A METHOD OF FABRICATING PERIODIC NANO-STRUCTURE ARRAYS WITH DIFFERENT FEATURE SIZES

Field of the Invention

The invention relates to the fabrication of nano-scale devices on a substrate. Specifically the invention relates to a method of fabricating arrays of different size features leading to the formation of devices of different sizes on the same substrate.

Background

The fabrication of nano-scale optical devices requires the formation of arrays of individual features representing light sources or photo detectors within such devices. It follows that the density of such features will determine the sensitivity of the device and so requiring the mass scale fabrication of said features in order to improve performance .

However, to increase flexibility and broaden the application of use, such devices require the fabrication of different features within the same device. For instance, to create multi-wavelength light sources and wide spectral responsivity photodetectors. Customizing the fabrication process to include regions of features of varying size is a time consuming and relatively expensive process compared to the fabrication of a device having uniform features.

Alternatively, substrates having uniform features but varying in size between said substrates may be combined to form an overall device. However, this may affect the density of the overall device and so lead to a loss of resolution.

It would therefore be useful to fabricate a device having features that vary in size and shape but at a lesser cost than the customized fabrication processes of the prior art.

Summary of the Invention

It is therefore an object of the present invention to provide a method of fabricating an array of features on a substrate using a method that is less expensive than methods of the prior art whilst maintaining resolution of the device.

Therefore in a first aspect the invention provides a method of fabricating a two dimensional nano-structure array of features comprising the steps of providing a substrate; forming an intermediate layer on said substrate, said intermediate layer having at least two selectively located regions of different uniform thickness; placing at least one layer of elements over said intermediate layer, said elements placed in a close-packed arrangement forming an array of voids between said elements; etching the intermediate layer through said voids, and so forming the array of features in said intermediate layer corresponding to the voids.

Thus, the invention includes two critical steps. The formation of an intermediate layer having regions of different uniform thickness and subsequently placing at least one layer of elements forming a mask with periodic voids through which the array of features may be etched. The variation in thickness of the intermediate layer provides a selective placement of features which are uniform within the region of uniform thickness but vary from other regions having different thickness. The simplicity of the formation of these layers reduces the cost of the fabrication of the device by reducing the steps and maintaining the required steps as known fabricating processes.

In a preferred embodiment, the etching step may continue until the features extend from the upper surface of the intermediate layer to the substrate. It follows that regions of different thickness, assuming a uniform rate of etching across the element layer, will produce features of different sizes depending upon which region the features are located. That is to say, subject to the type of etching process involved, not only will the features vary in depth but may also vary in plan dimension such as width and breadth. For a circular shape, the feature may vary in diameter on the basis that the etching process also etches the feature laterally as it etches into the intermediate layer.

In a preferred embodiment, on completion of etching of the features, the elemental layer may be removed so as to complete the fabrication process.

This may be performed by any number of known processes, for example, wet and dry etching.

The shape of the individual elements forming the elemental layer may vary subject to the requirement that the shapes form a close-packed arrangement. In a preferred embodiment, the elements may be spherical and may form a hexagonal close-packed arrangement. In this arrangement, the voids may be triangular in shape, from a plan view, and consequently the "windows" through which the etching process etches the intermediate layer may be triangular. In an alternative arrangement, the elements may be ovaloid.

In a preferred embodiment, the elements within the layer may be of uniform size and shape. Alternatively the elements may vary in size and/or shape subject to the condition that they must form a close-packed arrangement.

In a preferred embodiment, the intermediate layer may have only two regions of different thickness. Alternatively, the intermediate layer may have a plurality of regions having different thickness, which may correspond to selective placement of features of different size.

In a preferred embodiment a second layer of element may be placed. This second layer of elements may be arranged to maintain a close packed hexagonal arrangement creating a lower density of voids, said voids being hexagonal in shape.

In a second aspect, the invention provides a two dimensional nano-structure array of features, fabricated according to a method comprising the steps of providing a substrate; forming an intermediate layer on said substrate, said intermediate layer having at least two selectively located regions of different uniform thickness; placing at least one layer of elements over said intermediate layer, said elements placed in a close-packed arrangement forming an array of voids between said elements; etching the intermediate layer through said voids, and so forming the array of features in said intermediate layer corresponding to the voids.

