensions of the nozzle. It will be clear that because the ALD/ALE head deposits/etches a spot when immobile relative to the substrate, a line width of the first layer can be substantially constant, regardless of the direction in which the ALD/ALE head is moved relative to the substrate (x-direction, y-direction, or a combination thereof).

The second line can be drawn, i.e. deposited or etched, using an ALD/ALE head. The ALD/ALE head can be configured for depositing and/or etching, using the second precursor fluid, a spot when the ALD/ALE head is immobile relative to the substrate. Hence, the ALD/ALE head can differ from alternative ALD/ALE heads that are configured to deposit and/or etch, using the second precursor fluid, a line when the ALD/ALE head is immobile relative to the substrate. The ALD/ALE heads depositing and/or etching the line, using the second precursor fluid, when immobile relative to the substrate generally have an elongate deposition/etching slit and are used for blanket deposition/etching of the second precursor fluid when

moving relative to the substrate. The ALD/ALE head depositing and/or etching, using the second precursor fluid, a spot when immobile relative to the substrate can have a deposition/etching nozzle having comparable dimensions in all directions in a plane parallel to the substrate. The nozzle
5 can e.g. be circular. The ALD/ALE head drawing, using the second precursor fluid, a spot when not moving relative to the substrate can be used for depositing/etching the second layer as a line by moving the ALD/ALE head along the substrate, such as in a longitudinal direction of the second layer. It will be appreciated that the line width of the second layer can be
10 determined by the dimensions of the nozzle. It will be clear that because the ALD/ALE head deposits/etches a spot when immobile relative to the substrate, a line width of the second layer can be substantially constant, regardless of the direction in which the ALD/ALE head is moved relative to the substrate (x-direction, y-direction, or a combination thereof).

15 Optionally, the first and second lines are deposited and/or etched using a single ALD/ALE head. Especially when the first precursor fluid and the second precursor fluid are the same, the first and second lines can be deposited/etched using one and the same ALD/ALE head. The first line may be deposited/etched using a first ALD/ALE head and the second line may be
20 deposited/etched using a second ALD/ALE head.

Hence, the method enables fabrication of, e.g. three-dimensional, features that have smaller widths, in an X-Y plane parallel to the substrate, than the in-plane resolution of the individual deposited layers. The method exploits accurate and precise positioning capabilities of the ALD/ALE head
25 with respect to the substrate, when compared to the structural resolution of the individually deposited layers and/or etched gullies, to increase the spatial resolution of fabricated nanostructures. Various shaped nanostructures can be created with the method, including, e.g. free-standing, protrusion and indentations, such as linear and/or curved ridges
30 or linear and/or curved grooves, having a dimension in the X-Y plane that is

substantially smaller than the X-Y dimensions of the individual first and second layers that form the protrusions and indentations.

For example, if the first and second layers are deposited, at the overlap of the first and second layer, a projection can be formed having a
5 smaller width than the width of the first layer and the second layer. Also, a recess can be formed at the gap between two adjacent layers, the gap having a smaller width than the width of the first layer and the second layer.

Also, for example, if the first and second gullies are etched, at the overlap of the first and second gully, a recess can be formed having a
10 smaller width than the width of the first gully and the second gully. Also, a projection can be formed at the gap between two adjacent gullies, the gap having a smaller width than the width of the first gully and the second gully.

Also, for example, if the first line is deposited and second line is
15 etched, or vice versa, projections and recesses can be formed having a smaller width than the width of the first line and the second line.

The width of the projection and/or the width of the recess can be controlled by controlling a positioning relative to the substrate of the ALD/ALE head or heads depositing/etching the first and second line. The
20 positioning relative to the substrate of the ALD/ALE head or heads depositing/etching the first and second line can be effected using a positioning system. The positioning system can be configured for moving the ALD/ALE head(s) and/or the substrate. A controller can be configured to control the ALD/ALE head and the positioning system. The controller can be
25 configured to control the width of the protrusion and/or the width of the recess. The width of the protrusion and/or the width of the recess can be user-definable. The user may e.g. set the width of the protrusion and/or the width of the recess in a user interface of the controller. Various nanostructures can be fabricated this way, e.g. using a plurality of
30 superimposed layers.

The first and/or second line can deposited/etched by moving the ALD/ALE head and the substrate relative to each other in a longitudinal direction of the line, wherein the ALD/ALE head is configured to deposit/etch a spot when immobile relative to the substrate. The method can
5 include individually controlling a location on the substrate of the first line and a location on the substrate of the second line. The width of the first protrusion or first recess can be controlled by controlling a location on the substrate of the second line relative to first line.

Each deposited/etched line may have a minimum width. The
10 minimum width of a line may be defined in a direction transverse to a longitudinal direction of the line, which longitudinal direction may correspond to a depositing/etching direction, e.g. a printing or drawing direction. The depositing/etching direction may particularly relate to a direction in which an ALD/ALE head is moved relative to the substrate,
15 while depositing material. The minimum width may be considered as a smallest linewidth of a deposited/etched line. More particular, the minimum width may be considered as a smallest practically achievable linewidth an area-selective ALD/ALE system is capable of producing. It will be appreciated that the deposited/etched line can have a substantially constant
20 width. The deposited/etched line can have a substantially constant width regardless of the direction the deposited/etched line has on the substrate.

The layers can be deposited, and/or the gullies can be etched, using an ALD/ALE system having an ALD/ALE printer head, such as for example described in WO2020/245230A1, incorporated herein by reference. The
25 ALD/ALE head can be moved relative to the substrate to deposit/etch multiple lines in various patterns, so as to create a variety of nanostructures including nanopillars, nanoridges and nanoholes, for example for use in fabricating micro- and nanoscale electro-mechanic, opto-electronic, and opto-mechanic systems, or combinations thereof.

The first layer/gully and the second layer/gully may overlap each other in part. Hence, the overlap between the first line and the second line extends to only a part of the first line and also to only a part of the second line. Hence, the overlap does not extend to the entire first line or the entire
5 second line. For example, if only part of the second line covers the first line, only a part of the first line is covered by the second line. The first line for example includes an overlapping area where the first line is covered by the second line, and a non-overlapping area where the first line is not covered by the second line. The second line may thus, in this example, include an
10 overlapping area where the second line covers the first line, and a non-overlapping area where the second line does not cover the first line. The amount of overlap may be selected by properly positioning the ALD/ALE head(s) relative to the substrate.

The amount of overlap can be predetermined, yet does not include
15 a line in its entirety. The amount of overlap may be adjusted, for example, by positioning the ALD/ALE head and/or substrate appropriately.

