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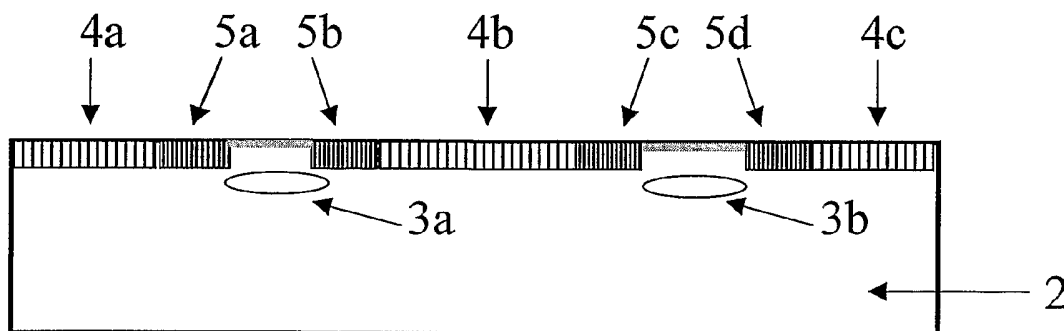


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(57) Abstract: A method of producing a patterned, porous semiconductor is disclosed. The method includes the steps of irradiating a semiconductor substrate (2) with at least one focused ion beam (1a, 1b), and scanning said at least one ion beam (1a, 1b) across a surface of said semiconductor substrate (2) in a predetermined manner to irradiate selected regions (3a, 3b) of said semiconductor substrate for predetermined times and with predetermined ion beam intensities. Then, the semiconductor substrate (2) is etched to form pores, wherein the rate of formation of said pores in said irradiated selected regions (3a, 3b) of said semiconductor substrate differs from the rate of formation of said pores in un-irradiated regions (4a, 4b, 4c) of said semiconductor substrate (2). Controlling the location and rate of formation of pores in the semiconductor substrate (2) enables the control of the wavelength and intensity of light emitted from the semiconductor substrate.

CONTROLLED PARTICLE SIZE AND WAVELENGTH EMISSION FROM POROUS SEMICONDUCTORS USING FOCUSED ION BEAMS

Field of the Invention

The present invention relates generally to semiconductors and, in particular, to light emission from porous semiconductors.

Background

A porous semiconductor results from etching a semiconductor wafer to produce a hollow, columnar structure. The column, or "pore", size can vary from a few nanometres to a few micrometres. Electrochemical etching (anodizing) of the semiconductor wafer is typically performed by placing the semiconductor wafer in a solution of hydrofluoric acid and ethanol, and then passing a current through the wafer. In those regions of the semiconductor wafer in which the current flows to the wafer surface, the hydrofluoric acid reacts with the surface of the semiconductor wafer, causing much of the semiconductor wafer to dissolve. The remaining part of the semiconductor wafer is a fragile, porous structure comprising columns with walls as thin as a few nanometres. Any means of locally preventing the flow of electrical current through the semiconductor wafer results in a reduction of the rate of formation of porous material, and changes the character of any porous material that does form.

Porous semiconductors are typically formed from bulk silicon semiconductor wafers. The formation of other porous semiconductor materials has also been studied, though to a lesser extent. For example, Schmuki et al Appl Phys Lett 72, 1039, (1998) relates to porous semiconductors formed from gallium arsenide, and Liu et al "Stable Blue-Green and Ultraviolet Photoluminescence from Silicon Carbide on Porous Silicon" Solid State Communications 106, 211, (1998) relates to the formation of silicon carbide porous semiconductors.

Silicon is widely utilised for semiconductor applications, as it is cheap and abundant and possesses intrinsic electronic and mechanical properties that make it suitable for the electronic industry. Bulk silicon is a very poor light emitter, and this property of silicon has hampered the integration of optical communications and photonics technology with silicon microelectronics. It has only relatively recently been determined that porous silicon can emit visible light when illuminated with shorter wavelength, ultraviolet radiation. See, for example, A G Cullis and L. T. Canham, "Visible Light

Emission due to Quantum Size Effects in Highly Porous Crystalline Silicon" *Nature* 353, 335, (1991), and V Lehmann, "Electrochemistry of Silicon", Wiley-VCH, Weinheim (2002).

One proposed explanation for the emission of visible light from porous semiconductors relates to the "quantum confinement" of atomic electrons within the narrow walls of the porous material. When the volume to which electrons are confined is smaller than the electron wave-function, the electronic band-structure of the semiconductor changes, resulting in the emission of visible light.

Varying the electrochemical etching conditions enables the production of porous semiconductors that emit different intensities and wavelengths, and hence colours, of visible light. There have been many attempts to produce patterned porous semiconductors, so that adjacent wafer portions emit different intensities of light. Some approaches have used ion beam irradiation to damage semiconductor wafers selectively, such that regions subjected to irradiation produce no emission of light. See, for example, X. M. Bao, H. Q. Yang and F. Yan, "Influence of ion irradiation damage on properties of porous silicon", *Journal of Applied Physics* 79, 1320 (1993) and J. Xu and A. J. Steckl, "Fabrication of visibly photoluminescent silicon microstructures by focused ion beam implantation and wet etching," *Applied Physics Letters* 65, 2081 (1994). Other approaches have used ion beam irradiation to produce the opposite effect in n-type silicon and gallium arsenide, whereby only those regions of the semiconductor wafers that are exposed to irradiation produce emission of light.

One method for patterning porous semiconductors to switch light emission off or on at the patterned regions involves projecting a black and white image on the semiconductor surface during the etching process to enhance or suppress pore formation in a predetermined manner. The emitted light from such patterned semiconductors produces images comprising "bright" and "dark" regions. However, known methods do not create true "grey-scale" images comprising many variations in emitted light intensity, or "colour" images comprising variations in emitted wavelength.

A need exists to control, on a micrometer lateral scale, the particle size and layer thickness of porous semiconductors to control the wavelength and intensity of emitted light.