Brief Description of Drawings

It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible, and consequently the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

Fig. 1 is a cross-sectional schematic drawing showing an intermediate layer with two different thicknesses formed on a selected substrate, according to an embodiment of the present invention.

Fig. 2a is a cross-sectional schematic drawing showing a monolayered latex spheres forming a hexagonal-close-packed arrangement on the surface of the intermediate layer according to an embodiment of the present invention.

Fig. 2b is a plan view of a schematic drawing showing a monolayered latex spheres forming a hexagonal-close-packed arranged on the surface of the intermediate layer;

Fig. 3 is a cross-sectional schematic drawing showing structures formed after dry etching of the sample shown in Fig 2;

Fig. 4a is a top view of schematic drawing showing bilayered latex spheres forming a hexagonal-close-packed arranged on the surface of the intermediate layer;

Fig. 4b is a top view of a schematic drawing showing the structures after dry etching of the sample shown in Fig 4a;

Fig. 5 is a cross-sectional schematic drawing showing the nano-structure arrays with different feature sizes after removing the latex spheres;

Fig. 6 is a cross-sectional view of schematic drawing showing nano-structure arrays with different feature sizes deposited selectively through the patterns formed by this method;

Fig. 7 is an experimental result showing the SEM image of SiO_2 patterns formed by dry etching through a monolayer of sphere assembled as etching mask.

Fig. 8 is an experimental result showing the SEM image of SiO_2 patterns formed by dry etching through a bilayer sphere assembled as etching mask.

Fig. 9a and 9b are experimental results showing the selective growth of $In_{0.25}Ga_{0.75}As/GaAs$ quantum bars with different feature size through the SiO_2 pattern arrays formed according to the present invention.

Description of Preferred Embodiment

The present invention seeks to provide a simple and fast method for fabricating multi-sized patterned arrays and nano-meter scale structured arrays having different sizes deposited through the patterned arrays. These different sized arrays may be used in fabricating semiconductor light sources having different emitting wavelengths, or fabricating semiconductor photodetectors having different response wavelength, or fabricating 2D photonic crystal materials having different properties

In the present invention, a method is provided for nano-meter scaled pattern formation on a selected substrate. This process opens a route for nano-meter

scale surface patterning by utilizing spontaneous self-assembly of latex spheres at length scales difficult to obtain by standard semiconductor lithography techniques. This method also provides an easy, inexpensive, and fast means for pattern transfer over large areas.

The method is based on the principle that elements, for instance spherical particles, serve as etching mask, which are also slowly etched away during dry etching resulting in the reduction of diameter of the elements. This effect results in etched walls of nano-windows of the intermediate layer being not vertical. Hence, the nano-windows formed on the intermediate layer will be enlarged at the regions where the layer is thinner compared to nano-windows on the thicker layer. The structures formed by this method can be used not only directly as functional materials, such as chemical sensors, photonic bandgap materials, but also serve as a mask to deposit selectively nanoparticles, for example, for growing InGaAs, GaAs, InGaAlP quantum dot arrays with different optoelectronic properties on a GaAs substrate by selective MOCVD through SiO_2 nano-patterned arrays.

Referring to Fig 1, an intermediate layer **20** with regions of different thickness **21** and **22** is formed on a selected substrate **10**. Then spherical particles **30** are placed on the surface of the intermediate layer **20** to form close-packed arrays by any suitable method in monolayer (as shown in Fig 2) or bilayer (as shown in Fig 4a). In this embodiment, said substrate material **10** is GaAs, but any other materials having a flat surface can be used such as Si,

SiO_2, GaAs, InP, Glass, metals etc. or combination of them, can be used depending on its application.