Optionally, the largest width of the first protrusion or first recess is at most 50% of the first or second linewidth, preferably at most 25%, more preferably at most 10%, more preferably at most 5%.

20 Optionally, the first line and the second line extend parallel to one another, at least along a part of their length, for forming an elongate first protrusion and/or first recess. Hence, a narrow ridge or narrow groove can be fabricated, wherein, if the first line and the second line are deposited, the ridge is formed at the overlap of the first and the second line and the groove
25 at the gap between the first and the second line, and if the first line and the second line are etched, the groove is formed at the overlap of the first and the second line and the ridge at the gap between the first and the second line. For example, the first layer and the second layer may be consecutively deposited as parallel lines that extend in a longitudinal direction and partly
30 overlap each other in a width direction transverse to the longitudinal

direction; the second layer partly overlapping the first layer, or vice versa. Alternatively, the first layer and the second layer may be consecutively or simultaneously deposited as parallel lines that extend in a longitudinal direction and are spaced apart from each other in a width direction

5 transverse to the longitudinal direction. The first and second line may be straight and/or curved.

One or more further lines may, for example, also be deposited and/or etched, e.g. overlapping the second line for creating a further ridge or groove. This way, a plurality of parallel ridges and/or grooves can be formed,

10 each ridge or groove having a width that is smaller than a width of the individual deposited lines.

The first line and the second line may also be deposited/etched as non-parallel lines, for example as curved lines that partly overlap in one or more locations. The first layer or gully and the second layer or gully may

15 also be deposited or etched as non-parallel lines, for example as curved lines that partly overlap in one or more locations.

Optionally, the first layer or gully is deposited or etched as a first line having a constant first linewidth, and the second layer or gully is deposited or etched as a second line having a constant second linewidth. The

20 first linewidth may be equal to the second linewidth. The linewidths may also differ. The linewidths are defined in the X-Y plane, particularly in a direction transverse to the length direction of the lines, e.g. determined by a printing direction, and are dependent on the characteristics of the depositing/etching head.

25 Optionally, the first line comprises a straight line section and/or the second line comprises a straight line section. The first line and the second line may for example extend straight and parallel to each other.

Optionally, the first layer is of a first material and the second layer is of a second material different from the first material. Optionally, the first

30 precursor fluid is a first material and the second precursor fluid is a second

material. Hence, multi-material structures can be formed, such as, for example, forming electrically conductive or insulative paths for directing a transport of charges, or forming photo-active surfaces for generating and transporting charge carriers. By using different materials, electronic,
5 mechanical, and optical properties of the resultant nanostructure can be adjusted.

Optionally, the first line is deposited or etched at a first temperature, and the second line is deposited or etched at a second temperature, different from the first temperature.

10 Optionally, the first layer of the first material is deposited at a first temperature, and the second layer of the second material is deposited at a second temperature, different from the first temperature.

Optionally, the method comprises drawing, using a third precursor fluid, a third line extending longitudinally and having, in lateral direction, a
15 third linewidth, wherein the third line partly overlaps the second line laterally by a predetermined amount such that a second protrusion and/or second recess is formed of which a largest width is smaller than the first, second and third linewidth.

Optionally, the drawing of the third line comprises depositing or
20 etching, using the third precursor fluid, a third layer or third gully as the third line.

Optionally, the method comprises depositing, using a third precursor fluid, a third layer. The third layer may be deposited as a third line extending longitudinally and having, in lateral direction, a third
25 linewidth, wherein the third line is deposited to partly overlap the second line laterally by a predetermined amount such that, e.g. at the overlap with the second line, a second protrusion or second recess is formed of which a largest width is smaller than the first, second and third linewidth.

Optionally, the method comprises etching, using a third precursor
30 fluid, a third gully. The third gully may be etched as a third line extending

longitudinally and having, in lateral direction, a third linewidth, wherein the third line is etched to partly overlap the second line laterally by a predetermined amount such that, e.g. at the overlap with the second line, a second protrusion or second recess is formed of which a largest width is
5 smaller than the first, second and third linewidth. The third line may be similar to the first line or second line. Hence, any features described in relation to the first line or second line, can equally apply to the third line.

For example, the first, second and third layers and/or gullies may be consecutively deposited and/or etched as parallel lines that extend in a longitudinal direction and partly overlap each other in a width direction
10 transverse to the longitudinal direction; the second layer partly overlapping the first layer, the third layer partly overlapping the second layer. The amount of overlap can be predetermined, for example by positioning the ALD/ALE head appropriately while depositing and/or etching the layers
15 and/or gullies.

Optionally, the width of the second protrusion and/or second recess is equal to the width of the first protrusion and/or first recess. Hence, a regular pattern of overlapping layers may be formed, e.g. for forming ridges.

Optionally, the third layer partly overlaps the first layer by a
20 predetermined amount. Hence, the third layer may overlap the second layer as well as the first layer, for example for forming a stepped structure. It will be appreciated that the third layer need not contact the first layer. The third layer may for example be deposited on part of the second layer, which second layer has been deposited on part of the first layer. An overlapping
25 area may for example exist where the first, second and third layers are overlapping; forming a stack of layers at the overlap.

Optionally, the amount of overlap between the third layer and the first layer is smaller than the amount of overlap between the first layer and the second layer. Hence a stepped structure may be created.

Optionally, a lateral distance between the first protrusion and the second protrusion is smaller than the first, second or third linewidth.

Optionally, a lateral distance between the first recess and the second recess is smaller than the first, second or third line width. Hence, multiple
5 nanostructures, e.g. multiple ridges and/or grooves, can be manufactured in a space (X and/or Y) smaller than a minimum linewidth of the ALD/ALE head.

Optionally, the third line is laterally spaced apart from the first line. The third line may, thus, not overlap the first line. This way, a recess
10 may be created, e.g. when the first line, second line and third line are deposited, defined between an overlapping area where first and the second lines overlap and an overlapping area where the second and the third lines overlap, which recess has a width, in lateral direction, smaller than the first, second or third linewidth.

Optionally, the method comprises drawing, using a fourth
15 precursor fluid, a fourth line extending longitudinally and having, in lateral direction, a fourth linewidth, wherein the fourth line is laterally spaced apart from the second line by a predetermined amount such that a third recess and/or third protrusion is formed of which a largest width is smaller
20 than the first, second and fourth linewidth.

Optionally, the method comprises depositing and/or etching, using the fourth precursor fluid, a fourth layer or gully, the fourth layer or gully being deposited or etched as the fourth line.