Summary

It is an object of the present invention to overcome substantially, or at least ameliorate, one or more disadvantages of existing arrangements.

Disclosed are arrangements that seek to control the particle size and dimensions of porous semiconductors, using ion beam irradiation and materials processing. Controlling the particle size and dimension of porous semiconductors enables control of the wavelength and intensity of light emission from patterned, porous semiconductors for optoelectronic and photonic applications.

According to a first aspect of the present disclosure, there is provided a method of producing a patterned, porous semiconductor. The method includes the steps of: irradiating a semiconductor substrate with at least one focused ion beam; and scanning the at least one ion beam across a surface of the semiconductor substrate in a predetermined manner to irradiate selected regions of the semiconductor substrate for predetermined times and with predetermined ion beam intensities. The irradiated semiconductor substrate is then etched to form pores in the semiconductor substrate, wherein the rate of formation of the pores in the irradiated selected regions of the semiconductor substrate differs from the rate of formation of the pores in un-irradiated regions of the semiconductor substrate.

According to a second aspect of the present disclosure, there is provided a method for producing an image from a semiconductor substrate, the method comprising the steps of: irradiating a semiconductor substrate with at least one focused ion beam; and scanning the at least one ion beam across a surface of the semiconductor substrate in a predetermined manner to irradiate selected regions of the semiconductor substrate for predetermined times and with predetermined ion beam intensities. The irradiated semiconductor substrate is then etched to form pores in the semiconductor substrate, wherein the rate of formation of the pores in the irradiated selected regions of the semiconductor substrate differs from the rate of formation of the pores in un-irradiated regions of the semiconductor substrate. Then, a stimulation source stimulates the etched semiconductor substrate to produce patterned light emission from the semiconductor substrate, the patterned light emission forming an image.

According to a third aspect of the present disclosure, there is provided a porous semiconductor including an irradiated region that has been irradiated by an ion beam in a predetermined manner and subsequently etched to form porous semiconductor material,

wherein the formation of porous semiconductor material at the irradiated region is dependent upon the duration and intensity of the irradiation applied to the irradiated region.

According to a fourth aspect of the present disclosure, there is provided a display device including a semiconductor substrate. The semiconductor substrate includes at least one irradiated region formed by applying at least one ion beam in a predetermined manner and at least one un-irradiated region that has not been irradiated by the ion beam. The semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at the at least one irradiated region differing from the rate of formation of semiconductor material at the at least one un-irradiated region. The display device further includes a stimulation source applied to the semiconductor substrate to stimulate visible light emission from the semiconductor substrate, wherein light emitted from the at least one irradiated region and light emitted from the at least one un-irradiated region differ in intensity and wavelength, dependent upon the predetermined manner in which the at least one ion beam was applied.

According to a fifth aspect of the present disclosure, there is provided a display arrangement including a plurality of semiconductor display devices. Each of the display devices includes a semiconductor substrate having: at least one irradiated region formed by applying at least one ion beam in a predetermined manner; and at least one un-irradiated region that has not been irradiated by the ion beam; wherein the semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at the at least one irradiated region differing from the rate of formation of semiconductor material at the at least one un-irradiated region. Each of the display devices further includes a stimulation source applied to the semiconductor substrate to stimulate visible light emission from the semiconductor substrate, wherein light emitted from the at least one irradiated region and light emitted from the at least one un-irradiated region differ in intensity and wavelength, dependent upon the predetermined manner in which the at least one ion beam was applied. The display arrangement further includes a controller to control each stimulation source applied to the semiconductor substrates of the semiconductor display devices to produce a composite image of light emitted from each of the semiconductor display devices.

According to a sixth aspect of the present disclosure, there is provided a display arrangement including a plurality of semiconductor display devices. Each of the display devices includes a semiconductor substrate having: at least one irradiated region formed

by applying at least one ion beam in a predetermined manner; and at least one un-irradiated region that has not been irradiated by the ion beam; wherein the semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at the at least one irradiated region differing from the rate of formation of semiconductor material at the at least one un-irradiated region. The display arrangement also includes a stimulation source applied to the semiconductor substrates of the semiconductor display devices to stimulate visible light emission from the semiconductor substrates, wherein light emitted from the at least one irradiated region and light emitted from the at least one un-irradiated region of respective semiconductor substrates differ in intensity and wavelength, dependent upon the predetermined manner in which the at least one ion beam was applied to the semiconductor substrate. The display arrangement further includes a controller to control the stimulation source to produce a composite image of light emitted from each of the semiconductor display devices.

According to another aspect of the present disclosure, there is provided an apparatus for implementing any one of the aforementioned methods.

According to another aspect of the present disclosure there is provided a computer program product including a computer readable medium having recorded thereon a computer program for implementing any one of the methods described above.

Other aspects of the invention are also disclosed.

Brief Description of the Drawings

Some aspects of the prior art and one or more embodiments of the present invention will now be described with reference to the drawings, in which:

Figs 1A and 1B are schematic block diagrams of a semiconductor wafer exposed to a mono-energetic, high-energy, focused ion beam;

Figs 2A and 2B are schematic block diagrams of a semiconductor wafer exposed to two doses of a mono-energetic, high-energy, focused ion beam;

Figs 3A and 3B are photoluminescence images of regions of silicon wafers that have been irradiated with high-energy ions; and

Fig. 4 is an image of light emission patterns from a silicon semiconductor wafer exposed to different doses of irradiation.

Detailed Description including Best Mode

Where reference is made in any one or more of the accompanying drawings to steps and/or features that have the same reference numerals, those steps and/or features have for the purposes of this description the same function(s) or operation(s), unless the contrary intention appears.

It is to be noted that the discussions contained in the "Background" section and that above relating to prior art arrangements relate to discussions of documents or devices which form public knowledge through their respective publication and/or use. Such should not be interpreted as a representation by the present inventor(s) or patent applicant that such documents or devices in any way form part of the common general knowledge in the art.