In this embodiment, a 100 nm SiO_2 is first deposited on the GaAs substrate by PECVD to form said intermediate layer **20**. Photolithography is used to form patterns and then the exposed areas are dry etched partially down to 50 nm to form the areas **21**. The other areas where the thickness of 100 nm is not etched are areas **22**. Normally, any other materials with a flat hydrophilic surface or having a flat hydrophilic surface formed after the etching process may be used as said intermediate layer **20**, depending on its application. The flat surface allows hexagonal close packing of spheres to be formed on the surface by a suitable method said methods being clearly within the knowledge of the skilled person. The thickness of the thickest areas depends on the dry etching properties of the intermediate layer **20** and the spherical particles **30** used. Thicker layer **20** can be used if the dry etching rate for the spherical particles **30** is less than that for the intermediate layer **20**. Otherwise, a thinner layer should be used.

Said spherical particles preferred to be polystyrene (PS) polymer, but not limited to this material. Any other organic or inorganic spherical material may be suitable including SiO_2, if the particles have good adherence with said intermediate layer which means that the spherical particles assemble in a regular and stable manner. In addition, the choice of the sphere material and the intermediate layer also depends on the applications of the nano-structures

fabricated through this method, e.g. there is at least one means available to remove the spherical material left on the intermediate layer surface after the dry etching process if the removing process is necessary for application of the nano-structures. The diameter of the particles may be in the range of 20 nm to 2000 nm, which are commercially available. In this preferred embodiment, the average diameter of the PS spherical particles is 300 nm with deviation of 5% available commercially. The solution containing 5 wt% PS spherical particles is diluted with DI water in the ratio of 1:5. Then the diluted solution containing the PS particles is spin-coated onto the said SiO_2 intermediate layer (referred as **20**) containing the areas **21** and **22**, which have different thicknesses, with a spin speed of 800 rpm for 3 min. A hexagonally close packing of sphere **30** is assembled in a monolayer as shown in Fig. 2a and 2b. There are many methods for forming close-packed monolayer spherical particles on a substrate, they can be found in patents and other sources such as Deckman and Dunsmuir, U.S. Pat. No. 4,407,695), Nagayama; Kuniaki et al, U.S. Pat. No. 5437892 and 5505996 the contents of which are incorporated herein by reference.

Referring to Fig 3, the sample is then loaded into an ICP chamber for dry etching to open nano-windows (**51** and **52** as shown in Fig. 5) in the intermediate layer SiO_2 **20** through the spaces **33** of the close-packed sphere assembly **30**, which serves as a etching mask. CF_4 with flow rate of 20 sccm, O_2 with flow rate of 5sccm, Ar with flow rate of 20 sccm, are used as etchants in

this process. Chamber pressure is kept at 5 Torr, RF power set at 500 W and ICP power of 200 W. Etching time is set as 5 min.

Dry etching for the SiO_2 **20** occurs through the spaces **33** between the spheres **30**. At the beginning of the etching, only the triangle shaped portions **33** (viewing from top of the sample as shown in Fig. 2) where the base length of the triangles is defined as ***a*** (as shown in Fig 3) can be etched due to the existence of the spheres **30**. However, the spheres **30** are also etched at these etching conditions. That means the diameter of the spheres **30** is gradually reduced to that of the small one **32** during the etching process. So the etched cross section profile of the SiO_2 has sloping sides as shown in Fig. 3 and the bottom of the etched pit ***a*** (equal to the base length of the triangles **33** viewed from top) maintains the same width until it reaches the GaAs substrate. But the surface portion ***b*** (as shown in Fig. 3) is enlarged by etching due to the reduction of diameter of the spheres **30**. When the base ***a'*** (as seen in Fig.3 at the thinner SiO_2 area **21**) reaches the GaAs substrate, the base ***a*** (at the thicker SiO_2 area **22**) is still within the intermediate layer. The bottom of the etched pit ***a'*** is enlarged further if the dry etching is carried out further, and the ***a'*** will enlarged to ***d*** at the thinner SiO_2 area **21** by the time ***a*** reaches the substrate **10** at the thicker SiO_2 area **22**. Then two kinds of window arrays **51** and **52** (see Fig 5) with different bottom sizes, ***d*** of the triangular shape at the thinner SiO_2 area **21** and ***a*** of the triangular shape at the thicker SiO_2 area **22**, are formed. Bottom size of both kinds of the opened windows **51** and **52** at areas **21** and areas **22** can be further enlarged by continuing the dry etching process.

