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STRESS REDUCTION FOR PILLAR FILLED STRUCTURES

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(54) **STRESS REDUCTION FOR PILLAR FILLED STRUCTURES**

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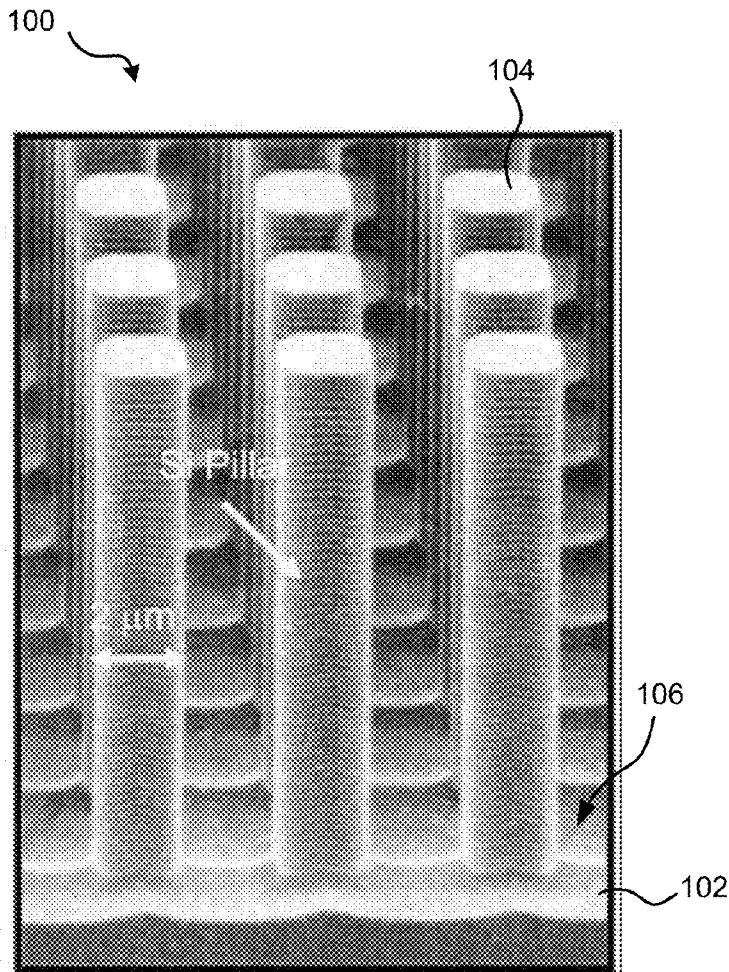
CPC ***G01T 3/00*** (2013.01)
USPC **250/370.05**; 250/390.01; 427/230; 216/83

(57) **ABSTRACT**

According to one embodiment, an apparatus for detecting neutrons includes an array of pillars, wherein each of the pillars comprises a rounded cross sectional shape where the cross section is taken perpendicular to a longitudinal axis of the respective pillar, a cavity region between each of the pillars, and a neutron sensitive material located in each cavity region.