The principles of the preferred method described herein have general applicability to semiconductors. However, for ease of explanation, the steps of the preferred method are described with reference to silicon semiconductors. However, it is not intended that the present invention be limited to the described method. For example, the invention may have application to p-type silicon, n-type silicon, gallium arsenide, silicon carbide and other semiconductor materials.

Prior art arrangements fail to disclose the use of ion beams, or any other form of wafer processing, to produce selectively, in a controlled manner, light emission of different wavelengths and intensity from adjacent, micron-size areas of porous semiconductors. Consequently, it has not been possible to "pattern" selectively the material microstructure of a porous semiconductor to produce colour images embedded into the semiconductor wafer or micron-size regions that act as light sources of different wavelengths for optical, optoelectronic and photonic applications.

A method of selectively damaging a semiconductor lattice in a highly controlled manner is disclosed, enabling the flow of current and hence rate of formation of porous material to be varied in an accurate, predetermined manner. Such control of the formation of porous material enables the production of controlled, visible wavelength light emission, and controlled emission intensity from porous semiconductors. The ionizing radiation is preferably a high-energy ion beam that is focused to spot sizes as small as one hundred nanometres, and scanned in a pre-defined manner over the surface of a semiconductor wafer, as described below with reference to Fig. 1A.

The method disclosed enables the control, on a micrometer lateral scale, of the particle size and layer thickness of porous semiconductors. Controlling the particle size enables control of the wavelength of light emitted from the porous semiconductor. Controlling the layer thickness of the porous semiconductor enables control of the intensity of light emitted from the porous semiconductor. The arrangements utilise a suitable form of ionizing radiation that is capable of modifying the properties of semiconductor lattices in a highly controlled manner, enabling the defect density to be tailored and accurately varied in areas as small as one hundred nanometres. In particular, the ionizing radiation is preferably a focused, high-energy ion beam, such as protons or helium nuclei. The ion beam is preferably in the Mega electron volt (MeV) range.

A high-energy ion beam is focused on the surface of a semiconductor wafer. The ion beam penetrates the semiconductor and loses energy as the ion beam collides with atomic electrons and atomic nuclei of the semiconductor material. The collisions with the atomic nuclei of the semiconductor material produce defects in the lattice structure of the semiconductor. The ion beam comes to rest at a well-defined end-of-range region. The end-of-range region refers to the depth of semiconductor material at which the energy of the ion beam is substantially reduced, which results in higher rates of defect formation. For example, a 2 MeV ion beam of protons incident on a silicon semiconductor comes to rest at a depth of approximately fifty micrometers (50 μ m).

The stopping process damages the irradiated region of the semiconductor wafer, producing defects in the semiconductor along the path of the ion beam. This results in localized regions of higher defect concentration. The irradiated semiconductor wafer is then electrochemically etched in a dilute solution of hydrogen fluoride. An electrical current is passed through the wafer, resulting in the formation of porous material at the surface of the semiconductor. Regions of the semiconductor wafer away from the irradiated areas become porous. The irradiated regions of the semiconductor wafer that were exposed to the ion beam etch at a rate slower than regions of the semiconductor wafer that were not irradiated. The relative slowness of the etching at the irradiated regions depends on the irradiated dose and the wafer conductivity. Consequently, less porous material is produced at the irradiated regions, as described below with reference to Fig. 1B.

Fig.1A is a schematic block diagram of first and second, mono-energetic, high-energy, focused ion beams (1a, 1b) of the same dose being applied to a semiconductor wafer (2). Each of the first and second ion beams (1a, 1b) penetrates the surface of the

semiconductor wafer (2) and the ions come to rest at a respective depth (d_1 , d_2) determined by the initial kinetic energy of each ion beam (1a, 1b). A predetermined pattern of the scanned ion beams (1a, 1b) over the surface of the semiconductor wafer (2) determines the distribution of the irradiated ions at respective first and second irradiated end-of-range regions (3a, 3b). The first and second ion beams (1a, 1b) incident on the semiconductor wafer (2) create defects in the semiconductor lattice. Many of these defects are located close to the end-of-range regions (3a, 3b), though a lower density of defects is also present all along the ion trajectories.

Fig. 1B is a schematic block diagram of the semiconductor wafer (2) of Fig. 1A, after electrochemical etching. Regions (4a, 4b, 4c) of the semiconductor wafer (2) that were not irradiated by the first and second ion beams (1a, 1b) become porous. The first and second irradiated regions (3a, 3b) etch at a reduced rate, dependent on the dose of the irradiated beams (1a, 1b) and the conductivity of the semiconductor wafer (2). Thus, the thickness of the porous material at the irradiated regions (3a, 3b) can be controlled.

The semiconductor wafer contains transition regions between the un-irradiated regions (4a, 4b, 4c) and the irradiated regions (3a, 3b). Moving from left to right across the surface of the semiconductor wafer (2), a first transition region (5a) is located between a first un-irradiated region (4a) and the first irradiated region (3a), a second transition region (5b) is located between the first irradiated region (3a) and a second un-irradiated region (4b), a third transition region (5c) is located between the second un-irradiated region (4b) and the second irradiated region (3b), and a fourth transition region (5d) is located between the second irradiated region (3b) and a third un-irradiated region (4c). In the transition regions (5a, 5b, 5c, 5d) between the irradiated and un-irradiated regions, porous material tends to form with a different porosity from the porous material in the un-irradiated regions (4a, 4b, 4c), producing material that emits light with a different wavelength to that of the other regions.

Applying a higher local beam dose to a region of a semiconductor wafer produces a higher defect concentration at that irradiated region of the semiconductor wafer. Thus, scanning a focused ion beam for different amounts of time at different locations across a semiconductor wafer enables the production of any predetermined pattern of localized damage in the semiconductor material, as described below with reference to Fig. 2A. After the semiconductor has been subjected to electrochemical etching, the pore size and subsequent light emission intensity depends on both the local distribution and dose of the

irradiated beam applied to the semiconductor, as described below with reference to Fig. 2B.