Optionally, the method comprises depositing, using a fourth
25 precursor fluid, a fourth layer, the fourth layer being deposited as a fourth line extending longitudinally and having, in lateral direction, a fourth linewidth, wherein the fourth line is deposited, at least partly, laterally spaced apart from the second line by a predetermined amount such that, at the spacing between the fourth and the second line, a third recess is formed

which third recess has a largest width which is smaller than the first, second and fourth linewidth.

Optionally, the method comprises etching, using a fourth precursor fluid, a fourth gully, the fourth gully being etched as a fourth line
5 extending longitudinally and having, in lateral direction, a fourth linewidth, wherein the fourth line is etched, at least partly, laterally spaced apart from the second line by a predetermined amount smaller than the first, second and fourth linewidth. Hence, the fourth line may be spaced from the second line, wherein the second line may partly overlap or be spaced from the first
10 line. For example, the first, second and fourth layers may be consecutively deposited as parallel lines that extend in a longitudinal direction wherein the first and second lines partly overlap each other in a width direction transverse to the longitudinal direction; the second line partly overlapping the first line, and the fourth line laterally spaced apart from the second line
15 in the width direction to define a gap between the fourth and the second line with a gap width smaller than a minimum width of any of the deposited lines. Alternatively, for example, the first, second and fourth layers may be consecutively or simultaneously deposited as parallel lines that extend next to each other in a longitudinal direction, wherein the first, second, and
20 fourth layers are laterally spaced apart from each other in a width direction transverse to the longitudinal direction. The spacing between consecutive layers may for example be equal to create a regular pattern of indentations.

It will be appreciated that the ALD/ALE method can include depositing and/or etching multiple first, second, third and/or fourth layers
25 and/or gullies according to a thickness requirement in the Z direction transverse to the plane of the substrate.

The method for example includes stacking multiple first layers in the Z direction and/or stacking multiple second layers in the Z-direction. The stacking may be in the positive Z-direction, by depositing multiple
30 layers on top of each other, or in the negative Z-direction by etching multiple

gullies below each other. Edge deviations of the individual layers or gullies of the stack may result in slightly inclined edges of the nanostructure. Mutual offset or overlap of the inclined edges can be used for manufacturing a recess or protrusion. For example, a recess or protrusion may be formed
5 between a stack of first layers or gullies and a stack of second layers of gullies. When stacking multiple identical width layers or gullies in the Z direction, deviations in lateral alignment can be used for shaping the form of the side walls of the nanostructure. The form of the side walls of the nanostructure can also be shaped by stacking multiple lines of differing
10 widths.

Optionally, the ALD/ALE method comprises, after depositing the first, the second, the third and/or the fourth layer(s), selectively removing at least in part any one of the first, second, third or fourth layers. This way, cavities in the nanostructure can for example be formed. One or more of the
15 deposited layers may be a sacrificial layer, arranged for being removed. A layer may for instance be removed by etching. Material-selective etching may be used, for example in case deposited layers are of respectively different materials.

According to a further aspect, an atomic layer deposition and/or
20 etching method is provided, comprising drawing, using a fifth precursor fluid, a fifth line extending longitudinally and having, in lateral direction, a fifth linewidth; drawing, using a sixth precursor fluid, a sixth line extending longitudinally and having, in lateral direction, a sixth linewidth; the fifth and sixth lines extending longitudinally in different directions than the first
25 and second lines; wherein the fifth and sixth lines partly overlap one another laterally by a predetermined amount which is smaller than the fifth linewidth and the sixth linewidth; and/or wherein the fifth and sixth lines are laterally spaced apart from one another by a predetermined amount which is smaller than the fifth linewidth and the sixth linewidth, such that
30 a fourth protrusion is formed of which a largest width in lateral direction is

smaller than the fifth linewidth and the sixth linewidth, and/or a fourth recess is formed of which a largest width, in lateral direction, is smaller than the fifth linewidth and the sixth linewidth. The fifth and/or sixth line can e.g. extend orthogonal, at an angle, or otherwise in a different direction, relative to the first and/or second line.

Hence, according to the aspect, an atomic layer depositing and/or etching method is can be provided comprising depositing or etching, using a fifth precursor fluid, a fifth layer or gully as a fifth line extending longitudinally and having, in lateral direction, a fifth linewidth; depositing or etching, using a sixth precursor fluid, a sixth layer or gully as a sixth line extending longitudinally and having, in lateral direction, a sixth linewidth; the fifth and sixth lines extending longitudinally in different directions than the first and second lines. The fifth and/or sixth line can e.g. extend orthogonal, at an angle, or otherwise in a different direction, relative to the first and/or second line.

Hence, according to the aspect, an atomic layer deposition method can be provided comprising depositing, using a fifth precursor fluid, a fifth layer, e.g. on a substrate, as a fifth line extending longitudinally and having, in lateral direction, a fifth linewidth; depositing, using a sixth precursor fluid, a sixth layer, e.g. on a substrate, as a sixth line extending longitudinally and having, in lateral direction, a sixth linewidth; the fifth and sixth lines extending longitudinally in different directions than the first and second lines. The fifth and/or sixth line can e.g. extend orthogonal, at an angle, or otherwise in a different direction, relative to the first and/or second line. The fifth and sixth lines are deposited to partly overlap one another laterally by a predetermined amount such that, at the overlap, a fourth protrusion is formed of which a largest width, in lateral direction, is smaller than the fifth linewidth or the sixth linewidth; and/or wherein the fifth and sixth lines are deposited to, at least partly, be laterally spaced apart from one another by a predetermined amount such that, at the spacing, a fourth

recess is formed of which a largest width, in lateral direction, is smaller than the fifth linewidth or the sixth linewidth.

Hence, according to the aspect, an atomic layer etching method is can be provided comprising etching, using a fifth precursor fluid, a fifth
5 gully as a fifth line extending longitudinally and having, in lateral direction, a fifth linewidth; etching, using a sixth precursor fluid, a sixth gully as a sixth line extending longitudinally and having, in lateral direction, a sixth linewidth; the fifth and sixth lines extending longitudinally in different directions than the first and second lines. The fifth and/or sixth line can e.g.
10 extend orthogonal, at an angle, or otherwise in a different direction, relative to the first and/or second line. The fifth and sixth lines are etched to partly overlap one another laterally by a predetermined amount such that, at the overlap, a fourth recess is formed of which a largest width, in lateral direction, is smaller than the fifth linewidth or the sixth linewidth; and/or
15 wherein the fifth and sixth lines are deposited to, at least partly, be laterally spaced apart from one another by a predetermined amount such that, at the spacing, a fourth protrusion is formed of which a largest width, in lateral direction, is smaller than the fifth linewidth or the sixth linewidth.