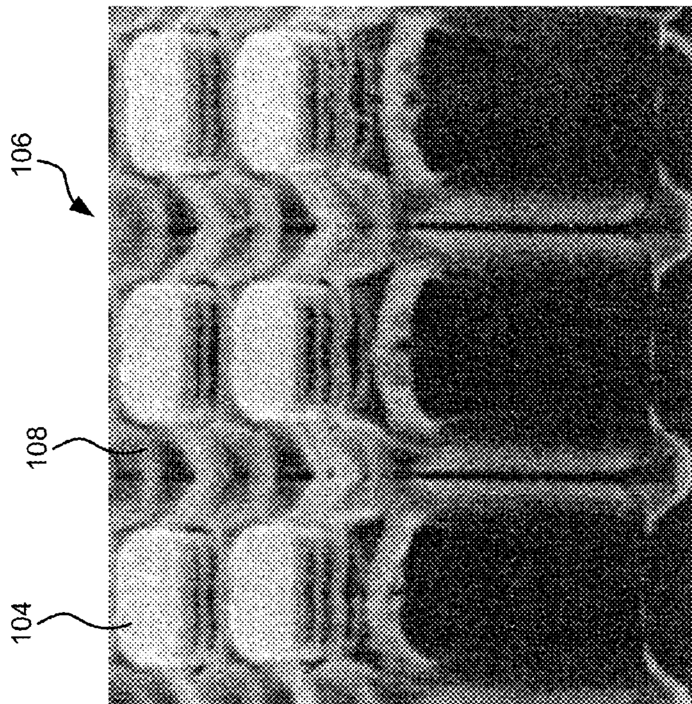


FIG.1B

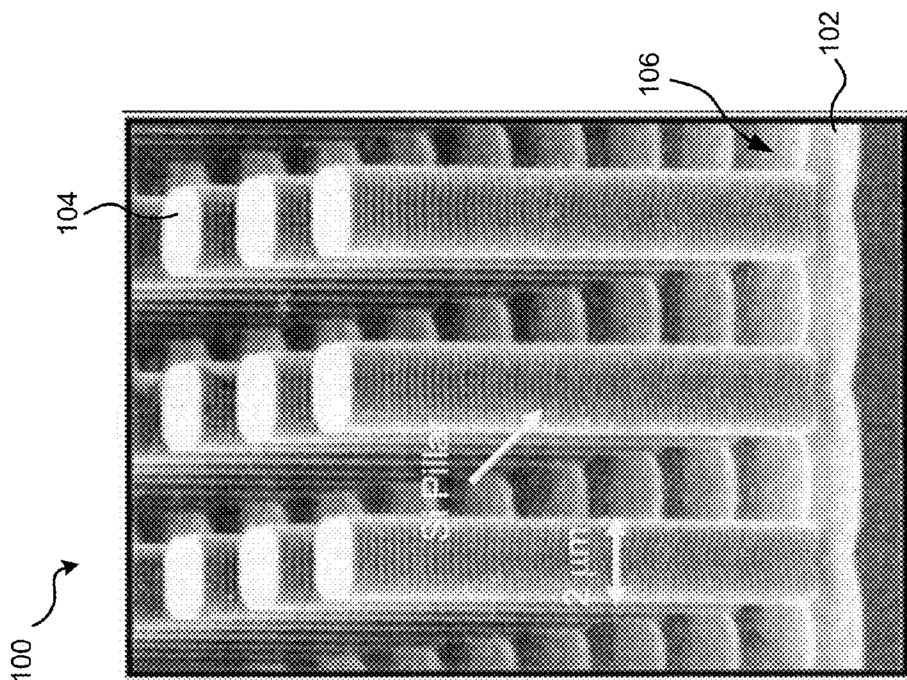


FIG.1A

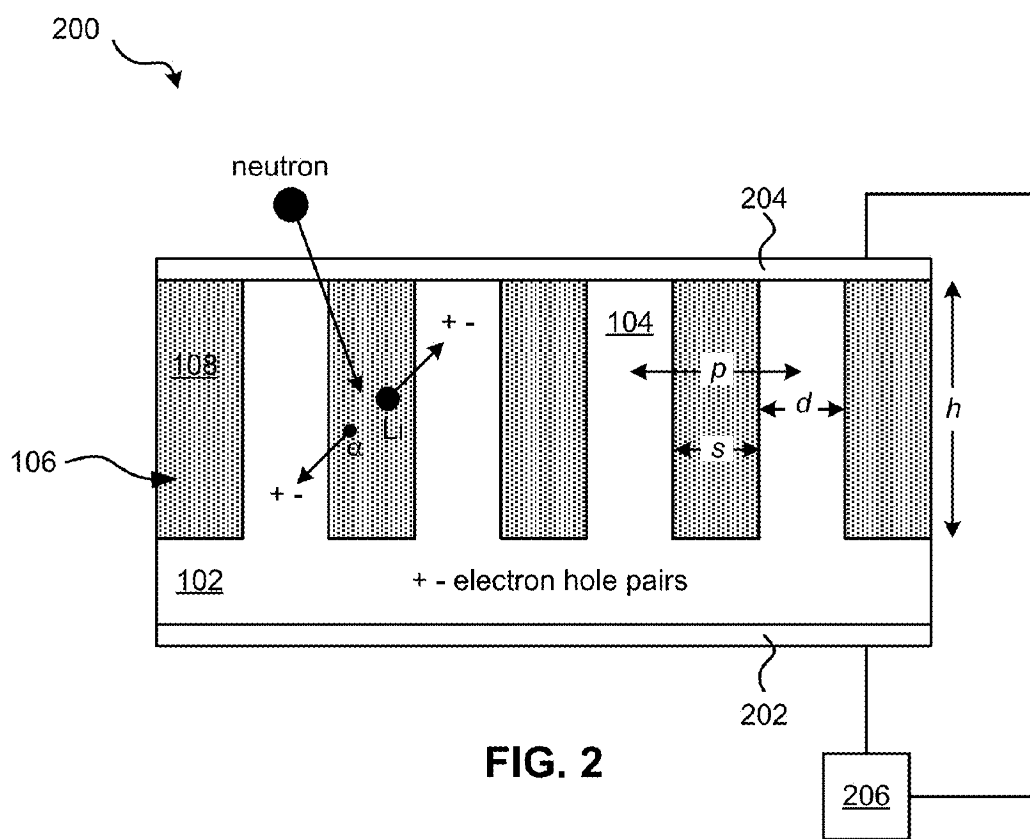


FIG. 2

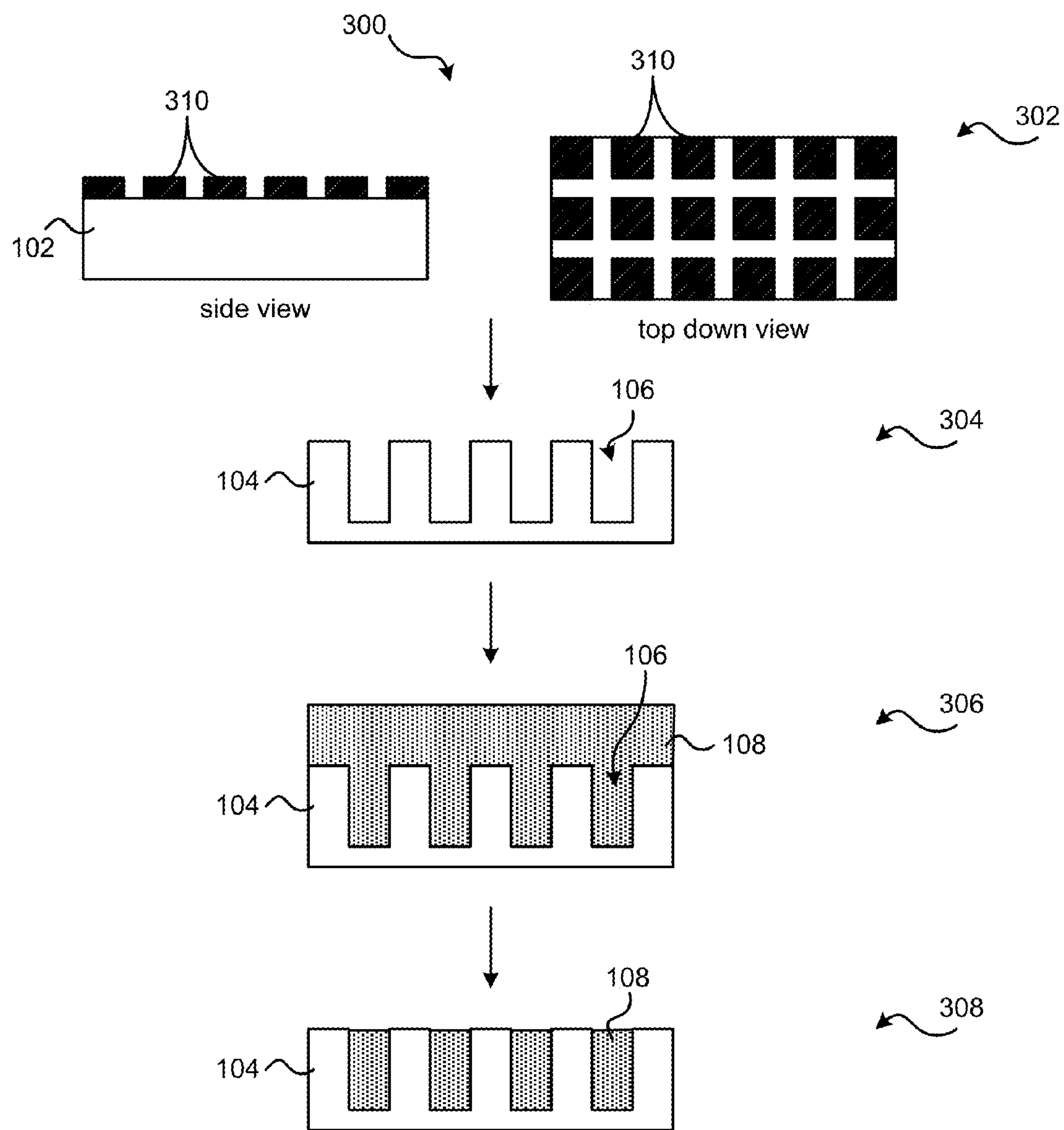


FIG. 3

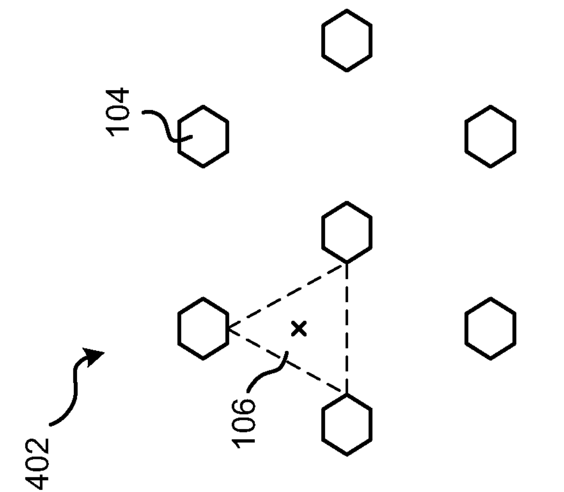


FIG. 4B

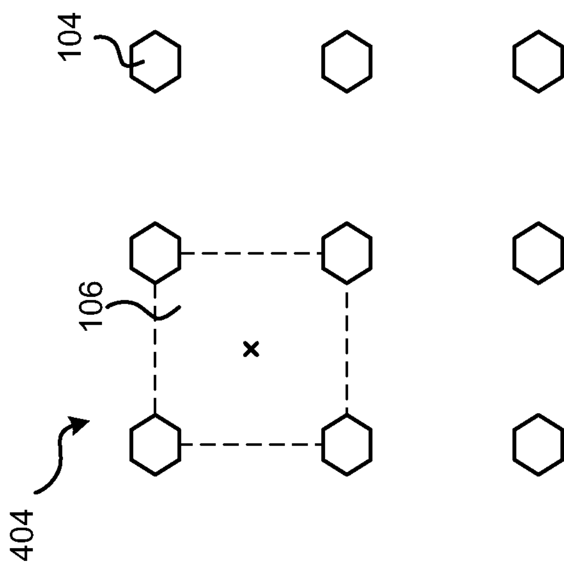


FIG. 4A

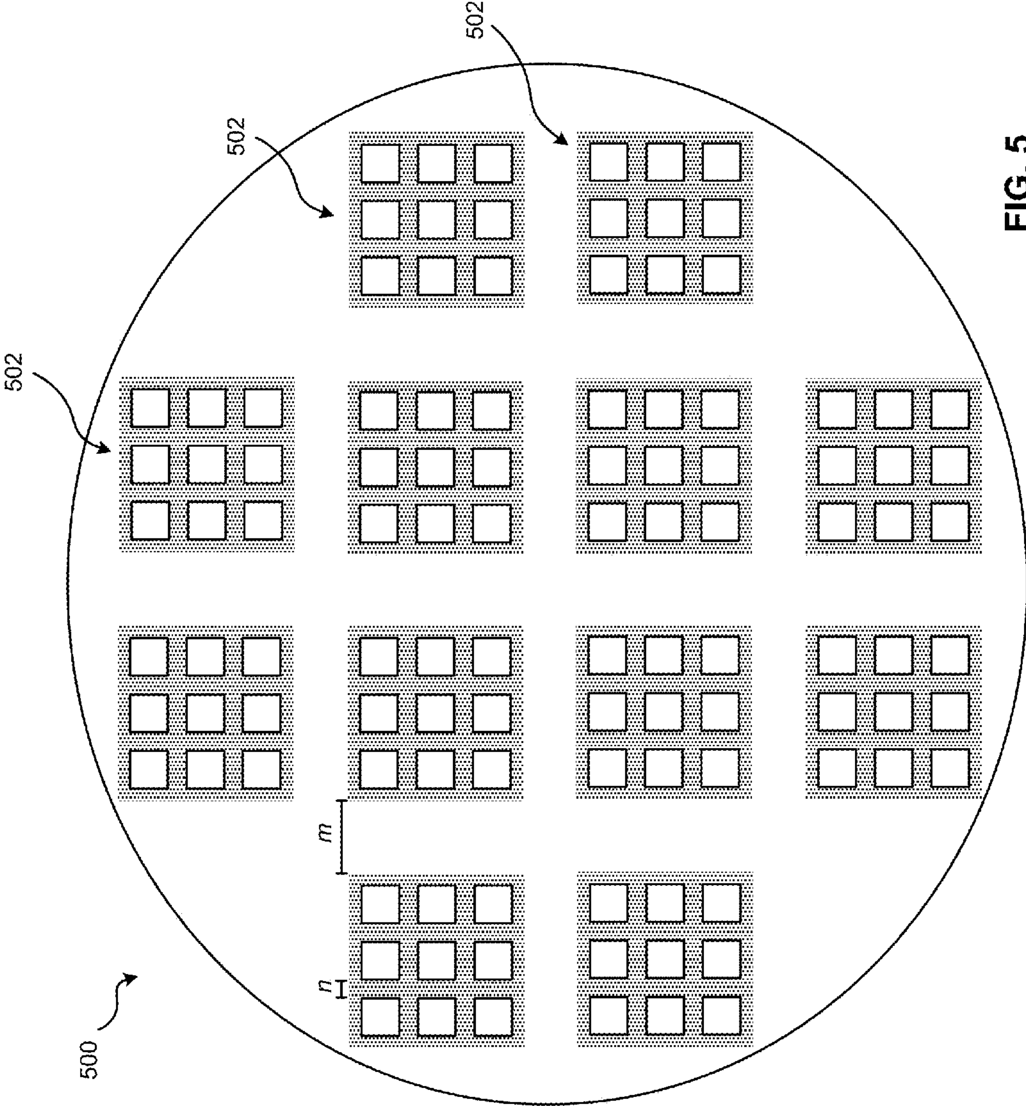


FIG. 5

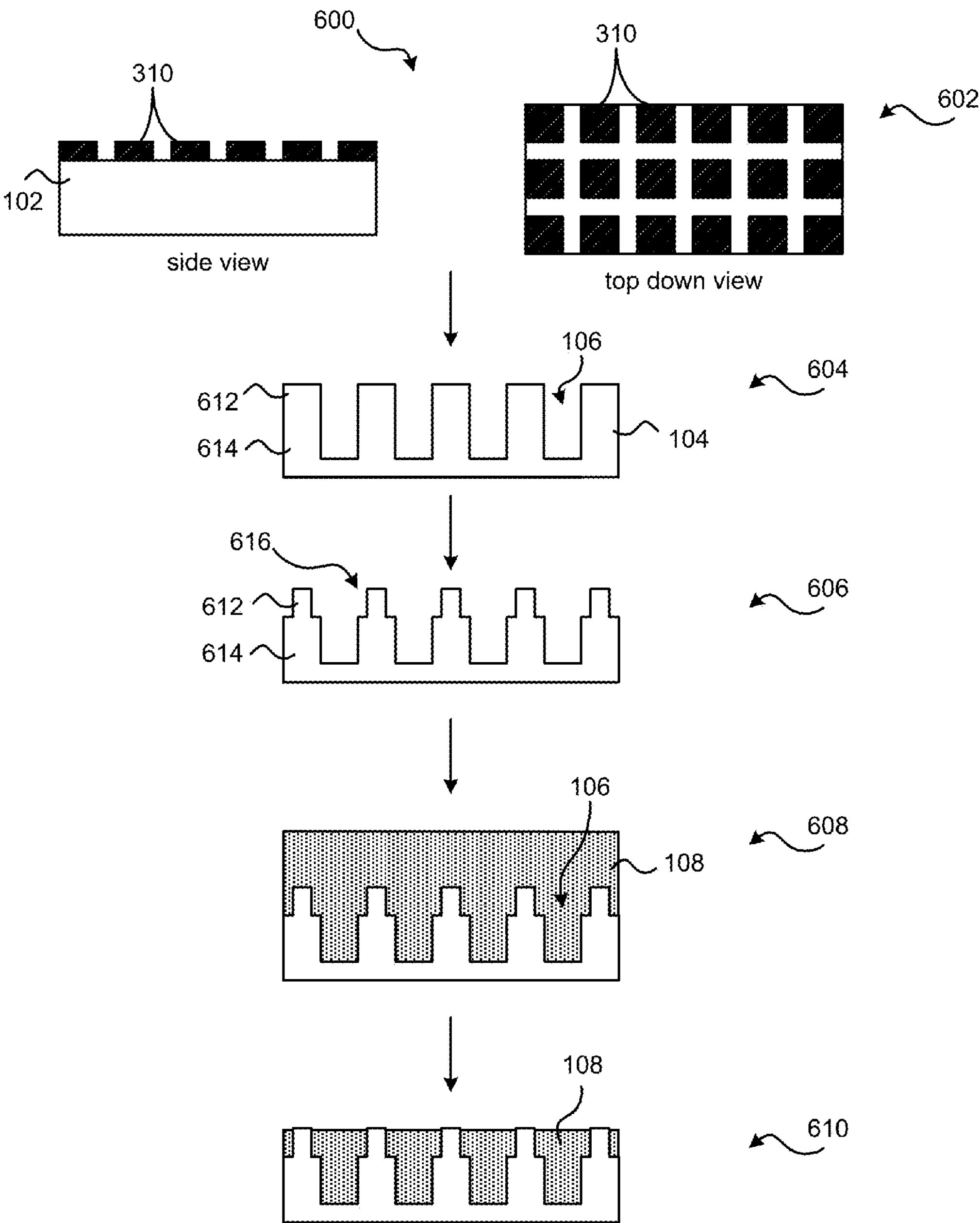


FIG. 6

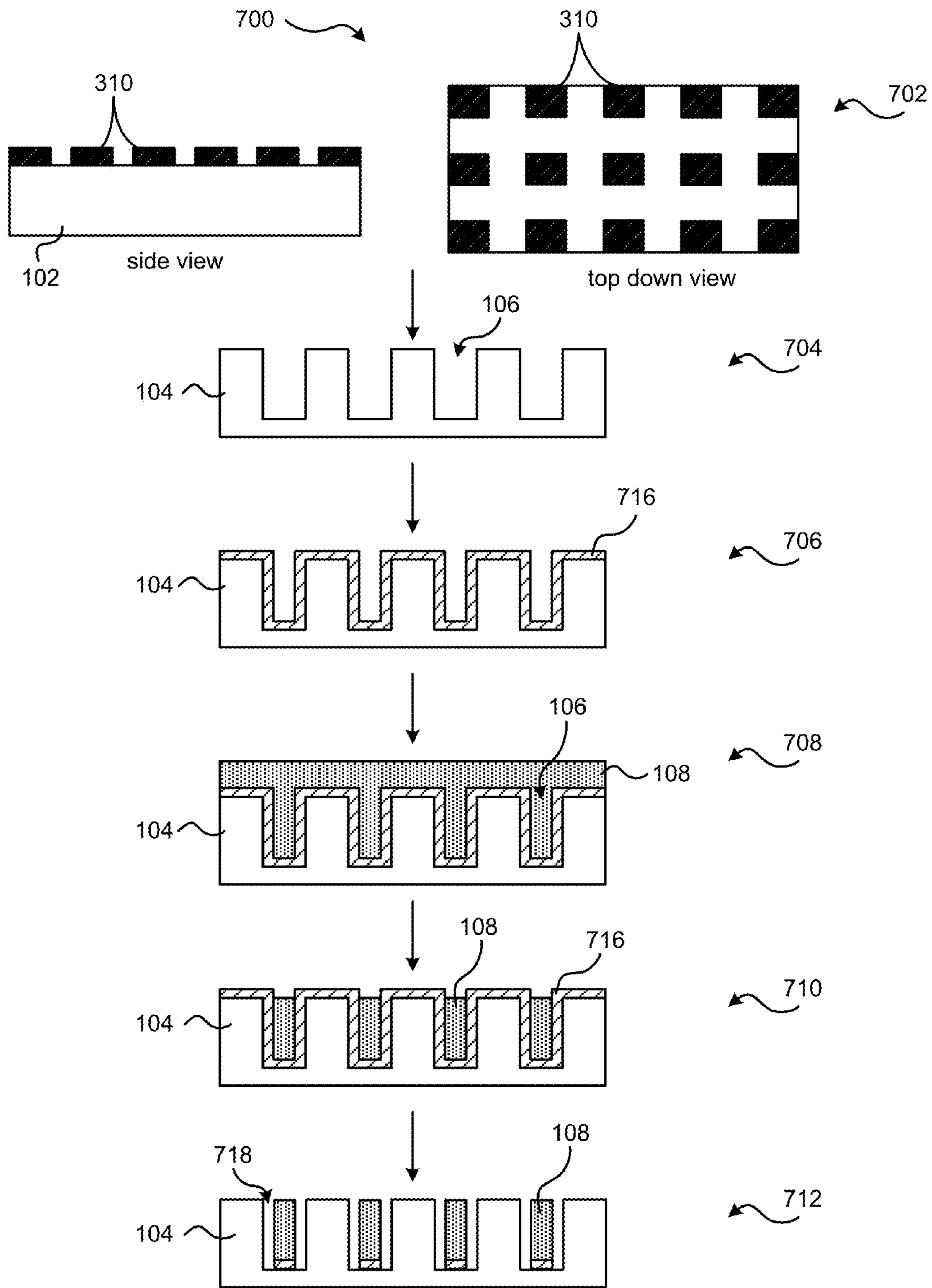


FIG. 7

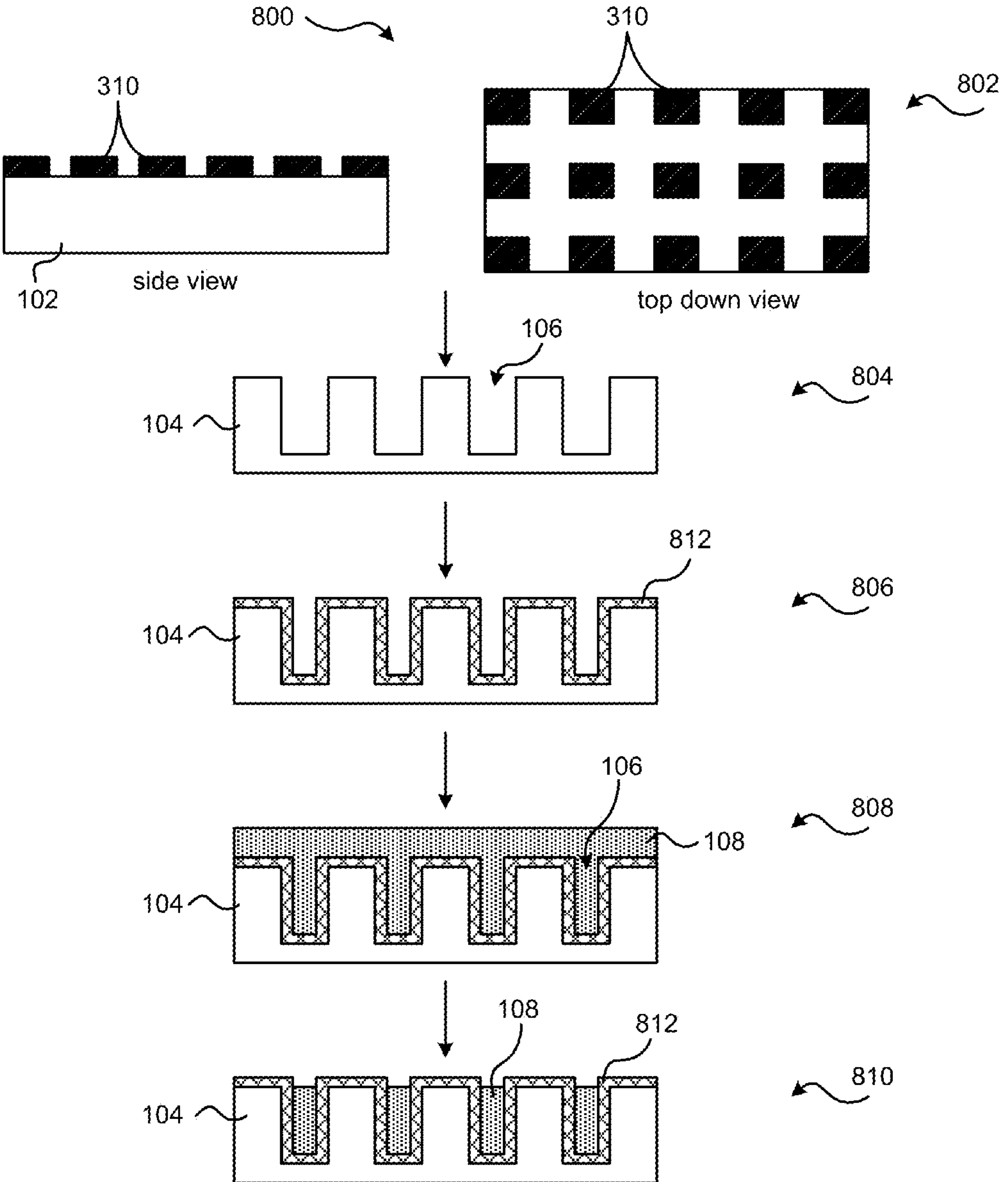


FIG. 8

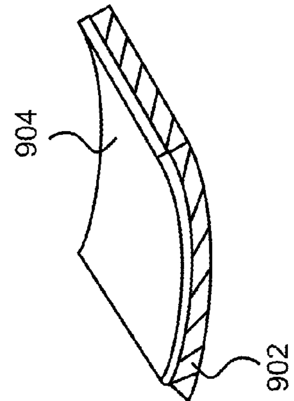


FIG. 9A

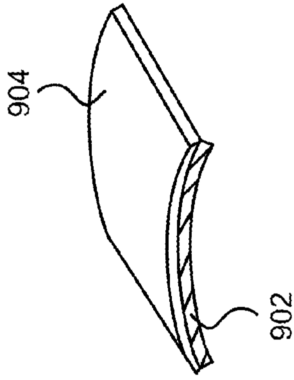


FIG. 9B

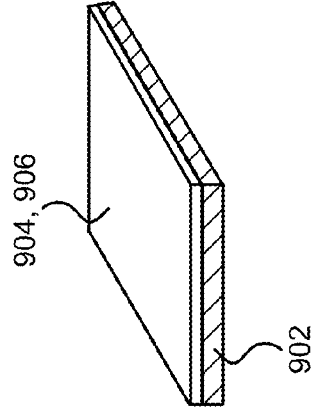


FIG. 9C

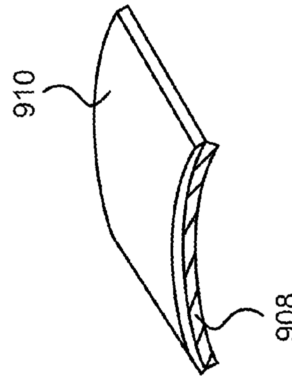


FIG. 9D

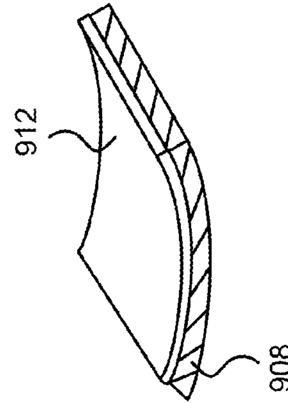


FIG. 9E

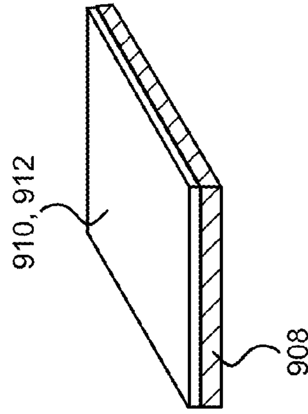


FIG. 9F

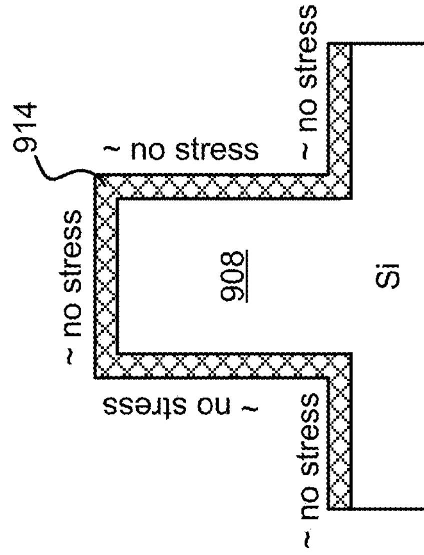


FIG. 9I

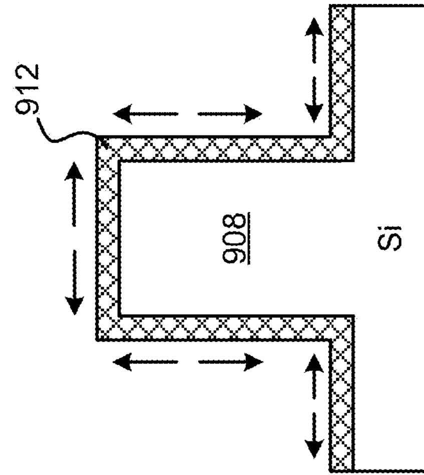


FIG. 9H

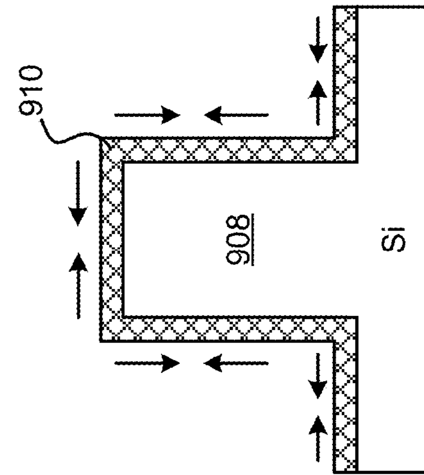


FIG. 9G

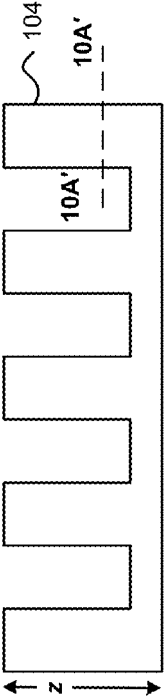


FIG. 10A

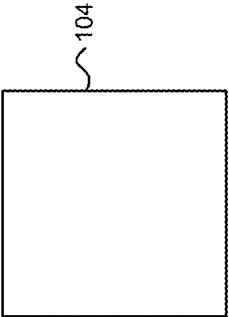


FIG. 10B

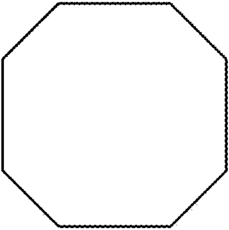


FIG. 10C

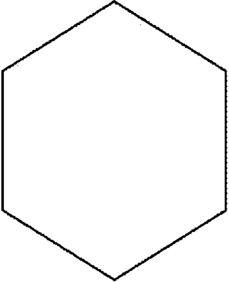


FIG. 10D

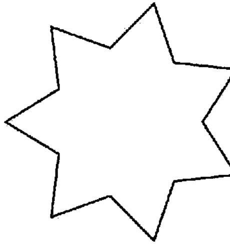


FIG. 10E

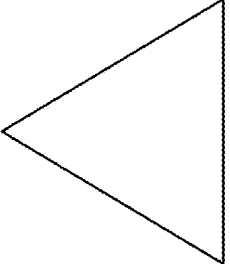


FIG. 10F

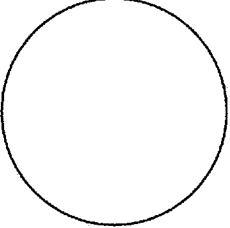


FIG. 10G

STRESS REDUCTION FOR PILLAR FILLED STRUCTURES

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application No. 61/589,771, filed Jan. 23, 2012, the contents of which are herein incorporated by reference.

[0002] The United States Government has rights in this invention pursuant to Contract No. DE-AC52-07NA27344 between the United States Department of Energy and Lawrence Livermore National Security, LLC for the operation of Lawrence Livermore National Laboratory.

FIELD OF THE INVENTION

[0003] The present invention relates to the detection of particles, and more particularly to the detection of neutrons using thermal neutron converter materials in three dimensional high efficiency configurations and related methods.

BACKGROUND

[0004] Since neutrons have no charge and do not interact significantly with most materials, neutron converters are needed to react with neutrons to produce charged particles that can be easily detected by semiconductor devices to generate electrical signals.

[0005] Conventional ^{3}He proportional tubes are simple neutron detectors that may achieve high thermal neutron detection efficiency. For example, a 2-inch diameter tube filled with 10 atm of ^{3}He gas may reach 80% detection efficiency, although the detector normally operates at lower pressure settings thereby reducing the efficiency. Furthermore, the use of these proportional counter type devices is somewhat encumbered by the required high voltage operation (1000 V), sensitivity to microphonics, and high pressure; resulting in significant complications in routine deployment and air transport.