Fig. 2A is a schematic block diagram of first and second, mono-energetic, high-energy, focused ion beams (10a, 10b) of different doses applied to a semiconductor wafer (20). In this example, the dose of the first ion beam (10a) is less than the dose of the second ion beam (10b). As described above in respect of Fig. 1A, each of the first and second ion beams (10a, 10b) penetrates the surface of the semiconductor wafer (20). The first and second ion beams (10a, 10b) produce first and second irradiated regions (30a, 30b) in the semiconductor wafer (20) at the same depth. However, the higher beam dose of the second ion beam (10b) produces a more damaged irradiated region (30b) in the semiconductor wafer (20) than the irradiated region (30a) that results from the lower beam dose of the first ion beam (10a).

Fig. 2B is a schematic block diagram of the semiconductor wafer (20) of Fig. 2A, after electrochemical etching. The electrochemical etching produces a layer of porous material at each of the irradiated regions (30a, 30b). The thickness of the porous layers at the irradiated regions (30a, 30b) depends on the dose of radiation to which each region has been exposed. In this example, the first irradiated region (30a) has a thicker layer of porous material after electrochemical etching than the second irradiated region (30b). The semiconductor wafer (20) contains transition regions (50a, 50b, 60a, 60b) between the irradiated regions (30a, 30b) and un-irradiated regions (40a, 40b, 40c). Thus, a first transition region (50a) is located between a first un-irradiated region (40a) and the first irradiated region (30a), a second transition region (50b) is located between the first irradiated region (30a) and a second un-irradiated region (40b), a third transition region (60a) is located between the second un-irradiated region (40b) and the second irradiated region (30b) and the fourth transition region (60b) is located between the second irradiated region (30b) and a third un-irradiated region (40c). The porosity of the semiconductor in the first and second transition regions (50a, 50b) is different to the porosity of the semiconductor in the third and fourth transition regions (60a, 60b).

Figs 3A and 3B are photoluminescence images of regions of silicon wafers that have been irradiated with high-energy ions, in accordance with an embodiment of the invention. The images of Figs 3A and 3B demonstrate patterned, multicolour light emission from a silicon wafer. To record the photoluminescence images of Figs 3A and 3B, an ultraviolet light source is used to illuminate the silicon wafers. The spectrum of different colours of visible light emitted from the silicon wafers is then detected.

Fig. 3A is a photoluminescence image (300) of a region of a silicon wafer that has been irradiated with high-energy ions. To create the image (300), a "dragon-shaped" region (310) of the silicon wafer is uniformly irradiated by high-energy ions. The silicon wafer is then electrochemically etched. The irradiation modifies the formation of porous silicon in the "dragon-shaped" region (310) during the electrochemical etching, resulting in light emission of a different wavelength, and thus colour, from the irradiated region (310) compared with the surrounding un-irradiated areas (320). The resultant image consists of two different colours.

Fig. 3B is a photoluminescence image (350) of a horizontal region of a silicon wafer that has been irradiated with different doses of high-energy ions. The dose of the irradiation increases from right to left across the irradiated region (360). The formation of porous silicon is altered in a continuous manner along the length of the irradiated region (360), resulting in continuously changing colours of light emission across the silicon wafer. Thus, different doses of high-energy ions are applied to a semiconductor wafer to produce "multi-colour" images.

In an alternate embodiment, an electrical current is applied to a porous silicon wafer to produce an electroluminescent image. The electrical current passes through the silicon wafer to stimulate emission of light from the porous silicon wafer. Irradiating the silicon wafer in a predetermined manner before etching the silicon, as described above in respect of Figs 3A and 3B, and subsequently applying the electrical current enables the production of an electroluminescent image of desired wavelengths and intensities.

Fig. 4 is an image (400) of light emission patterns from a silicon semiconductor wafer that has been exposed to different doses of irradiation. The semiconductor wafer was irradiated with a checkerboard pattern of horizontal and vertical lines of different doses, resulting in areas of different intensity of light emission after subsequent electrochemical etching. Where the lines of irradiation cross on the semiconductor wafer, such as shown for example at intersections (410, 420, 430), the accumulated dose of irradiation is higher. The accumulated doses of irradiation result in areas of different intensity of light emission after subsequent electrochemical etching.

The application of ion beam irradiation to a semiconductor wafer to control the intensity and wavelength of emitted light from porous semiconductors enables the fabrication of patterned porous semiconductors without the use of a surface mask. As no masks are required, the irradiated patterns are independent of the restrictions inherent in the application of masks, resulting in greater flexibility of irradiated patterns. Further, it

is possible to vary widely the localised ion irradiation dose applied to a semiconductor wafer, providing increased control of the amount of damage caused to the semiconductor lattice and hence light emission wavelength and intensity. Further still, rapid prototyping of patterned porous semiconductor microstructures is enabled.

The method and arrangements disclosed above can be integrated with conventional methods of ion implantation and irradiation using surface masks. Further, the method and arrangements disclosed above can be integrated with conventional semiconductor wafer processing methods. Further still, the method and arrangements disclosed above enable the use of patterned, three-dimensional semiconductor wafers for fabricating porous semiconductor microstructures at different depths in localised semiconductor wafer regions.

Porous semiconductors produced using the methodology described above can be applied in optoelectronics, integrated opto/microelectronics, communications, display and photonics technologies, particularly with respect to optical interconnects and switches. Such applications include waveguides, couplers, filters, and Bragg gratings.

For example, a device produced using the described methodology has a single silicon wafer containing: (i) circuitry and devices for microelectronics data processing; and (ii) an integrated porous semiconductor device to produce light emission in a predetermined pattern. The integrated porous semiconductor facilitates the connection of the microelectronics circuitry to optical communications devices such as optical fibres, multiplexers and detectors. The integrated porous semiconductor device in this example removes the need for an external device, such as a photodiode, to convert the electrical signals of the microelectronics circuitry to optical signals required by the optical communications devices.