Fig. 7 shows an experimental result of the nanopatterns (the nano-windows have not been opened) fabricated through the monolayered sphere assembly of the PS latex spheres on the surface of SiO_2.

Similarly, a bilayer close-packed assembly of the spheres can also be used as an etching mask to fabricate multi-sized pattern arrays. However, the period and features of the window arrays (region between the spheres) are different to that formed through monolayered spheres as shown in Fig. 4. Fig. 4a displays a top view of schematic drawing showing the sample before the dry etching process with a bilayer assembly of the latex spheres on the surface of the intermediate layer. Fig. 4b displays a top view of schematic drawing showing the structures after dry etching of the sample shown in Fig 4a;

Fig. 8 shows an experimental result of the nanopatterns (the nano-windows have not been opened) fabricated through the bilayer assembly of the PS latex spheres on the surface of SiO_2.

It follows that, patterned arrays with multi-sizes can be obtained according to this invention by using an intermediate layer with areas having different thicknesses.

Referring to Fig. 5, after the dry etching, the PS spheres are then removed by toluene treated in with ultrasonic for 5 min to form a nanopattern array **51**

with a larger feature size (bottom portion of the nano-windows) located at the thinner area **21** and **52** with a smaller feature size located at the thicker area **22**, though the top portion of the nano-window is almost the same.

Referring to Fig. 6, an $In_{0.25}Ga_{0.75}As$ layer sandwiched between GaAs layers is then grown on the GaAs substrate by selective MOCVD at 600^0 C through the SiO_2 patterned arrays. Two kinds of nano-sized bar-like structures **61** and **62** are formed due to the different sizes of the SiO_2 windows.

Fig. 9a and 9b are experimental results showing the selective growth of $In_{0.25}Ga_{0.75}As$/GaAs nano bars with different feature sizes growing through the SiO_2 pattern arrays formed by this invention. The average dimension of the larger nano bars with multi-facets are, ~150nm long, ~100nm wide and ~80 nm high, while the small ones are ~100nm long, ~30 nm wide and ~30nm high.

The claims defining the invention are as follows :

1. A method of fabricating a two dimensional nano-structure array of features comprising the steps of :

providing a substrate;

forming an intermediate layer on said substrate, said intermediate layer having at least two selectively located regions of different uniform thickness;

placing at least one layer of elements over said intermediate layer, said elements placed in a close-packed arrangement forming an array of voids between said elements;

etching the intermediate layer through said voids, and so forming the array of features in said intermediate layer corresponding to the voids.

2. The method according to claim 1, further including the step of progressively etching the intermediate layer until said array of features extends from an upper surface of the intermediate layer to the substrate, such that the features in each of the at least two regions of different thickness are of a different size.

3. The method according to claim 2, wherein the different size includes differences in any one or a combination of the dimensions of depth, breadth, width and diameter of the features.

4. The method according to any one of the preceding claims, further including the step of removing the layer of elements after the etching step.

5. The method according to any one of the preceding claims, wherein the elements are spherical.

6. The method according to claim 5, wherein the close-packed arrangement is a close-packed hexagonal arrangement.

7. The method according to any one of the preceding claims, further including the step of placing a further layer of close-packed elements before the etching step.

8. The method according to claim 7, wherein the combination of the two layers of elements form hexagonal voids.

9. The method according to any one of the preceding claims, wherein the elements are of uniform size and shape.

10. The method according to any one of claims 1 to 8, wherein the elements vary in size and/or shape.

11. The method according to any one of the preceding claims, wherein the intermediate layer includes different materials or layers.

12. The method according to claim 5, wherein the region having the greatest thickness has a thickness less than half the diameter of said spherical elements if a dry etching rate of said elements is greater than the dry etching rate of the intermediate layer.

13. A two dimensional nano-structure array of features fabricated according to a method of claims 1 to 12.