[0006] Solid state thermal neutron detection techniques generally utilize a planar semiconductor detector over which a neutron reactive film has been deposited. Upon a surface of the semiconductor detector is attached a coating that responds to ionizing radiation reaction products upon the interaction with a neutron. The ionizing radiation reaction products can then enter into the semiconductor material of the detector thereby creating a charge cloud of electrons and "holes," which can be sensed to indicate the occurrence of a neutron interaction within the neutron sensitive film. The charges are swept through such configured detectors via methods known by those of ordinary skill in the art and registered as an electrical signal.

[0007] Another geometry includes etched trenches, slots, or holes in semiconductor materials having dimensions on the micron scale or larger that are filled with predetermined converter materials and configured with electrodes so as to produce detectors similar to the planar detector geometries discussed above.

[0008] Conventional solid state radiation detectors, however, suffer from efficiency, flexibility and scalability issues.

SUMMARY

[0009] According to one embodiment, an apparatus for detecting neutrons includes an array of pillars, wherein each of the pillars comprises a rounded cross sectional shape where the cross section is taken perpendicular to a longitudinal axis of the respective pillar, a cavity region between each of the pillars, and a neutron sensitive material located in each cavity region.

[0010] According to another embodiment, an apparatus for detecting neutrons includes an array of pillars, wherein a separation between each of the pillars is about uniform, a cavity region between each of the pillars, and a neutron sensitive material located in the cavity region.

[0011] According to yet another embodiment, an apparatus for detecting neutrons includes a substrate, an array of pillars above the substrate, wherein each of the pillars has an upper portion and a lower portion, wherein the lower portion of each of the pillars is positioned towards the substrate, wherein the upper portion of each pillar has a smaller average diameter relative to an average diameter of the lower portion of the pillar where the diameters are oriented perpendicular to a longitudinal axis of the pillar, a cavity region between each of the pillars, and a neutron sensitive material located in the cavity region.