In another example, a plurality of porous semiconductor devices produced using the described methodology are connected in a predetermined array. An electrical current is applied to the array of semiconductor devices to stimulate emission of light. The emitted light produces a large image consisting of the constituent images of each of the individual semiconductor devices. Controlling the electrical current applied to each of the semiconductor devices enables control of the resultant large image. In one embodiment, control of the electrical current is performed by standard microelectronics circuitry, as would be readily implemented by a person skilled in the art.

The aforementioned preferred method(s) comprise a particular control flow. There are many other variants of the preferred method(s) that use different control flows without

departing from the spirit or scope of the invention. Furthermore, one or more of the steps of the preferred method(s) may be performed in parallel rather than sequentially.

Industrial Applicability

It is apparent from the above that the arrangements described are applicable to the optoelectronic and photonic industries.

The foregoing describes only some embodiments of the present invention, and modifications and/or changes can be made thereto without departing from the scope and spirit of the invention, the embodiments being illustrative and not restrictive.

We claim:

1. A method of producing a patterned, porous semiconductor, said method comprising the steps of:
 - irradiating a semiconductor substrate with at least one focused ion beam;
 - scanning said at least one ion beam across a surface of said semiconductor substrate in a predetermined manner to irradiate selected regions of said semiconductor substrate for predetermined times and with predetermined ion beam intensities; and
 - etching said irradiated semiconductor substrate to form pores in said semiconductor substrate, wherein the rate of formation of said pores in said irradiated selected regions of said semiconductor substrate differs from the rate of formation of said pores in un-irradiated regions of said semiconductor substrate.
2. The method according to claim 1, wherein energy associated with each of said at least one ion beam is in the range of 1 MeV to 100 MeV.
3. The method according to claim 1, wherein each of said at least one ion beam has a width in the range of 1 micrometre (μm) to 1 millimetre (mm).
4. The method according to claim 1, wherein at least one of said at least one ion beam is mono-energetic.
5. The method according to claim 1, wherein said semiconductor substrate is p-type silicon.
6. The method according to claim 1, wherein said semiconductor substrate is n-type silicon.
7. The method according to claim 1, wherein said semiconductor substrate is gallium arsenide.
8. The method according to claim 1, wherein said semiconductor substrate is silicon carbide.

9. The method according to claim 1, wherein each of said at least one ion beam comprises ions selected from the group of ions consisting of: protons, and helium nuclei.
10. The method according to claim 1, wherein said etching is electrochemical etching.
11. The method according to claim 10, wherein said electrochemical etching utilises hydrofluoric acid.
12. The method according to claim 1, wherein said predetermined times control the intensity of light emitted from said selected regions.
13. The method according to claim 1, wherein said predetermined ion beam intensities control the wavelength of light emitted from said selected regions.
14. A method of producing an image from a semiconductor substrate, said method comprising the steps of:
 - irradiating a semiconductor substrate with at least one focused ion beam;
 - scanning said at least one ion beam across a surface of said semiconductor substrate in a predetermined manner to irradiate selected regions of said semiconductor substrate for predetermined times and with predetermined ion beam intensities;
 - etching said irradiated semiconductor substrate to form pores in said semiconductor substrate, wherein the rate of formation of said pores in said irradiated selected regions of said semiconductor substrate differs from the rate of formation of said pores in un-irradiated regions of said semiconductor substrate; and
 - stimulating said etched semiconductor substrate with a stimulation source to produce patterned light emission from said semiconductor substrate, said patterned light emission forming an image.
15. The method according to claim 14, wherein said stimulation source is a light source having a wavelength shorter than the wavelengths of said patterned light emission.
16. The method according to claim 14, wherein said stimulation source is an ultraviolet light source.

17. The method according to claim 14, wherein said stimulation source is an electrical current applied to said semiconductor substrate.

18. A porous semiconductor comprising:

an irradiated region that has been irradiated by an ion beam in a predetermined manner and subsequently etched to form porous semiconductor material, wherein the formation of porous semiconductor material at said irradiated region is dependent upon the duration and intensity of the irradiation applied to said irradiated region.

19. The porous semiconductor according to claim 18, further comprising:

an un-irradiated region that has not been irradiated by said ion beam, wherein said un-irradiated region has been etched to form porous semiconductor material, in the same etching process applied to the irradiated region, and further wherein the rate of formation of porous semiconductor material at said irradiated region differs from the rate of formation of porous semiconductor material at said un-irradiated region.

20. A display device comprising:

a semiconductor substrate including:

at least one irradiated region formed by applying at least one ion beam in a predetermined manner; and

at least one un-irradiated region that has not been irradiated by said ion beam;

wherein said semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at said at least one irradiated region differing from the rate of formation of semiconductor material at said at least one un-irradiated region; and

a stimulation source applied to said semiconductor substrate to stimulate visible light emission from said semiconductor substrate, wherein light emitted from said at least one irradiated region and light emitted from said at least one un-irradiated region differ in intensity and wavelength, dependent upon the predetermined manner in which said at least one ion beam was applied.

21. The display device according to claim 20, wherein said predetermined manner controls the intensity of said at least one ion beam.

22. The display device according to claim 20, wherein said predetermined manner controls the duration of application of said at least one ion beam.

23. The display device according to claim 20, wherein said stimulation source is an ultraviolet light source incident on said semiconductor substrate.

24. The display device according to claim 20, wherein said stimulation source is an electrical current.

25. A display arrangement comprising:

a plurality of semiconductor display devices, each of said display devices including:

a semiconductor substrate including:

at least one irradiated region formed by applying at least one ion beam in a predetermined manner; and

at least one un-irradiated region that has not been irradiated by said ion beam;

wherein said semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at said at least one irradiated region differing from the rate of formation of semiconductor material at said at least one un-irradiated region; and

a stimulation source applied to said semiconductor substrate to stimulate visible light emission from said semiconductor substrate, wherein light emitted from said at least one irradiated region and light emitted from said at least one un-irradiated region differ in intensity and wavelength, dependent upon the predetermined manner in which said at least one ion beam was applied; and

a controller to control each stimulation source applied to said semiconductor substrates of said semiconductor display devices to produce a composite image of light emitted from each of said semiconductor display devices.