It will be appreciated that the ALD/ALE method can include
20 depositing and/or etching multiple first, second, third, fourth, fifth and/or sixth layers and/or gullies according to a thickness requirement in the Z direction transverse to the plane of the substrate.

According to another aspect, a nanostructure is provided obtainable by an atomic layer deposition and/or etching method as described
25 herein.

In particular, a nanostructure is provided obtainable by atomic layer deposition and/or etching in which material layers are deposited and/or gullies are etched as material lines extending longitudinally and having, in lateral direction, a linewidth, wherein the nanostructure

comprises a material structure having a largest width, in lateral direction, being smaller than the linewidth of the lines.

Optionally, the nanostructure comprises a first line, drawn, using a first precursor fluid, extending longitudinally and having, in lateral
5 direction a first linewidth; and a second line, drawn, using a second precursor fluid, extending longitudinally and having, in lateral direction, a second linewidth, wherein the first line and the second line partly overlap one another laterally by a predetermined amount which is smaller than the first linewidth and the second linewidth; and/or wherein the first line and
10 the second line are, at least partly, laterally spaced apart from one another by a predetermined amount which is smaller than the first linewidth and the second linewidth, such that a first protrusion is formed of which a largest width in lateral direction is smaller than the first linewidth and the second linewidth, and/or a first recess is formed of which a largest width, in
15 lateral direction, is smaller than the first linewidth and the second linewidth.

Optionally, the drawing of the first line comprises depositing or etching, using the first precursor fluid, a first layer or gully as the first line; and the drawing of the second line comprises depositing or etching, using
20 the second precursor fluid, a second layer or gully as the second line,

Optionally, the nanostructure comprises a first layer, being deposited, using a first precursor fluid, as a first line extending longitudinally and having, in lateral direction a first linewidth; and a second layer, being deposited, using a second precursor fluid, as a second line
25 extending longitudinally and having, in lateral direction, a second linewidth. The first line and the second line partly overlap each other laterally by a predetermined amount such that, at the overlap, a first protrusion is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth; and/or the first layer and
30 the second layer are, at least partly, laterally spaced apart from one another

by a predetermined amount such that, at the spacing, a recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth.

Optionally, the nanostructure comprises a first gully, being etched,
5 using a first precursor fluid, as a first line extending longitudinally and having, in lateral direction a first linewidth; and a second gully, being etched, using a second precursor fluid, as a second line extending longitudinally and having, in lateral direction, a second linewidth. The first line and the second line partly overlap each other laterally by a
10 predetermined amount such that, at the overlap, a first recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth; and/or the first gully and the second gully are, at least partly, laterally spaced apart from one another by a predetermined amount such that, at the spacing, a protrusion is formed of
15 which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth.

According to an aspect, an atomic layer deposition and/or etching method is provided, for example in accordance with any method described herein. The method comprises depositing and/or etching a plurality of layers
20 and/or gullies as parallel lines that extend longitudinally and at least partly overlap each other in longitudinal direction, wherein the ends of the lines are shifted with respect to each other in longitudinal direction by a predetermined amount so as to create a material layer having a variable thickness in longitudinal direction. For example, the respective lines can
25 have different lengths and/or be shifted relative to each other. Hence, the superimposed lines may create a step-wise increasing and/or decreasing thickness of material layer in longitudinal direction. The material thickness may for example be a gradually increasing or decreasing.

It will be appreciated that the methods described herein may be
30 executed using an atomic layer deposition and/or atomic layer etching

system. An exemplary ALD/ALE system may comprise a substrate plate for holding a substrate, and an ALD/ALE head, e.g. a printer head, positioned opposite the substrate plate. The ALD/ALE head may comprise a number of openings, e.g. provided in a head plate, including one or more first exit

5 openings and one or more first supply channels connected to the one or more first exit openings for guiding a first precursor fluid onto the substrate through the one or more first exit openings. The one or more first exit openings may each be configured for providing the first precursor fluid as a spot when the ALD/ALE head is immobile relative to the substrate plate.

10 The one or more first exit openings can each have comparable dimensions in all directions in a plane parallel to the substrate plate. The one or more first exit openings can be circular.

The system may also comprise one or more second exit openings and one or more second supply channels connected to the one or more

15 second exit openings for guiding a second precursor fluid onto the substrate through the one or more second exit openings. The one or more second exit openings may each be configured for providing the second precursor fluid as a spot when the ALD/ALE head is immobile relative to the substrate plate. The one or more second exit openings can each have comparable dimensions

20 in all directions in a plane parallel to the substrate plate. The one or more second exit openings can be circular. The system may also comprise one or more third exit openings and one or more third supply channels connected to the one or more third exit openings for guiding an inert fluid onto the substrate through the one or more third exit openings.

25 The ALD/ALE head may be movable relative to the substrate plate, e.g. along an axis, in an X-Y plane defined by an X axis and an Y axis being perpendicular in relation to each other, and optionally along a Z axis being perpendicular to the X-Y plane. The system may comprise a positioning system configured for moving the ALD/ALE head and/or the substrate.

According to an aspect is provided an atomic layer deposition and or etching system, in particular a patterning system, comprising a substrate plate configured to support a substrate and an ALD/ALE head configured for drawing, e.g. depositing and/or etching, a first line and/or second line on
5 the substrate, the first line extending longitudinally and having, in lateral direction, a first linewidth, the second line extending longitudinally and having, in lateral direction, a second linewidth. The system comprises a positioning system for positioning the ALD/ALE head and the substrate relative to each other. The system comprises a controller, configured to
10 control the ALD/ALE head and the positioning system such that the first and second lines are drawn to partly overlap one another laterally by a predetermined amount smaller than the first linewidth and the second linewidth, and/or the first and second lines are drawn to, at least partly, be laterally spaced apart from one another by a predetermined amount smaller
15 than the first linewidth and the second linewidth, such that at the overlap, a first protrusion or recess is formed of which a largest width in lateral direction is smaller the first linewidth and the second line width and/or at the spacing a first recess and/or protrusion is formed of which a largest width in lateral direction is smaller the first linewidth and the second line
20 width.

Optionally, the ALD/ALE head is configured to deposit and/or etch a spot when immobile relative to the substrate, and the controller is configured to move the ALD/ALE head and the substrate relative to each other in a longitudinal direction of the line while depositing and/or etching
25 the first and/or second line.

Optionally, the controller is configured for controlling the width of the first protrusion or first recess by controlling a location on the substrate of the second line relative to first line.

Optionally, the controller is configured for individually controlling a location on the substrate of the first line and a location on the substrate of the second line.

The first and second line may be drawn using one and the same
5 ALD/ALE head. Alternatively, the first line may be drawn using a first ALD/ALE head and the second line may be drawn using a second ALD/ALE head. The first and second ALD/ALE heads may be identical.