[0012] According to a further embodiment, an apparatus for detecting neutrons, includes an array of pillars, a cavity region between each of the pillars, a neutron sensitive material located in each cavity region, and a stress-reducing layer coating at least a portion of each of the pillars and positioned between the pillars and the neutron sensitive material, wherein the stress-reducing layer at least partially counteracts a tensile and/or compressive stress exerted on the pillars by the neutron sensitive material.

[0013] Other aspects and embodiments of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] For a fuller understanding of the nature and advantages of the present invention, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

[0015] FIG. **1**A shows a schematic of a structure including an array of three dimensional high aspect ratio pillars with cavity regions etched between each of the pillars, according to one embodiment.

[0016] FIG. **1**B shows a schematic of a structure including an array of three dimensional high aspect ratio pillars with a neutron sensitive material located in cavity regions between each of the pillars, according to one embodiment.

[0017] FIG. **2** shows a schematic of a thermal neutron detector including a three dimensional array of high aspect ratio pillars, according to one embodiment.

[0018] FIG. **3** shows a flowchart of a method for fabricating a three dimensional array of high aspect ratio pillars, according to one embodiment.

[0019] FIG. **4**A shows a schematic of a square packed pillar array, according to one embodiment. FIG. **4**B shows a schematic of a hexagonally close packed array, according to one embodiment.

[0020] FIG. **5** shows a schematic of a structure including a segmented array of pillars, according to one embodiment.

[0021] FIG. **6** shows a flowchart of a method for fabricating a three dimensional array of high aspect ratio pillars, according to one embodiment.

[0022] FIG. **7** shows a flowchart of a method for fabricating a three dimensional array of high aspect ratio pillars, according to one embodiment.

[0023] FIG. **8** shows a flowchart of a method for fabricating a three dimensional array of high aspect ratio pillars, according to one embodiment.

[0024] FIGS. **9**A to **9**I show schematics of an array of pillars with varying types and degrees of stress, according to one embodiment.

[0025] FIGS. **10**A to **10**G show schematics of various cross sectional shapes of the pillars, according to some embodiments.

DETAILED DESCRIPTION

[0026] The following description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein. Further, particular features described herein can be used in combination with other described features in each of the various possible combinations and permutations.

[0027] Unless otherwise specifically defined herein, all terms are to be given their broadest possible interpretation including meanings implied from the specification as well as meanings understood by those skilled in the art and/or as defined in dictionaries, treatises, etc.

[0028] It must also be noted that, as used in the specification and the appended claims, the singular forms “a,” “an” and “the” include plural referents unless otherwise specified.

[0029] The following description discloses several preferred embodiments of neutron radiation detection using thermal neutron converter materials in three dimensional high efficiency configurations and/or related systems and methods.

[0030] In one general embodiment, an apparatus for detecting neutrons includes an array of pillars, wherein each of the pillars comprises a rounded cross sectional shape where the cross section is taken perpendicular to a longitudinal axis of the respective pillar, a cavity region between each of the pillars, and a neutron sensitive material located in each cavity region.

[0031] In another general embodiment, an apparatus for detecting neutrons includes an array of pillars, wherein a separation between each the pillars is about uniform, a cavity region between each of the pillars, and a neutron sensitive material located in the cavity region.

[0032] In yet another general embodiment, an apparatus for detecting neutrons includes a substrate, an array of pillars above the substrate, wherein each of the pillars has an upper portion and a lower portion, wherein the lower portion of each of the pillars is positioned towards the substrate, wherein the upper portion of each pillar has a smaller average diameter relative to an average diameter of the lower portion of the pillar where the diameters are oriented perpendicular to a longitudinal axis of the pillar, a cavity region between each of the pillars, and a neutron sensitive material located in the cavity region.

[0033] In a further general embodiment, an apparatus for detecting neutrons, includes an array of pillars, a cavity region between each of the pillars, a neutron sensitive material located in each cavity region, and a stress-reducing layer coating at least a portion of each of the pillars and positioned between the pillars and the neutron sensitive material, wherein the stress-reducing layer at least partially counteracts a tensile and/or compressive stress exerted on the pillars by the neutron sensitive material.

[0034] Three dimensional high aspect ratio pillars with a neutron sensitive material located in cavity regions between the pillars may be designed to decouple physical parameters by using two or more distinct materials. For example, one material may comprise the pillar material (e.g. silicon), which may act as a charge collecting media. Additionally, a second material may comprise a neutron sensitive material (e.g. Boron-10), which may absorb and/or interact with ionizing or non-ionizing matter (e.g. neutrons, gamma rays, x-rays etc).

[0035] In some instances, these three dimensional pillars may suffer from stress, such as a tensile and/or compressive stress, due to the physical contact between the neutron sensitive material and the pillars. The stress may lead to delamination of the neutron sensitive material, cracking of the pillars and unwanted electrical changes within the pillars. Consequently, embodiments of the present invention are directed to provide various structures, methods, etc. to reduce said stress. For instance, some exemplary approaches to alleviate the stress may include: modifying the shape, arrangement and geometry of the pillars; depositing a stress-reducing layer with an opposite polarity of stress as compared to the pillars, e.g. a stress-reducing layer having a compressive stress to compensate a tensile stress of the pillars, a stress reducing layer having a tensile stress to compensate a compressive stress of the pillars, or any combination thereof; depositing a sacrificial layer on the pillars; inclusion of dopants in the pillars and/or neutron sensitive material; altering and/or controlling the quantity of neutron sensitive material deposited in the cavity regions, etc.

[0036] FIGS. **1**A and **1**B depict structures **100** including a three dimensional array of high aspect ratio pillars, in accordance with one embodiment. As an option, the present structures **100** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such structures **100** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein.

[0037] As shown in FIG. **1**A according to one approach, a substrate **102** is etched to form an array of pillars **104** with cavity regions **106** between each of the pillars. The substrate may include, but is not limited to, a semiconductor material, silicon, quartz, etc. or other suitable substrates as would be understood by one skilled in the art upon reading the present disclosure.

[0038] In some approaches, an upper portion of each of the pillars **104** may include a p^+ layer (not shown in FIG. **1**A), where the upper portion of each of the pillars **104** is positioned away from the substrate **102**. In additional approaches, the substrate **102** may serve as an n^+ layer, such that the array of pillars on the substrate forms a p-i-n diode array. A high doping layer may be applied to cover the top layer of the pillars, and/or to cover all surfaces of the pillars, etc., in various approaches.

[0039] As depicted in FIG. **1**B, a neutron sensitive material **108** is deposited in the cavity regions **106** between each pillar **104** in the array. The neutron sensitive material **108** may be an atomic or molecular medium, a polymer, semiconductor, dielectric, etc. In preferred embodiments, the neutron sensitive material **108** is Boron-10 (^{10}B).

[0040] A second material, not shown in FIG. **1**B, may also fill the cavity regions **106**. In some approaches, the second material may provide stability for the array and may or may not be active in terms of the functionality of the pillar array (e.g. with regard to neutron detection). For example, the second material may include a non-rigid material, a polymer, etc.

[0041] The structure **100** may also include a coating of a functional or support material (not shown in FIG. **1**A or **1**B) deposited on the bottom surface of the substrate **102** and/or atop the pillar array. As an example, this coating may be metallic to form electrical contacts, e.g. electrodes, to serve as a sensor or detector. For instance, in one approach, aluminum may be sputtered on the bottom surface of the substrate **102** and/or atop the pillar array to form the electrodes.

[0042] Additionally, a structure comprising a three dimensional array of high aspect ratio pillars may be included in a neutron detector **200**, as shown in FIG. **2** per another embodiment. The neutron sensitive material **108** (e.g. ^{10}B) deposited in the cavity regions **106** between the pillars **104** may possess a relatively high cross section for thermal neutron interactions. For instance, interaction between a neutron and the neutron sensitive material (e.g. ^{10}B) results in the generation of alpha and ^{7}Li particles. These particles subsequently interact with the pillars (e.g. composed of Si) to produce electron-hole pairs. A voltage may then be applied to a pair of electrodes **202**, **204** coupled to the upper and/or lower surfaces of the detector **200** to promote the collection of the electrical signals generated by the electron-hole pairs. Processing hardware **206** of a type known in the art may be coupled to the electrodes **202**, **204** for detecting, processing, etc. the electrical signals generated by the neutron interaction with neutron sensitive material **108**. Any known detector components (e.g. pre-amplifiers, amplifiers, multi-channel analyzers, computers, etc.) may be used in combination with the novel structures presented herein to create neutron detectors, according to various embodiments.

[0043] In various approaches, the pillars **104** may have a high aspect ratio, thus the effect of neutron streaming through the pillars without passing through the neutron sensitive material is negligible, e.g. less than about 1%. For example, the aspect ratio of the pillars **104**, defined as the ratio of the height of the pillars relative to its width and/or pitch, may be in a range of about 1:1 to about 1000:1 or higher, e.g., about 1:1, about 10:1, about 25:1, about 50:1, and about 100:1.

[0044] With continued reference to FIG. **2**, each of the pillars **104** in the array may also have a diameter, d, of about 0.5 to about 5 μm in some approaches. In addition, each of the pillars may have a pitch, p, of about 2 to about 10 μm and a height (e.g. an etch depth), h, of about 2 to about 100 μm, e.g., about 4 μm, about 10 μm, about 12 μm, about 20 μm, about 50 μm, or about 100 μm, in more approaches. Further, the separation, s, between adjacent pillars may be in a range from about 1 μm to about 10 μm. It is important to note, however, that said pillar dimensions (diameter, pitch, height, aspect ratio, etc.) serve only as an example and are not limiting in any way, and various embodiments may have larger or smaller dimensions.

[0045] Furthermore, in exemplary approaches, the detector **200** including the three dimensional array of high aspect ratio pillars may offer various advantages over conventional neutron detectors, such as ^{3}He tubes and two dimensional solid-state thermal detectors. For example, the detector **200** may be capable of operating at a low voltage (e.g. less than about 5V); may be insensitive to vibrations and consequently well suited for handheld deployment/use; may achieve a high thermal neutron detection efficiency (e.g. greater than about 50%); may substantially discriminate between neutron and gamma ray measurement signals, preferably achieving a gamma discrimination of about 10^5; may be cost effective to fabricate/produce; may comprise a compact size, e.g. 1×1×0.1 cm^3, etc.

[0046] Referring now to FIG. **3**, a method **300** for fabricating an array of pillars that may form the support structure of a sensor, such a thermal neutron detector, is shown according to yet another embodiment. As an option, the present method **300** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such method **300** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein. Moreover, more or less operations than those shown in FIG. **3** may be included in method **300**, according to various embodiments. Furthermore, while exemplary processing techniques are presented, other known processing techniques may be used for various steps.

[0047] As shown in FIG. **3** according to one approach, a photolithographic mask **310** is applied to a substrate **102**. The substrate **102** is then etched to form an array of pillars **104**, with the array pattern defined by the photolithographic mask **310**. See transition from structure **302** to structure **304**. Etching the substrate **102** may include such techniques as dry etching by high density plasma (e.g. reactive ion etching), wet etching with or without using a surfactant, etc. Additionally, if the substrate **102** has been etched using a high density plasma etch, an optional step may include further wet etching the pillar surfaces using a surfactant or other etches that etch silicon in order to remove any plasma etch damage. Surfactants used during the wet etching may include ammonium fluoro alkyl sulfonamide in water or potassium hydroxide with isopropyl alcohol.

[0048] After the pillars have been formed, a neutron sensitive material **108** is deposited into the cavity regions **106** between each of the pillars **104** resulting in structure **306**. The neutron sensitive material **108** may be deposited via chemical vapor deposition (CVD), solution, nanoparticle based approaches, etc. according to various embodiments.

[0049] Overfilling the pillar array such that a large amount of the neutron sensitive material **108** is deposited on the pillars **104**, may cause substantial stress in the pillar array, may cause delamination of the neutron sensitive material **108**, cracking of the pillars and unwanted electrical changes in the pillars that may give rise to leakage current. Thus, in numerous approaches, the deposition of the neutron sensitive material **108** may be stopped such that the pillar structures are under-filled. Consequently, the neutron sensitive material **108** may not completely fill the cavity regions **106**, thereby defining gaps in the cavity regions **106** that are not filled with the neutron sensitive material **108**, in some approaches. Further, said gaps between the neutron sensitive material **108** and at least an upper portion of each pillar (e.g. the region positioned away from the substrate **102**) may exhibit a physical characteristic of reducing a stress (e.g. a tensile and/or compressive stress) of the pillar array in more approaches.

[0050] In yet another approach, the neutron sensitive material **108** may have a dopant or additional element (designating a higher concentration) therein, e.g. an additive, where the dopant has a physical characteristic of modifying, and preferably reducing a stress, e.g. a tensile and/or compressive

stress, of the neutron sensitive material **108**. For example, the dopant may modify the stress by changing the bonding configuration of the neutron sensitive material **108** in some approaches. The dopant may include, but is not limited to, nitrogen, oxygen, carbon, hydrogen or other such suitable dopants as would be understood by one skilled in the art.

[0051] A second material may be optionally deposited in the above mentioned gaps to provide support to the pillar structure, in a further approach. Preferably, this second material may not impart significant additional stress to the pillar array. This second material may be, for example, a non-rigid material, a polymer, etc. In preferred embodiments, the second material may be different from the material of the pillars **104** and/or the neutron sensitive material **108**. In addition, the second material may be deposited via chemical vapor deposition, spin coating, etc.

[0052] With continued reference to FIG. **3**, the neutron sensitive material **108** extending above the pillars **104** is etched back so that at least a section of an upper portion of the pillars **104** is exposed, where the upper portion of each of the pillars is positioned away from the substrate. See resulting structure **308**. Etching back the neutron sensitive material **108** may be achieved using such techniques as plasma beam etching, ion beam etching, lapping, applying an adhesive to delaminate or “tear off” the top layer, etc. In various approaches, after etching back the neutron sensitive material **108**, the thickness of the remaining neutron sensitive material **108** may be less than or equal to the height of the pillars **104**, where the thickness of the neutron sensitive material is measured parallel to the longitudinal axis of the respective material. For example is some approaches, the thickness of the neutron sensitive material **108** may be between about 2 μm to 100 μm, e.g. about 50 μm, etc.

[0053] As mentioned above, the photolithographic mask defines the geometry, arrangement and shape of each of the pillars **104** on the substrate **102**. For example, as shown in FIGS. **10**A-G according to some embodiments, illustrative cross sectional shapes of the pillars **104** as each one would be seen if viewed in cross section along a plane (denoted by line **10**A') oriented perpendicular to its longitudinal axis (z) may include, but is not limited to, a square (FIG. **10**B), octagon (FIG. **10**C), hexagon (FIG. **10**D), star (FIG. **10**E), triangle (FIG. **10**F), circle (FIG. **10**G), etc., or other such suitable shapes. However, pillars with cross sectional shapes having sharp corners (e.g. square, octagon, star, triangle etc.) may create high stress fields, which, when coupled with the stress induced from the neutron sensitive material deposited in the cavity regions, may cause the pillars to crack in some approaches. In addition, the deposition rate of a neutron sensitive material such as ^{10}B may be faster on flat edges than corners, creating further areas of stress in other approaches. Therefore, in preferred embodiments, each of the pillars may comprise a rounded cross sectional shape, where, as mentioned above, the cross section is taken perpendicular to a longitudinal axis. In further preferred embodiments, the rounded cross sectional shape of each of the pillars may be at least one of circular and ellipsoid. The rounded cross sectional shape of each of the pillars **104** may also have a physical characteristic of reducing a tensile and/or compressive stress associated with pillar array according to other exemplary approaches.

[0054] In some approaches, a pillar with a rounded cross sectional shape may be formed using a lithographic mask with the rounded feature therein. Alternatively, in other approaches, the lithographic mask may contain sharp corners thereby producing pillars with sharp corners that may subsequently be rounded, e.g., by overexposure during the lithographic exposure step, photoresist reflow, wet etching or plasma etching, etc.

[0055] Additionally, it may be preferable to achieve a high fill factor of the neutron sensitive material **108** within the array of pillars. However, where the neutron sensitive material **108** is deposited in the cavity regions **106** using a conformal coating method such as chemical vapor deposition, areas of the array may fill faster or slower than others, leading to areas having more or less neutron sensitive material relative to the other areas. This partial filling mechanism may be another source of stress formation within the array of pillars. Thus, in a preferred embodiment, the pillars may be arranged in the array such that a separation between each of the pillars is about uniform. For instance, in one approach, the array of pillars may be arranged in a hexagonally close packed (HCP) array **402** as shown in FIG. **4**B. With a HCP array **402**, the cavity regions **106** between each pillar **104** may be conceptually thought of as sections each having a generally triangular cross sectional shape. An HCP array **402** may provide a lower stress configuration than a square array **404** in exemplary approaches. Again, in some approaches, this reduction in stress may be because the distance from one pillar to the next is more uniform for the HCP array **402** than the square array **404**, shown in FIG. **4**A, and because there is less of a gap in the center of the cavity regions **106** (represented as an “x” in FIGS. **4**A and **4**B) of the HCP array **402** than the square array **404**.

[0056] Referring now to FIG. **5**, a structure **500** including a segmented array of pillars is shown according to a further embodiment. As an option, the present structure **500** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such structure **500** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein.

[0057] As shown in FIG. **5** according to one approach, an array of pillars is segmented into discrete segments **502** of the pillars, where the average distance, n, between adjacent pillars in each of the segments **502** is less than an average distance, m, between adjacent segments **502**. According to some embodiments, the size of each of the segments may be less than a crack domain size of 50-500 microns, where the domain size is defined as the diameter of a region with no cracked boron. By limiting the area of continuous pillars (e.g. the segments) to less than the crack domain size, the deleterious effects of stress (pillar cracking, delamination of the neutron sensitive material, etc.) may be avoided in various approaches.

[0058] According to some approaches the average distance, n, between adjacent pillars in each of the segments **502** may be in a range of about 1 μm to about 6 μm. In other approaches the cross sectional area of each of the segments **502** may be in a range between about 0.1 mm^2 to about 10 cm^2, or higher, where the cross sectional area is taken perpendicular to a longitudinal axis of the pillars in the respective segments. In even more approaches, a peripheral shape of the discrete segments **502** of pillars may be square, rectangular, rounded, ellipsoid, etc. and combinations of differing shapes.

[0059] Now referring to FIG. **6**, a method **600** for fabricating an array of pillars where each pillar has a tapered profile **616**, is shown according to one embodiment. As an option, the present method **600** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such method **600** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein. Moreover, more or less operations than those shown in FIG. **6** may be included in method **600**, according to various embodiments. Furthermore, while exemplary processing techniques are presented, other known processing techniques may be used for various steps.

[0060] As shown in FIG. **6** according to one approach, a substrate **102** is etched to form an array of pillars **104** and cavity regions **106**, with the array pattern defined by a photolithographic mask **310**. See the transition from structure **602** to structure **604**. Etching the substrate **102** may include such techniques as, dry etching by high density plasma (e.g. reactive ion etching), wet etching using a surfactant, etc. Additionally, if the substrate **102** has been etched using a high density plasma etch, an optional step may include further wet etching the pillar surfaces using a surfactant in order to achieve an isotropic etch and reduce plasma etch damage. Surfactants used during the wet etching may include ammonium fluoro alkyl sulfonamide in water, which may be used to lower the surface tension of the mixture making the solution wettable to silicon, or other suitable surfactant(s) as would be understood by one having skill in the art upon reading the present disclosure.

[0061] As shown in FIG. **6**, each pillar **104** in the array has an upper portion **612** and a lower portion **614**, where the lower portion of each of the pillars is positioned towards the substrate **102**. After the pillars **104** have been formed, the upper portions **612** of the pillars **104** are etched to reduce the average diameters thereof, resulting in structure **606**. Etching the upper portions **612** of the pillars **104** may involve wet etching without use of a surfactant. In some approaches, the wet etchant may be a silicon etchant, a mixture of hydrofluoric acid, nitric acid and acetic acid, etc. An illustrative etch rate may be in a range between about 500 Å/min to about 1500 Å/min.

[0062] In some approaches, application of a wet chemical etchant on the pillars **104** without a surfactant to wet the surface of the pillars may only isotropically wet etch the entrance (e.g. the upper portion **612**) of the pillars. In more embodiments, the wet etch may be confined to the upper portions **612** of the pillars **104** by adjusting the concentrations and temperature of the wet etchant. Additionally, at least the upper portions **612** of the pillars **104** may include dopants (e.g. boron, phosphorus, arsenic, etc.) therein, which may modify the etch rate and/or aid in confining the etching to specific portions of the pillars **104**. For example, in numerous approaches, the dopant may have a physical characteristic of increasing an etch rate of the upper portion **612** of the pillars **104**.

[0063] As a result of the etching, the upper portion **612** of each pillar **104** may have a smaller average diameter relative to an average diameter of the lower portion **614** of the pillar **104** according to one approach, where diameters are oriented perpendicular to a longitudinal axis of the pillar **104**. Further, the diameter of each lower portion **614** and the diameter of each upper portion **612** may be about constant along the longitudinal axis of the associated pillar **104** in yet another approach.

[0064] Referring to structure **608**, a neutron sensitive material **108** is deposited into the cavity regions **106** between each of the pillars **104**. The neutron sensitive material **108** extending above the pillars is etched back so that at least a section of an upper portion of the pillars **104** is exposed, resulting in structure **610**. Etching back the neutron sensitive material **108** may be achieved using such techniques as plasma beam etching, ion beam etching, lapping, etc. In various embodiments, after etching back the neutron sensitive material **108**, the thickness of the remaining neutron sensitive material **108** may be greater than, equal to or preferably less than the height of the pillars **104**, where the thickness of the neutron sensitive material is measured parallel to the longitudinal axis of any of the pillars.

[0065] The tapered profile **616** of the pillars, where the average diameters of the upper portions **612** of the pillars **104** are less than the average diameters of the lower portions **614** of the pillars **104**, may facilitate, allow, etc. a substantially conformal coating of the neutron sensitive material **108** in the cavity regions **106** without "over-filling." Over-filling occurs when there is buildup of material near the upper portions **612** of the pillars **104**. Such over-filling may cause additional strain and stress in the array of pillars in some approaches. Thus, pillars **104** with a tapered profile **616** may have a physical characteristic of reducing a stress, e.g. a tensile and/or compressive stress, associated with the array of pillars. Moreover, such overfilling may result in closure of the cavity region near the upper portions **612** of the pillars, thereby preventing complete filling of the cavity regions **106** along the lower portions **614** of the pillars **104**.

[0066] Referring now to FIG. **7**, a method **700** for fabricating an array of pillars is shown according to one embodiment. As an option, the present method **700** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such method **700** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein. Moreover, more or less operations than those shown in FIG. **7** may be included in method **700**, according to various embodiments. Furthermore, while exemplary processing techniques are presented, other known processing techniques may be used for various steps.

[0067] As shown in FIG. **7** according to one approach, a substrate **102** is etched to form an array of pillars **104** and cavity regions **106**, with the array pattern defined by a photolithographic mask **310**. See the transition from structure **702** to structure **704**. Etching the substrate **102** may include such techniques as, dry etching by high density plasma (e.g. reactive ion etching), wet etching using a surfactant which may allow a wettable surface due to lowered surface tension, etc. Additionally, if the substrate **102** has been etched using a high density plasma etch, an optional step may include further wet etching the pillar surfaces using a surfactant in order to remove any plasma etch damage. Surfactants used during the wet etching may include ammonium fluoro alkyl sulfonamide in water, in some approaches.

[0068] After the pillars have been formed, a sacrificial layer **716** may be applied and/or deposited on the pillars **104** resulting in structure **706**. The sacrificial layer **716** may be depos-

ited on and/or applied to the pillars **104** via numerous techniques, including but not limited to chemical vapor deposition, dry or wet oxidation, atomic layer deposition, etc.

[0069] In one embodiment the sacrificial layer may have a thickness in a range of about 500 Å to about 2000 Å, but could be higher or lower. In another embodiment, the sacrificial layer **716** may include an oxide, SiO_2, etc. In yet another embodiment, the sacrificial layer **716** may be chosen based on its ability to be selectively etched by various etchants. For instance, the sacrificial layer **716** may be selected such that an etching process, e.g. wet etching, may selectively etch the sacrificial layer material without etching the pillar material and/or neutron sensitive material.

[0070] Referring to structure **708**, a neutron sensitive material **108** is deposited into the cavity regions **106** over the sacrificial layer **716**. In one approach, the neutron sensitive material **108** may include Boron-10 (^{10}B), which has a very high thermal neutron cross section of 3837 barns. An upper portion of the neutron sensitive material **108** extending above the pillars is then removed to expose a portion of the sacrificial layer **716**, as shown in structure **710**. In various approaches, after etching back the neutron sensitive material **108**, the thickness of the remaining neutron sensitive material **108** may be greater than, less than or equal to the height of the pillars **104**, where the thickness of the neutron sensitive material **108** is measured parallel to the longitudinal axes of the pillars **104**.

[0071] After removing the upper portion of the neutron sensitive material **108**, an etchant is applied to substantially remove the sacrificial layer **716**, preferably at least 90% thereof by volume. See resulting structure **712**. The wet etchant may be chosen based on its ability to selectively etch the sacrificial layer while not affecting (i.e. etching) the pillar material or neutron sensitive material. For example, the etchant may include a buffered oxide etch (BOE)/HF (with or without a surfactant) solution in some approaches.

[0072] After application of the etchant to substantially remove the sacrificial layer **716**, a spacing **718** may be present between the pillars **104** and the neutron sensitive material **108**. In preferred embodiments, the spacing may be empty and have physical characteristics of a previously-present sacrificial layer **716** that has been removed after formation of the neutron sensitive material **108** in the cavity **106**. Typically, stress associated with the array of pillars may arise due to the large internal stress of the neutron sensitive material **108**, such as ^{10}B, which may then transfer to the pillars **104** because of the contact between the pillars **104** and the neutron sensitive material **108**. Consequently, the spacing **718** may remove the source of the stress from the pillars **104** in various approaches. Additionally, the array of pillars may retain, trap, store etc. electrical charge due to the contact between the neutron sensitive material **108** and the pillars **104**, thus the spacing **718** may reduce the capacitance (e.g. the ability to store charge) associated with the array of pillars.

[0073] Referring now to FIG. **8**, method **800** for fabricating an array of pillars that may form the support structure of a sensor, such a thermal neutron detector, is shown according to yet another embodiment. As an option, the present method **800** may be implemented in conjunction with features from any other embodiment listed herein, such as those described with reference to the other FIGS. Of course, however, such method **900** and others presented herein may be used in various applications and/or in permutations, which may or may not be specifically described in the illustrative embodiments listed herein. Moreover, more or less operations than those shown in FIG. **8** may be included in method **800**, according to various embodiments. Furthermore, while exemplary processing techniques are presented, other known processing techniques may be used for various steps.

[0074] As shown in FIG. **8** according to one approach, a substrate **102** is etched to form an array of pillars **104** and cavity regions **106**, with the array pattern defined by a photolithographic mask **310**. See the transition from structure **802** to structure **804**. Etching the substrate **102** may include such techniques as, dry etching by high density plasma (e.g. reactive ion etching), wet etching using a surfactant, etc. Additionally, if the substrate **102** has been etched using a high density plasma etch, an optional step may include further wet etching the pillar surfaces using a surfactant in order to remove any plasma etch damage. Surfactants used during the wet etching may include ammonium fluoro alkyl sulfonamide in water, in some approaches.

[0075] After the pillars have been formed, a stress-reducing layer **812** is deposited to coat at least one portion of the pillars in the array, resulting in structure **806**. The stress-reducing layer **812** may include, but is not limited to, dielectric materials, SiO_2, Si_3N_4, SiN_x, SiO_xN_y, Ta_2O_5, Al_2O_3, amorphous silicon and poly silicon, etc. The stress-reducing layer **812** may also have a thickness in a range of about 500 Å to about 2000 Å, in some approaches, but could be higher or lower.

[0076] After deposition of the stress-reducing layer **812**, a neutron sensitive material **108** is deposited in the cavity regions **106** between the pillars **104** in the array, such that the stress-reducing layer **812** is positioned between the pillars **104** and the neutron sensitive material **108**, as shown in structure **808**. The neutron sensitive material **108** extending above the pillars **104** is then etched back so that at least a section of an upper portion of the stress-reducing layer **812** is exposed, where the upper portion of the stress-reducing layer is positioned away from the substrate. See structure **810**. Etching back the neutron sensitive material **108** may be achieved using such techniques as plasma beam etching, ion beam etching, lapping, etc. In various approaches, after etching back the neutron sensitive material **108**, the thickness of the remaining neutron sensitive material **108** may be greater than, less than or equal to the height of the stress-reducing layer **812**, where the thickness of the neutron sensitive material is measured parallel to the longitudinal axes of the pillars **104**. Additionally the thickness of the remaining neutron sensitive material **108** may be greater than, less than or equal to the height of the pillars **104** in the direction parallel to the axes, according to other approaches.

[0077] The neutron sensitive material **108**, such as ^{10}B, may subject the pillars in the array to stress, e.g. a tensile and/or compressive stress, ultimately leading to such deleterious effects as pillar cracking. Thus, in some approaches, the stress-reducing layer **812** may at least partially counteract a tensile and/or compressive stress exerted on the pillars by the neutron sensitive material. An example is provided in FIGS. **9**A-**9**F, according to one embodiment. As shown in FIG. **9**A, a substrate **902**, e.g. a silicon substrate, coated with a stress-reducing layer **904**, such as SiO_2, may exhibit a compressive stress. As shown in FIG. **9**B, a substrate **902** coated with a layer **906** comprising, e.g. a neutron sensitive material such as ^{10}B, may exhibit a tensile stress. However, a substrate **902** coated with both the stress-reducing layer **904** and the layer **906** may exhibit no stress, as illustrated in FIG. **9**C.

[0078] In another embodiment, a substrate **908** (e.g. silicon) coated with a stress-reducing layer **910** may exhibit a tensile stress, as shown in FIG. **9**D. Conversely, a substrate **908** coated with a layer **912** comprising, e.g. a neutron sensitive material such as ^{10}B, may exhibit a compressive stress, as shown in FIG. **9**E. Accordingly, the substrate **902** coated with the stress-reducing layer **910** and the layer **906** may exhibit no stress, as illustrated in FIG. **9**F.

[0079] Further, as shown in FIG. **9**G, a silicon pillar **908** coated with a SiO_2 compressive layer **910** may subject the pillar **908** to a compressive stress (as indicated by the direction of the illustrated arrows) in one approach. Conversely, a silicon pillar **908** coated with a SiN_x compressive layer **912** may subject the pillar **908** to a tensile stress (as indicated by the illustrative arrows) in another approach shown in FIG. **9**H. Consequently, tuning the relative amounts of oxygen and nitrogen in a SiO_xN_y compressive layer **914** present on a pillar **908** may result in about no stress to the silicon pillar **908**, as shown in FIG. **9**I according to yet another approach.

[0080] With continued reference to FIG. **8**, one or more parameters during the deposition, e.g. chemical vapor deposition, of the stress-reducing layer **812** may be modified to alter counteraction of a stress, e.g. a tensile and/or compressive stress, according to one embodiment. Said parameters may include, but are not limited to, temperature, RF power, concentration of one or more backflowing gases, etc.

[0081] In another embodiment, the stress-reducing layer **812** may have a physical characteristic of mitigating diffusion of H and/or ^{10}B into the pillars during a deposition process. In yet another embodiment, the stress-reducing layer **812** may have a physical characteristic of reducing leakage current arising from bandgap shrinkage.

[0082] Any of the methods described above, taken individually or in combination, in whole or in part, may be included in or used to make one or more systems, structures, etc. For example, a thermal neutron detector may include a structure having an array of pillars, a cavity region between the pillars and a neutron sensitive material located in each cavity. Further said apparatus may implement the features from any other embodiments listed herein.

[0083] In addition, any of the features presented herein may be combined in any combination to create various embodiments, any of which fall within the scope of the present invention. Following are several examples of general and specific embodiments.

[0084] For example, in one embodiment, each of the pillars may comprise silicon (Si). In other embodiments, each of the pillars may comprise an aspect ratio of less than about 5:1, less than about 10:1; less than about 25:1; less than about 50:1; or less than about 100:1.

[0085] In yet another embodiment, each of the pillars may have a rounded cross sectional shape where the cross section is taken perpendicular to a longitudinal axis of the respective pillar. The rounded cross sectional shape of the pillars may be at least one of circular and ellipsoid in some approaches. In more approaches, the rounded cross sectional shape of each of the pillars may have a physical characteristic of reducing a stress, e.g. a tensile and/or compressive stress, associated with an array of pillars. In other approaches, the rounded cross sectional shape of each of the pillars may have a physical characteristic of reducing a deposition rate of the neutron sensitive material on each of the pillars.

[0086] In a further embodiment, a separation between each of the pillars may be about uniform. The about uniform separation between each of the pillars may have a physical characteristic of reducing a stress associated with the array of pillars in some approaches. For example, an about uniform separation between the pillars may result where the pillars are arranged in a hexagonally close packed (HCP) array (see **502** of FIG. **5**). In such approaches where the pillars may be arranged in a HCP array, the cavity regions between each of the pillars may be conceptually thought of as sections each having a generally triangular cross sectional shape.

[0087] Additionally, in one embodiment, each of the pillars may have a tapered profile, as shown in FIG. **6**. For instance, each pillar, having an upper portion and a lower portion, where the lower portion of each of the pillars is positioned towards a substrate, may have an upper portion with a smaller average diameter relative to an average diameter of the lower portion of the pillar, where the diameters are oriented perpendicular to a longitudinal axis of the pillar. In some approaches, the diameter of each lower portion and the diameter of each upper portion may be about constant along the longitudinal axis of the associated pillar. In others approaches, the upper portions of the pillars may have a dopant therein, where the dopant may have a physical characteristic of modifying, preferably increasing, an etch rate of the upper portion of each of the pillars. The dopant may include carbon, nitrogen, oxygen, hydrogen or other such suitable dopant as would be recognized by one skilled in the art upon reading the present disclosure.

[0088] According to another embodiment, the neutron sensitive material may not completely fill the cavity regions, thereby defining gaps in the cavity region that are not filled with the neutron sensitive material. Said gaps between the neutron sensitive material and at least an upper portion of each of the pillars may, in certain approaches, have a physical characteristic of reducing a stress, e.g. a tensile and/or compressive stress, associated with array of pillars. In additional approaches, the gaps may be filled with a second material such as a non-rigid material, a polymer, etc. to make the pillar array more robust, while preferably not imparting significant additional stress on the pillar array. In preferred approaches, the second material may be composed of a different material than the pillar and/or the neutron sensitive material.

[0089] According to yet another embodiment, the neutron sensitive material may have a dopant therein, where the dopant may have a physical characteristic of modifying, and preferably reducing, a stress (e.g. a tensile and/or compressive stress) associated with the neutron sensitive material. In various approaches, the dopant may include, but is not limited to, carbon, nitrogen, hydrogen, oxygen, etc.

[0090] According to a further embodiment, the neutron sensitive material filling the cavity regions may have physical characteristics of being formed via chemical vapor deposition. For example, the neutron sensitive material may comprise a conformal coating of said material within the cavity regions between the pillars. In an additional embodiment, the neutron sensitive material may be Boron-10 (^{10}B).

[0091] In yet another embodiment, a spacing may be present between the pillars and the neutron sensitive material. In various approaches, the spacing may have a physical characteristic of a previously-present sacrificial layer that has been removed after formation of the neutron sensitive material in the cavity regions between each of the pillars. In preferred approaches, the spacing may be empty, e.g. devoid of at least 90% by volume of a previously-present sacrificial layer.

[0092] Further, in one embodiment, the array of pillars may comprise a stress-reducing layer coating at least a portion of each of the pillars, where the stress-reducing layer may be positioned between the pillars and neutron sensitive material. The stress-reducing layer may comprise a dielectric material, SiO_2, Si_3N_4, SiO_xN_y, Ta_2O_5, Al_2O_3, amorphous silicon, poly silicon, etc. The stress-reducing layer may also have a thickness of less than about 2000 Å, less than about 1000 Å, less than about 500 Å, etc. in one approach.

[0093] In some approaches the stress-reducing layer may at least partially counteract a tensile and/or compressive stress exerted on the pillars by the neutron sensitive material (e.g. as shown in FIG. **9**A-F). In other approaches, the stress-reducing layer may have a physical characteristic of reducing current leakage arising from bandgap shrinkage. In even more approaches, the stress-reducing layer may have a characteristic of mitigating diffusion of H and/or ^{10}B into the pillars during a chemical vapor deposition process.

[0094] In additional embodiments, the array of pillars may be segmented into discrete segments of the pillars, where an average distance between adjacent pillars in each of the segments is less than an average distance between adjacent segments, as shown in FIG. **5**. Moreover, a size of each of the segments may be less than a crack domain size, where the crack domain size is defined as the diameter or a region with no cracked boron.

[0095] While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. An apparatus for detecting neutrons, comprising:

an array of pillars, wherein each of the pillars comprises a rounded cross sectional shape where the cross section is taken perpendicular to a longitudinal axis of the respective pillar;

a cavity region between each of the pillars; and

a neutron sensitive material located in each cavity region.

2. The apparatus of claim **1**, wherein the neutron sensitive material is Boron-10 (^{10}B).

3. The apparatus of claim **1**, wherein each of the pillars comprises an aspect ratio of less than about 50:1.

4. The apparatus of claim **1**, wherein each of the pillars comprises silicon (Si).

5. The apparatus of claim **1**, wherein the rounded cross sectional shape of each of the pillars is at least one of circular and ellipsoid.

6. The apparatus of claim **1**, wherein the neutron sensitive material does not completely fill the cavity region, thereby defining gaps in the cavity region that are not filled with the neutron sensitive material.

7. The apparatus of claim **6**, wherein the gaps are filled with a second material.

8. The apparatus of claim **1**, wherein the array is segmented into discrete segments of the pillars, wherein an average distance between adjacent pillars in each of the segments is less than an average distance between adjacent segments.

9. The apparatus of claim **1**, wherein a spacing is present between the pillars and the neutron sensitive material.

10. A method for forming the apparatus of claim **9**, the method comprising:

forming the pillars;

applying a sacrificial layer to the pillars;

depositing the neutron sensitive material in the cavity region over the sacrificial layer;

removing an upper portion of the neutron sensitive material to expose a portion of the sacrificial layer; and

applying an etchant to substantially remove the sacrificial layer.

11. The apparatus of claim **1**, wherein the neutron sensitive material has a dopant therein, the dopant having a physical characteristic of modifying a stress of the neutron sensitive material.

12. An apparatus for detecting neutrons, comprising:

an array of pillars, wherein a separation between each the pillars is about uniform;

a cavity region between each of the pillars; and

a neutron sensitive material located in the cavity region.

13. The apparatus of claim **12**, wherein the neutron sensitive material is Boron-10 (^{10}B).

14. The apparatus of claim **12**, wherein the array of pillars are arranged in a hexagonally close packed array.

15. The apparatus of claim **12**, wherein the neutron sensitive material does not completely fill the cavity region, thereby defining gaps in the cavity region that are not filled with the neutron sensitive material.

16. The apparatus of claim **15**, wherein the gaps are filled with a second material.

17. The apparatus of claim **12**, wherein a spacing is present between the pillars and the neutron sensitive material.

18. A method for forming the apparatus of claim **17**, the method comprising:

forming the pillars;

applying a sacrificial layer to the pillars;

depositing the neutron sensitive material in the cavity region over the sacrificial layer;

removing an upper portion of the neutron sensitive material to expose a portion of the sacrificial layer; and

applying an etchant to substantially remove the sacrificial layer.

19. The apparatus of claim **12**, wherein the neutron sensitive material has a dopant therein, the dopant having a physical characteristic of modifying a stress of the neutron sensitive material.

20. An apparatus for detecting neutrons, comprising:

a substrate;

an array of pillars above the substrate, wherein each of the pillars has an upper portion and a lower portion, wherein the lower portion of each of the pillars is positioned towards the substrate, wherein the upper portion of each pillar has a smaller average diameter relative to an average diameter of the lower portion of the pillar where the diameters are oriented perpendicular to a longitudinal axis of the pillar;

a cavity region between each of the pillars; and

a neutron sensitive material located in the cavity region.

21. The apparatus of claim **20**, wherein the neutron sensitive material is Boron-10 (^{10}B).

22. The apparatus of claim **20**, wherein a diameter of each lower portion is about constant along the longitudinal axis of the associated pillar, wherein a diameter of each upper portion is about constant along the longitudinal axis of the associated pillar.

23. The apparatus of claim **20**, further comprising a dopant in the upper portion of each of the pillars, wherein the dopant

has a physical characteristic of increasing an etch rate of the upper portion of each of the pillars.

24. The apparatus of claim **20**, wherein the neutron sensitive material does not completely fill the cavity region, thereby defining gaps in the cavity region that are not filled with the neutron sensitive material.

25. The apparatus of claim **24**, wherein the gaps are filled with a second material.

26. A method for forming the apparatus of claim **20**, the method comprising:

forming the pillars;

etching the upper portions of the pillars for reducing the average diameters thereof; and

depositing the neutron sensitive material in the cavity region between the pillars.

27. The method of claim **26**, wherein the neutron sensitive material is deposited via chemical vapor deposition.

28. The method of claim **26**, wherein etching the upper portions of the pillars comprises wet etching.

29. The apparatus of claim **20**, wherein a spacing is present between the pillars and the neutron sensitive material.

30. A method for forming the apparatus of claim **29**, the method comprising:

forming the pillars;

applying a sacrificial layer to the pillars;

depositing the neutron sensitive material in the cavity region over the sacrificial layer;

removing an upper portion of the neutron sensitive material to expose a portion of the sacrificial layer; and

applying an etchant to substantially remove the sacrificial layer.

31. The apparatus of claim **20**, wherein the neutron sensitive material has a dopant therein, the dopant having a physical characteristic of modifying a stress of the neutron sensitive material.

32. An apparatus for detecting neutrons, comprising:

an array of pillars;

a cavity region between each of the pillars;

a neutron sensitive material located in each cavity region; and

a stress-reducing layer coating at least a portion of each of the pillars and positioned between the pillars and the neutron sensitive material, wherein the stress-reducing layer at least partially counteracts a tensile and/or compressive stress exerted on the pillars by the neutron sensitive material.

33. The apparatus of claim **32**, wherein the neutron sensitive material is Boron-10 (^{10}B).

34. The apparatus of claim **32**, wherein the stress-reducing layer has a thickness of less than about 2000 Å.

35. The apparatus of claim **32**, wherein the stress-reducing layer comprises a dielectric material.

36. The apparatus of claim **32**, wherein the neutron sensitive material does not completely fill the cavity region, thereby defining gaps in the cavity region that are not filled with the neutron sensitive material.

37. The apparatus of claim **36**, wherein the gaps are filled with a second material.

38. A method for forming the apparatus of claim **32**, the method comprising:

forming the pillars;

depositing the stress-reducing layer to at least one portion of each of the pillars;

and depositing the neutron sensitive material in the cavity region.

39. The method of claim **38**, further comprising modifying a parameter during deposition of the stress-reducing layer to alter counteraction of the tensile and/or compressive stress.

40. The method of claim **38**, wherein the stress-reducing layer has a physical characteristic of mitigating diffusion of H and/or ^{10}B into the pillars during a chemical vapor deposition process.

41. The apparatus of claim **32**, wherein a spacing is present between the pillars and the neutron sensitive material.

42. A method for forming the apparatus of claim **41**, the method comprising:

forming the pillars;

applying a sacrificial layer to the pillars;

depositing the neutron sensitive material in the cavity region over the sacrificial layer;

removing an upper portion of the neutron sensitive material to expose a portion of the sacrificial layer; and

applying an etchant to substantially remove the sacrificial layer.

43. The apparatus of claim **32**, wherein the neutron sensitive material has a dopant therein, the dopant having a physical characteristic of modifying.

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