26. A display arrangement comprising:

a plurality of semiconductor display devices, each of said display devices including:

a semiconductor substrate including:

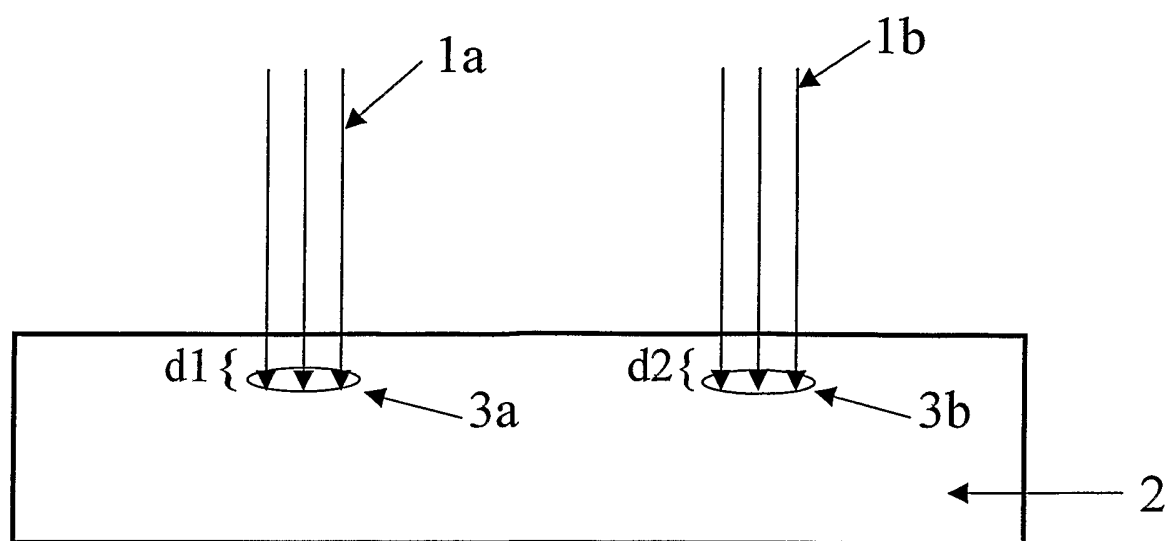
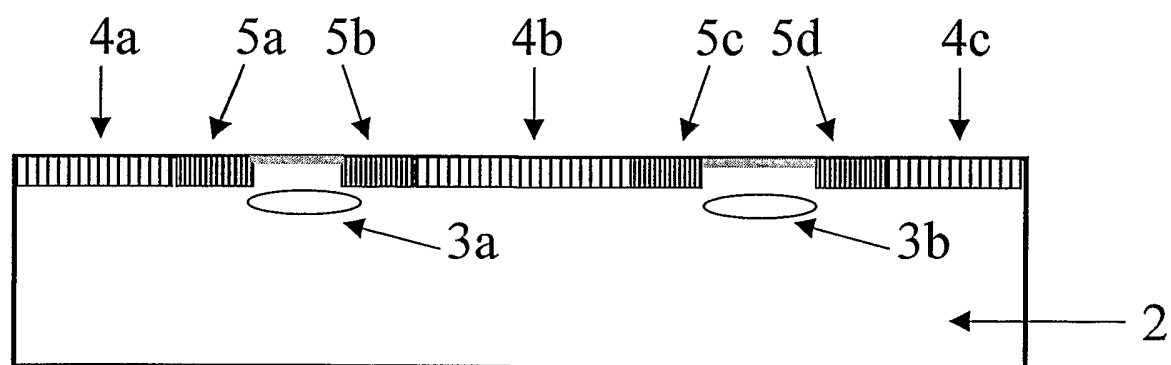
at least one irradiated region formed by applying at least one ion beam in a predetermined manner; and