It will be appreciated that any one or more of the aspects, features and options described herein can be combined. In particular, it will be
10 appreciated that any of the aspects, features, and options described in view of the atomic layer deposition method apply equally to the nanostructure and system, and vice versa.

BRIEF DESCRIPTION OF THE DRAWINGS

15 Embodiments of the present invention will now be described in detail with reference to the accompanying drawings in which:

Figures 1A and 1B shows schematic cross-sectional views of exemplary nanostructures formed by an atomic layer deposition and/or etching method;

20 Figure 2 shows a schematic cross-sectional view of an exemplary nanostructure formed by an atomic layer deposition and/or etching method;

Figure 3 shows a schematic cross-sectional view of an exemplary nanostructure by an atomic layer deposition and/or etching method;

25 Figures 4A-4C schematically show a formation of an exemplary nanostructure using an atomic layer deposition and/or etching method;

Figures 5A-5C schematically show a formation of an exemplary nanostructure using an atomic layer deposition and/or etching method

Figure 6 shows an image of an exemplary nanostructure;

Figure 7 shows an image of an exemplary nanostructure;

30 Figure 8 shows an image of an exemplary nanostructure;

Figure 9 shows an image of an exemplary nanostructure;
Figure 10 shows an image of an exemplary nanostructure; and
Figure 11 shows an example of a system.

5 DETAILED DESCRIPTION

Figures 1A and 1B show schematic cross-sectional views of
exemplary nanostructures obtained by an atomic layer deposition
(ALD/ALE) method, in which a substrate 50 is provided and wherein a first
layer 100 is deposited at a selective first area of the substrate 50. The first
10 layer 100 may for example be deposited using a deposition head, for example
as described in WO2020/245230A1.

In this example, the first layer 100 has an atomic-scale thickness,
measured in a Z-direction. In a plane of the substrate (X-Y plane), the first
layer 100 has a first width, here measured in the X-direction. In this
15 example, the first width is about 50 micrometer.

After depositing the first layer 100, a second layer 200 is deposited
at a selective second area of the substrate different from the first area where
the first layer 100 has been deposited. In this example, the second layer 200
has an atomic-scale thickness, measured in a Z-direction. In a plane of the
20 substrate (X-Y plane), the second layer 200 has a second width, here
measured in the X-direction. In this example, the second width is about 50
micrometer.

In this example, the layers are deposited using an atomic layer
deposition (ALD) and/or atomic layer etching (ALE) system 600, here
25 referred to as ALD/ALE system 600, as shown in figure 11. Here, the
ALD/ALE system 600 includes an ALD/ALE head 610 and a substrate plate
620 for supporting a substrate 50. The ALD/ALE system 600 includes a
positioning system 630 configured for moving the ALD/ALE head 610
relative to the substrate 50.

The ALD/ALE head 610 is configured for depositing the first and/or second layer by directing a stream 640 of first and/or second precursor fluid to the substrate 50. Alternatively, or additionally, The ALD/ALE head 610 can be configured for etching first and/or second gullies into the substrate by directing a stream 640 of first and/or second precursor fluid to the substrate 50.

Here, the ALD/ALE system 600 includes a controller, configured to control the ALD/ALE head 610 and the positioning system 630. Hence, the controller 650 can determine the position on the substrate where the ALD/ALE head deposits the first and/or second layer or etches the first and/or second gully.

In this example, the first layer 100 is deposited using the ALD/ALE head 610. The ALD/ALE head is configured for providing the first precursor to the substrate as a spot when the ALD/ALE head is immobile relative to the substrate 50. The spot size is substantially equal to the first width. Here, the spot size of deposition or etching on the substrate is about 50 micrometer across. Here, the spot has comparable dimensions in all directions on the substrate. The spot is approximately circular in this example. By moving the ALD/ALE head 610 relative to the substrate 50 while continuously providing the first precursor, a line is deposited or etched having the first width, here about 50 micrometers, as width, and a length (here in the Y-direction) that is determined by the movement of the ALD/ALE head relative to the substrate plate. Hence, the ALD/ALE system allows for patterning on the substrate by deposition and/or etching. In this example, the second layer 200 is deposited using the same or a different ALD/ALE head. The ALD/ALE head is configured for providing the second precursor to the substrate as a spot when the ALD/ALE head is immobile relative to the substrate. The spot size is substantially equal to the second width. Here, the spot size of deposition or etching on the substrate is about 50 micrometer across. Here, the spot has comparable dimensions in all

directions on the substrate. The spot is approximately circular in this example. By moving the ALD/ALE head relative to the substrate while continuously providing the second precursor, a line is deposited or etched having the second width, here about 50 micrometers, as width, and a length
5 (here in the Y-direction) that is determined by the movement of the ALD/ALE head relative to the substrate plate. Hence, the ALD/ALE system allows for patterning on the substrate by deposition and/or etching. A positioning system can be provided for positioning the ALD/ALE head relative to the substrate plate. The controller 650 is configured to position
10 the second line relative to the position of the first line, such that the second line overlaps the first line laterally by an amount such that, at the overlap, when depositing a first protrusion is formed of which a largest width in lateral direction, is smaller than the first linewidth and the second linewidth. Alternatively, or additionally, the controller 650 can be
15 configured to position the second line relative to the position of the first line, such that the first and second lines are spaced apart from each other by an amount such that, at the overlap, when depositing a first recess is formed of which a largest width in lateral direction, is smaller than the first linewidth and the second linewidth. The controller 650 may be configured to position
20 the first and/or second line as a straight line, a curved line, a continuous line with straight and/or curved line segments, etc..

In the example of figure 1A, the second layer 200 overlaps, in part, the first layer 100. Hence, an overlapping area 150 is formed between the first 100 and the second layer 200. As the first and the second layers 100,
25 200 only partly overlap, the first and the second layers 100, 200 also include a non-overlapping area where the layers do not overlap.

At the overlapping area 150, a thickness of the deposited material corresponds to the sum of the first layer thickness, and the second layer thickness. Hence, at the overlapping area 150, a protrusion 160 is formed.

Outside of the overlapping area 150 the thickness of the deposited material is smaller, e.g. either the thickness of the first or the second layer.

A width of the protrusion 160 in the X-direction, can be adapted for example by positioning the ALD/ALE head accordingly relative to the first
5 layer when depositing the second layer. The width of the protrusion, formed by the overlapping layers, is smaller than the respective widths of the first and second layers 100, 200.

In this example, the first layer 100 and the second layer 200 are deposited as a first line and second line respectively that extend in
10 longitudinal direction into the plane of Figure 1, here the Y-direction. The width of the layers, in the X-direction, is substantially fixed and depends on the characteristics of the deposition head 610. In particular, the width of the layers, in the X-direction, here depends on the spot size of deposition by the ALD/ALE head. A line structure may be deposited by moving the deposition
15 head relative to the substrate 50 in the longitudinal direction, while depositing material. Hence a length, in the Y-direction, of the first layer can be adapted, by the relative motion between the substrate 50 and the deposition head 610. Hence, in this example, the overlapping area 150 forms a ridge that extends in a longitudinal direction into the plane of figure 1. It
20 will be appreciated that the nanostructure can include multiple first and second layers stacked according to a thickness requirement in the Z direction.

In figure 1B, the first layer 100 and the second layer 100 are spaced apart from one another so as to form a gap 120 between the layers.
25 The gap 120 has a gap width that is less than a width of each of the first 100 and second layers 200. The gap width may be predetermined, e.g. using the ALD/ALE head. Hence, between the first and the second layers 100, 200 a recess 170 is formed.

In this example, a third layer 300 is also deposited, which third
30 layer 300, here, overlaps the first layer 100, as well as the second layer 200.

In this example, a recess is formed between the two overlapping areas, i.e. between the overlapping area of the third layer 300 with the first layer 100 and the overlapping area of the third 300 with the second layer 200. The width of the recess is equal to the gap width. It will be appreciated that the nanostructure can include multiple first, second and third layers stacked according to a thickness requirement in the Z direction.

Figure 2 shows a schematic cross-sectional view of another exemplary nanostructure obtained by an atomic layer deposition (ALD/ALE) method, similar to the nanostructure as shown in figure 1. In this example, the overlapping area 150 between the first layer 100 and the second layer 200 is larger compared to the overlapping area 150 of the example as shown in figure 1. Furthermore, a third layer 300 is deposited, which third layer 300 overlaps, in part, the second layer 200. In this example, the overlapping area 150 is equal to the overlapping area 250 of the third layer 300 with the second layer 200, for creating a regular pattern. Also, in this example, the third layer 300 overlaps in part the first layer 100. Hence, at an overlap of the overlapping areas 150 and 250, the first, second and third layers are stacked in the Z-direction.

Further, a fourth layer 400 is deposited, which fourth layer 400 similarly overlaps, in part, the third layer 300 with an overlapping area 350, here, equal to the previously described overlapping areas 150 and 250, and also partly overlapping the second layer 200. It will be appreciated that the nanostructure could be extended by adding more layers. It will be appreciated that the nanostructure can include multiple first, second and third layers stacked according to a thickness requirement in the Z direction.

Hence, an array of overlapping layers is deposited which form a nanostructure having substantially flat top surface, and a, e.g. regularly, stepped edge.

Figure 3 shows an exemplary nanostructure wherein multiple first layers 100, and multiple second layers 200 are stacked in the Z direction,

forming respectively a first stack 110 and a second stack 210. The second stack 210 of stacked second layers 200 partly overlaps the first stack 110 of stacked first layers 100 in this example. Edge deviations of the individual layers of each stack may result in slightly inclined edges of the stacks.

5 Deviations in lateral alignment of the layers of a stack of layers, can be used for shaping the form of the side walls of the nanostructure. The individual layers of a stack may for example be laterally misaligned with respect to each other. Various nanostructures can be created by partly overlapping stacks of layers with each other.

10 In the example shown in figure 3, the first stack 110 includes eight first layers 100, and the second stack 210 includes eight identical width second layers 200, wherein the second stack 210 partly overlap the first stack 110. A recess is formed between the two stacks, having a varying width with respect to the Z direction.

15 Figures 4A-4C show an exemplary ALD/ALE method, in which, in a first stage, shown in figure 4A, a plurality of, here four, layers are consecutively and overlappingly deposited as lines that extend longitudinally in the Y-direction. Here, the lines extend parallel and into the plane of the figure. Each line is deposited partly on top of a previously
20 deposited line. Hence, each line overlaps in part an adjacent line in lateral direction, here the X-direction, wherein at the overlapping areas an array of, in this example three, parallel ridges is formed, each ridge having a width that is much smaller than the linewidth of the deposited lines.

 In a second stage of the exemplary method, shown in figure 4B, a
25 further plurality of, here four, layers are deposited, also as lines that extend longitudinally in the Y-direction, on top of the layers that have been deposited in the first stage. More particular, in this example, the first stage and the second stage of the method are identical, but in the second stage, the lines have shifted laterally, in the X-direction, by a predetermined
30 amount, such that an array of parallel ridges is created in between the

ridges that had been formed in the first stage of the method. Hence, in this example two ridges are created within the width of a single deposited line. More in general, it will be appreciated that with this method multiple (e.g. 2, 3, 4, 5, 6, 8, 10, 20 or more) nanostructures, e.g. multiple ridges or other
5 structures, can be manufactured in a space (X and/or Y) smaller than a minimum linewidth of the ALD/ALE head.

In this example, a third and a fourth stage of the exemplary method, substantially repeat the first and the second stage respectively, wherein the longitudinal orientation of the deposited lines is changed, in
10 this example rotated 90 degrees about the Z-axis. Hence, in this example, in the first and the second stage, the lines are deposited as lines extending longitudinally in the Y-direction, whereas in the third and fourth stage the lines are deposited as lines extending longitudinally in the X-direction. It will be appreciated that, instead of transverse, other orientations of the
15 lines in the third and fourth stage are also possible.

Figure 4C shows a schematic height-map of the superimposed lines. A nanostructure is created having a varying thickness profile. In this example, a lattice, in the X-Y plane, of regularly distributed free-standing nanopillars is formed, wherein a width dimension, in the X-Y plane, of each
20 nanopillar is much smaller than the width dimension of the individually deposited lines. The nanopillars are, in this example, formed by a stack of six layers. The nanopillars are particularly formed at a crossing of ridges, wherein each ridge has a smaller width than any one of the deposited lines. It will be clear that in the example of Figures 4A-4C the steps of the method
25 can be repeated, e.g. identically, for increasing a thickness of the structure in the Z direction.

Figure 5A shows a schematic cross-sectional view of another exemplary nanostructure obtained by an atomic layer deposition and/or etching method. In this example, a blanket layer 100 is deposited onto the
30 substrate. A first gully 200 and a second gully 300 are here etched as a first

line and a second line respectively, wherein a gap 120 is provided between the first gully and the second gully. The etching of the first gully 200 and the second gully 300, here, selectively removes material of the blanket layer 100. At the gap 120 between the first gully 200 and the second gully 300, a freestanding protrusion is formed, here at a central portion of the substrate 50. Also, here, two additional freestanding protrusions are formed, at opposite lateral ends of the first line 100.

Figure 5B shows a schematic cross-sectional view of another exemplary nanostructure obtained by an atomic layer deposition and/or etching method. Here, a first layer 100 is deposited as a first line, and a second layer 200 is deposited as a second line, wherein a spacing is provided between the first layer 100 and the second layer 200 to define a gap 120 therebetween. Here, a third gully 300 and a fourth gully 400 are etched, respectively as a third line and fourth line. The etching of the third line 300 and the fourth line 400 removes material of respectively the first layer 100 and the second layer 200, so as to obtain two freestanding protrusions with, here, equal widths 150, separated by the gap 120. The two free standing protrusions have a width smaller than the line widths of the first, second third and fourth lines. Also, the gap width 120 is smaller than the line widths of the first, second third and fourth lines. Here, the first, second, third and fourth lines have equal line widths.

Figure 5C shows a schematic cross-sectional view of another exemplary nanostructure obtained by an atomic layer deposition and/or etching method. Here, a first layer 100 and a second layer 200 are respectively deposited as a relatively wide first line and second line on top of each other, i.e. stacked. A third gully 300 and a fourth gully 400 are here overlappingly etched as a third line and a fourth line respectively. At the overlap 150, here at a center of the substrate 50, a recess is formed, having a width that is smaller than the third line width and fourth line width.

Figure 6 shows an imaging ellipsometry map of an exemplary nanostructure formed by an array of layers being deposited as parallel non-overlapping lines, wherein between each of the lines, a recess is formed that is much smaller than a linewidth of the individually deposited lines.

5 Further, in this example, a material-gradient is applied in the direction in which the deposited lines extend. Here, the length of the deposited lines in the Y-direction gradually decreases, resulting in gradually changing thickness of the material. Hence, in this example, the nanostructure is given a sloping face. It will be appreciated that the lines of gradually decreasing
10 length may be deposited in any desired order for obtaining the gradually changing thickness of the material.

Figure 7 shows an imaging ellipsometry map of an exemplary nanostructure formed by an array of partly overlapping layers. The deposited layers are deposited as partly overlapping parallel lines,
15 extending in a single direction. At the left and right edges, a stepped increase in the thickness of the deposited structure can be seen, with a plateau of constant thickness in X-direction in between. In this example, from the left and right edges, the plateau is reached in eight thickness steps. In this example the width of these eight thickness steps together
20 corresponds to the linewidth of a single deposited line. Also in Figure 7 the deposited structure displays a gradually changing thickness of the material in the Y-direction. Further, dark colored lines in the Y-direction indicate where a gap is present between adjacent lines, forming a recess in the deposited structure.

25 Figure 8 shows a heightmap image of an exemplary nanostructure formed by an array of partly overlapping layers. The deposited lines extend in two transverse directions, similar to as explained in conjunction to figures 4A-4C, creating a raster-like structure of protrusions and indentations. In this example, at the left, right, top and bottom edges, a stepped increase in
30 the thickness of the deposited structure can be seen, with a plateau of

constant thickness in between. In this example, from the left, right, top and bottom edges, the plateau is reached in eight thickness steps. In this example the width of these eight thickness steps together corresponds to the linewidth of a single deposited line. Further, light colored lines in the X-
5 direction and Y-direction indicate where a ridge is at the plateau, formed by specific overlap of the deposited lines.

Figure 9 shows an imaging ellipsometry map of a close-up nanostructure, having a raster-like pattern of protrusions (light colored lines) and indentations (dark colored lines) similar to the nanostructure as
10 shown in figure 8.

Figure 10 shows another imaging ellipsometry map of a close-up of a nanostructure, particular of a gap area between consecutively deposited atomic lines.

Herein, the invention is described with reference to specific
15 examples of embodiments of the invention. It will, however, be evident that various modifications and changes may be made therein, without departing from the essence of the invention. For the purpose of clarity and a concise description features are described herein as part of the same or separate embodiments, however, alternative embodiments having combinations of all
20 or some of the features described in these separate embodiments are also envisaged.

Although in the examples, layers are deposited as straight lines, it will be appreciated that alternatively, or additionally, curved lines can be deposited. It will also be possible that lines may deposited which overlap
25 and/or are spaced apart along a portion of their length.

However, other modifications, variations, and alternatives are also possible. The specifications, drawings and examples are, accordingly, to be regarded in an illustrative sense rather than in a restrictive sense.

For the purpose of clarity and a concise description features are
30 described herein as part of the same or separate embodiments, however, it

will be appreciated that the scope of the invention may include embodiments having combinations of all or some of the features described.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word 'comprising' does not
5 exclude the presence of other features or steps than those listed in a claim. Furthermore, the words 'a' and 'an' shall not be construed as limited to 'only one', but instead are used to mean 'at least one', and do not exclude a plurality. The mere fact that certain measures are recited in mutually
different claims does not indicate that a combination of these measures
10 cannot be used to an advantage.

Claims

1. Atomic layer deposition and/or etching method comprising
drawing, using a first precursor fluid, on a substrate a first line
extending longitudinally and having, in lateral direction, a first linewidth;
drawing, using a second precursor fluid, on the substrate a second
5 line extending longitudinally and having, in lateral direction, a second
linewidth;
wherein the first and second lines partly overlap one another
laterally by a predetermined amount which is smaller than the first
linewidth and the second linewidth; and/or
10 wherein the first and second lines are laterally spaced apart from
one another by a predetermined amount which is smaller than the first
linewidth and the second linewidth,
such that a first protrusion is formed of which a largest width in
lateral direction is smaller than the first linewidth and the second
15 linewidth, and/or a first recess is formed of which a largest width, in lateral
direction, is smaller than the first linewidth and the second linewidth.
2. Method of claim 1, wherein the drawing of the first line
comprises:
20 depositing, using the first precursor fluid, a first layer as the first
line, or etching, using the first precursor fluid, a first gully as the first line;
and wherein the drawing of the second line comprises:
depositing, using the second precursor fluid, a second layer as the
second line, or etching, using the second precursor fluid, a second gully as
25 the second line.
3. Method of claim 1 or 2, wherein the largest width of the first
protrusion or first recess is at most 50% of the first or second linewidth,

preferably at most 25%, more preferably at most 10%, more preferably at most 5%.

4. Method of any preceding claim, wherein the first line and the
5 second line are drawn with an ALD/ALE head, wherein the ALD/ALE head is configured to deposit and/or etch a spot when immobile relative to the substrate, and wherein the first and/or second line is drawn by moving the ALD/ALE head and the substrate relative to each other in a longitudinal direction of the line.
10
5. Method of any preceding claim, wherein the width of the first protrusion or first recess is controlled by controlling a location on the substrate of the second line relative to first line.
- 15 6. Method of any preceding claim, including individually controlling a location on the substrate of the first line and a location on the substrate of the second line.
7. Method of any preceding claim, wherein the first line and the
20 second line extend parallel to one another for forming an elongate first protrusion and/or first recess.
8. Method of any preceding claim, wherein the first line and the second line have a constant and optionally equal linewidth.
- 25 9. Method of any preceding claim, wherein the first line comprises a first straight line section and/or the second line comprises a second straight line section.

10. Method of any of claims 2-9, wherein the first precursor fluid is a first material, and the second precursor fluid is a second material different from the first material.
- 5 11. Method of any preceding claim, comprising drawing, using a third precursor fluid, a third line extending longitudinally and having, in lateral direction, a third linewidth, wherein the third line partly overlaps the second line laterally by a predetermined amount such that a second protrusion and/or second recess is formed of which a largest width is smaller
10 than the first, second and third linewidth.
12. Method of claim 11, wherein the drawing of the third line comprises depositing, using the third precursor fluid, a third layer as the third line, or etching, using the third precursor fluid, a third gully as the
15 third line.
13. Method of claim 12, wherein the width of the second protrusion and/or second recess is equal to the width of the first protrusion and/or first recess.
20
14. Method of claim 12 or 13, wherein a lateral distance between the first protrusion and/or recess and the second protrusion and/or recess is smaller than the first, second or third linewidth.
- 25 15. Method of claim 12, 13 or 14, wherein the third line is, at least partly, laterally spaced apart from the first line by a predetermined amount.
16. Method of any preceding claim, comprising drawing, using a fourth precursor fluid, a fourth line extending longitudinally and having, in
30 lateral direction, a fourth linewidth, wherein the fourth line is laterally

spaced apart from the second line by a predetermined amount such that a third recess and/or third protrusion is formed of which a largest width is smaller than the first, second and fourth linewidth.

5 17. Method of any of claims 1-16, wherein the drawing of the fourth line comprises depositing, using the fourth precursor fluid, a fourth layer as the fourth line, or etching, using the fourth precursor fluid, a fourth gully as the fourth line.

10 18. Method of any preceding claim, comprising, after depositing the first, the second, the third and/or the fourth layer, selectively removing, at least in part, any one of the first, second, third or fourth layers.

19. Method of any preceding claim, comprising
15 drawing, using a fifth precursor fluid, a fifth line extending longitudinally and having, in lateral direction, a fifth linewidth;
drawing, using a sixth precursor fluid, a sixth line extending longitudinally and having, in lateral direction, a sixth linewidth;
the fifth and sixth lines extending longitudinally in different
20 directions than the first and second lines;
wherein the fifth and sixth lines partly overlap one another laterally by a predetermined amount which is smaller than the fifth linewidth and the sixth linewidth; and/or
wherein the fifth and sixth lines are laterally spaced apart from
25 one another by a predetermined amount which is smaller than the fifth linewidth and the sixth linewidth,
such that a fourth protrusion is formed of which a largest width in lateral direction is smaller than the fifth linewidth and the sixth linewidth, and/or a fourth recess is formed of which a largest width, in lateral
30 direction, is smaller than the fifth linewidth and the sixth linewidth.

20. Method of claim, wherein the drawing of the fifth line comprises:
depositing, using the fifth precursor fluid, the fifth layer as the
fifth line, or etching, using the fifth precursor fluid, a fifth gully as the fifth
5 line;
and wherein the drawing of the sixth line comprises depositing,
using the sixth precursor fluid, a sixth layer as the sixth line, or etching,
using the sixth precursor fluid, a sixth gully as the sixth line.
- 10 21. Nanostructure obtainable by atomic layer deposition and/or
atomic layer etching in which material layers are deposited and/or gullies
are etched as lines extending longitudinally and having, in lateral direction,
a line width, the nanostructure including a material structure having a
largest width, in lateral direction, which is smaller than the line width of
15 the lines.
22. Nanostructure according to claim 21, comprising
a first line, drawn, using a first precursor fluid, extending
longitudinally and having, in lateral direction a first linewidth; and
20 a second line, drawn, using a second precursor fluid, extending
longitudinally and having, in lateral direction, a second linewidth,
wherein the first line and the second line partly overlap one
another laterally by a predetermined amount which is smaller than the first
linewidth and the second linewidth; and/or
25 wherein the first line and the second line are, at least partly,
laterally spaced apart from one another by a predetermined amount which
is smaller than the first linewidth and the second linewidth,
such that a first protrusion is formed of which a largest width in
lateral direction is smaller than the first linewidth and the second

linewidth, and/or a first recess is formed of which a largest width, in lateral direction, is smaller than the first linewidth and the second linewidth.

23. Nanostructure of claim 22, wherein the drawing of the first line
5 comprises:
depositing, using the first precursor fluid, a first layer as the first line, or etching, using the first precursor fluid, a first gully as the first line;
and wherein the drawing of the second line comprises:
depositing, using the second precursor fluid, a second layer as the
10 second line, or etching, using the second precursor fluid, a second gully as the second line.

24. Atomic layer deposition and/or etching system comprising:
a substrate plate configured to support a substrate;
15 an ALD/ALE head configured for drawing a first line and/or second line on the substrate, the first line extending longitudinally and having, in lateral direction, a first linewidth, the second line extending longitudinally and having, in lateral direction, a second linewidth;
a positioning system for positioning the ALD/ALE head and the
20 substrate relative to each other;
a controller, configured to control the ALD/ALE head and the positioning system such that:
the first and second lines partly overlap one another laterally by a predetermined amount; and/or
25 the first and second lines are, at least partly, laterally spaced apart from one another by a predetermined amount,
such that a first protrusion is formed of which a largest width in lateral direction, is smaller than the first linewidth and the second linewidth, and/or a first recess is formed of which a largest width, in lateral
30 direction, is smaller than the first linewidth and the second linewidth.

25. System of claim 24, wherein the ALD/ALE head is configured to deposit and/or etch a spot when immobile relative to the substrate, and the controller is configured to move the ALD head and the substrate relative to
5 each other in a longitudinal direction of the line while drawing the first and/or second line.

26. System of claim 24 or 25, wherein the controller is configured for controlling the width of the first protrusion or first recess by controlling a
10 location on the substrate of the second line relative to first line.

27. System of claim 24, 25 or 26, wherein the controller is configured for individually controlling a location on the substrate of the first line and a
15 location on the substrate of the second line.

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