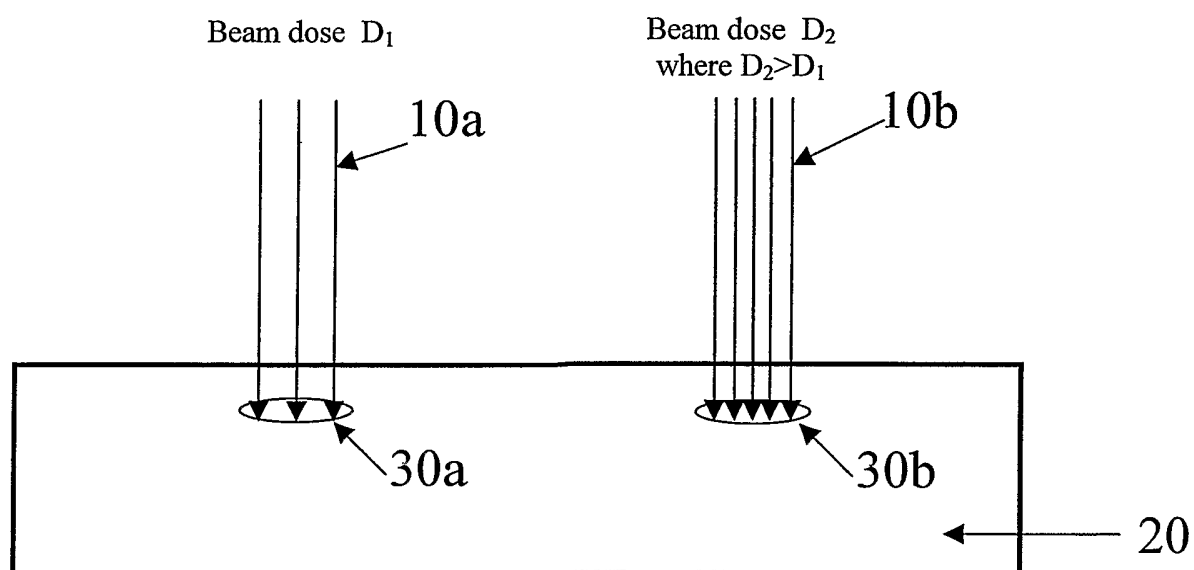
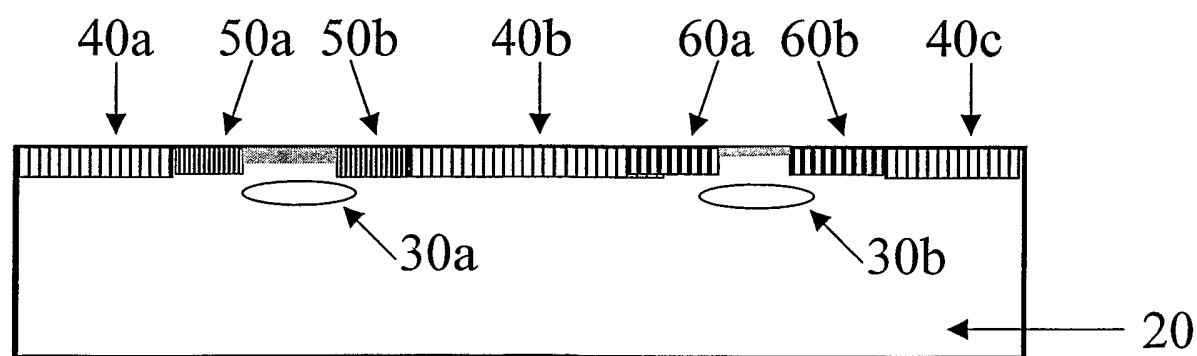
at least one un-irradiated region that has not been irradiated by said ion beam;

wherein said semiconductor substrate has been etched to form porous semiconductor material, the rate of formation of semiconductor material at said at least one irradiated region differing from the rate of formation of semiconductor material at said at least one un-irradiated region;

a stimulation source applied to said semiconductor substrates of said semiconductor display devices to stimulate visible light emission from said semiconductor substrates, wherein light emitted from said at least one irradiated region and light emitted from said at least one un-irradiated region of respective semiconductor substrates differ in intensity and wavelength, dependent upon the predetermined manner in which said at least one ion beam was applied to said semiconductor substrate; and

a controller to control said stimulation source to produce a composite image of light emitted from each of said semiconductor display devices.

**Fig. 1A****Fig. 1B**

**Fig. 2A****Fig. 2B**

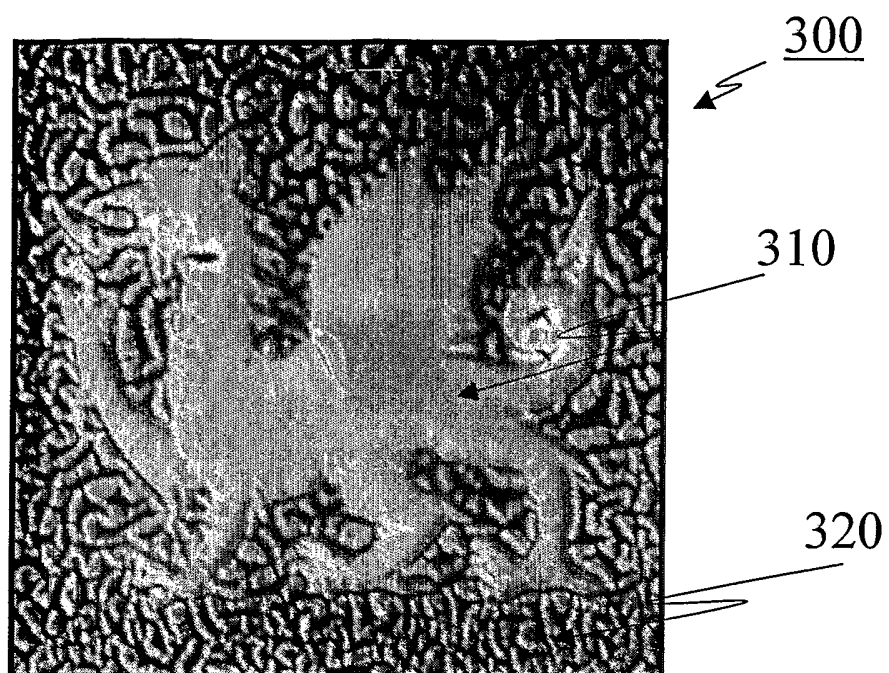


Fig. 3A

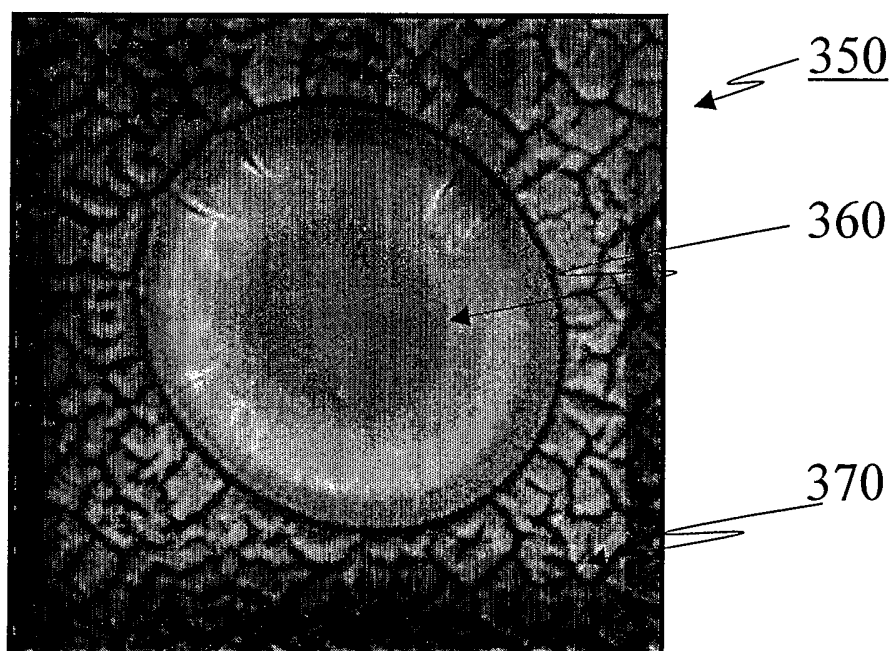


Fig. 3B

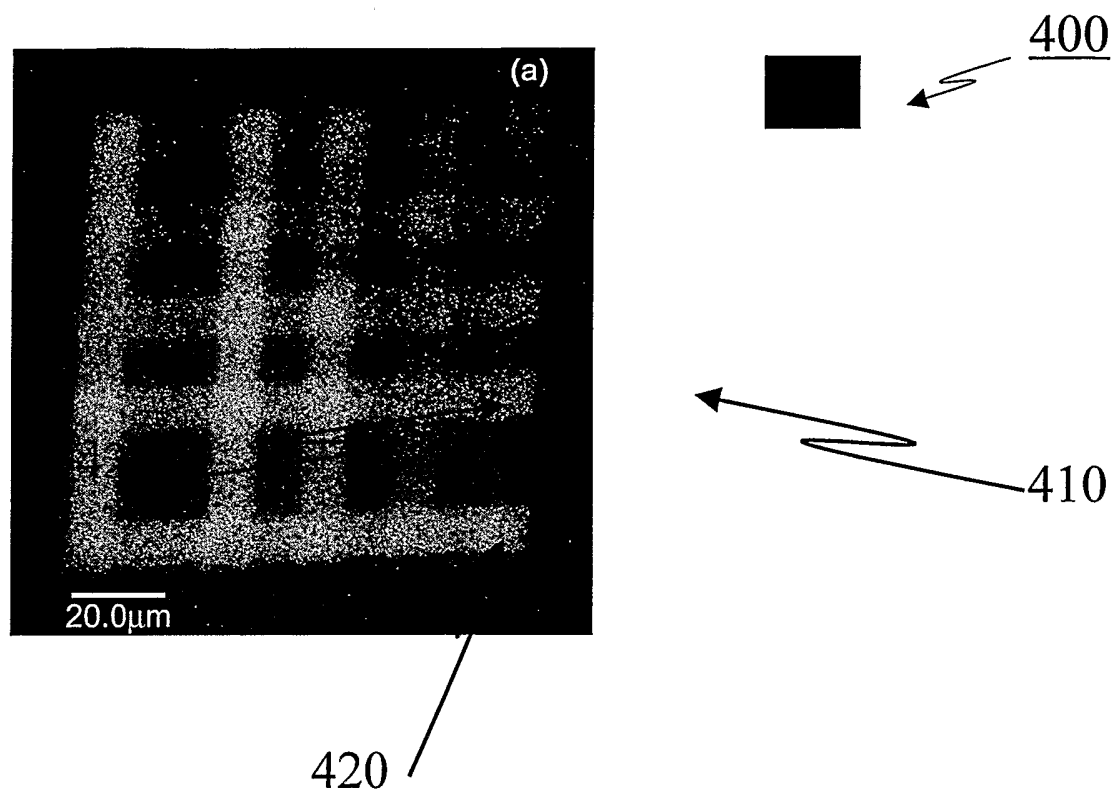


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2005/000140

A. CLASSIFICATION OF SUBJECT MATTER		
Int. Cl. ⁷ : H05B 33/10, H05B 33/14, F21K 2/00, C09K 11/59		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) DWPI & JAPIO: IPC: C09K 11/- OR H05B 33/- with keywords: semiconductor, silicon, porous, pore, irradiate, ion, beam, source, light, emit, emission, photoluminescence, electroluminescence, etch. INSPEC: keywords: semiconductor, silicon, porous, pore, irradiate, ion, beam, source, etch, anodise.		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6518603 B1 (SCHMUKI et al.) 11 February 2003 Whole document	1, 3-16, 18-23
X	Patent Abstracts of Japan, 06-267931 A (SHARP CORP) 22 September 1994 (machine translation, retrieved 12 July 2005 from Internet) <URL: http://www4.ipdl.ncipi.go.jp/Tokujitu/PAJdetail.ipdl?N0000=60&N0120=01&N2001=2&N3001=H06-267931 >	1-12, 18-19
X	P. SCHMUKI et al., "Predefined initiation of porous GaAs using focused ion beam surface sensitization.", Journal of the Electrochemical Society, vol. 146, no.2, pp. 735-740, Feb 1999, ISSN 0013-4651 Whole document	1, 4-10
☒ Further documents are listed in the continuation of Box C ☒ See patent family annex		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 12 July 2005		Date of mailing of the international search report 2 AUG 2005
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustalia.gov.au Facsimile No. (02) 6285 3929		Authorized officer KURT TOBLER Telephone No : (02) 6283 2469

INTERNATIONAL SEARCH REPORT

International application No.

PCT/SG2005/000140

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	J. XU et al., "Fabrication of visibly photoluminescent Si microstructures by focused ion beam implantation and wet etching", Applied Physics Letters, vol.65, no.16, pp. 2081-2083, 17 October 1994, ISSN 0003-6951 Whole document	1, 3-11, 14-16
X	D.A REDMAN et al., "Photoluminescence of silicon nanostructures formed by ion beam implantation", Beam Solid Interactions: Fundamentals and Applications Symposium, pp. 201 – 206, Published; Pittsburgh, PA, USA, 1993, xvii+913 pp. Whole document	1, 4-11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/SG2005/000140

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member	
US	6518603	US	6284671
		CA	2254275
JP	6267931	NONE	

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX