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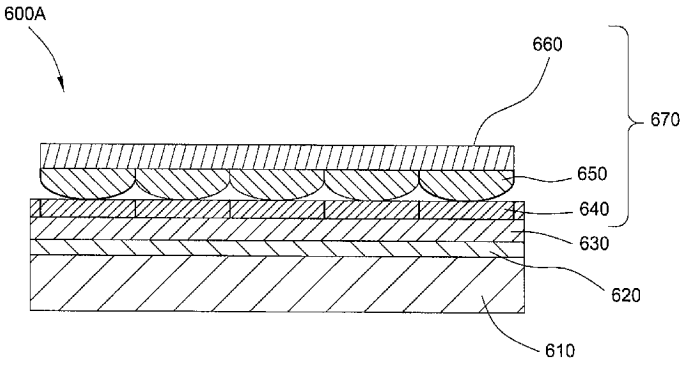

FIG. 6A

(57) Abstract: Embodiments of the invention generally relate to epitaxial lift off (ELO) thin films and devices and methods used to form such films and devices. The ELO thin films generally contain epitaxially grown layers which are formed on a sacrificial layer disposed on or over a substrate, such as a wafer. A support handle may be disposed on the opposite side of the epitaxial material than the substrate. The support handle may be used to stabilize the epitaxial material, such as by providing compression to the epitaxial material. Furthermore, the support handle may be used to grip and hold the epitaxial material during the etching and removal steps of the ELO process. In various embodiments, the support handle may include a pre-curved handle, a multi-layered handle, a non-uniform wax handle, and two shrinkage-induced handles which universally or unidirectional shrink to provide compression to the epitaxial material.

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EPITAXIAL LIFT OFF STACKS AND METHODS

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] Embodiments of the invention generally relate to the fabrication of solar, semiconductor, and electronic devices, and more particularly to epitaxial lift off (ELO) devices and methods.

Description of the Related Art

[0002] One phase in device fabrication involves handling and packaging of thin films used as solar devices, semiconductor devices, or other electronic devices. Such thin film devices may be manufactured by utilizing a variety of processes for depositing and removing materials onto a wafer or other substrate. One uncommon technique for manufacturing thin film devices is known as the epitaxial lift off (ELO) process. The ELO process includes depositing an epitaxial layer or film on a sacrificial layer on a growth substrate, then etching the sacrificial layer to separate the epitaxial layer from the growth substrate. The thin epitaxial layer removed is known as the ELO film or layer and typically includes thin films used as solar devices, semiconductor devices, or other electronic devices.

[0003] The thin ELO films are very difficult to manage or handle, such as when bonding to a substrate or while packaging, since the ELO films are very fragile and have narrow dimensions. The ELO films crack under very small forces. Also, the ELO films are very difficult to align due to their extremely narrow dimensions.

[0004] The sacrificial layer is typically very thin and is usually etched away via a wet chemical process. The speed of the overall process may be limited by the lack of delivery or exposure of reactant to the etch front, which leads to less removal of by products from the etch front. This described process is a diffusion limited process and if the films were maintained in their as deposited geometries, a very narrow and long opening would form to severely limit the overall speed of the process. To lessen the transport constraint of the diffusion processes, it may be

beneficial to open up the resulting gap created by the etched or removed sacrificial layer and bending the epitaxial layer away from the growth substrate. A crevice is formed between the epitaxial layer and the growth substrate – which geometry provides greater transport of species both towards and away the etch front. Reactants move towards the etch front while by-products generally move away from the etch front.

[0005] The bending of the epitaxial layer however can induce stresses there within and the amount of bending is limited by the strength of the film. The epitaxial layer usually contains a brittle material, which does not undergo plastic deformation before failure, and as such may be subject to crack induced failures.

[0006] To minimize the potential for crack propagation, the brittle epitaxial layer may be maintained under a compressive stress. Cracks usually do not propagate through regions of residual compressive stress. The epitaxial layer is placed under tensile stress while bending the epitaxial layer away from the growth substrate since the epitaxial layer is on the outside of the curvature of the crevice. The tensile stress limits the amount of crevice curvature and reduces the speed of the etch process. To overcome this limitation, a residual compressive stress may be instilled within the epitaxial layer before etching the sacrificial layer. This initial compressive stress may be offset by tensile stress caused by the bending and therefore allows for a greater amount bending during the separation process.

[0007] Therefore, there is a need for more robust ELO thin films, as well as for methods to form, remove, and handle ELO thin films.

SUMMARY OF THE INVENTION

[0008] Embodiments of the invention generally relate to epitaxial lift off (ELO) thin films and devices and methods used to form such films and devices. The ELO thin films generally contain epitaxially grown layers which are formed on a sacrificial layer disposed on or over a substrate, such as a wafer. A support material or support handle may be disposed on the opposite side of the epitaxial material than

the substrate. The support handle may be used to stabilize the epitaxial material, such as by providing compression to the epitaxial material. Furthermore, the support handle may be used to grip and hold the epitaxial material during the etching and removal steps of the ELO process. In various embodiments, the support material or support handle may include a pre-curved handle, a multi-layered handle, a non-uniform wax handle, and two shrinkage-induced handles which universally or unidirectional shrink to provide compression to the epitaxial material.

[0009] In one embodiment, a method for forming a thin film material during an ELO process is provided which includes forming an epitaxial material on or over a sacrificial layer, which is disposed on or over on a substrate, adhering a multi-layered support handle onto the epitaxial material, removing the sacrificial layer during an etching process, and peeling the epitaxial material from the substrate while forming an etch crevice therebetween while maintaining compression in the epitaxial material during the etching process. The method further provides that the multi-layered support handle contains a stiff support layer disposed on or over or adhered to the epitaxial material, a soft support layer adhered to the stiff support layer, and a handle plate adhered to the soft support layer.

[0010] In one example, the multi-layered support handle contains a stiff support layer disposed over the epitaxial material, a soft support layer disposed over the stiff support layer, and a handle plate disposed over the soft support layer. The multi-layered support handle is disposed on and maintains compression of the epitaxial material. In some embodiments, the stiff support layer may contain a polymer, a copolymer, an oligomer, derivatives thereof, or combinations thereof. In one example, the stiff support layer contains a copolymer, such as an ethylene/vinylacetate (EVA) copolymer or a derivative thereof. In other examples, the stiff support layer may contain a hot-melt adhesive, an organic material or organic coating, an inorganic material, or combinations thereof. In one example, the inorganic material contains multiple inorganic layers, such as metal layers and/or dielectric layers. In another example, the stiff support layer may contain composite materials or patterned composite materials, such as organic/inorganic materials.

The composite materials may contain at least one organic material and at least one inorganic material. In some examples, the inorganic material may contain a metal layer, a dielectric layer, or combinations thereof. In another example, the stiff support layer may contain wax or derivatives thereof, such as black wax.

[0011] In other embodiments, the soft support layer may contain an elastomer, such as rubber, foam, or derivatives thereof. Alternatively, the soft support layer may contain a material such as neoprene, latex, or derivatives thereof. The soft support layer may contain a monomer. For example, the soft support layer may contain an ethylene propylene diene monomer or derivatives thereof. In another embodiment, the soft support layer may contain a liquid or a fluid contained within a membrane. Alternatively, the soft support layer may contain a gas contained within a membrane. The membrane may contain a material such as rubber, foam, neoprene, latex, or derivatives thereof. In one example, the membrane is a balloon, such as a rubber balloon or a latex balloon.

[0012] In another embodiment, the handle plate may be made from or contain a plastic material, a polymeric material, or an oligomeric material, derivatives thereof, mixtures thereof, or combinations thereof. In one example, the handle plate may contain polyester or derivatives thereof. The handle plate may have a thickness within a range from about 50.8 μm to about 127.0 μm, such as about 23.4 μm.

[0013] In one embodiment, the method further includes removing the epitaxial material from the substrate and attaching a support substrate to an exposed surface of the epitaxial material. The support substrate may be bonded to the exposed surface of the epitaxial material by an adhesive, thereby forming an adhesive layer therebetween. In one example, the adhesive is an optical adhesive and/or may be UV-curable (e.g., cured by ultraviolet light exposure). In some examples, the adhesive may contain a mercapto ester compound. In other examples, the adhesive may further contain a material such as butyl octyl phthalate, tetrahydrofurfuryl methacrylate, acrylate monomer, derivatives thereof, or combinations thereof.

[0014] In another embodiment, a thin film material, such as an ELO thin film stack, is provided which includes a support substrate disposed on or over a first surface of the epitaxial material, and a support handle disposed on or over the other surface of the epitaxial material. An adhesive layer may be disposed between the epitaxial material and the support substrate. In one example, the support handle may be a multi-layered support handle which contains the stiff support layer disposed on or over the epitaxial material, the soft support layer disposed on or over the stiff support layer, and the handle plate disposed on or over the soft support layer.

[0015] In another embodiment, the ELO thin film stack is provided which includes a sacrificial layer disposed on a substrate, an epitaxial material disposed on or over the sacrificial layer, and a flattened, pre-curved support material or handle disposed on or over the epitaxial material. The flattened, pre-curved support handle is under tension while the epitaxial material is under compression. The flattened, pre-curved support handle may contain a single layer or multiple layers. The flattened, pre-curved support handle may contain wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, or combinations thereof. In some examples, the flattened, pre-curved support handle contains wax. In other examples, the flattened, pre-curved support handle contains polyethylene terephthalate polyester or derivatives thereof. In other examples, the flattened, pre-curved support handle contains polyolefin or derivatives thereof.

[0016] In some embodiments, the flattened, pre-curved support handle contains a first layer having wax and a second layer having a polymer disposed over the first layer. For example, the second layer may contain polyethylene terephthalate polyester or derivatives thereof. In other examples, the flattened, pre-curved support handle contains at least three layers. The third layer may contain wax and be disposed on or over the second layer. In some examples, the third layer contains another polymer (*e.g.*, polyethylene or derivatives thereof) and is disposed on or over the second layer. In other embodiments, an adhesive is disposed between the flattened, pre-curved support handle and the epitaxial material.

[0017] In other embodiments, a method for forming a thin film material, such as an ELO thin film stack, during an ELO process, is provided which includes forming an epitaxial material on or over a sacrificial layer on a substrate, adhering a flattened, pre-curved support material or handle onto or over the epitaxial material, removing the sacrificial layer during an etching process, and peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the flattened, pre-curved support handle to have substantial curvature. The flattened support handle is under tension to put the epitaxial material under compression. The flattened support handle may be formed by flattening a curved support material.

[0018] In another embodiment, the ELO thin film stack is provided which includes a sacrificial layer disposed on or over a substrate, an epitaxial material disposed on or over the sacrificial layer, and a universal shrinkable support handle disposed on or over the epitaxial material, wherein the support handle contains a universal shrinkable material, which upon being shrunk, forms tension in the support handle and compression in the epitaxial material. In one example, the universal shrinkable material contains an amorphous material. The amorphous material may be crystallized to undergo a net volume reduction during a universal shrinkage process. The universal shrinkable material may contain a plastic, a polymer, an oligomer, derivatives thereof, mixtures thereof, or combinations thereof. In some examples, the universal shrinkable support handle contains a heat shrink polymer.

[0019] In another embodiment, a method for forming the ELO thin film stack during an ELO process, is provided which includes forming an epitaxial material on or over a sacrificial layer, which is disposed on or over a substrate, adhering a universal shrinkable support handle onto or over the epitaxial material, wherein the support handle contains a universal shrinkable material, shrinking the support handle to form tension in the support handle and compression in the epitaxial material during a universal shrinkage process, removing the sacrificial layer during an etching process, and peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the support handle to have

substantial curvature. The universal shrinkage support handle may contain one layer or multiple layers.

[0020] In another embodiment, a thin film stack material is provided which includes a sacrificial layer disposed on or over a substrate, an epitaxial material disposed on or over the sacrificial layer, and a unidirectional shrinkable support handle disposed on or over the epitaxial material. The unidirectional shrinkable support handle may contain a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material. The shrinkable material shrinks unidirectional and tangential to the reinforcement fibers to form tension in the support handle and compression in the epitaxial material.

[0021] The reinforcement fibers are high-strength polymeric fibers. In one example, the reinforcement fibers contain polyethylene or derivatives thereof. In some examples, the reinforcement fibers contain a negative linear thermal expansion coefficient along the length of the fiber. Generally, the reinforcement fibers have a tensile moduli within a range from about 15 GPa to about 134 GPa.

[0022] In other embodiments, a method for forming a thin film material during an ELO process is provided which includes forming an epitaxial material on or over a sacrificial layer on a substrate, adhering a unidirectional shrinkable support handle onto the epitaxial material, wherein the support handle contains a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material, and shrinking the support handle tangential to the reinforcement fibers to form tension in the support handle and compression in the epitaxial material during a unidirectional shrinkage process. The method further includes removing the sacrificial layer during an etching process, peeling the epitaxial material from the substrate while forming an etch crevice therebetween, and bending the support handle to have substantial curvature.

[0023] In other embodiments, a thin film stack material is provided which includes a sacrificial layer disposed on or over a substrate, an epitaxial material disposed on or over the sacrificial layer, and a non-uniform support handle disposed on or over

the epitaxial material, wherein the non-uniform support handle contains a wax film having a varying thickness.

[0024] In another embodiment, a method for forming a thin film material during an ELO process, is provided which includes forming an epitaxial material disposed on or over a sacrificial layer on a substrate, and adhering a non-uniform support handle onto or over the epitaxial material, wherein the non-uniform support handle contains a wax film having a varying thickness. The method further includes removing the sacrificial layer during an etching process, peeling the epitaxial material from the substrate while forming an etch crevice therebetween, and bending the non-uniform support handle to form compression in the epitaxial material during the etching process.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] So that the manner in which the above recited features of the invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0026] Figure 1 depicts an ELO thin film stack on a wafer according to embodiments described herein;

[0027] Figure 2A depicts a pre-curved support handle according to an embodiment described herein;

[0028] Figures 2B-2C depict an ELO thin film stack containing the pre-curved support handle according to embodiments described herein;

[0029] Figure 2D depicts the pre-curved support handle and an epitaxial material after being removed from the wafer, as described in embodiments herein;

[0030] Figures 3A-3C depict an ELO thin film stack containing a universal shrinkable support handle according to another embodiment described herein;

[0031] Figure 3D depicts the universal shrinkable support handle and the epitaxial material after being removed from the wafer, as described in embodiments herein;

[0032] Figures 4A-4C depict an ELO thin film stack containing a unidirectional shrinkable support handle according to other embodiments described herein;

[0033] Figure 4D depicts the unidirectional shrinkable handle and the epitaxial material after being removed from the wafer, as described in embodiments herein;

[0034] Figures 5A-5B depict non-uniform wax support handles disposed on or over a thin film stack according to other embodiments described herein;

[0035] Figure 6A depict a multi-layered support handle disposed over a thin film stack on a substrate according to another embodiment described herein; and

[0036] Figure 6B depict the multi-layered support handle and the thin film stack disposed on a support substrate according to another embodiment described herein.

DETAILED DESCRIPTION

[0037] Figure 1 depicts substrate 100 containing ELO thin film stack 150 disposed on wafer 102, as described in one embodiment herein. ELO thin film stack 150 may have sacrificial layer 104 disposed on or over wafer 102, epitaxial material 106 disposed on or over sacrificial layer 104, and support handle 108 disposed on or over epitaxial material 106. In various embodiments, support handle 108 is under tension while the epitaxial material 106 is under compression. The ELO process includes removing sacrificial layer 104 during an etching process, while peeling epitaxial material 106 from wafer 102 and forming an etch crevice therebetween until epitaxial material 106 and support handle 108 are removed from wafer 102. Sacrificial layer 104 generally contains aluminum arsenide.

[0038] Wafer 102 may contain or be formed of a variety of materials, such as Group III/V materials, and may be doped with other elements. In one embodiment, wafer 106 contains gallium arsenide or a derivative thereof. A gallium arsenide wafer has thermal expansion coefficient of about 5.73×10^{-6} $°C^{-1}$. In various embodiments, support handle 108 contains materials (*e.g.*, wax or polymers) which have a higher coefficient of thermal expansion.

[0039] Support handle 108 may be a single layer of material or multiple layers. In the various embodiments, support handle 108 may be a flattened, pre-curved support handle that is formed by flattening a curved support material. In another embodiment, support handle 108 may contain a shrinkable material, such as a thermally shrinkable plastic. In an alternative embodiment, support handle 108 may contain a shrinkable material having reinforcement fibers extending unidirectional throughout the shrinkable material. In another embodiment, support handle 108 may contain a wax film having a varying or non-uniform thickness across substrate 100. In another embodiment, support handle 108 may be a multi-layered handle.

Pre-Curved Handle

[0040] Figures 2A-2D depict a pre-curved support material or handle during various aspects of an ELO process or within an ELO thin film stack, as described in one embodiment herein. Figure 2A illustrates a pre-curved support material, such as pre-curved support handle 202. Pre-curved support handle 202 contains top surface 211 and bottom surface 213. In one embodiment, pre-curved support handle 202 may be flattened or straightened prior to adhering or attaching to the substrate 200, such as to epitaxial material 204. Alternatively, pre-curved support handle 202 may be flattened or straightened while adhering or attaching to the substrate 200. Once flattened or straightened, pre-curved support handle 202 is under tension, which is utilized to produce compression to the underlying layers (e.g., epitaxial material 204) when adhered or attached to the substrate 200.

[0041] Figure 2B depicts substrate 200 containing ELO thin film stack 250 disposed on or over wafer 208, as described in one embodiment herein. ELO thin film stack 250 may have sacrificial layer 206 disposed on or over wafer 208,

epitaxial material 204 disposed on or over sacrificial layer 206, and pre-curved support handle 202 disposed on or over epitaxial material 204. During the etching process, flattened pre-curved support handle 202 bends towards top surface 211, as depicted in Figure 2C. Pre-curved support handle 202 may have a radius of curvature within a range from about 10 cm to about 100 cm.

[0042] In some embodiments, pre-curved support handle 202 contains multiple layers, such as a first layer of wax and a second layer of a polymer disposed on or over the first layer. For example, the second layer may contain polyethylene terephthalate polyester, such as a MYLAR® polymeric film. In other examples, pre-curved support handle 202 contains at least three layers. The third layer may be disposed on or over the second layer. In some examples, the third layer contains another polymer (*e.g.*, polyethylene or derivatives thereof) or wax, which is disposed on or over the second layer.

[0043] Figure 2B depicts substrate 200 containing pre-curved support handle 202 after being flattened. The flattened, pre-curved support handle 202 may be disposed on or over epitaxial material 204, which may be disposed on or over sacrificial layer 206. Sacrificial layer 206 may be disposed on or over wafer 208.

[0044] In some embodiments, an adhesive (not shown) may be disposed between pre-curved support handle 202 and epitaxial material 204. The adhesive may be a pressure sensitive adhesive, a hot melt adhesive, an ultraviolet (UV) curing adhesive, a natural adhesive, a synthetic adhesive, derivatives thereof, or combinations thereof.

[0045] In some embodiments, sacrificial layer 206 may contain aluminum arsenide, alloys thereof, derivatives thereof, or combinations thereof. In one example, sacrificial layer 206 contains an aluminum arsenide layer. Sacrificial layer 206 may have a thickness of about 20 nm or less, preferably, within a range from about 1 nm to about 10 nm, and more preferably, from about 4 nm to about 6 nm. Wafer 208 may be a wafer or a substrate and usually contains gallium arsenide, gallium arsenide alloys or other derivatives, and may be n-doped or p-doped. In one

example, wafer 208 contains n-doped gallium arsenide material. In another example, wafer 208 contains p-doped gallium arsenide material.

[0046] In some embodiments, epitaxial material 204 may contain gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. Epitaxial material 204 may contain one layer, but usually contains multiple layers. In some examples, epitaxial material 204 contains a layer having gallium arsenide and another layer having aluminum gallium arsenide. In another example, epitaxial material 204 contains a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

[0047] The gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 300 nm, the aluminum gallium arsenide passivation layer may have a thickness within a range from about 10 nm to about 50 nm, such as about 30 nm, and the gallium arsenide active layer may have a thickness within a range from about 500 nm to about 2,000 nm, such as about 1,000 nm. In some examples, epitaxial material 204 further contains a second aluminum gallium arsenide passivation layer. The second gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 300 nm.

[0048] In other embodiments herein, epitaxial material 204 may have a cell structure containing multiple layers. The cell structure may contain gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof.

[0049] Figure 2C depicts the formation of etch crevice 210 while sacrificial layer 206 is etched away and pre-curved support handle 202 and the epitaxial material are peeled away from wafer 208 during an ELO etch process, as described in an embodiment herein. Figure 2D illustrates pre-curved support handle 202 and epitaxial material 204 after being removed from wafer 208. The flattened, pre-

curved support handle 202 is under tension while epitaxial material 204 is under compression.

[0050] In one embodiment of a method for forming the thin film material, sacrificial layer 206 may be disposed on or over substrate 200, such as wafer 208, epitaxial material 204 disposed on or over sacrificial layer 206, and the flattened, pre-curved support material or handle may be disposed on or over epitaxial material 204. The flattened, pre-curved support material or handle may contain a single layer or multiple layers. The flattened, pre-curved support material or handle may contain wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, or combinations thereof. In some examples, the flattened, pre-curved support handle 202 contains wax. In other examples, the flattened, pre-curved support handle 202 contains polyethylene terephthalate polyester or derivatives thereof, such as a MYLAR® film. In other examples, pre-curved support handle 202 contains polyolefin or derivatives thereof.

[0051] In another embodiment, the method for forming the thin film material during an ELO process is provided which includes forming epitaxial material 204 over or on sacrificial layer 206 that is disposed on substrate 200, such as wafer 208. The method further provides adhering or attaching a flattened pre-curved support material, such as pre-curved support handle 202, over or onto epitaxial material 204, wherein the flattened pre-curved support handle 202 is formed by flattening a curved support material, and the flattened pre-curved support handle 202 is under tension while epitaxial material 204 is under compression, removing sacrificial layer 206 during an etching process, and peeling epitaxial material 204 from the substrate while forming the etch crevice therebetween and bending the flattened pre-curved support handle 202 to have substantial curvature.

[0052] In some embodiments, sacrificial layer 206 may be exposed to a wet etch solution during an ELO etching process. In some examples, the wet etch solution contains hydrofluoric acid and may contain a surfactant and/or a buffer. Sacrificial layer 206 may be etched at a rate of about 0.3 mm/hr or greater, preferably, about 1 mm/hr or greater, and more preferably, about 5 mm/hr or greater.

[0053] In an alternative embodiment, sacrificial layer 206 may be exposed to an electrochemical etch during the ELO etching process. The electrochemical etch may be a biased process or a galvanic process. Also, sacrificial layer 206 may be exposed to a vapor phase etch during the ELO etching process in another embodiment described herein. The vapor phase etch includes exposing sacrificial layer 206 to hydrogen fluoride vapor. The ELO etching process may be a photochemical etch, a thermally enhanced etch, a plasma enhanced etch, a stress enhanced etch, derivatives thereof, or combinations thereof.

Induced-Shrinkage Handle (universal shrinkage)

[0054] Figures 3A-3D depict a universal shrinkable support material or handle during various aspects of an ELO process or within an ELO thin film stack, as described in some embodiments herein. Figure 3A illustrates substrate 300 containing ELO thin film stack 350 disposed on or over wafer 308, as described in one embodiment herein. ELO thin film stack 350 may include sacrificial layer 306 disposed on or over wafer 308, epitaxial material 304 disposed on or over sacrificial layer 306, and universal shrinkable support handle 302 disposed on or over epitaxial material 304. Figure 3B depicts force/stress 320 as applied to universal shrinkable support handle 302 provides universal shrinkage 322 across the plain of substrate 300.

[0055] Shrinkable support handle 302 contains a universal shrinkable material, such as wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, or combinations thereof. In one example, shrinkable support handle 302 contains wax. In some examples, shrinkable support handle 302 contains polyethylene terephthalate polyester or derivatives thereof, such as a MYLAR® film. In other examples, shrinkable support handle 302 contains polyolefin or derivatives thereof. In other examples, shrinkable support handle 302 contains a first layer having wax and a second layer having a polymer (*e.g.*, polyethylene terephthalate polyester) disposed over the first layer.

[0056] Universal shrinkable support handle 302 may contain three layers or more layers. For example, shrinkable support handle 302 further may have a third layer

containing wax or a polymer and disposed over the second layer. The third layer may contain polyethylene or derivatives thereof.

[0057] Shrinkable support handle 302 contains a bottom surface and a top surface and the bottom surface is adhered to or above epitaxial material 304. Shrinkable support handle 302 bends towards the top surface during the etching process. In another embodiment, the universal shrinkable material contains an amorphous material and the amorphous material may be crystallized to undergo a net volume reduction during the shrinkage process. The universal shrinkable material may contain at least one plastic, rubber, polymer, oligomer, derivatives thereof, or combinations thereof. In one specific example, the universal shrinkable material contains polyester or derivatives thereof. In other example, a heat shrinkable adhesive tape may be used as universal shrinkable support handle 302.

[0058] In other embodiments, shrinkable support handle 302 may be heated during the shrinkage process. Shrinkable support handle 302 may contain a heat shrink plastic or polymer. Alternatively, shrinkable support handle 302 may be shrunk by removing solvent from the shrinkable material. Shrinkable support handle 302 may be bent to have a radius of curvature within a range from about 10 cm to about 100 cm.

[0059] In some embodiments, an adhesive (not shown) may be disposed between universal shrinkable support handle 302 and epitaxial material 304. The adhesive may be a pressure sensitive adhesive, a hot melt adhesive, an ultraviolet (UV) curing adhesive, a natural adhesive, a synthetic adhesive, derivatives thereof, or combinations thereof. In some examples, a heat shrinkable tape containing the adhesive on one side may be used as shrinkable support handle 302

[0060] In some embodiments, epitaxial material 304 may contain gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. Epitaxial material 304 may contain one layer, but usually contains multiple layers. In some examples, epitaxial material 304 contains a layer having gallium arsenide and another layer having aluminum gallium arsenide. In another example, epitaxial material 304 contains a gallium arsenide

buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

[0061] The gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 300 nm, the aluminum gallium arsenide passivation layer may have a thickness within a range from about 10 nm to about 50 nm, such as about 30 nm, and the gallium arsenide active layer may have a thickness within a range from about 500 nm to about 2,000 nm, such as about 1,000 nm. In some examples, epitaxial material 304 further contains a second aluminum gallium arsenide passivation layer. The second gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 300 nm.

[0062] In other embodiments herein, epitaxial material 304 may have a cell structure containing multiple layers. The cell structure may contain gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof.

[0063] In another embodiment, sacrificial layer 306 may contain aluminum arsenide, alloys thereof, derivatives thereof, or combinations thereof. In one example, sacrificial layer 306 contains an aluminum arsenide layer. Sacrificial layer 306 may have a thickness of about 20 nm or less, preferably, within a range from about 1 nm to about 10 nm, and more preferably, from about 4 nm to about 6 nm. Wafer 308 may be a wafer or a substrate and usually contains gallium arsenide, gallium arsenide alloys, or other derivatives, and may be n-doped or p-doped. In one example, wafer 308 contains n-doped gallium arsenide material. In another example, wafer 308 contains p-doped gallium arsenide material.

[0064] Figure 3C depicts the formation of etch crevice 310 while sacrificial layer 306 is etched away and shrinkable support handle 302 and epitaxial material 304 are peeled away from wafer 308. Figure 3D illustrates shrinkable support handle 302 and epitaxial material 304 after being removed from wafer 308.

[0065] In one embodiment of a method for forming a thin film material during an ELO process, epitaxial material 304 may be formed or deposited over sacrificial layer 306 disposed on or over substrate 300, such as wafer 308, and adhering shrinkable support handle 302 over or onto epitaxial material 304. Shrinkable support handle 302 contains a universal shrinkable material. The method further provides shrinking or reducing the size of shrinkable support handle 302 to form tension in shrinkable support handle 302 and compression in epitaxial material 304 during a shrinkage process, removing sacrificial layer 306 during an etching process, and peeling epitaxial material 304 from the substrate while forming etch crevice 310 therebetween and bending shrinkable support handle 302 to have substantial curvature. Shrinkable support handle 302 may contain one layer or multiple layers.

[0066] In another embodiment, a method for forming a thin film material during an ELO process is provided which includes positioning substrate 300 containing epitaxial material 304 disposed on or over sacrificial layer 306, which is disposed on or over wafer 308, and adhering shrinkable support handle 302 onto epitaxial material 304. Shrinkable support handle 302 contains a universal shrinkable material. The method further provides shrinking or reducing the size of shrinkable support handle 302 to form tension in shrinkable support handle 302 and compression in epitaxial material 304 during a shrinkage process, and removing sacrificial layer 306 during an etching process. The method further provides that the etching process further contains peeling epitaxial material 304 from the substrate, forming etch crevice 310 between epitaxial material 304 from the substrate, and bending shrinkable support handle 302 to have substantial curvature.

[0067] In other embodiments, a thin film stack material is provided which includes sacrificial layer 306 disposed on a substrate, epitaxial material 304 disposed over sacrificial layer 306, and shrinkable support handle 302 disposed over epitaxial material 304. Shrinkable support handle 302 contains a universal shrinkable material that upon being shrunk, forms tension in shrinkable support handle 302 and compression in epitaxial material 304. In one example, the shrinkable material contains an amorphous material. The amorphous material may be crystallized to

undergo a net volume reduction during the shrinkage process. The shrinkable material may contain at least one plastic, polymer, oligomer, derivatives thereof, or combinations thereof. In some examples, shrinkable support handle 302 contains a heat shrink plastic or polymer.

[0068] In some embodiments, sacrificial layer 306 may be exposed to a wet etch solution during the etching process. The wet etch solution contains hydrofluoric acid and may contain a surfactant and/or a buffer. In some examples, sacrificial layer 306 may be etched at a rate of about 0.3 mm/hr or greater, preferably, about 1 mm/hr or greater, and more preferably, about 5 mm/hr or greater.

[0069] In an alternative embodiment, sacrificial layer 306 may be exposed to an electrochemical etch during the etching process. The electrochemical etch may be a biased process or a galvanic process. Also, sacrificial layer 306 may be exposed to a vapor phase etch during the etching process in another embodiment described herein. The vapor phase etch includes exposing sacrificial layer 306 to hydrogen fluoride vapor. The etching process may be a photochemical etch, a thermally enhanced etch, a plasma enhanced etch, a stress enhanced etch, derivatives thereof, or combinations thereof.

Induced-Shrinkage Handle (unidirectional shrinkage)

[0070] Figures 4A-4D depict a unidirectional shrinkable support material or handle during various aspects of an ELO process or within an ELO thin film stack, as described in one embodiment herein. Figure 4A illustrates substrate 400 containing ELO thin film stack 450 disposed on or over wafer 408, as described in one embodiment herein. ELO thin film stack 450 may have sacrificial layer 406 disposed on or over wafer 408, epitaxial material 404 disposed on or over sacrificial layer 406, and unidirectional shrinkable support handle 402 disposed on or over epitaxial material 404.

[0071] Unidirectional shrinkable support handle 402 contains a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material, which upon being shrunk, shrinks tangential to the reinforcement fibers to form tension in shrinkable support handle 402 and compression in epitaxial material

404. Figure 4B depicts force/stress 420 as applied to shrinkable support handle 402 provides unidirectional shrinkage 422 across the plain of substrate 400.

[0072] Shrinkable support handle 402 contains a bottom surface and a top surface and the bottom surface is adhered to or above epitaxial material 404. Shrinkable support handle 402 may bend towards the top surface during the etching process. In one example, the unidirectional shrinkable material contains an amorphous material, which may be crystallized to undergo a net volume reduction during the unidirectional shrinkage process. In another example, the unidirectional shrinkable material may contain plastic, polymer, oligomer, derivatives thereof, or combinations thereof. In one example, the unidirectional shrinkable material contains polyester or derivatives thereof.

[0073] The reinforcement fibers may be high-strength polymeric fibers. The reinforcement fibers may contain polyethylene or derivatives thereof. In some examples, the reinforcement fibers contain a negative linear thermal expansion coefficient along the length of the fiber. Generally, the reinforcement fibers have a tensile moduli within a range from about 15 GPa to about 134 GPa.

[0074] In some examples, unidirectional shrinkable support handle 402 may be heated during the shrinkage process. Shrinkable support handle 402 may contain a heat shrink polymer and high-strength polymeric fibers. In other examples, shrinkable support handle 402 is shrunk by contains removing solvent from the shrinkable material. Shrinkable support handle 402 may be bent to have a radius of curvature within a range from about 10 cm to about 100 cm.

[0075] In some embodiments, an adhesive (not shown) may be disposed between unidirectional shrinkable support handle 402 and epitaxial material 404. The adhesive may be a pressure sensitive adhesive, a hot melt adhesive, an ultraviolet (UV) curing adhesive, a natural adhesive, a synthetic adhesive, derivatives thereof, or combinations thereof.

[0076] In some embodiments herein, epitaxial material 404 may contain gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. Epitaxial material 404 may contain one

layer, but usually contains multiple layers. In some examples, epitaxial material 404 contains a layer having gallium arsenide and another layer having aluminum gallium arsenide. In another example, epitaxial material 404 contains a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

[0077] The gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 400 nm, the aluminum gallium arsenide passivation layer may have a thickness within a range from about 10 nm to about 50 nm, such as about 30 nm, and the gallium arsenide active layer may have a thickness within a range from about 500 nm to about 2,000 nm, such as about 1,000 nm. In some examples, epitaxial material 404 further contains a second aluminum gallium arsenide passivation layer. The second gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 400 nm.

[0078] In other embodiments herein, epitaxial material 404 may have a cell structure containing multiple layers. The cell structure may contain gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof.

[0079] In another embodiment, sacrificial layer 406 may contain aluminum arsenide, alloys thereof, derivatives thereof, or combinations thereof. In one example, sacrificial layer 406 contains an aluminum arsenide layer. Sacrificial layer 406 may have a thickness of about 20 nm or less, preferably, within a range from about 1 nm to about 10 nm, and more preferably, from about 4 nm to about 6 nm. Wafer 408 may be a wafer or a substrate and usually contains gallium arsenide, gallium arsenide alloys, or other derivatives, and may be n-doped or p-doped. In one example, wafer 408 contains n-doped gallium arsenide material. In another example, wafer 408 contains p-doped gallium arsenide material.

[0080] Figure 4C depicts the formation of etch crevice 410 while sacrificial layer 406 is etched away and shrinkable support handle 402 and epitaxial material 404

are peeled away from wafer 408. Figure 4D illustrates shrinkable support handle 402 and epitaxial material 404 after being removed from wafer 408.

[0081] In another embodiment, a method for forming a thin film material during an ELO process is provided which includes forming epitaxial material 404 over sacrificial layer 406 on substrate 400, adhering shrinkable support handle 402 onto epitaxial material 404, wherein shrinkable support handle 402 contains a unidirectional shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material, and shrinking or reducing shrinkable support handle 402 tangential to the reinforcement fibers to form tension in shrinkable support handle 402 and compression in epitaxial material 404 during a shrinkage process. The method further includes removing sacrificial layer 406 during an etching process, and peeling epitaxial material 404 from the substrate while forming an etch crevice therebetween and bending unidirectional shrinkable support handle 402 to have substantial curvature.

[0082] In one embodiment of a method for forming a thin film material during an ELO process is provided which includes depositing epitaxial material 404 on or over sacrificial layer 406 that is disposed on wafer 408 of substrate 400, and adhering shrinkable support handle 402 onto epitaxial material 404. Shrinkable support handle 402 contains a unidirectional shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material. The method further provides shrinking or reducing shrinkable support handle 402 tangential to the reinforcement fibers to form tension in shrinkable support handle 402 and compression in epitaxial material 404 during a shrinkage process, and removing sacrificial layer 406 during an etching process. The etching process contains peeling epitaxial material 404 from the substrate, forming an etch crevice between epitaxial material 404 from the substrate, and bending unidirectional shrinkable support handle 402 to have substantial curvature.

[0083] In some embodiments, sacrificial layer 406 may be exposed to a wet etch solution during the etching process. The wet etch solution contains hydrofluoric acid and may contain a surfactant and/or a buffer. In some examples, sacrificial layer

406 may be etched at a rate of about 0.3 mm/hr or greater, preferably, about 1 mm/hr or greater, and more preferably, about 5 mm/hr or greater.

[0084] In an alternative embodiment, sacrificial layer 406 may be exposed to an electrochemical etch during the etching process. The electrochemical etch may be a biased process or a galvanic process. Also, sacrificial layer 406 may be exposed to a vapor phase etch during the etching process in another embodiment described herein. The vapor phase etch includes exposing sacrificial layer 406 to hydrogen fluoride vapor. The etching process may be a photochemical etch, a thermally enhanced etch, a plasma enhanced etch, a stress enhanced etch, derivatives thereof, or combinations thereof.

Non-uniform Wax Handle

[0085] Figures 5A-5B depict substrate 500 containing ELO thin film stack 550 disposed on or over wafer 508, as described in one embodiment herein. ELO thin film stack 550 may have sacrificial layer 506 disposed on or over wafer 508, epitaxial material 504 disposed on or over sacrificial layer 506, and non-uniform support handle 502 disposed on or over epitaxial material 504. In one embodiment, non-uniform support handle 502 contains a wax film having a varying thickness, as described in some embodiments herein. In one example, the varying thickness of non-uniform support handle 502 is thickest in or near middle 510a of non-uniform support handle 502, as depicted in Figure 5A. In another example, the varying thickness of non-uniform support handle 502 is thinnest in or near middle 510b of non-uniform support handle 502, as depicted in Figure 5B.

[0086] In another embodiment, ELO thin film stack 550 contains sacrificial layer 506 disposed on a substrate, epitaxial material 504 under disposed over sacrificial layer 506, and non-uniform support handle 502 disposed over epitaxial material 504, wherein non-uniform support handle 502 contains a wax film having a varying thickness or non-uniform thickness.

[0087] In other embodiments, a method for forming a thin film material during an ELO process, is provided which includes forming epitaxial material 504 over sacrificial layer 506 on a substrate, adhering non-uniform support handle 502 onto

epitaxial material 504, wherein non-uniform support handle 502 contains a wax film having a varying thickness, removing sacrificial layer 506 during an etching process, and peeling epitaxial material 504 from the substrate while forming an etch crevice therebetween and bending non-uniform support handle 502 to form compression in epitaxial material 504 during the etching process.

[0088] In another embodiment, a method for forming a thin film material during an ELO process, is provided which includes positioning a substrate containing epitaxial material 504 disposed over sacrificial layer 506 on the substrate, adhering non-uniform support handle 502 onto epitaxial material 504, wherein non-uniform support handle 502 contains a wax film having a varying thickness, and removing sacrificial layer 506 during an etching process, wherein the etching process further contains peeling epitaxial material 504 from the substrate, forming an etch crevice between epitaxial material 504 from the substrate, and bending non-uniform support handle 502 to form compression in epitaxial material 504 during the etching process.

[0089] In some embodiments, non-uniform support handle 502 contains a bottom surface of the wax film and a top surface of a flexible member, and the bottom surface is adhered to epitaxial material 504. Non-uniform support handle 502 may bend towards the top surface. Non-uniform support handle 502 may be bent to have a radius of curvature within a range from about 10 cm to about 100 cm. The flexible member may contain plastic, polymer, oligomer, derivatives thereof, or combinations thereof, for example, polyester or a polyester derivative. The flexible member may have a film thickness within a range from about 50.8 μm (about 20 gauge) to about 127.0 μm (about 500 gauge), preferably, about 23.4 μm (about 92 gauge).

[0090] In other examples, the wax film contains wax which has a softening point temperature within a range from about 65°C to about 95°C, preferably, from about 80°C to about 90°C, such as about 85°C. In one example, the varying thickness of the wax film is thickest in or near the middle of the wax film (Figure 5A) or thinnest in or near the middle of the wax film (Figure 5B). In various embodiments, the varying thickness of the wax film may be within a range from about 1 μm to about 100 μm. In one embodiment, the wax film has a thinnest section having a thickness within a

range from about 1 μm to about 25 μm and has a thickest section having a thickness within a range from about 25 μm to about 100 μm.

[0091] In some embodiments herein, epitaxial material 504 may contain gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. Epitaxial material 504 may contain one layer, but usually contains multiple layers. In some examples, epitaxial material 504 contains a layer having gallium arsenide and another layer having aluminum gallium arsenide. In another example, epitaxial material 504 contains a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

[0092] The gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 500 nm, the aluminum gallium arsenide passivation layer may have a thickness within a range from about 10 nm to about 50 nm, such as about 30 nm, and the gallium arsenide active layer may have a thickness within a range from about 500 nm to about 2,000 nm, such as about 1,000 nm. In some examples, epitaxial material 504 further contains a second aluminum gallium arsenide passivation layer. The second gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 500 nm.

[0093] In other embodiments herein, epitaxial material 504 may have a cell structure containing multiple layers. The cell structure may contain gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof.

[0094] In another embodiment, sacrificial layer 506 may contain aluminum arsenide, alloys thereof, derivatives thereof, or combinations thereof. In one example, sacrificial layer 506 contains an aluminum arsenide layer. Sacrificial layer 506 may have a thickness of about 20 nm or less, preferably, within a range from about 1 nm to about 10 nm, and more preferably, from about 4 nm to about 6 nm. Wafer 508 may be a wafer or a substrate and usually contains gallium arsenide,

gallium arsenide alloys, or other derivatives, and may be n-doped or p-doped. In one example, wafer 508 contains n-doped gallium arsenide material. In another example, wafer 508 contains p-doped gallium arsenide material.

[0095] In some embodiments, sacrificial layer 506 may be exposed to a wet etch solution during the etching process. The wet etch solution contains hydrofluoric acid and may contain a surfactant and/or a buffer. In some examples, sacrificial layer 506 may be etched at a rate of about 0.3 mm/hr or greater, preferably, about 1 mm/hr or greater, and more preferably, about 5 mm/hr or greater.

[0096] In an alternative embodiment, sacrificial layer 506 may be exposed to an electrochemical etch during the etching process. The electrochemical etch may be a biased process or a galvanic process. Also, sacrificial layer 506 may be exposed to a vapor phase etch during the etching process in another embodiment described herein. The vapor phase etch includes exposing sacrificial layer 506 to hydrogen fluoride vapor. The etching process may be a photochemical etch, a thermally enhanced etch, a plasma enhanced etch, a stress enhanced etch, derivatives thereof, or combinations thereof.

Multi-Layered Support Handle

[0097] Embodiments of the invention generally relate to ELO thin film materials and devices and methods used to form such materials and devices. In one embodiment, a method for forming a thin film material during an ELO process is provided which includes depositing or otherwise forming an epitaxial material over a sacrificial layer on a substrate, adhering a support handle onto the epitaxial material, removing the sacrificial layer during an etching process, and peeling the epitaxial material from the substrate while forming an etch crevice therebetween while maintaining compression in the epitaxial material during the etching process. The method further provides that the support handle contains a stiff support layer adhered to the epitaxial material, a soft support layer adhered to the stiff support layer, and a handle plate adhered to the soft support layer.

[0098] In one embodiment, as depicted in Figure 6A, ELO thin film stack 600A is provided which includes sacrificial layer 620 disposed on or over a substrate, such

as wafer 610, epitaxial material 630 disposed on or over sacrificial layer 620, and multi-layered support handle 670 disposed on or over epitaxial material 630. In one example, multi-layered support handle 670 contains stiff support layer 640 disposed over epitaxial material 630, soft support layer 650 disposed over stiff support layer 640, and handle plate 660 disposed over soft support layer 650. Multi-layered support handle 670 is disposed on and maintains compression of epitaxial material 630.

[0099] In some examples, stiff support layer 640 may contain a polymer, a copolymer, an oligomer, derivatives thereof, or combinations thereof. In one embodiment, stiff support layer 640 contains a copolymer. In one example, the copolymer may be an ethylene/vinylacetate (EVA) copolymer or derivatives thereof. An EVA copolymer which is useful as stiff support layer 640 is WAFER GRIP adhesive film, commercially available from Dynatex International, located in Santa Rosa, CA. In other examples, stiff support layer 640 may contain a hot-melt adhesive, an organic material or organic coating, an inorganic material, or combinations thereof.

[0100] In one embodiment, stiff support layer 640 contains an inorganic material having multiple inorganic layers, such as metal layers, dielectric layers, or combinations thereof. In another example, stiff support layer 640 may contain composite materials or patterned composite materials, such as organic/inorganic materials. The composite materials may contain at least one organic material and at least one inorganic material. In some examples, the inorganic material may contain a metal layer, a dielectric layer, or combinations thereof. A composite material may be used to optimize device performance, such as an increase in reflectivity, conductivity, and/or yield. In another embodiment, stiff support layer 640 may contain wax or derivatives thereof, such as black wax.

[0101] In another embodiment, soft support layer 650 may contain an elastomer, such as rubber, foam, or derivatives thereof. Alternatively, soft support layer 650 may contain a material such as neoprene, latex, or derivatives thereof. Soft support

layer 650 may contain a monomer. For example, soft support layer 650 may contain an ethylene propylene diene monomer or derivatives thereof.

[0102] In another embodiment, soft support layer 650 may contain a liquid or a fluid contained within a membrane. Alternatively, soft support layer 650 may contain a gas contained within a membrane. The membrane may contain a material such as rubber, foam, neoprene, latex, or derivatives thereof. In one example, the membrane is a balloon of rubber or latex.

[0103] In another embodiment, handle plate 660 may contain a material such as plastic, polymer, oligomer, derivatives thereof, or combinations thereof. In one example, handle plate 660 may contain polyester or derivatives thereof. Handle plate 660 may have a thickness within a range from about 50.8 μm to about 127.0 μm, such as about 23.4 μm.

[0104] In one embodiment, the method further includes removing sacrificial layer 620 to separate epitaxial material 630 from the substrate, such as wafer 610, as depicted in Figure 6A, and subsequently adhering or attaching epitaxial material 630 to support substrate 680 by bonding therebetween with an adhesive to form adhesive layer 690, as depicted in Figure 6B. Support substrate 680 may be bonded to an exposed surface of epitaxial material 630 by the adhesive. In one example, adhesive layer 690 may be formed from or contain an optical adhesive and/or a UV-curable, such as commercially available as Norland UV-curable optical adhesive. In some examples, the adhesive may contain a mercapto ester compound. In other examples, the adhesive may further contain a material such as butyl octyl phthalate, tetrahydrofurfuryl methacrylate, acrylate monomer, derivatives thereof, or combinations thereof.

[0105] In one example, as depicted in Figure 6B, ELO thin film stack 600B is provided which includes support substrate 680 disposed over a first surface of epitaxial material 630, and multi-layered support handle 670 disposed over the other surface of epitaxial material 630. Adhesive layer 690 may be disposed between epitaxial material 630 and support substrate 680. Multi-layered support handle 670 contains stiff support layer 640 disposed over epitaxial material 630, soft support

layer 650 disposed over stiff support layer 640, and handle plate 660 disposed over soft support layer 640.

[0106] In one example, adhesive layer 690 may be formed from adhesive that has been exposed to UV radiation during a curing process. Generally, the adhesive may be exposed to the UV radiation for a time period within a range from about 1 minute to about 10 minutes, preferably, from about 3 minutes to about 7 minutes, such as about 5 minutes. The adhesive may be cured at a temperature within a range from about 25°C to about 75°C, such as about 50°C.

[0107] In other examples, the adhesive of adhesive layer 690 may be a silicone adhesive or may contain sodium silicate. In these examples, the adhesive may be cured for a time period within a range from about 10 hours to about 100 hours, preferably, from about 20 hours to about 60 hours, and more preferably, from about 30 hours to about 50 hours, for example, about 42 hours. The adhesive may be cured at a temperature within a range from about 25°C to about 75°C, such as about 50°C. Also the adhesive may be cured at a pressure within a range from about 1 psi (pounds per square inch) to about 50 psi, preferably, from about 3 psi to about 25 psi, and more preferably, from about 5 psi to about 15 psi. In one example, the pressure may be about 9 psi.

[0108] Sacrificial layer 620 may be exposed to an etching process to remove epitaxial material 630 from the substrate. In some embodiments, sacrificial layer 620 may be exposed to a wet etch solution during the etching process. The wet etch solution contains hydrofluoric acid and may contain a surfactant and/or a buffer. In some examples, sacrificial layer 620 may be etched at a rate of about 0.3 mm/hr or greater, preferably, about 1 mm/hr or greater, and more preferably, about 5 mm/hr or greater. In an alternative embodiment, sacrificial layer 620 may be exposed to an electrochemical etch during the etching process. The electrochemical etch may be a biased process or a galvanic process. Also, sacrificial layer 620 may be exposed to a vapor phase etch during the etching process in another embodiment described herein. The vapor phase etch includes exposing sacrificial layer 620 to hydrogen fluoride vapor. The etching process may

be a photochemical etch, a thermally enhanced etch, a plasma enhanced etch, a stress enhanced etch, derivatives thereof, or combinations thereof.

[0109] In embodiments herein, epitaxial material 630 may contain gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. Epitaxial material 630 may have a rectangular geometry, a square geometry, or other geometries. Epitaxial material 630 may contain one layer, but usually contains multiple layers. In some examples, epitaxial material 630 contains a layer having gallium arsenide and another layer having aluminum gallium arsenide. In another example, epitaxial material 630 contains a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer. The gallium arsenide buffer layer may have a thickness within a range from about 100 nm to about 500 nm, such as about 300 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, such as about 30 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm, such as about 1,000 nm. In some examples, epitaxial material 630 further contains a second aluminum gallium arsenide passivation layer.

[0110] In other embodiments herein, epitaxial material 630 may contain a cell structure containing multiple layers. The cell structure may contain gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, or combinations thereof. In many examples, the gallium arsenide is n-doped or p-doped.

[0111] In some embodiments, sacrificial layer 620 may contain aluminum arsenide, alloys thereof, derivatives thereof, or combinations thereof. In one example, sacrificial layer 620 contains an aluminum arsenide layer and has a thickness of about 20 nm or less, preferably, within a range from about 1 nm to about 10 nm, and more preferably, from about 4 nm to about 6 nm. The substrates, such as wafer 610 and/or support substrate 680, usually contain gallium arsenide or derivatives thereof, and may be n-doped or p-doped.

[0112] While the foregoing is directed to embodiments of the invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

Claims:

1. A method for forming a thin film material during an epitaxial lift off process, comprising:

forming an epitaxial material over a sacrificial layer on a substrate;

adhering a flattened, pre-curved support handle onto the epitaxial material, wherein the flattened, pre-curved support handle is formed by flattening a curved support material, and the flattened, pre-curved support handle is under tension while the epitaxial material is under compression;

removing the sacrificial layer during an etching process; and

peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the flattened, pre-curved support handle to have substantial curvature.

2. The method of claim 1, wherein the curved support material comprises a material selected from the group consisting of wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, and combinations thereof.

3. The method of claim 2, wherein the curved support material comprises polyethylene terephthalate polyester, polyolefin, or derivatives thereof.

4. The method of claim 1, wherein the curved support material comprises a first layer comprising wax and a second layer comprising a polymer disposed over the first layer.

5. The method of claim 4, wherein the second layer comprises polyethylene terephthalate polyester or derivatives thereof.

6. The method of claim 4, wherein the curved support material further comprises a third layer comprising wax and disposed over the second layer or comprises a third layer comprising another polymer and disposed over the second layer.

7. The method of claim 6, wherein the third layer comprises polyethylene or derivatives thereof.

8. The method of claim 1, wherein the flattened, pre-curved support handle comprises a bottom surface and a top surface, the bottom surface is adhered to the epitaxial material and the flattened, pre-curved support handle bends towards the top surface.

9. The method of claim 1, wherein an adhesive is used to adhere the flattened, pre-curved support handle onto the epitaxial material, and the adhesive is selected from the group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

10. The method of claim 1, wherein the sacrificial layer is exposed to a wet etch solution during the etching process, the wet etch solution comprises hydrofluoric acid, a surfactant, and a buffer.

11. The method of claim 10, wherein the sacrificial layer is etched at a rate of about 5 mm/hr or greater.

12. The method of claim 1, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

13. The method of claim 12, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

14. The method of claim 13, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

15. The method of claim 14, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

16. The method of claim 14, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

17. The method of claim 1, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

18. The method of claim 1, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

19. The method of claim 18, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

20. The method of claim 1, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

21. A method for forming a thin film material during an epitaxial lift off process, comprising:

positioning a substrate comprising an epitaxial material disposed over a sacrificial layer on the substrate;

adhering a flattened, pre-curved support handle onto the epitaxial material, wherein the flattened, pre-curved support handle is formed by flattening a curved support material, and the flattened, pre-curved support handle is under tension while the epitaxial material is under compression; and

removing the sacrificial layer during an etching process, wherein the etching process further comprises:

peeling the epitaxial material from the substrate while forming an etch crevice therebetween; and

bending the flattened, pre-curved support handle to have substantial curvature.

22. A thin film stack material, comprising:

a sacrificial layer disposed on a substrate;

an epitaxial material disposed over the sacrificial layer; and

a flattened, pre-curved support material disposed over the epitaxial material, wherein the flattened, pre-curved support material is under tension while the epitaxial material is under compression.

23. The thin film stack material of claim 22, wherein the flattened, pre-curved support material comprises a material selected from the group consisting of wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, and combinations thereof.

24. The thin film stack material of claim 23, wherein the flattened, pre-curved support material comprises polyethylene terephthalate polyester, polyolefin, or derivatives thereof.

25. The thin film stack material of claim 22, wherein the flattened, pre-curved support material comprises a first layer comprising wax and a second layer comprising a polymer disposed over the first layer.

26. The thin film stack material of claim 25, wherein the second layer comprises polyethylene terephthalate polyester.

27. The thin film stack material of claim 25, wherein the flattened, pre-curved support material further comprises a third layer comprising another polymer and disposed over the second layer.

28. The thin film stack material of claim 27, wherein the third layer comprises polyethylene or derivatives thereof.

29. The thin film stack material of claim 22, wherein an adhesive is disposed between flattened, pre-curved support and the epitaxial material, and the adhesive is selected from the group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

30. The thin film stack material of claim 29, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

31. The thin film stack material of claim 30, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

32. The thin film stack material of claim 30, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

33. The thin film stack material of claim 32, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

34. The thin film stack material of claim 32, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

35. The thin film stack material of claim 22, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

36. The thin film stack material of claim 22, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

37. The thin film stack material of claim 36, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

38. The thin film stack material of claim 37, wherein the thickness is within a range from about 1 nm to about 10 nm.

39. The thin film stack material of claim 38, wherein the thickness is within a range from about 4 nm to about 6 nm.

40. The thin film stack material of claim 22, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

41. A method for forming a thin film material during an epitaxial lift off process, comprising:

forming an epitaxial material over a sacrificial layer on a substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a shrinkable material;

shrinking the support handle to form tension in the support handle and compression in the epitaxial material during a shrinkage process;

removing the sacrificial layer during an etching process; and

peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the support handle to have substantial curvature.

42. The method of claim 41, wherein the support handle comprises a material selected from the group consisting of wax, polyethylene, polyester, polyolefin, polyethylene terephthalate polyester, rubber, derivatives thereof, and combinations thereof.

43. The method of claim 42, wherein the support handle comprises polyethylene terephthalate polyester, polyolefin, or derivatives thereof.

44. The method of claim 41, wherein the support handle comprises a first layer comprising wax and a second layer comprising a polymer disposed over the first layer.

45. The method of claim 44, wherein the second layer comprises polyethylene terephthalate polyester or derivatives thereof.

46. The method of claim 44, wherein the support handle further comprises a third layer comprising wax and disposed over the second layer or the support handle further comprises a third layer comprising another polymer and disposed over the second layer.

47. The method of claim 46, wherein the third layer comprises polyethylene or derivatives thereof.

48. The method of claim 41, wherein the support handle comprises a bottom surface and a top surface, the bottom surface is adhered to the epitaxial material and the support handle bends towards the top surface.

49. The method of claim 41, wherein the shrinkable material comprises an amorphous material, and the amorphous material is crystallized to undergo a net volume reduction during the shrinkage process.

50. The method of claim 41, wherein the shrinkable material comprises a material selected from the group consisting of plastic, rubber, polymer, oligomer, derivatives thereof, and combinations thereof.

51. The method of claim 41, wherein the shrinkable material comprises polyester or derivatives thereof.

52. The method of claim 41, wherein the support handle comprises a heat shrink polymer and the support handle is heated during the shrinkage process.

53. The method of claim 41, wherein an adhesive is used to adhere the support handle onto the epitaxial material, and the adhesive is selected from the group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

54. The method of claim 41, wherein the sacrificial layer is exposed to a wet etch solution during the etching process, the wet etch solution comprises hydrofluoric acid, a surfactant, and a buffer.

55. The method of claim 54, wherein the sacrificial layer is etched at a rate of about 5 mm/hr or greater.

56. The method of claim 41, wherein the sacrificial layer is exposed to hydrogen fluoride vapor during the etching process.

57. The method of claim 41, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

58. The method of claim 57, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

59. The method of claim 57, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

60. The method of claim 59, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

61. The method of claim 59, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

62. The method of claim 41, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

63. The method of claim 41, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

64. The method of claim 63, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

65. The method of claim 41, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

66. A method for forming a thin film material during an epitaxial lift off process, comprising:

positioning a substrate comprising an epitaxial material disposed over a sacrificial layer on the substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a shrinkable material;

shrinking the support handle to form tension in the support handle and compression in the epitaxial material during a shrinkage process; and

removing the sacrificial layer during an etching process, wherein the etching process further comprises:

peeling the epitaxial material from the substrate;

forming an etch crevice between the epitaxial material from the substrate; and

bending the support handle to have substantial curvature.

67. A thin film stack material, comprising:

a sacrificial layer disposed on a substrate;

an epitaxial material disposed over the sacrificial layer; and

a support handle disposed over the epitaxial material, wherein the support handle comprises a shrinkable material, which upon being shrunk, forms tension in the support handle and compression in the epitaxial material.

68. The thin film stack material of claim 67, wherein the shrinkable material comprises an amorphous material which is crystallized to undergo a net volume reduction during the shrinkage process.

69. The thin film stack material of claim 67, wherein the shrinkable material comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

70. The thin film stack material of claim 67, wherein the support handle comprises a heat shrink polymer.

71. The thin film stack material of claim 67, wherein an adhesive is between the support handle and the epitaxial material, and the adhesive is selected from the

group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

72. The thin film stack material of claim 67, wherein the epitaxial material comprises at least one material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

73. The thin film stack material of claim 72, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

74. The thin film stack material of claim 72, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

75. The thin film stack material of claim 74, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

76. The thin film stack material of claim 72, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

77. The thin film stack material of claim 67, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium

arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

78. The thin film stack material of claim 67, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

79. The thin film stack material of claim 78, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

80. The thin film stack material of claim 79, wherein the thickness is within a range from about 1 nm to about 10 nm.

81. The thin film stack material of claim 80, wherein the thickness is within a range from about 4 nm to about 6 nm.

82. The thin film stack material of claim 67, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

83. A method for forming a thin film material during an epitaxial lift off process, comprising:

forming an epitaxial material over a sacrificial layer on a substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material;

shrinking the support handle tangential to the reinforcement fibers to form tension in the support handle and compression in the epitaxial material during a shrinkage process;

removing the sacrificial layer during an etching process; and

peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the support handle to have substantial curvature.

84. The method of claim 83, wherein the support handle comprises a bottom surface and a top surface, the bottom surface is adhered to the epitaxial material, and the support handle bends towards the top surface.

85. The method of claim 83, wherein the shrinkable material comprises an amorphous material which is crystallized to undergo a net volume reduction during the shrinkage process.

86. The method of claim 83, wherein the shrinkable material comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

87. The method of claim 83, wherein the shrinkable material comprises polyester or derivatives thereof.

88. The method of claim 83, wherein the reinforcement fibers are high-strength polymeric fibers.

89. The method of claim 88, wherein the reinforcement fibers comprise polyethylene or derivatives thereof.

90. The method of claim 88, wherein the reinforcement fibers comprise a negative linear thermal expansion coefficient along the length of the fiber.

91. The method of claim 88, wherein the reinforcement fibers comprise a tensile moduli within a range from about 15 GPa to about 134 GPa.

92. The method of claim 83, wherein the support handle is heated during the shrinkage process, and the support handle comprises a heat shrink polymer and high-strength polymeric fibers.

93. The method of claim 83, wherein shrinking the support handle comprises removing solvent from the shrinkable material.

94. The method of claim 83, wherein an adhesive is used to adhere the support handle onto the epitaxial material, and the adhesive is selected from the group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

95. The method of claim 83, wherein the sacrificial layer is exposed to a wet etch solution during the etching process, the wet etch solution comprises hydrofluoric acid, a surfactant, and a buffer.

96. The method of claim 95, wherein the sacrificial layer is etched at a rate of about 5 mm/hr or greater.

97. The method of claim 83, wherein the sacrificial layer is exposed to hydrogen fluoride vapor during the etching process.

98. The method of claim 83, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

99. The method of claim 98, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

100. The method of claim 98, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

101. The method of claim 100, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

102. The method of claim 100, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

103. The method of claim 83, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

104. The method of claim 83, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

105. The method of claim 104, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

106. The method of claim 83, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

107. A method for forming a thin film material during an epitaxial lift off process, comprising:

positioning a substrate comprising an epitaxial material disposed over a sacrificial layer on the substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material;

shrinking the support handle tangential to the reinforcement fibers to form tension in the support handle and compression in the epitaxial material during a shrinkage process; and

removing the sacrificial layer during an etching process, wherein the etching process further comprises:

peeling the epitaxial material from the substrate;

forming an etch crevice between the epitaxial material from the substrate; and

bending the support handle to have substantial curvature.

108. A thin film stack material, comprising:

a sacrificial layer disposed on a substrate;

an epitaxial material disposed over the sacrificial layer; and

a support handle disposed over the epitaxial material, wherein the support handle comprises a shrinkable material and reinforcement fibers extending unidirectional throughout the shrinkable material, which upon being shrunk, shrinks tangential to the reinforcement fibers to form tension in the support handle and compression in the epitaxial material.

109. The thin film stack material of claim 108, wherein the shrinkable material comprises an amorphous material which is crystallized to undergo a net volume reduction during the shrinkage process.

110. The thin film stack material of claim 108, wherein the shrinkable material comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

111. The thin film stack material of claim 108, wherein the reinforcement fibers are high-strength polymeric fibers.

112. The thin film stack material of claim 108, wherein the reinforcement fibers comprise polyethylene.

113. The thin film stack material of claim 108, wherein the reinforcement fibers comprise a negative linear thermal expansion coefficient along the length of the fiber.

114. The thin film stack material of claim 108, wherein the reinforcement fibers comprise a tensile moduli within a range from about 15 GPa to about 134 GPa.

115. The thin film stack material of claim 108, wherein the support handle comprises a heat shrink polymer and high-strength polymeric fibers.

116. The thin film stack material of claim 108, wherein an adhesive is between the support handle and the epitaxial material, and the adhesive is selected from the group consisting of pressure sensitive adhesive, hot melt adhesive, UV curing adhesive, natural adhesive, synthetic adhesive, derivatives thereof, and combinations thereof.

117. The thin film stack material of claim 108, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

118. The thin film stack material of claim 117, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

119. The thin film stack material of claim 117, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

120. The thin film stack material of claim 119, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

121. The thin film stack material of claim 119, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

122. The thin film stack material of claim 108, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

123. The thin film stack material of claim 108, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

124. The thin film stack material of claim 123, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

125. The thin film stack material of claim 124, wherein the thickness is within a range from about 1 nm to about 10 nm.

126. The thin film stack material of claim 125, wherein the thickness is within a range from about 4 nm to about 6 nm.

127. The thin film stack material of claim 108, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

128. A method for forming a thin film material during an epitaxial lift off process, comprising:

forming an epitaxial material over a sacrificial layer on a substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a wax film having a varying thickness;

removing the sacrificial layer during an etching process; and

peeling the epitaxial material from the substrate while forming an etch crevice therebetween and bending the support handle to form compression in the epitaxial material during the etching process.

129. The method of claim 128, wherein the support handle comprises a bottom surface of the wax film and a top surface of a flexible member, the bottom surface is adhered to the epitaxial material, and the support handle bends towards the top surface.

130. The method of claim 129, wherein the flexible member comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

131. The method of claim 129, wherein the flexible member comprises polyester or derivatives thereof.

132. The method of claim 128, wherein the wax film comprises wax which has a softening point temperature within a range from about 65°C to about 95°C.

133. The method of claim 132, wherein the softening point temperature is within a range from about 80°C to about 90°C.

134. The method of claim 132, wherein the varying thickness of the wax film is thinnest at or near the middle of the wax film.

135. The method of claim 132, wherein the varying thickness of the wax film is thickest at or near the middle of the wax film.

136. The method of claim 128, wherein the sacrificial layer is exposed to a wet etch solution during the etching process, the wet etch solution comprises hydrofluoric acid, a surfactant, and a buffer.

137. The method of claim 136, wherein the sacrificial layer is etched at a rate of about 5 mm/hr or greater.

138. The method of claim 128, wherein the sacrificial layer is exposed to hydrogen fluoride vapor during the etching process.

139. The method of claim 128, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

140. The method of claim 139, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

141. The method of claim 139, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

142. The method of claim 141, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

143. The method of claim 141, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

144. The method of claim 128, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

145. The method of claim 128, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

146. The method of claim 145, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

147. The method of claim 128, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

148. A method for forming a thin film material during an epitaxial lift off process, comprising:

positioning a substrate comprising an epitaxial material disposed over a sacrificial layer on the substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a wax film having a varying thickness; and

removing the sacrificial layer during an etching process, wherein the etching process further comprises:

peeling the epitaxial material from the substrate;

forming an etch crevice between the epitaxial material from the substrate; and

bending the support handle to form compression in the epitaxial material during the etching process.

149. A thin film stack material, comprising:

a sacrificial layer disposed on a substrate;

an epitaxial material under disposed over the sacrificial layer; and

a support handle disposed over the epitaxial material, wherein the support handle comprises a wax film having a varying thickness.

150. The thin film stack material of claim 149, wherein the support handle comprises a bottom surface of the wax film and a top surface of a flexible member, and the bottom surface is adhered to the epitaxial material.

151. The thin film stack material of claim 150, wherein the flexible member comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

152. The thin film stack material of claim 150, wherein the flexible member comprises polyester or derivatives thereof.

153. The thin film stack material of claim 150, wherein the flexible member comprises a film thickness within a range from about 50.8 μm to about 127.0 μm.

154. The thin film stack material of claim 149, wherein the wax film comprises wax which has a softening point temperature within a range from about 65°C to about 95°C.

155. The thin film stack material of claim 154, wherein the softening point temperature is within a range from about 80°C to about 90°C.

156. The thin film stack material of claim 154, wherein the varying thickness of the wax film is thinnest at or near the center of the wax film.

157. The thin film stack material of claim 154, wherein the varying thickness of the wax film is thickest at or near the center of the wax film.

158. The thin film stack material of claim 154, wherein the varying thickness of the wax film is within a range from about 1 μm to about 100 μm.

159. The thin film stack material of claim 154, wherein the varying thickness of the wax film comprises a thinnest section and a thickest section.

160. The thin film stack material of claim 159, wherein the thinnest section has a thickness within a range from about 1 μm to about 25 μm.

161. The thin film stack material of claim 159, wherein the thickest section has a thickness within a range from about 25 μm to about 100 μm.

162. The thin film stack material of claim 149, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide,

aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

163. The thin film stack material of claim 162, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

164. The thin film stack material of claim 162, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

165. The thin film stack material of claim 164, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

166. The thin film stack material of claim 164, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

167. The thin film stack material of claim 149, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

168. The thin film stack material of claim 149, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

169. The thin film stack material of claim 168, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness of about 20 nm or less.

170. The thin film stack material of claim 169, wherein the thickness is within a range from about 1 nm to about 10 nm.

171. The thin film stack material of claim 170, wherein the thickness is within a range from about 4 nm to about 6 nm.

172. The thin film stack material of claim 149, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

173. A method for forming a thin film material during an epitaxial lift off process, comprising:

forming an epitaxial material over a sacrificial layer on a substrate;

adhering a support handle onto the epitaxial material, wherein the support handle comprises a stiff support layer adhered to the epitaxial material, a soft support layer adhered to the stiff support layer, and a handle plate adhered to the soft support layer;

removing the sacrificial layer during an etching process; and

peeling the epitaxial material from the substrate while forming an etch crevice therebetween while maintaining compression in the epitaxial material during the etching process.

174. The method of claim 173, further comprising removing the epitaxial material from the substrate.

175. The method of claim 174, further comprising attaching a support substrate to an exposed surface of the epitaxial material.

176. The method of claim 174, wherein the support substrate is bonded to the exposed surface of the epitaxial material by an adhesive.

177. The method of claim 176, wherein the adhesive is an optical adhesive or an UV-curable adhesive.

178. The method of claim 176, wherein the adhesive further comprises a material selected from the group consisting of butyl octyl phthalate, tetrahydrofurfuryl methacrylate, acrylate monomer, derivatives thereof, and combinations thereof.

179. The method of claim 176, wherein the adhesive is a silicone adhesive or the adhesive comprises sodium silicate.

180. The method of claim 176, wherein the adhesive is cured for a time period within a range from about 20 hours to about 60 hours, at a temperature within a range from about 25°C to about 75°C, and at a pressure within a range from about 5 psi to about 15 psi.

181. The method of claim 173, wherein the stiff support layer comprises a material selected from the group consisting of polymer, copolymer, oligomer, derivatives thereof, and combinations thereof.

182. The method of claim 181, wherein the stiff support layer comprises an ethylene/vinylacetate copolymer or derivatives thereof.

183. The method of claim 173, wherein the stiff support layer comprises a material selected from the group consisting of a hot-melt adhesive, an organic material, an organic coating, an inorganic material, and combinations thereof.

184. The method of claim 183, wherein the stiff support layer comprises multiple layers of the inorganic material, and the multiple layers further comprise a metal layer, a dielectric layer, or combinations thereof.

185. The method of claim 173, wherein the soft support layer comprises an elastomer, and the elastomer comprises rubber, foam, or derivatives thereof.

186. The method of claim 173, wherein the soft support layer comprises a material selected from the group consisting of neoprene, latex, and derivatives thereof.

187. The method of claim 173, wherein the soft support layer comprises an ethylene propylene diene monomer or derivatives thereof.

188. The method of claim 173, wherein the handle plate comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

189. The method of claim 173, wherein the handle plate comprises polyester or derivatives thereof.

190. The method of claim 173, wherein the sacrificial layer is exposed to a wet etch solution during the etching process, the wet etch solution comprises hydrofluoric acid, a surfactant, and a buffer.

191. The method of claim 173, wherein the sacrificial layer is etched at a rate of about 5 mm/hr or greater.

192. The method of claim 173, wherein the sacrificial layer is exposed to a hydrogen fluoride vapor during the etching process.

193. The method of claim 173, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

194. The method of claim 193, wherein the epitaxial material comprises a layer comprising gallium arsenide and another layer comprising aluminum gallium arsenide.

195. The method of claim 194, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

196. The method of claim 195, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

197. The method of claim 195, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

198. The method of claim 173, wherein the epitaxial material comprises a cell structure comprising multiple layers, the cell structure comprises a material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

199. The method of claim 173, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

200. The method of claim 199, wherein the sacrificial layer comprises an aluminum arsenide layer having a thickness within a range from about 1 nm to about 10 nm.

201. A thin film stack material, comprising:

a sacrificial layer disposed on a substrate;

an epitaxial material disposed over the sacrificial layer; and

a support handle disposed over the epitaxial material, wherein the support handle comprises:

a stiff support layer disposed over the epitaxial material;

a soft support layer disposed over the stiff support layer; and

a handle plate disposed over the soft support layer.

202. The thin film stack material of claim 201, wherein the epitaxial material is under compression.

203. The thin film stack material of claim 201, wherein the stiff support layer comprises an ethylene/vinylacetate copolymer or derivatives thereof.

204. The thin film stack material of claim 201, wherein the stiff support layer comprises a material selected from the group consisting of a hot-melt adhesive, an organic coating, an organic material, an inorganic material, and combinations thereof.

205. The thin film stack material of claim 204, wherein the stiff support layer comprises multiple layers of the inorganic material, and the multiple layers further comprise a metal layer, a dielectric layer, or combinations thereof.

206. The thin film stack material of claim 201, wherein the soft support layer comprises an elastomer and the elastomer comprises rubber, foam, or derivatives thereof.

207. The thin film stack material of claim 201, wherein the soft support layer comprises a material selected from the group consisting of neoprene, latex, and derivatives thereof.

208. The thin film stack material of claim 201, wherein the soft support layer comprises an ethylene propylene diene monomer or derivatives thereof.

209. The thin film stack material of claim 201, wherein the handle plate comprises a material selected from the group consisting of plastic, polymer, oligomer, derivatives thereof, and combinations thereof.

210. The thin film stack material of claim 209, wherein the handle plate comprises polyester or derivatives thereof.

211. The thin film stack material of claim 209, wherein the handle plate has a thickness within a range from about 50.8 μm to about 127.0 μm.

212. The thin film stack material of claim 201, wherein the epitaxial material comprises a material selected from the group consisting of gallium arsenide, aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

213. The thin film stack material of claim 212, wherein the epitaxial material comprises a gallium arsenide buffer layer, an aluminum gallium arsenide passivation layer, and a gallium arsenide active layer.

214. The thin film stack material of claim 213, wherein the gallium arsenide buffer layer has a thickness within a range from about 100 nm to about 500 nm, the aluminum gallium arsenide passivation layer has a thickness within a range from about 10 nm to about 50 nm, and the gallium arsenide active layer has a thickness within a range from about 500 nm to about 2,000 nm.

215. The thin film stack material of claim 213, wherein the epitaxial material further comprises a second aluminum gallium arsenide passivation layer.

216. The thin film stack material of claim 201, wherein the epitaxial material comprises a cell structure containing multiple layers comprising at least one material selected from the group consisting of gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, aluminum gallium arsenide, n-doped aluminum gallium arsenide, p-doped aluminum gallium arsenide, indium gallium phosphide, alloys thereof, derivatives thereof, and combinations thereof.

217. The thin film stack material of claim 201, wherein the sacrificial layer comprises a material selected from the group consisting of aluminum arsenide, alloys thereof, derivatives thereof, and combinations thereof.

218. The thin film stack material of claim 201, wherein the substrate comprises gallium arsenide, n-doped gallium arsenide, p-doped gallium arsenide, or derivatives thereof.

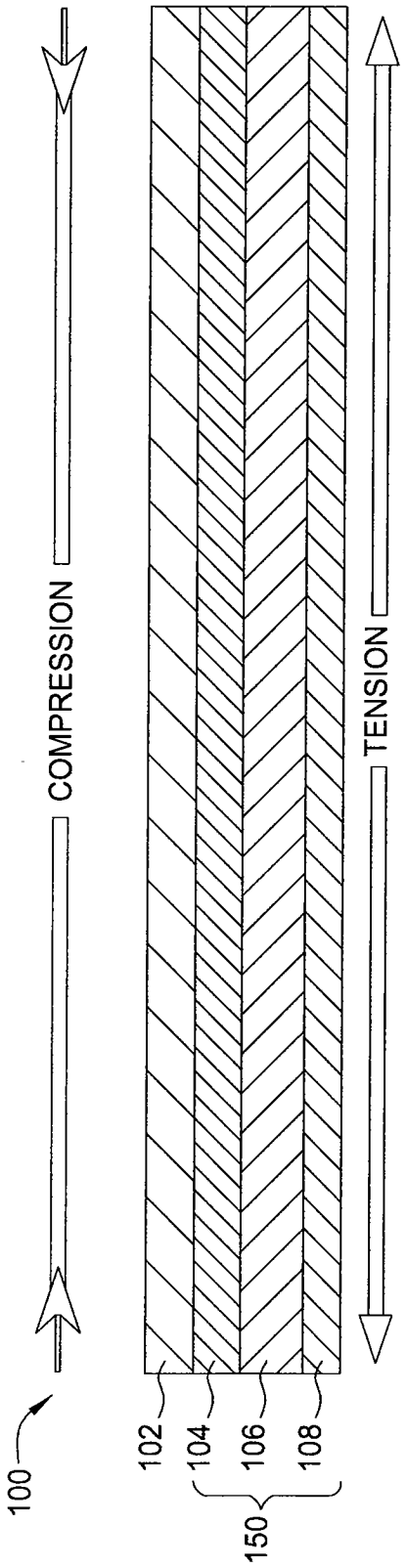

FIG. 1

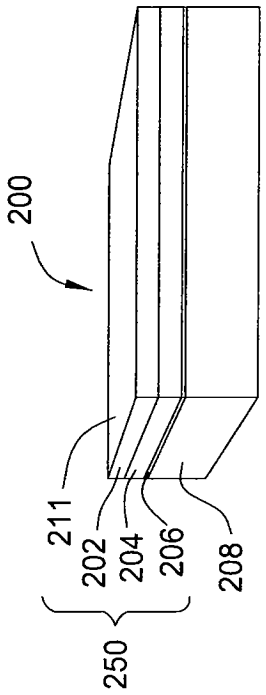

FIG. 2B

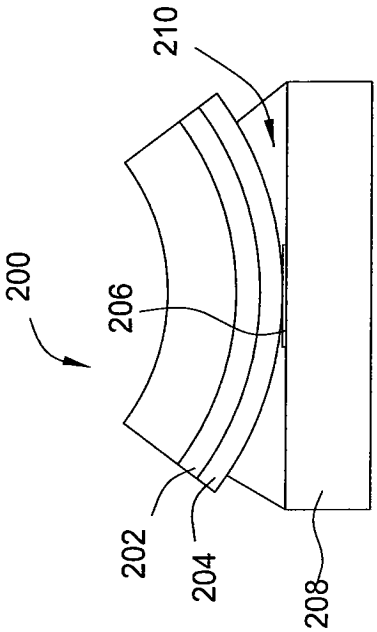

FIG. 2C

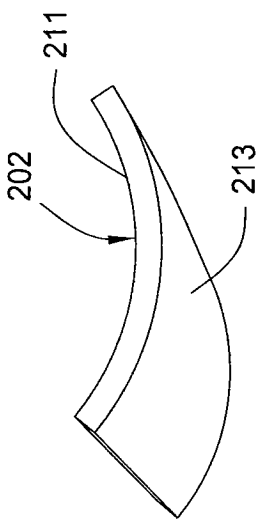

FIG. 2A

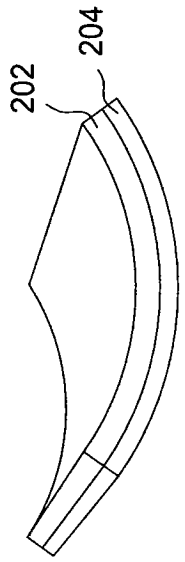

FIG. 2D

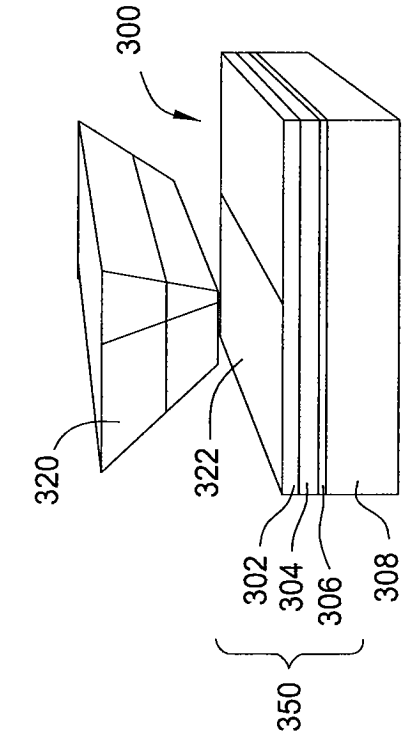

FIG. 3B

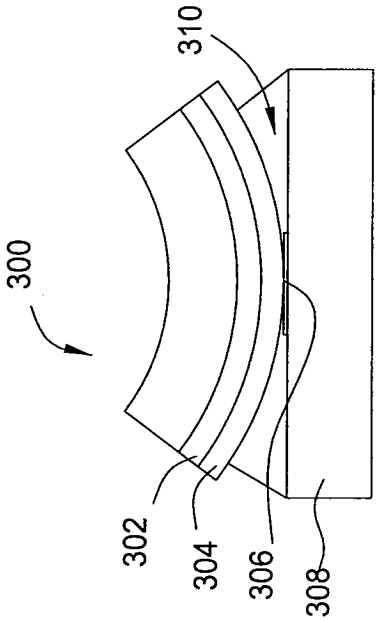

FIG. 3C

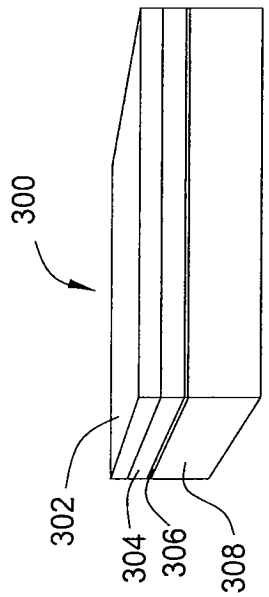

FIG. 3A

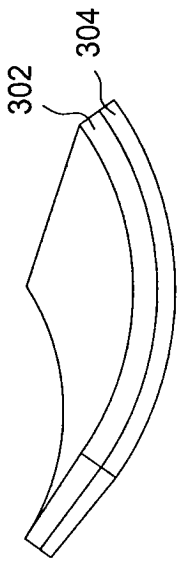

FIG. 3D

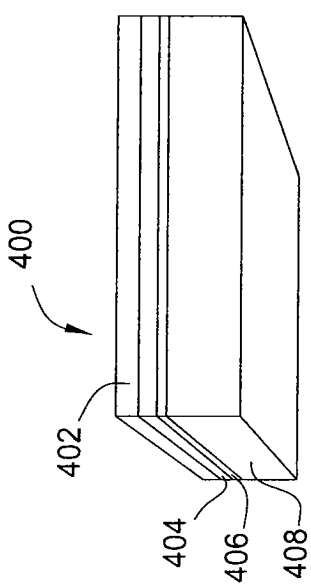

FIG. 4A

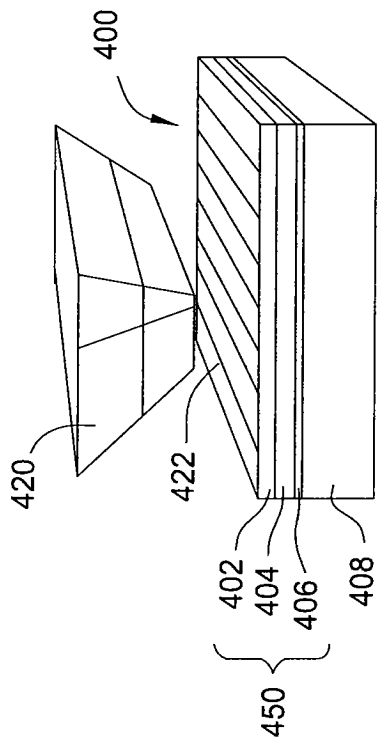

FIG. 4B

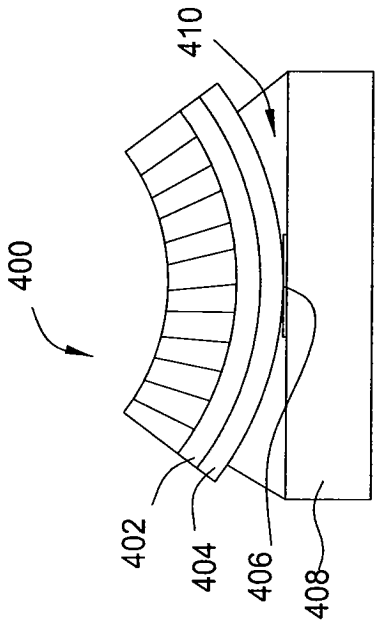

FIG. 4C

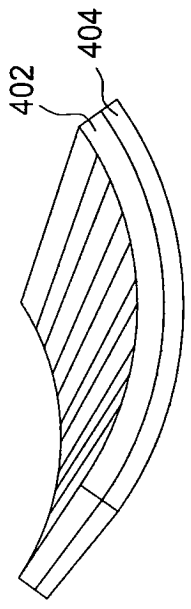

FIG. 4D

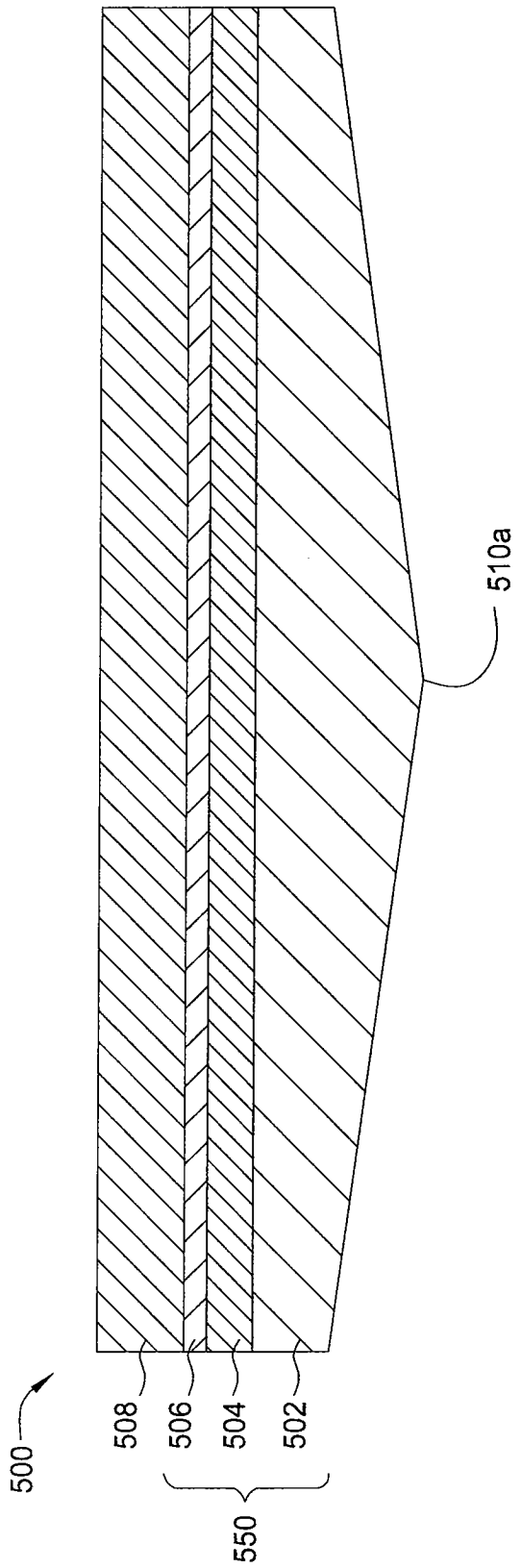

FIG. 5A

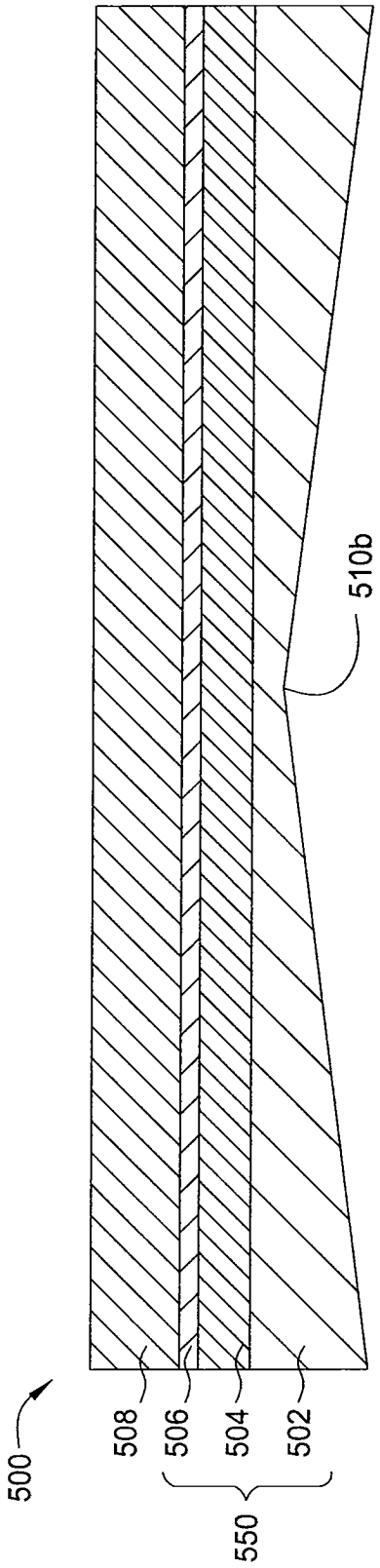

FIG. 5B

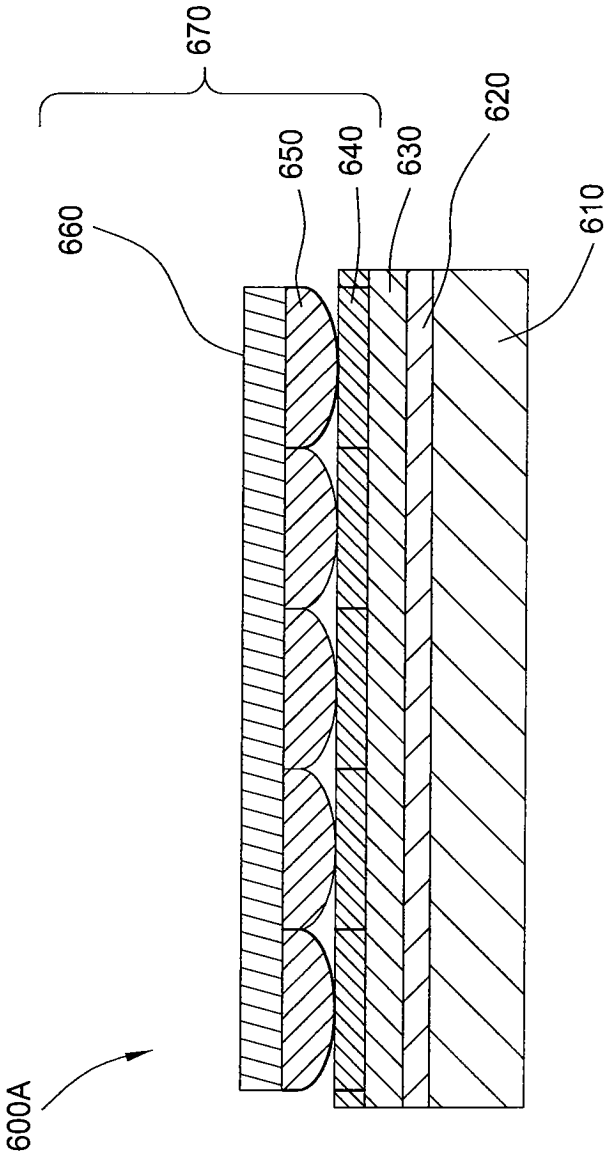

FIG. 6A

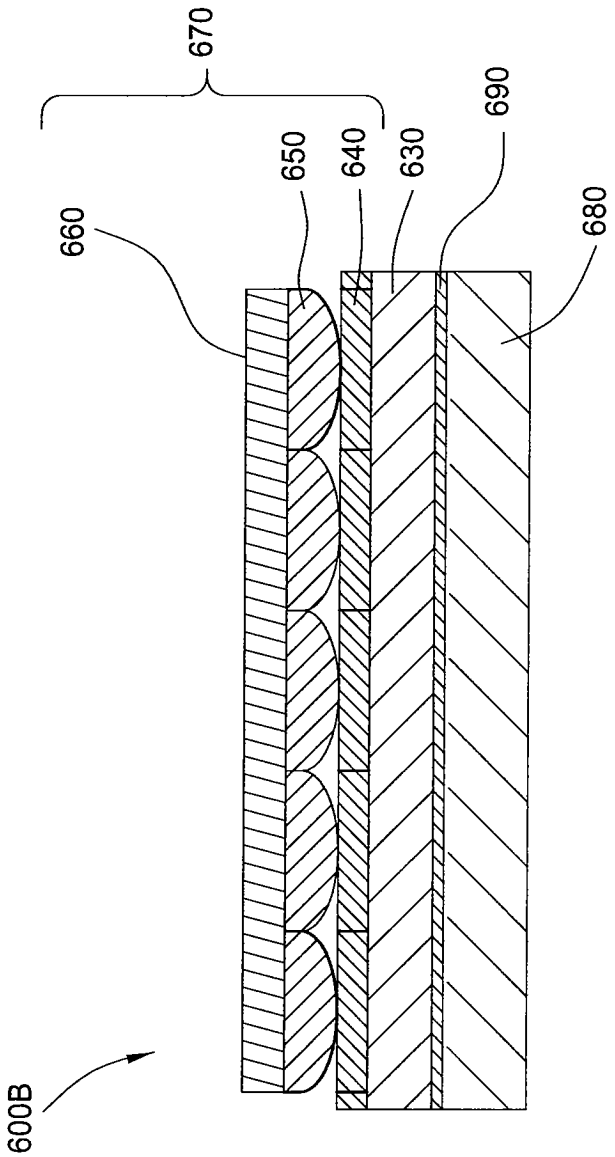

FIG. 6B

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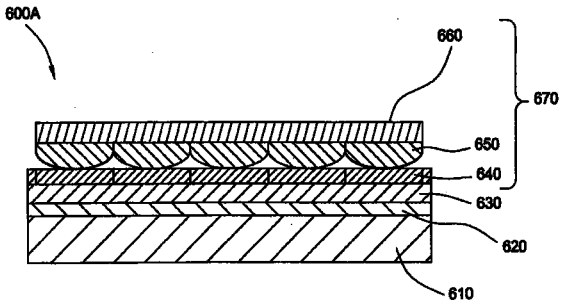
权利要求书 14 页 说明书 14 页 附图 7 页

(54)发明名称

外延迁移堆栈和方法

(57)摘要

本发明的实施方案通常涉及外延迁移(ELO)薄膜和器件，以及用来形成这类膜和器件的方法。ELO薄膜通常包括外延生长层，其在配置于基底例如晶片之上或上方的牺牲层上形成。支撑柄可配置在除了基底外的外延材料的相对侧上。支撑柄可例如通过给外延材料提供压缩来稳定外延材料。此外，在ELO工艺的蚀刻和移除步骤期间，支撑柄可用于抓紧以及支撑住外延材料。在不同实施方案中，支撑柄可包括预先弯曲的柄、多层柄、非均匀蜡柄和两个收缩诱发柄，其普通地或单向地收缩，以给外延材料提供压缩。



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1. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

在基底上的牺牲层上方形成外延材料；

将压平的预先弯曲的支撑柄黏合至所述外延材料之上，其中所述压平的预先弯曲的支撑柄通过压平弯曲的支撑材料而形成，且所述压平的预先弯曲的支撑柄承受张力，而所述外延材料受到压缩；

在蚀刻工艺期间移除所述牺牲层；以及

从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝，以及使所述压平的预先弯曲的支撑柄弯曲，以具有相当大的曲率。

2. 如权利要求 1 所述的方法，其中所述弯曲的支撑材料包括选自由下列项组成的组的材料：蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物和其组合。

3. 如权利要求 2 所述的方法，其中所述弯曲的支撑材料包括聚对苯二甲酸乙二酯聚酯、聚烯烃或其衍生物。

4. 如权利要求 1 所述的方法，其中所述弯曲的支撑材料包括：包含蜡的第一层；及包含聚合物并配置在所述第一层上方的第二层。

5. 如权利要求 4 所述的方法，其中所述第二层包括聚对苯二甲酸乙二酯聚酯或其衍生物。

6. 如权利要求 4 所述的方法，其中所述弯曲的支撑材料还包括包含蜡并配置在所述第二层上方的第三层；或包括包含另一聚合物并配置在所述第二层上方的第三层。

7. 如权利要求 6 所述的方法，其中所述第三层包括聚乙烯或其衍生物。

8. 如权利要求 1 所述的方法，其中所述压平的预先弯曲的支撑柄包括底表面和顶表面，所述底表面黏合至所述外延材料，且所述压平的预先弯曲的支撑柄朝所述顶表面弯曲。

9. 如权利要求 1 所述的方法，其中粘合剂用来将所述压平的预先弯曲的支撑柄黏合至所述外延材料之上，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

10. 如权利要求 1 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于湿蚀刻溶液，所述湿蚀刻溶液包括氢氟酸、表面活性剂和缓冲剂。

11. 如权利要求 10 所述的方法，其中所述牺牲层以约 5 毫米 / 小时或更大的速度被蚀刻。

12. 如权利要求 1 所述的方法，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

13. 如权利要求 12 所述的方法，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

14. 如权利要求 13 所述的方法，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

15. 如权利要求 14 所述的方法，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

16. 如权利要求 14 所述的方法，其中所述外延材料还包括第二砷化铝镓钝化层。

17. 如权利要求 1 所述的方法，其中所述外延材料包括晶胞结构，所述晶胞结构包含多

层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

18. 如权利要求 1 所述的方法，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

19. 如权利要求 18 所述的方法，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

20. 如权利要求 1 所述的方法，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

21. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

定位基底，所述基底包括配置在所述基底上的牺牲层上方的外延材料；

将压平的预先弯曲的支撑柄黏合至所述外延材料之上，其中所述压平的预先弯曲的支撑柄通过压平弯曲的支撑材料而形成，且所述压平的预先弯曲的支撑柄承受张力，而所述外延材料受到压缩；以及

在蚀刻工艺期间移除所述牺牲层，其中所述蚀刻工艺还包括：

从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝；以及

使所述压平的预先弯曲的支撑柄弯曲，以具有相当大的曲率。

22. 一种薄膜堆栈材料，包括：

牺牲层，其配置在基底上；

外延材料，其配置在所述牺牲层上方；以及

压平的预先弯曲的支撑材料，其配置在所述外延材料上方，其中所述压平的预先弯曲的支撑材料承受张力，而所述外延材料受到压缩。

23. 如权利要求 22 所述的薄膜堆栈材料，其中所述压平的预先弯曲的支撑材料包括选自由下列项组成的组的材料：蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物和其组合。

24. 如权利要求 23 所述的薄膜堆栈材料，其中所述压平的预先弯曲的支撑材料包括聚对苯二甲酸乙二酯聚酯、聚烯烃或其衍生物。

25. 如权利要求 22 所述的薄膜堆栈材料，其中所述压平的预先弯曲的支撑材料包括：包含蜡的第一层；及包含聚合物并配置在所述第一层上方的第二层。

26. 如权利要求 25 所述的薄膜堆栈材料，其中所述第二层包括聚对苯二甲酸乙二酯聚酯。

27. 如权利要求 25 所述的薄膜堆栈材料，其中所述压平的预先弯曲的支撑材料还包括包含另一聚合物并配置在所述第二层上方的第三层。

28. 如权利要求 27 所述的薄膜堆栈材料，其中所述第三层包括聚乙烯或其衍生物。

29. 如权利要求 22 所述的薄膜堆栈材料，其中粘合剂配置在所述压平的预先弯曲的支撑材料和所述外延材料之间，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

30. 如权利要求 29 所述的薄膜堆栈材料，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

31. 如权利要求 30 所述的薄膜堆栈材料，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

32. 如权利要求 30 所述的薄膜堆栈材料，其中所述外延材料包括：砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

33. 如权利要求 32 所述的薄膜堆栈材料，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

34. 如权利要求 32 所述的薄膜堆栈材料，其中所述外延材料还包括第二砷化铝镓钝化层。

35. 如权利要求 22 所述的薄膜堆栈材料，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

36. 如权利要求 22 所述的薄膜堆栈材料，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

37. 如权利要求 36 所述的薄膜堆栈材料，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

38. 如权利要求 37 所述的薄膜堆栈材料，其中所述厚度在从约 1nm 至约 10nm 的范围内。

39. 如权利要求 38 所述的薄膜堆栈材料，其中所述厚度在从约 4nm 至约 6nm 的范围内。

40. 如权利要求 22 所述的薄膜堆栈材料，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

41. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

在基底上的牺牲层上方形成外延材料；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括可收缩材料；

在收缩工艺期间收缩所述支撑柄，以形成所述支撑柄中的张力和所述外延材料中的压缩；

在蚀刻工艺期间移除所述牺牲层；以及

从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝，并使所述支撑柄弯曲，以具有相当大的曲率。

42. 如权利要求 41 所述的方法，其中所述支撑柄包括选自由下列项组成的组的材料：蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物和其组合。

43. 如权利要求 42 所述的方法，其中所述支撑柄包括聚对苯二甲酸乙二酯聚酯、聚烯烃或其衍生物。

44. 如权利要求 41 所述的方法，其中所述支撑柄包括：包含蜡的第一层及包含聚合物并配置在所述第一层上方的第二层。

45. 如权利要求 44 所述的方法，其中所述第二层包括聚对苯二甲酸乙二酯聚酯或其衍生物。

46. 如权利要求 44 所述的方法，其中所述支撑柄还包括包含蜡并配置在所述第二层上

方的第三层；或所述支撑柄还包括包含另一聚合物并配置在所述第二层上方的第三层。

47. 如权利要求 46 所述的方法，其中所述第三层包括聚乙烯或其衍生物。

48. 如权利要求 41 所述的方法，其中所述支撑柄包括底表面和顶表面，所述底表面黏合至所述外延材料，且所述支撑柄朝所述顶表面弯曲。

49. 如权利要求 41 所述的方法，其中所述可收缩材料包括无定形材料，且所述无定形材料在所述收缩工艺期间结晶，以经历净体积缩小。

50. 如权利要求 41 所述的方法，其中所述可收缩材料包括选自由下列项组成的组的材料：塑料、橡胶、聚合物、低聚物、其衍生物和其组合。

51. 如权利要求 41 所述的方法，其中所述可收缩材料包括聚酯或其衍生物。

52. 如权利要求 41 所述的方法，其中所述支撑柄包括热缩聚合物，且所述支撑柄在所述收缩工艺期间被加热。

53. 如权利要求 41 所述的方法，其中粘合剂用来将所述支撑柄黏合至所述外延材料之上，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

54. 如权利要求 41 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于湿蚀刻溶液，所述湿蚀刻溶液包括氢氟酸、表面活性剂和缓冲剂。

55. 如权利要求 54 所述的方法，其中所述牺牲层以约 5 毫米 / 小时或更大的速度被蚀刻。

56. 如权利要求 41 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于氟化氢蒸汽。

57. 如权利要求 41 所述的方法，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

58. 如权利要求 57 所述的方法，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

59. 如权利要求 57 所述的方法，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

60. 如权利要求 59 所述的方法，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

61. 如权利要求 59 所述的方法，其中所述外延材料还包括第二砷化铝镓钝化层。

62. 如权利要求 41 所述的方法，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

63. 如权利要求 41 所述的方法，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

64. 如权利要求 63 所述的方法，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

65. 如权利要求 41 所述的方法，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化

镓或其衍生物。

66. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

定位基底，所述基底包括配置在所述基底上的牺牲层上方的外延材料；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括可收缩材料；

在收缩工艺期间收缩所述支撑柄，以形成所述支撑柄中的张力和所述外延材料中的压缩；以及

在蚀刻工艺期间移除所述牺牲层，其中所述蚀刻工艺还包括：

从所述基底剥离所述外延材料；

在所述外延材料和所述基底之间形成蚀刻裂缝；以及

使所述支撑柄弯曲，以具有相当大的曲率。

67. 一种薄膜堆栈材料，包括：

牺牲层，其配置在基底上；

外延材料，其配置在所述牺牲层上方；以及

支撑柄，其配置在所述外延材料上方，其中所述支撑柄包括可收缩材料，所述可收缩材料在收缩时形成所述支撑柄中的张力和所述外延材料中的压缩。

68. 如权利要求 67 所述的薄膜堆栈材料，其中所述可收缩材料包括无定形材料，所述无定形材料在收缩工艺期间结晶，以经历净体积缩小。

69. 如权利要求 67 所述的薄膜堆栈材料，其中所述可收缩材料包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

70. 如权利要求 67 所述的薄膜堆栈材料，其中所述支撑柄包括热缩聚合物。

71. 如权利要求 67 所述的薄膜堆栈材料，其中粘合剂在所述支撑柄和所述外延材料之间，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

72. 如权利要求 67 所述的薄膜堆栈材料，其中所述外延材料包括选自由下列项组成的组的至少一种材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

73. 如权利要求 72 所述的薄膜堆栈材料，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

74. 如权利要求 72 所述的薄膜堆栈材料，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

75. 如权利要求 74 所述的薄膜堆栈材料，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

76. 如权利要求 72 所述的薄膜堆栈材料，其中所述外延材料还包括第二砷化铝镓钝化层。

77. 如权利要求 67 所述的薄膜堆栈材料，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

78. 如权利要求 67 所述的薄膜堆栈材料，其中所述牺牲层包括选自由下列项组成的组

的材料：砷化铝、其合金、其衍生物和其组合。

79. 如权利要求 78 所述的薄膜堆栈材料，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

80. 如权利要求 79 所述的薄膜堆栈材料，其中所述厚度在从约 1nm 至约 10nm 的范围内。

81. 如权利要求 80 所述的薄膜堆栈材料，其中所述厚度在从约 4nm 至约 6nm 的范围内。

82. 如权利要求 67 所述的薄膜堆栈材料，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

83. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

在基底上的牺牲层上方形成外延材料；

将支撑柄黏合至外延材料之上，其中所述支撑柄包括可收缩材料和补强纤维，所述补强纤维单向延伸贯穿所述可收缩材料；

在收缩工艺期间收缩正切于所述补强纤维的所述支撑柄，以形成所述支撑柄中的张力和所述外延材料中的压缩；

在蚀刻工艺期间移除所述牺牲层；以及

从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝，并使所述支撑柄弯曲，以具有相当大的曲率。

84. 如权利要求 83 所述的方法，其中所述支撑柄包括底表面和顶表面，所述底表面黏合至所述外延材料，且所述支撑柄朝所述顶表面弯曲。

85. 如权利要求 83 所述的方法，其中所述可收缩材料包括无定形材料，所述无定形材料在所述收缩工艺期间结晶，以经历净体积缩小。

86. 如权利要求 83 所述的方法，其中所述可收缩材料包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

87. 如权利要求 83 所述的方法，其中所述可收缩材料包括聚酯或其衍生物。

88. 如权利要求 83 所述的方法，其中所述补强纤维为高强度聚合物纤维。

89. 如权利要求 88 所述的方法，其中所述补强纤维包括聚乙烯或其衍生物。

90. 如权利要求 88 所述的方法，其中所述补强纤维沿着纤维长度包括负的线性热膨胀系数。

91. 如权利要求 88 所述的方法，其中所述补强纤维包括在从约 15GPa 至约 134GPa 的范围内的拉伸模量。

92. 如权利要求 83 所述的方法，其中所述支撑柄在所述收缩工艺期间被加热，且所述支撑柄包括热缩聚合物和高强度聚合物纤维。

93. 如权利要求 83 所述的方法，其中收缩所述支撑柄包括从所述可收缩材料移除溶剂。

94. 如权利要求 83 所述的方法，其中粘合剂用来将所述支撑柄黏合至所述外延材料之上，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

95. 如权利要求 83 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于湿蚀刻溶液，所述湿蚀刻溶液包括氢氟酸、表面活性剂和缓冲剂。

96. 如权利要求 95 所述的方法，其中所述牺牲层以约 5 毫米 / 小时或更大的速度被蚀刻。

97. 如权利要求 83 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于氟化氢蒸汽。

98. 如权利要求 83 所述的方法，其中所述外延材料包括选自由下列项组成的组的材料 ：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

99. 如权利要求 98 所述的方法，其中所述外延材料包括 ：包含砷化镓的一层及包含砷化铝镓的另一层。

100. 如权利要求 98 所述的方法，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

101. 如权利要求 100 所述的方法，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度 ；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度 ；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

102. 如权利要求 100 所述的方法，其中所述外延材料还包括第二砷化铝镓钝化层。

103. 如权利要求 83 所述的方法，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料 ：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

104. 如权利要求 83 所述的方法，其中所述牺牲层包括选自由下列项组成的组的材料 ：砷化铝、其合金、其衍生物和其组合。

105. 如权利要求 104 所述的方法，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

106. 如权利要求 83 所述的方法，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

107. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤 ：

定位基底，所述基底包括配置在所述基底上的牺牲层上方的外延材料 ；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括可收缩材料和补强纤维，所述补强纤维单向延伸贯穿所述可收缩材料 ；

在收缩工艺期间收缩正切于所述补强纤维的所述支撑柄，以形成所述支撑柄中的张力和所述外延材料中的压缩 ；及

在蚀刻工艺期间移除所述牺牲层，其中所述蚀刻工艺还包括 ：

从所述基底剥离所述外延材料 ；

在所述外延材料和所述基底之间形成蚀刻裂缝 ；以及

使所述支撑柄弯曲，以具有相当大的曲率。

108. 一种薄膜堆栈材料，包括 ：

牺牲层，其配置在基底上 ；

外延材料，其配置在所述牺牲层上方 ；以及

支撑柄，其配置在所述外延材料上方，其中所述支撑柄包括可收缩材料和补强纤维，所述补强纤维单向延伸贯穿所述可收缩材料，所述可收缩材料在收缩时正切于所述补强纤维

而收缩，以形成所述支撑柄中的张力和所述外延材料中的压缩。

109. 如权利要求 108 所述的薄膜堆栈材料，其中所述可收缩材料包括无定形材料，所述无定形材料在所述收缩工艺期间结晶，以经历净体积缩小。

110. 如权利要求 108 所述的薄膜堆栈材料，其中所述可收缩材料包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

111. 如权利要求 108 所述的薄膜堆栈材料，其中所述补强纤维为高强度聚合物纤维。

112. 如权利要求 108 所述的薄膜堆栈材料，其中所述补强纤维包括聚乙烯。

113. 如权利要求 108 所述的薄膜堆栈材料，其中所述补强纤维沿着纤维长度包括负的线性热膨胀系数。

114. 如权利要求 108 所述的薄膜堆栈材料，其中所述补强纤维包括在从约 15GPa 至约 134GPa 的范围内的拉伸模量。

115. 如权利要求 108 所述的薄膜堆栈材料，其中所述支撑柄包括热缩聚合物和高强度聚合物纤维。

116. 如权利要求 108 所述的薄膜堆栈材料，其中粘合剂在所述支撑柄和所述外延材料之间，且所述粘合剂选自由下列项组成的组：压敏粘合剂、热熔性粘合剂、UV 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物和其组合。

117. 如权利要求 108 所述的薄膜堆栈材料，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

118. 如权利要求 117 所述的薄膜堆栈材料，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

119. 如权利要求 117 所述的薄膜堆栈材料，其中所述外延材料包括：砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

120. 如权利要求 119 所述的薄膜堆栈材料，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

121. 如权利要求 119 所述的薄膜堆栈材料，其中所述外延材料还包括第二砷化铝镓钝化层。

122. 如权利要求 108 所述的薄膜堆栈材料，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

123. 如权利要求 108 所述的薄膜堆栈材料，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

124. 如权利要求 123 所述的薄膜堆栈材料，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

125. 如权利要求 124 所述的薄膜堆栈材料，其中所述厚度在从约 1nm 至约 10nm 的范围内。

126. 如权利要求 125 所述的薄膜堆栈材料，其中所述厚度在从约 4nm 至约 6nm 的范围内。

127. 如权利要求 108 所述的薄膜堆栈材料，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

128. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

在基底上的牺牲层上方形成外延材料；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括具有变化厚度的蜡膜；

在蚀刻工艺期间移除所述牺牲层；以及

在所述蚀刻工艺期间，从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝，并使所述支撑柄弯曲，以形成所述外延材料中的压缩。

129. 如权利要求 128 所述的方法，其中所述支撑柄包括所述蜡膜的底表面和柔性构件的顶表面，所述底表面黏合至所述外延材料，且所述支撑柄朝所述顶表面弯曲。

130. 如权利要求 129 所述的方法，其中所述柔性构件包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

131. 如权利要求 129 所述的方法，其中所述柔性构件包括聚酯或其衍生物。

132. 如权利要求 128 所述的方法，其中所述蜡膜包括蜡，所述蜡具有在从约 65℃至约 95℃的范围内的软化点温度。

133. 如权利要求 132 所述的方法，其中所述软化点温度在从约 80℃至约 90℃的范围内。

134. 如权利要求 132 所述的方法，其中所述蜡膜的变化厚度在所述蜡膜中央中或附近最薄。

135. 如权利要求 132 所述的方法，其中所述蜡膜的变化厚度在所述蜡膜中央中或附近最厚。

136. 如权利要求 128 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于湿蚀刻溶液，所述湿蚀刻溶液包括氢氟酸、表面活性剂和缓冲剂。

137. 如权利要求 136 所述的方法，其中所述牺牲层以约 5 毫米 / 小时或更大的速度被蚀刻。

138. 如权利要求 128 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于氟化氢蒸汽。

139. 如权利要求 128 所述的方法，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

140. 如权利要求 139 所述的方法，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

141. 如权利要求 139 所述的方法，其中所述外延材料包括：砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

142. 如权利要求 141 所述的方法，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

143. 如权利要求 141 所述的方法，其中所述外延材料还包括第二砷化铝镓钝化层。

144. 如权利要求 128 所述的方法，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化

镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

145. 如权利要求 128 所述的方法，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

146. 如权利要求 145 所述的方法，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

147. 如权利要求 128 所述的方法，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

148. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

定位基底，所述基底包括配置在所述基底上的牺牲层上方的外延材料；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括具有变化厚度的蜡膜；以及

在蚀刻工艺期间移除所述牺牲层，其中所述蚀刻工艺还包括：

从所述基底剥离所述外延材料；

在所述外延材料和所述基底之间形成蚀刻裂缝；以及

在所述蚀刻工艺期间，使所述支撑柄弯曲，以形成所述外延材料中的压缩。

149. 一种薄膜堆栈材料，包括：

牺牲层，其配置在基底上；

外延材料，其配置在所述牺牲层上方；以及

支撑柄，其配置在所述外延材料上方，其中所述支撑柄包括具有变化厚度的蜡膜。

150. 如权利要求 149 所述的薄膜堆栈材料，其中所述支撑柄包括所述蜡膜的底表面和柔性构件的顶表面，且所述底表面黏合至所述外延材料。

151. 如权利要求 150 所述的薄膜堆栈材料，其中所述柔性构件包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

152. 如权利要求 150 所述的薄膜堆栈材料，其中所述柔性构件包括聚酯或其衍生物。

153. 如权利要求 150 所述的薄膜堆栈材料，其中所述柔性构件包括在从约 50.8μm 至约 127.0μm 的范围内的膜厚度。

154. 如权利要求 149 所述的薄膜堆栈材料，其中所述蜡膜包括蜡，所述蜡具有在从约 65℃至约 95℃的范围内的软化点温度。

155. 如权利要求 154 所述的薄膜堆栈材料，其中所述软化点温度在从约 80℃至约 90℃的范围内。

156. 如权利要求 154 所述的薄膜堆栈材料，其中所述蜡膜的变化厚度在所述蜡膜的中心处或附近最薄。

157. 如权利要求 154 所述的薄膜堆栈材料，其中所述蜡膜的变化厚度在所述蜡膜的中心处或附近最厚。

158. 如权利要求 154 所述的薄膜堆栈材料，其中所述蜡膜的变化厚度在从约 1μm 至约 100μm 的范围内。

159. 如权利要求 154 所述的薄膜堆栈材料，其中所述蜡膜的变化厚度包括最薄段和最厚段。

160. 如权利要求 159 所述的薄膜堆栈材料，其中所述最薄段具有在从约 1μm 至约

25μm 的范围内的厚度。

161. 如权利要求 159 所述的薄膜堆栈材料，其中所述最厚段具有从约 25μm 至约 100μm 的范围内的厚度。

162. 如权利要求 149 所述的薄膜堆栈材料，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

163. 如权利要求 162 所述的薄膜堆栈材料，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

164. 如权利要求 162 所述的薄膜堆栈材料，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

165. 如权利要求 164 所述的薄膜堆栈材料，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

166. 如权利要求 164 所述的薄膜堆栈材料，其中所述外延材料还包括第二砷化铝镓钝化层。

167. 如权利要求 149 所述的薄膜堆栈材料，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

168. 如权利要求 149 所述的薄膜堆栈材料，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

169. 如权利要求 168 所述的薄膜堆栈材料，其中所述牺牲层包括具有约 20nm 或更小的厚度的砷化铝层。

170. 如权利要求 169 所述的薄膜堆栈材料，其中所述厚度在从约 1nm 至约 10nm 的范围内。

171. 如权利要求 170 所述的薄膜堆栈材料，其中所述厚度在从约 4nm 至约 6nm 的范围内。

172. 如权利要求 149 所述的薄膜堆栈材料，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

173. 一种用于在外延迁移工艺期间形成薄膜材料的方法，包括下列步骤：

在基底上的牺牲层上方形成外延材料；

将支撑柄黏合至所述外延材料之上，其中所述支撑柄包括：黏合至所述外延材料的硬性支撑层；黏合至所述硬性支撑层的软性支撑层；及黏合至所述软性支撑层的柄板；

在蚀刻工艺期间移除所述牺牲层；以及

在所述蚀刻工艺期间，从所述基底剥离所述外延材料，同时在其间形成蚀刻裂缝，同时维持所述外延材料中的压缩。

174. 如权利要求 173 所述的方法，还包括从所述基底移除所述外延材料。

175. 如权利要求 174 所述的方法，还包括将支撑基底附接至所述外延材料的暴露表面。

176. 如权利要求 174 所述的方法，其中所述支撑基底以粘合剂接合至所述外延材料的

所述暴露表面。

177. 如权利要求 176 所述的方法，其中所述粘合剂为光学粘合剂或 UV 固化型粘合剂。

178. 如权利要求 176 所述的方法，其中所述粘合剂还包括选自由下列项组成的组的材料：邻苯二甲酸丁辛酯、甲基丙烯酸四氢糠酯、丙烯酸酯单体、其衍生物和其组合。

179. 如权利要求 176 所述的方法，其中所述粘合剂为有机硅粘合剂，或所述粘合剂包括硅酸钠。

180. 如权利要求 176 所述的方法，其中所述粘合剂在从约 25℃至约 75℃的范围内的温度下和在从约 5psi 至约 15psi 的范围内的压力下，在从约 20 小时至约 60 小时的范围内的一段时间内被固化。

181. 如权利要求 173 所述的方法，其中所述硬性支撑层包括选自由下列项组成的组的材料：聚合物、共聚物、低聚物、其衍生物和其组合。

182. 如权利要求 181 所述的方法，其中所述硬性支撑层包括乙烯 / 乙酸乙烯酯共聚物或其衍生物。

183. 如权利要求 173 所述的方法，其中所述硬性支撑层包括选自由下列项组成的组的材料：热熔性粘合剂、有机材料、有机涂层、无机材料和其组合。

184. 如权利要求 183 所述的方法，其中所述硬性支撑层包括多层无机材料，且所述多层还包括金属层、介电层或其组合。

185. 如权利要求 173 所述的方法，其中所述软性支撑层包括弹性体，且所述弹性体包括橡胶、泡沫或其衍生物。

186. 如权利要求 173 所述的方法，其中所述软性支撑层包括选自由下列项组成的组的材料：氯丁橡胶、胶乳和其衍生物。

187. 如权利要求 173 所述的方法，其中所述软性支撑层包括乙烯丙烯二烯单体或其衍生物。

188. 如权利要求 173 所述的方法，其中所述柄板包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

189. 如权利要求 173 所述的方法，其中所述柄板包括聚酯或其衍生物。

190. 如权利要求 173 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于湿蚀刻溶液，所述湿蚀刻溶液包括氢氟酸、表面活性剂和缓冲剂。

191. 如权利要求 173 所述的方法，其中所述牺牲层以约 5 毫米 / 小时或更大的速度被蚀刻。

192. 如权利要求 173 所述的方法，其中所述牺牲层在所述蚀刻工艺期间暴露于氟化氢蒸汽。

193. 如权利要求 173 所述的方法，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

194. 如权利要求 193 所述的方法，其中所述外延材料包括：包含砷化镓的一层及包含砷化铝镓的另一层。

195. 如权利要求 194 所述的方法，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

196. 如权利要求 195 所述的方法，其中所述砷化镓缓冲层具有在从约 100nm 至约

500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

197. 如权利要求 195 所述的方法，其中所述外延材料还包括第二砷化铝镓钝化层。

198. 如权利要求 173 所述的方法，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

199. 如权利要求 173 所述的方法，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

200. 如权利要求 199 所述的方法，其中所述牺牲层包括具有在从约 1nm 至约 10nm 的范围内的厚度的砷化铝层。

201. 一种薄膜堆栈材料，包括：

牺牲层，其配置在基底上；

外延材料，其配置在所述牺牲层上方；以及

支撑柄，其配置在所述外延材料上方，其中所述支撑柄包括：

硬性支撑层，其配置在所述外延材料上方；

软性支撑层，其配置在所述硬性支撑层上方；以及

柄板，其配置在所述软性支撑层上方。

202. 如权利要求 201 所述的薄膜堆栈材料，其中所述外延材料受到压缩。

203. 如权利要求 201 所述的薄膜堆栈材料，其中所述硬性支撑层包括乙烯 / 乙酸乙烯酯共聚物或其衍生物。

204. 如权利要求 201 所述的薄膜堆栈材料，其中所述硬性支撑层包括选自由下列项组成的组的材料：热熔性粘合剂、有机涂层、有机材料、无机材料和其组合。

205. 如权利要求 204 所述的薄膜堆栈材料，其中所述硬性支撑层包括多层无机材料，且所述多层还包括金属层、介电层或其组合。

206. 如权利要求 201 所述的薄膜堆栈材料，其中所述软性支撑层包括弹性体，且所述弹性体包括橡胶、泡沫或其衍生物。

207. 如权利要求 201 所述的薄膜堆栈材料，其中所述软性支撑层包括选自由下列项组成的组的材料：氯丁橡胶、胶乳和其衍生物。

208. 如权利要求 201 所述的薄膜堆栈材料，其中所述软性支撑层包括乙烯丙烯二烯单体或其衍生物。

209. 如权利要求 201 所述的薄膜堆栈材料，其中所述柄板包括选自由下列项组成的组的材料：塑料、聚合物、低聚物、其衍生物和其组合。

210. 如权利要求 209 所述的薄膜堆栈材料，其中所述柄板包括聚酯或其衍生物。

211. 如权利要求 209 所述的薄膜堆栈材料，其中所述柄板具有在从约 50.8μm 至约 127.0μm 的范围内的厚度。

212. 如权利要求 201 所述的薄膜堆栈材料，其中所述外延材料包括选自由下列项组成的组的材料：砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

213. 如权利要求 212 所述的薄膜堆栈材料，其中所述外延材料包括砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

214. 如权利要求 213 所述的薄膜堆栈材料，其中所述砷化镓缓冲层具有在从约 100nm 至约 500nm 的范围内的厚度；所述砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度；且所述砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度。

215. 如权利要求 213 所述的薄膜堆栈材料，其中所述外延材料还包括第二砷化铝镓钝化层。

216. 如权利要求 201 所述的薄膜堆栈材料，其中所述外延材料包括晶胞结构，所述晶胞结构包括多层，所述晶胞结构包括选自由下列项组成的组的至少一种材料：砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物和其组合。

217. 如权利要求 201 所述的薄膜堆栈材料，其中所述牺牲层包括选自由下列项组成的组的材料：砷化铝、其合金、其衍生物和其组合。

218. 如权利要求 201 所述的薄膜堆栈材料，其中所述基底包括砷化镓、n 掺杂砷化镓、p 掺杂砷化镓或其衍生物。

外延迁移堆栈和方法

[0001] 发明背景

发明领域

[0002] 本发明的实施方案通常涉及太阳能器件、半导体器件和电子器件的制造，且更具体地，涉及外延迁移 (epitaxial lift off，ELO) 器件和方法。

[0003] 相关技术的描述

[0004] 器件制造中的一个阶段包括处理和封装用作太阳能器件、半导体器件或其他电子器件的薄膜。这类薄膜器件可通过使用各种用于在晶片或其他基底上沉积并移除材料的工艺来制造。用于制造薄膜器件的一种罕见技术称为外延迁移 (ELO) 工艺。ELO 工艺包括在生长基底上的牺牲层上沉积外延层或膜，接着蚀刻牺牲层以将外延层与生长基底分隔。所移除的薄外延层称为 ELO 膜或层，并一般包括用作太阳能器件、半导体器件或其他电子器件的薄膜。

[0005] 例如，当接合至基底或当封装时，薄 ELO 膜非常难以管理或处理，因为 ELO 膜非常易碎并具有窄尺寸。ELO 膜在非常小的力之下产生裂纹。此外，由于其极端窄的尺寸，ELO 膜非常难以对准。

[0006] 牺牲层一般非常薄，且通常经由湿化学工艺被蚀去。总工艺的速率可受限于反应物到蚀刻前缘的传送或暴露的缺乏，这导致副产品较少从蚀刻前缘移除。此所述工艺为有限扩散工艺，且如果膜维持所沉积的几何形状，则非常窄且长的开口将形成，以严格限制工艺的总速率。为了减少扩散工艺的输送限制，可能有利的是，展开由蚀刻或移除的牺牲层产生的作为结果的间隙，并使外延层远离生长基底弯曲。在外延层和生长基底之间形成裂缝 - 其几何形状提供朝着和远离蚀刻前缘的更大的物种输送。反应物朝着蚀刻前缘移动，而副产品通常远离蚀刻前缘移动。

[0007] 然而，外延层的弯曲可在其内部诱发应力，且弯曲量受限于膜强度。外延层通常包含脆性材料，其在故障前不经历塑性变形，并因此可能遭受裂纹所诱发的故障。

[0008] 为了最小化裂纹传播的可能性，脆性外延层可维持在压缩应力下。裂纹通常不会通过残留压缩应力的区域传播。由于外延层位于裂缝曲率的外侧，当使外延层远离生长基底弯曲时，外延层置于拉伸应力下。拉伸应力限制裂缝曲率量，并降低蚀刻工艺的速率。为了克服此限制，在蚀刻牺牲层前，可在外延层内部灌输残留的压缩应力。此初始的压缩应力可通过弯曲所导致的拉伸应力来偏移，并因而允许在分隔工艺期间的较大量弯曲。

[0009] 因此，需要有更强健的 ELO 薄膜和形成、移除并处理 ELO 薄膜的方法。

[0010] 发明概述

[0011] 本发明的实施方案通常涉及外延迁移 (ELO) 薄膜和器件，以及用来形成这类薄膜和器件的方法。ELO 薄膜通常包含外延生长层，其在配置于基底例如晶片之上或上方的牺牲层上形成。支撑材料或支撑柄可配置在除了基底外的外延材料的相对侧上。支撑柄可例如通过提供对外延材料的压缩来用于稳定外延材料。此外，在 ELO 工艺的蚀刻和移除步骤期间，支撑柄可用于抓紧以及支撑住外延材料。在不同实施方案中，支撑材料或支撑柄可包含

预先弯曲的柄、多层柄、非均匀蜡柄和两个收缩诱发柄 (shrinkage-induced handle)，其普通地或单向地收缩，以给外延材料提供压缩。

[0012] 在一个实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括在牺牲层之上或上方形成外延材料，牺牲层配置在基底之上或上方；将多层支撑柄黏合至外延材料之上；在蚀刻工艺期间移除牺牲层；以及在蚀刻工艺期间，从基底剥离外延材料，同时在其间形成蚀刻裂缝，同时维持外延材料中的压缩。该方法进一步规定，多层支撑柄包含：硬性支撑层，其配置在外延材料之上或上方或黏合至外延材料；软性支撑层，其黏合至硬性支撑层；及柄板，其黏合至软性支撑层。

[0013] 在一个实例中，多层支撑柄包含：硬性支撑层，其配置在外延材料上方；软性支撑层，其配置在硬性支撑层上方；及柄板，其配置在软性支撑层上方。多层支撑柄配置在外延材料之上并维持外延材料的压缩。在一些实施方案中，硬性支撑层可包含聚合物、共聚物、低聚物、其衍生物或其组合。在一个实例中，硬性支撑层包含共聚物，例如，乙烯 / 乙酸乙烯酯 (EVA) 共聚物或其衍生物。在其他实例中，硬性支撑层可包含热熔性粘合剂、有机材料或有机涂层、无机材料或其组合。在一个实例中，无机材料包含多个无机层，例如，金属层和 / 或介电层。在另一实例中，硬性支撑层可包含复合材料或图案化复合材料，例如，有机 / 无机材料。复合材料可包含至少一种有机材料和至少一种无机材料。在一些实例中，无机材料可包含金属层、介电层或其组合。在另一实例中，硬性支撑层可包含蜡或其衍生物，例如黑蜡。

[0014] 在其他实施方案中，软性支撑层可包含弹性体，例如橡胶、泡沫或其衍生物。可选地，软性支撑层可包含材料，例如氯丁橡胶、胶乳或其衍生物。软性支撑层可包含单体。举例来说，软性支撑层可包含乙烯丙烯二烯单体或其衍生物。在另一实施方案中，软性支撑层可包含液体或流体，其包含在膜内部。可选地，软性支撑层可包含气体，其包含在膜内部。膜可包含材料，例如橡胶、泡沫、氯丁橡胶、胶乳或其衍生物。在一个实例中，膜为气球，例如橡胶气球或胶乳气球。

[0015] 在另一实施方案中，柄板可以由塑料材料、聚合物材料、或低聚物材料、其衍生物、其混合物或其组合制成或包含这些材料。在一个实例中，柄板可包含聚酯或其衍生物。柄板可具有在从约 50.8μm 至约 127.0μm 的范围内的厚度，例如，约 23.4μm。

[0016] 在一个实施方案中，该方法进一步包括从基底移除外延材料以及将支撑基底附接至外延材料的暴露表面。支撑基底可以由粘合剂接合至外延材料的暴露表面，从而在其间形成粘合层。在一个实例中，粘合剂为光学粘合剂和 / 或可为紫外线固化型（例如，通过紫外光暴露而固化）。在一些实例中，粘合剂可包含巯基酯化合物。在其他实例中，粘合剂可进一步包含材料，例如，邻苯二甲酸丁辛酯、甲基丙烯酸四氢糠酯、丙烯酸酯单体、其衍生物或其组合。

[0017] 在另一实施方案中，提供薄膜材料，例如 ELO 薄膜堆栈，其包含：支撑基底，其配置在外延材料的第一表面之上或上方；及支撑柄，其配置在外延材料的另一表面之上或上方。粘合层可配置在外延材料和支撑基底之间。在一个实例中，支撑柄可为多层支撑柄，其包含：硬性支撑层，其配置在外延材料之上或上方；软性支撑层，其配置在硬性支撑层之上或上方；及柄板，其配置在软性支撑层之上或上方。

[0018] 在另一实施方案中，提供 ELO 薄膜堆栈，其包含：牺牲层，其配置在基底之上；外延

材料，其配置在牺牲层之上或上方；及压平的预先弯曲的支撑材料或柄，其配置在外延材料之上或上方。当外延材料受到压缩时，压平的预先弯曲的支撑柄承受张力。压平的预先弯曲的支撑柄可包含单层或多层。压平的预先弯曲的支撑柄可包含蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物或其组合。在一些实例中，压平的预先弯曲的支撑柄包含蜡。在其他实例中，压平的预先弯曲的支撑柄包含聚对苯二甲酸乙二酯聚酯或其衍生物。在其他实例中，压平的预先弯曲的支撑柄包含聚烯烃或其衍生物。

[0019] 在一些实施方案中，压平的预先弯曲的支撑柄包含第一层，其具有蜡；及第二层，其具有聚合物，且配置在第一层上方。举例来说，第二层可包含聚对苯二甲酸乙二酯聚酯或其衍生物。在其他实例中，压平的预先弯曲的支撑柄包含至少三层。第三层可包含蜡，并配置在第二层之上或上方。在一些实例中，第三层包含另一聚合物（例如，聚乙烯或其衍生物），并配置在第二层之上或上方。在其他实施方案中，粘合剂配置在压平的预先弯曲的支撑柄和外延材料之间。

[0020] 在其他实施方案中，提供用于在 ELO 工艺期间形成薄膜材料例如 ELO 薄膜堆栈的方法，其包括在基底上的牺牲层之上或上方形成外延材料；将压平的预先弯曲的支撑材料或柄黏合至外延材料之上或上方；在蚀刻工艺期间移除牺牲层；及从基底剥离外延材料，同时在其间形成蚀刻裂缝；及使压平的预先弯曲的支撑柄弯曲以具有相当大的曲率。压平的支撑柄承受张力，以使外延材料受压缩。压平的支撑柄可通过压平弯曲的支撑材料来形成。

[0021] 在另一实施方案中，提供 ELO 薄膜堆栈，其包含：牺牲层，其配置在基底之上或上方；外延材料，其配置在牺牲层之上或上方；及普通可收缩支撑柄，其配置在外延材料之上或上方，其中支撑柄包含普通可收缩材料，其在收缩时即形成支撑柄中的张力和外延材料中的压缩。在一个实例中，普通可收缩材料包含无定形材料。在普通收缩工艺期间，无定形材料可结晶，以经历净体积缩小。普通可收缩材料可包含塑料、聚合物、低聚物、其衍生物、其混合物或其组合。在一些实例中，普通可收缩支撑柄包含热缩聚合物。

[0022] 在另一实施方案中，提供用于在 ELO 工艺期间形成 ELO 薄膜堆栈的方法，其包括在牺牲层之上或上方形成外延材料，牺牲层配置在基底之上或上方；将普通可收缩支撑柄黏合到外延材料之上或上方，其中支撑柄包含普通可收缩材料；在普通收缩工艺期间，使支撑柄收缩，以形成支撑柄中的张力和外延材料中的压缩；在蚀刻工艺期间移除牺牲层；及从基底剥离外延材料，同时在其间形成蚀刻裂缝；及使支撑柄弯曲以具有相当大的曲率。普通可收缩支撑柄可包含一层或多层。

[0023] 在另一实施方案中，提供薄膜堆栈材料，其包含：牺牲层，其配置在基底之上或上方；外延材料，其配置在牺牲层之上或上方；及单向可收缩支撑柄，其配置在外延材料之上或上方。单向可收缩支撑柄可包含可收缩材料和补强纤维，补强纤维单向延伸贯穿可收缩材料。可收缩材料单向收缩并正切于补强纤维，以形成支撑柄中的张力和外延材料中的压缩。

[0024] 补强纤维为高强度聚合物纤维。在一个实例中，补强纤维包含聚乙烯或其衍生物。在一些实例中，补强纤维沿着纤维长度包含负的线性热膨胀系数。一般说来，补强纤维具有在从约 15GPa 至约 134GPa 的范围内的拉伸模量。

[0025] 在其他实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括在基

底上的牺牲层之上或上方形成外延材料；将单向可收缩支撑柄黏合至外延材料之上，其中支撑柄包含可收缩材料和补强纤维，补强纤维单向延伸贯穿可收缩材料；及在单向收缩工艺期间，收缩正切于补强纤维的支撑柄，以形成支撑柄中的张力和外延材料中的压缩。该方法进一步包括在蚀刻工艺期间移除牺牲层；从基底剥离外延材料，同时在其间形成蚀刻裂缝；及使支撑柄弯曲以具有相当大的曲率。

[0026] 在其他实施方案中，提供薄膜堆栈材料，其包含：牺牲层，其配置在基底之上或上方；外延材料，其配置在牺牲层之上或上方；及非均匀支撑柄，其配置在外延材料之上或上方，其中非均匀支撑柄包含具有变化厚度的蜡膜。

[0027] 在另一实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括形成配置在基底上的牺牲层之上或上方的外延材料；及将非均匀支撑柄黏合至外延材料之上或上方，其中非均匀支撑柄包含具有变化厚度的蜡膜。该方法进一步包括在蚀刻工艺期间移除牺牲层；从基底剥离外延材料，同时在其间形成蚀刻裂缝；及在蚀刻工艺期间，使非均匀支撑柄弯曲，以形成外延材料中的压缩。

[0028] 附图简述

[0029] 参照在附图中示出的一些实施方案可提供对上文简要概述的本发明的更具体的描述，以便可详细地理解本发明的上述特征的方式。然而，须注意，附图仅示出此发明的典型实施方案，且因此不应视为对本发明范围的限制，因为本发明可容许其他同样有效的实施方案。

[0030] 图 1 示出根据此处所述的实施方案的在晶片上的 ELO 薄膜堆栈；

[0031] 图 2A 示出根据此处所述的实施方案的预先弯曲的支撑柄；

[0032] 图 2B 至 2C 示出根据此处所述的实施方案的包含预先弯曲的支撑柄的 ELO 薄膜堆栈；

[0033] 图 2D 示出如此处的实施方案中所述的在从晶片被移除后的预先弯曲的支撑柄和外延材料；

[0034] 图 3A 至 3C 示出根据此处所述的另一实施方案的包含普通可收缩支撑柄的 ELO 薄膜堆栈；

[0035] 图 3D 示出如此处的实施方案中所述的在从晶片被移除后的普通可收缩支撑柄和外延材料；

[0036] 图 4A 至 4C 示出根据此处所述的其他实施方案的包含单向可收缩支撑柄的 ELO 薄膜堆栈；

[0037] 图 4D 示出如此处的实施方案中所述的在从晶片被移除后的单向可收缩柄和外延材料；

[0038] 图 5A 至 5B 示出根据此处所述的其他实施方案的配置在薄膜堆栈之上或上方的非均匀蜡支撑柄；

[0039] 图 6A 示出根据此处所述的另一实施方案的配置在基底上的薄膜堆栈上方的多层支撑柄；以及

[0040] 图 6B 示出根据此处所述的另一实施方案的配置在支撑基底上的多层支撑柄和薄膜堆栈。

[0041] 详述

[0042] 图 1 示出基底 100，其包含配置在晶片 102 上的 ELO 薄膜堆栈 150，如此处的一个实施方案中所述的。ELO 薄膜堆栈 150 可具有：牺牲层 104，其配置在晶片 102 之上或上方；外延材料 106，其配置在牺牲层 104 之上或上方；及支撑柄 108，其配置在外延材料 106 之上或上方。在不同的实施方案中，支撑柄 108 承受张力，而外延材料 106 受到压缩。ELO 工艺包括在蚀刻工艺期间移除牺牲层 104，同时从晶片 102 剥离外延材料 106，并在其间形成蚀刻裂缝，直到外延材料 106 和支撑柄 108 从晶片 102 移除为止。牺牲层 104 通常包含砷化铝。

[0043] 晶片 102 可包含各种材料例如 III/V 族材料或由各种材料例如 III/V 族材料制成，并可掺杂有其他元素。在一个实施方案中，晶片 106 包含砷化镓或其衍生物。砷化镓晶片具有约 $5.73\times10^{-6}℃^{-1}$ 的热膨胀系数。在不同的实施方案中，支撑柄 108 包含具有较高的热膨胀系数的材料（例如，蜡或聚合物）。

[0044] 支撑柄 108 可为单层材料或多层。在不同的实施方案中，支撑柄 108 可为压平的预先弯曲的支撑柄，其通过压平弯曲的支撑材料而形成。在另一实施方案中，支撑柄 108 可包含可收缩材料，例如热缩塑料。在一个可选的实施方案中，支撑柄 108 可包含可收缩材料，其具有补强纤维，补强纤维单向延伸贯穿可收缩材料。在另一实施方案中，支撑柄 108 可包含蜡膜，其具有在整个基底 100 上变化或非均匀的厚度。在另一实施方案中，支撑柄 108 可为多层柄。

[0045] 预先弯曲的柄

[0046] 图 2A 至 2D 示出如此处的一个实施方案所述的在 ELO 工艺的不同方面期间或在 ELO 薄膜堆栈内部的预先弯曲的支撑材料或柄。图 2A 示出预先弯曲的支撑材料，例如预先弯曲的支撑柄 202。预先弯曲的支撑柄 202 包含顶表面 211 和底表面 213。在一个实施方案中，预先弯曲的支撑柄 202 可在黏合或附接至基底 200 例如外延材料 204 之前被压平或弄直。可选地，预先弯曲的支撑柄 202 可在黏合或附接至基底 200 的同时被压平或弄直。一旦被压平或弄直，预先弯曲的支撑柄 202 就承受张力，这用于在黏合或附接至基底 200 时产生对下方的层（例如，外延材料 204）的压缩。

[0047] 图 2B 示出基底 200，其包含配置在晶片 208 之上或上方的 ELO 薄膜堆栈 250，如此处的一个实施方案中所述的。ELO 薄膜堆栈 250 可具有：牺牲层 206，其配置在晶片 208 之上或上方；外延材料 204，其配置在牺牲层 206 之上或上方；及预先弯曲的支撑柄 202，其配置在外延材料 204 之上或上方。在蚀刻工艺期间，压平的预先弯曲的支撑柄 202 朝顶表面 211 弯曲，如图 2C 所示的。预先弯曲的支撑柄 202 可具有在从约 10cm 至约 100cm 的范围内的曲率半径。

[0048] 在一些实施方案中，预先弯曲的支撑柄 202 包含多层，例如，第一蜡层和配置在第一层之上或上方的第二聚合物层。举例来说，第二层可包含聚对苯二甲酸乙二酯聚酯，例如 MYLAR® 聚合物膜。在其他实例中，预先弯曲的支撑柄 202 包含至少三层。第三层可配置在第二层之上或上方。在一些实例中，第三层包含另一聚合物（例如，聚乙烯或其衍生物）或蜡，其配置在第二层之上或上方。

[0049] 图 2B 示出基底 200，其包含压平后的预先弯曲的支撑柄 202。压平的预先弯曲的支撑柄 202 可配置在外延材料 204 之上或上方，外延材料 204 可配置在牺牲层 206 之上或上方。牺牲层 206 可配置在晶片 208 之上或上方。

[0050] 在一些实施方案中，粘合剂（未显示）可配置在预先弯曲的支撑柄 202 和外延材料 204 之间。粘合剂可为压敏粘合剂、热熔性粘合剂、紫外线 (UV) 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物或其组合。

[0051] 在一些实施方案中，牺牲层 206 可包含砷化铝、其合金、其衍生物或其组合。在一个实例中，牺牲层 206 包含砷化铝层。牺牲层 206 可具有约 20nm 或更小的厚度，优选地在从约 1nm 至约 10nm 的范围内的厚度，以及更优选地从约 4nm 至约 6nm 的厚度。晶片 208 可为晶片或基底，且通常包含砷化镓、砷化镓合金或其他衍生物，并可为 n 掺杂或 p 掺杂。在一个实例中，晶片 208 包含 n 掺杂的砷化镓材料。在另一实例中，晶片 208 包含 p 掺杂的砷化镓材料。

[0052] 在一些实施方案中，外延材料 204 可包含砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。外延材料 204 可包含一层，但通常包含多层。在一些实例中，外延材料 204 包含具有砷化镓的一层及具有砷化铝镓的另一层。在另一实例中，外延材料 204 包含砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

[0053] 砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 300nm ；砷化铝镓钝化层可具有在从约 10nm 至约 50nm 的范围内的厚度，例如，约 30nm ；且砷化镓活性层可具有在从约 500nm 至约 2000nm 的范围内的厚度，例如，约 1000nm。在一些实例中，外延材料 204 进一步包含第二砷化铝镓钝化层。第二砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 300nm。

[0054] 在此处的其他实施方案中，外延材料 204 可具有晶胞结构，其包含多层。晶胞结构可包含砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。

[0055] 如此处的实施方案所述，图 2C 示出在 ELO 蚀刻工艺期间，形成蚀刻裂缝 210，同时蚀去牺牲层 206，并从晶片 208 剥离预先弯曲的支撑柄 202 和外延材料。图 2D 示出在从晶片 208 移除后的预先弯曲的支撑柄 202 和外延材料 204。压平的预先弯曲的支撑柄 202 承受张力，而外延材料 204 受到压缩。

[0056] 在用于形成薄膜材料的方法的一个实施方案中，牺牲层 206 可配置在基底 200 例如晶片 208 之上或上方 ；外延材料 204 配置在牺牲层 206 之上或上方 ；以及压平的预先弯曲的支撑材料或柄可配置在外延材料 204 之上或上方。压平的预先弯曲的支撑材料或柄可包含单层或多层。压平的预先弯曲的支撑材料或柄可包含蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物或其组合。在一些实例中，压平的预先弯曲的支撑柄 202 包含蜡。在其他实例中，压平的预先弯曲的支撑柄 202 包含聚对苯二甲酸乙二酯聚酯或其衍生物，例如MYLAR®膜。在其他实例中，预先弯曲的支撑柄 202 包含聚烯烃或其衍生物。

[0057] 在另一实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括在配置于基底 200 例如晶片 208 上的牺牲层 206 之上或上方形成外延材料 204。该方法进一步提供 ：将压平的预先弯曲的支撑材料例如预先弯曲的支撑柄 202 黏合或附接至外延材料 204 之上或上方，其中压平的预先弯曲的支撑柄 202 通过压平弯曲的支撑材料而形成，且压平的预先弯曲的支撑柄 202 承受张力，而外延材料 204 受到压缩 ；在蚀刻工艺期间移除牺牲层 206 ；及从基底剥离外延材料 204，同时在其间形成蚀刻裂缝 ；及使压平的预先弯曲的支撑柄 202 弯曲，以具有相当大的曲率。

[0058] 在一些实施方案中，牺牲层 206 可在 ELO 蚀刻工艺期间暴露于湿蚀刻溶液。在一些实例中，湿蚀刻溶液包含氢氟酸，并可包含表面活性剂和 / 或缓冲剂。牺牲层 206 可以按约 0.3 毫米 / 小时或更大的速度被蚀刻，优选地是约 1 毫米 / 小时或更大，且更优选地是约 5 毫米 / 小时或更大。

[0059] 在一个可选的实施方案中，牺牲层 206 可在 ELO 蚀刻工艺期间暴露于电化学蚀刻。电化学蚀刻可为偏压工艺 (biased process) 或电镀工艺 (galvanic process)。同样地，在此处所述的另一实施方案中，牺牲层 206 可在 ELO 蚀刻工艺期间暴露于蒸汽相蚀刻。蒸汽相蚀刻包括将牺牲层 206 暴露于氟化氢蒸汽。ELO 蚀刻工艺可为光化学蚀刻、热增强蚀刻、等离子体增强蚀刻、应力增强蚀刻、其衍生物或其组合。

[0060] 诱发收缩柄（普通收缩）

[0061] 图 3A 至 3D 示出如此处的一些实施方案所述的在 ELO 工艺的不同方面期间或在 ELO 薄膜堆栈内部的普通可收缩支撑材料或柄。图 3A 示出基底 300，其包含配置在晶片 308 之上或上方的 ELO 薄膜堆栈 350，如此处的一个实施方案中所述的。ELO 薄膜堆栈 350 可包含：牺牲层 306，其配置在晶片 308 之上或上方；外延材料 304，其配置在牺牲层 306 之上或上方；及普通可收缩支撑柄 302，其配置在外延材料 304 之上或上方。图 3B 示出力 / 应力 320 在施加至普通可收缩支撑柄 302 时提供在整个基底 300 的平面上的普通收缩 322。

[0062] 可收缩支撑柄 302 包含普通可收缩材料，例如蜡、聚乙烯、聚酯、聚烯烃、聚对苯二甲酸乙二酯聚酯、橡胶、其衍生物或其组合。在一个实例中，可收缩支撑柄 302 包含蜡。在一些实例中，可收缩支撑柄 302 包含聚对苯二甲酸乙二酯聚酯或其衍生物，例如MYLAR®膜。在其他实例中，可收缩支撑柄 302 包含聚烯烃或其衍生物。在其他实例中，可收缩支撑柄 302 包含：第一层，其具有蜡；及第二层，其具有聚合物（例如，聚对苯二甲酸乙二酯聚酯），并配置在第一层上方。

[0063] 普通可收缩支撑柄 302 可包含三层或更多层。举例来说，可收缩支撑柄 302 还可具有第三层，其包含蜡或聚合物，并配置在第二层上方。第三层可包含聚乙烯或其衍生物。

[0064] 可收缩支撑柄 302 包含底表面和顶表面，且底表面黏合至外延材料 304 或位于外延材料 304 之上。在蚀刻工艺期间，可收缩支撑柄 302 朝顶表面弯曲。在另一实施方案中，普通可收缩材料包含无定形材料，且在收缩工艺期间，无定形材料可结晶，以经历净体积缩小。普通可收缩材料可包含至少一种塑料、橡胶、聚合物、低聚物、其衍生物或其组合。在一个特定实例中，普通可收缩材料包含聚酯或其衍生物。在其他实例中，可使用热缩粘合带作为普通可收缩支撑柄 302。

[0065] 在其他实施方案中，可收缩支撑柄 302 可在收缩工艺期间被加热。可收缩支撑柄 302 可包含热缩塑料或聚合物。可选地，可收缩支撑柄 302 可通过从可收缩材料移除溶剂而收缩。可收缩支撑柄 302 可弯曲，以具有在从约 10cm 至约 100cm 的范围内的曲率半径。

[0066] 在一些实施方案中，粘合剂（未显示）可配置在普通可收缩支撑柄 302 和外延材料 304 之间。粘合剂可为压敏粘合剂、热熔性粘合剂、紫外线 (UV) 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物或其组合。在一些实例中，可使用在一侧上包含粘合剂的热缩带作为可收缩支撑柄 302。

[0067] 在一些实施方案中，外延材料 304 可包含砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。外延材料 304 可包含一层，但通常包含多层。在一些实例中，外延材料

304 包含具有砷化镓的一层；及具有砷化铝镓的另一层。在另一实例中，外延材料 304 包含砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

[0068] 砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 300nm；砷化铝镓钝化层可具有在从约 10nm 至约 50nm 的范围内的厚度，例如，约 30nm；且砷化镓活性层可具有在从约 500nm 至约 2000nm 的范围内的厚度，例如，约 1000nm。在一些实例中，外延材料 304 进一步包含第二砷化铝镓钝化层。第二砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 300nm。

[0069] 在此处的其他实施方案中，外延材料 304 可具有晶胞结构，其包含多层。晶胞结构可包含砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。

[0070] 在另一实施方案中，牺牲层 306 可包含砷化铝、其合金、其衍生物或其组合。在一个实例中，牺牲层 306 包含砷化铝层。牺牲层 306 可具有约 20nm 或更小的厚度，优选地在从约 1nm 至约 10nm 的范围内的厚度，更优选地从约 4nm 至约 6nm 的厚度。晶片 308 可为晶片或基底，且通常包含砷化镓、砷化镓合金或其他衍生物，并可为 n 掺杂或 p 掺杂。在一个实例中，晶片 308 包含 n 掺杂的砷化镓材料。在另一实例中，晶片 308 包含 p 掺杂的砷化镓材料。

[0071] 图 3C 示出形成蚀刻裂缝 310，同时蚀去牺牲层 306，并从晶片 308 剥离可收缩支撑柄 302 和外延材料 304。图 3D 示出从晶片 308 移除后的可收缩支撑柄 302 和外延材料 304。

[0072] 在用于在 ELO 工艺期间形成薄膜材料的方法的一个实施方案中，外延材料 304 可形成或沉积在牺牲层 306 上方，牺牲层 306 配置在基底 300 例如晶片 308 之上或上方；及将可收缩支撑柄 302 黏合至外延材料 304 之上或上方。可收缩支撑柄 302 包含普通可收缩材料。该方法进一步提供：在收缩工艺期间收缩或减小可收缩支撑柄 302 的尺寸，以形成可收缩支撑柄 302 中的张力和外延材料 304 中的压缩；在蚀刻工艺期间移除牺牲层 306；及从基底剥离外延材料 304，同时在其间形成蚀刻裂缝 310；及使可收缩支撑柄 302 弯曲，以具有相当大的曲率。可收缩支撑柄 302 可包含一层或多层。

[0073] 在另一实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括：定位基底 300，其包含配置于牺牲层 306 之上或上方的外延材料 304，牺牲层 306 配置在晶片 308 之上或上方；及将可收缩支撑柄 302 黏合至外延材料 304 之上。可收缩支撑柄 302 包含普通可收缩材料。该方法进一步提供在收缩工艺期间收缩或减小可收缩支撑柄 302 的尺寸，以形成可收缩支撑柄 302 中的张力和外延材料 304 中的压缩；及在蚀刻工艺期间移除牺牲层 306。该方法进一步规定：蚀刻工艺进一步包括：从基底剥离外延材料 304；在外延材料 304 和基底之间形成蚀刻裂缝 310；及使可收缩支撑柄 302 弯曲，以具有相当大的曲率。

[0074] 在其他实施方案中，提供薄膜堆栈材料，其包含：牺牲层 306，其配置在基底之上；外延材料 304，其配置在牺牲层 306 上方；及可收缩支撑柄 302，其配置在外延材料 304 上方。可收缩支撑柄 302 包含普通可收缩材料，其在收缩时形成可收缩支撑柄 302 中的张力和外延材料 304 中的压缩。在一个实例中，可收缩材料包含无定形材料。在收缩工艺期间，无定形材料可结晶，以经历净体积缩小。可收缩材料可包含至少一种塑料、聚合物、低聚物、其衍生物或其组合。在一些实例中，可收缩支撑柄 302 包含热缩塑料或聚合物。

[0075] 在一些实施方案中，牺牲层 306 可在蚀刻工艺期间暴露于湿蚀刻溶液。湿蚀刻溶

液包含氢氟酸，并可包含表面活性剂和 / 或缓冲剂。在一些实例中，牺牲层 306 可以按约 0.3 毫米 / 小时或更大的速度被蚀刻，优选地是约 1 毫米 / 小时或更大，且更优选地是约 5 毫米 / 小时或更大。

[0076] 在一个可选实施方案中，牺牲层 306 可在蚀刻工艺期间暴露于电化学蚀刻。电化学蚀刻可为偏压工艺或电镀工艺。同样地，在此处所述的另一实施方案中，牺牲层 306 可在蚀刻工艺期间暴露于蒸汽相蚀刻。蒸汽相蚀刻包括将牺牲层 306 暴露于氟化氢蒸汽。蚀刻工艺可为光化学蚀刻、热增强蚀刻、等离子体增强蚀刻、应力增强蚀刻、其衍生物或其组合。

[0077] 诱发收缩柄（单向收缩）

[0078] 图 4A 至 4D 示出如此处的一个实施方案中所述的在 ELO 工艺的不同方面期间或在 ELO 薄膜堆栈内部的单向可收缩支撑材料或柄。图 4A 示出基底 400，其包含配置在晶片 408 之上或上方的 ELO 薄膜堆栈 450，如此处的一个实施方案中所述的。ELO 薄膜堆栈 450 可具有牺牲层 406，其配置在晶片 408 之上或上方；外延材料 404，其配置在牺牲层 406 之上或上方；及单向可收缩支撑柄 402，其配置在外延材料 404 之上或上方。

[0079] 单向可收缩支撑柄 402 包含可收缩材料和补强纤维，补强纤维单向延伸贯穿可收缩材料，其在收缩时正切于补强纤维而收缩，以形成可收缩支撑柄 402 中的张力和外延材料 404 中的压缩。图 4B 示出力 / 应力 420 在施加至可收缩支撑柄 402 时提供在整个基底 400 的平面上的单向收缩 422。

[0080] 可收缩支撑柄 402 包含底表面和顶表面，且底表面黏合至外延材料 404 或位于外延材料 404 之上。在蚀刻工艺期间，可收缩支撑柄 402 可朝顶表面弯曲。在一个实例中，单向可收缩材料包含无定形材料，在单向收缩工艺期间，无定形材料可结晶，以经历净体积缩小。在另一实例中，单向可收缩材料可包含塑料、聚合物、低聚物、其衍生物或其组合。在一个实例中，单向可收缩材料包含聚酯或其衍生物。

[0081] 补强纤维可为高强度聚合物纤维。补强纤维可包含聚乙烯或其衍生物。在一些实例中，补强纤维沿着纤维长度包含负的线性热膨胀系数。一般说来，补强纤维具有在从约 15GPa 至约 134GPa 的范围内的拉伸模量。

[0082] 在一些实例中，单向可收缩支撑柄 402 可在收缩工艺期间被加热。可收缩支撑柄 402 可包含热缩聚合物和高强度聚合物纤维。在其他实例中，可收缩支撑柄 402 通过从可收缩材料移除溶剂而收缩。可收缩支撑柄 402 可弯曲，以具有在从约 10cm 至约 100cm 的范围内的曲率半径。

[0083] 在一些实施方案中，粘合剂（未显示）可配置在单向可收缩支撑柄 402 和外延材料 404 之间。粘合剂可为压敏粘合剂、热熔性粘合剂、紫外线 (UV) 固化粘合剂、天然粘合剂、合成粘合剂、其衍生物或其组合。

[0084] 在此处的一些实施方案中，外延材料 404 可包含砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。外延材料 404 可包含一层，但通常包含多层。在一些实例中，外延材料 404 包含具有砷化镓的一层及具有砷化铝镓的另一层。在另一实例中，外延材料 404 包含砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

[0085] 砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 400nm；砷化铝镓钝化层可具有在从约 10nm 至约 50nm 的范围内的厚度，例如，约 30nm；且砷化镓活性层可具有在从约 500nm 至约 2000nm 的范围内的厚度，例如，约 1000nm。在一些实例中，外

延材料 404 进一步包含第二砷化铝镓钝化层。第二砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 400nm。

[0086] 在此处的其他实施方案中，外延材料 404 可具有晶胞结构，其包含多层。晶胞结构可包含砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。

[0087] 在另一实施方案中，牺牲层 406 可包含砷化铝、其合金、其衍生物或其组合。在一个实例中，牺牲层 406 包含砷化铝层。牺牲层 406 可具有约 20nm 或更小的厚度，优选地在从约 1nm 至约 10nm 的范围内的厚度，且更优选地从约 4nm 至约 6nm 的厚度。晶片 408 可为晶片或基底，且通常包含砷化镓、砷化镓合金或其他衍生物，并可为 n 掺杂或 p 掺杂。在一个实例中，晶片 408 包含 n 掺杂的砷化镓材料。在另一实例中，晶片 408 包含 p 掺杂的砷化镓材料。

[0088] 图 4C 示出形成蚀刻裂缝 410，同时蚀去牺牲层 406，并从晶片 408 剥离可收缩支撑柄 402 和外延材料 404。图 4D 示出从晶片 408 移除后的可收缩支撑柄 402 和外延材料 404。

[0089] 在另一实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括：在基底 400 上的牺牲层 406 上方形成外延材料 404；将可收缩支撑柄 402 黏合至外延材料 404 之上，其中可收缩支撑柄 402 包含单向可收缩材料和补强纤维，补强纤维单向延伸贯穿可收缩材料；及在收缩工艺期间，收缩或减小正切于补强纤维的可收缩支撑柄 402，以形成可收缩支撑柄 402 中的张力和外延材料 404 中的压缩。该方法进一步包括：在蚀刻工艺期间移除牺牲层 406；从基底剥离外延材料 404，同时在其间形成蚀刻裂缝；及使单向可收缩支撑柄 402 弯曲，以具有相当大的曲率。

[0090] 在一个实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括：在牺牲层 406 之上或上方沉积外延材料 404，牺牲层 406 配置在基底 400 的晶片 408 之上；及将可收缩支撑柄 402 黏合至外延材料 404 之上。可收缩支撑柄 402 包含单向可收缩材料和补强纤维，补强纤维单向延伸贯穿可收缩材料。该方法进一步提供：在收缩工艺期间收缩或减小正切于补强纤维的可收缩支撑柄 402，以形成可收缩支撑柄 402 中的张力和外延材料 404 中的压缩；及在蚀刻工艺期间移除牺牲层 406。蚀刻工艺包括：从基底剥离外延材料 404；在外延材料 404 和基底之间形成蚀刻裂缝；及使单向可收缩支撑柄 402 弯曲，以具有相当大的曲率。

[0091] 在一些实施方案中，牺牲层 406 可在蚀刻工艺期间暴露于湿蚀刻溶液。湿蚀刻溶液包含氢氟酸，并可包含表面活性剂和 / 或缓冲剂。在一些实例中，牺牲层 406 可以按约 0.3 毫米 / 小时或更大的速度被蚀刻，优选地是约 1 毫米 / 小时或更大，且更优选地是约 5 毫米 / 小时或更大。

[0092] 在一个可选实施方案中，牺牲层 406 可在蚀刻工艺期间暴露于电化学蚀刻。电化学蚀刻可为偏压工艺或电镀工艺。同样地，在此处所述的另一实施方案中，牺牲层 406 可在蚀刻工艺期间暴露于蒸汽相蚀刻。蒸汽相蚀刻包括将牺牲层 406 暴露于氟化氢蒸汽。蚀刻工艺可为光化学蚀刻、热增强蚀刻、等离子体增强蚀刻、应力增强蚀刻、其衍生物或其组合。

[0093] 非均匀蜡柄

[0094] 图 5A 至 5B 示出基底 500，其包含配置在晶片 508 之上或上方的 ELO 薄膜堆栈 550，如此处的一个实施方案中所述的。ELO 薄膜堆栈 550 可具有：牺牲层 506，其配置在晶片 508

之上或上方；外延材料 504，其配置在牺牲层 506 之上或上方；及非均匀支撑柄 502，其配置在外延材料 504 之上或上方。在一个实施方案中，非均匀支撑柄 502 包含具有变化厚度的蜡膜，如在此处的一些实施方案中所述的。在一个实例中，非均匀支撑柄 502 的变化厚度在非均匀支撑柄 502 的中央 510a 中或附近最厚，如图 5A 所示出的。在另一实例中，非均匀支撑柄 502 的变化厚度在非均匀支撑柄 502 的中央 510b 中或附近最薄，如图 5B 所示出的。

[0095] 在另一实施方案中，ELO 薄膜堆栈 550 包含：牺牲层 506，其配置在基底之上；外延材料 504，其配置在牺牲层 506 上方；及非均匀支撑柄 502，其配置在外延材料 504 上方，其中非均匀支撑柄 502 包含蜡膜，其具有变化厚度或非均匀厚度。

[0096] 在其他实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括：在基底上的牺牲层 506 上方形成外延材料 504；将非均匀支撑柄 502 黏合至外延材料 504 之上，其中非均匀支撑柄 502 包含具有变化厚度的蜡膜；在蚀刻工艺期间移除牺牲层 506；及从基底剥离外延材料 504，同时在其间形成蚀刻裂缝；及在蚀刻工艺期间使非均匀支撑柄 502 弯曲，以形成外延材料 504 中的压缩。

[0097] 在另一实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括：定位基底，其包含配置在基底上的牺牲层 506 上方的外延材料 504；将非均匀支撑柄 502 黏合至外延材料 504 之上，其中非均匀支撑柄 502 包含具有变化厚度的蜡膜；及在蚀刻工艺期间移除牺牲层 506，其中蚀刻工艺进一步包括从基底剥离外延材料 504；在外延材料 504 和基底之间形成蚀刻裂缝；及在蚀刻工艺期间使非均匀支撑柄 502 弯曲，以形成外延材料 504 中的压缩。

[0098] 在一些实施方案中，非均匀支撑柄 502 包含蜡膜的底表面和柔性构件的顶表面，且底表面黏合至外延材料 504。非均匀支撑柄 502 可朝顶表面弯曲。非均匀支撑柄 502 可弯曲，以具有在从约 10cm 至约 100cm 的范围内的曲率半径。柔性构件可包含塑料、聚合物、低聚物、其衍生物或其组合，例如，聚酯或聚酯衍生物。柔性构件可具有在从约 50.8μm（约 20 锭距 (gauge)）至约 127.0μm（约 500 锭距）的范围内的薄膜厚度，优选地是约 23.4μm（约 92 锭距）。

[0099] 在其他实例中，蜡膜包含蜡，其具有在从约 65℃至约 95℃的范围内的软化点温度，优选地是从约 80℃至约 90℃的温度，例如约 85℃。在一个实例中，蜡膜的变化厚度在蜡膜中央中或附近最厚（图 5A），或在蜡膜中央中或附近最薄（图 5B）。在不同的实施方案中，蜡膜的变化厚度可在从约 1μm 至约 100μm 的范围内。在一个实施方案中，蜡膜具有最薄的段，其具有在从约 1μm 至约 25μm 的范围内的厚度，并具有最厚的段，其具有在从约 25μm 至约 100μm 的范围内的厚度。

[0100] 在此处的一些实施方案中，外延材料 504 可包含砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。外延材料 504 可包含一层，但通常包含多层。在一些实例中，外延材料 504 包含具有砷化镓的一层及具有砷化铝镓的另一层。在另一实例中，外延材料 504 包含砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。

[0101] 砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 500nm；砷化铝镓钝化层可具有在从约 10nm 至约 50nm 的范围内的厚度，例如，约 30nm；且砷化镓活性层可具有在从约 500nm 至约 2000nm 的范围内的厚度，例如，约 1000nm。在一些实例中，外延材料 504 进一步包含第二砷化铝镓钝化层。第二砷化镓缓冲层可具有在从约 100nm 至约

500nm 的范围内的厚度，例如，约 500nm。

[0102] 在此处的其他实施方案中，外延材料 504 可具有晶胞结构，其包含多层。晶胞结构可包含砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。

[0103] 在另一实施方案中，牺牲层 506 可包含砷化铝、其合金、其衍生物或其组合。在一个实例中，牺牲层 506 包含砷化铝层。牺牲层 506 可具有约 20nm 或更小的厚度，优选地在从约 1nm 至约 10nm 的范围内的厚度，且更优选地从约 4nm 至约 6nm 的厚度。晶片 508 可为晶片或基底，且通常包含砷化镓、砷化镓合金或其他衍生物，并可为 n 掺杂或 p 掺杂。在一个实例中，晶片 508 包含 n 掺杂的砷化镓材料。在另一实例中，晶片 508 包含 p 掺杂的砷化镓材料。

[0104] 在一些实施方案中，牺牲层 506 可在蚀刻工艺期间暴露于湿蚀刻溶液。湿蚀刻溶液包含氢氟酸，并可包含表面活性剂和 / 或缓冲剂。在一些实例中，牺牲层 506 可以按约 0.3 毫米 / 小时或更大的速度被蚀刻，优选地是约 1 毫米 / 小时或更大，且更优选地是约 5 毫米 / 小时或更大。

[0105] 在一个可选实施方案中，牺牲层 506 可在蚀刻工艺期间暴露于电化学蚀刻。电化学蚀刻可为偏压工艺或电镀工艺。同样地，在此处所述的另一实施方案中，牺牲层 506 可在蚀刻工艺期间暴露于蒸汽相蚀刻。蒸汽相蚀刻包括将牺牲层 506 暴露于氟化氢蒸汽。蚀刻工艺可为光化学蚀刻、热增强蚀刻、等离子体增强蚀刻、应力增强蚀刻、其衍生物或其组合。

[0106] 多层支撑柄

[0107] 本发明的实施方案通常涉及 ELO 薄膜材料和器件，以及用来形成这类材料和器件的方法。在一个实施方案中，提供用于在 ELO 工艺期间形成薄膜材料的方法，其包括 ：在基底上的牺牲层上方沉积或以其他方式形成外延材料 ；将支撑柄黏合至外延材料之上 ；在蚀刻工艺期间移除牺牲层 ；以及在蚀刻工艺期间，从基底剥离外延材料，同时在其间形成蚀刻裂缝，同时维持外延材料中的压缩。该方法进一步规定 ：支撑柄包含 ：硬性支撑层，其黏合至外延材料 ；软性支撑层，其黏合至硬性支撑层 ；及柄板，其黏合至软性支撑层。

[0108] 如图 6A 所示出的，在一个实施方案中，提供 ELO 薄膜堆栈 600A，其包含 ：牺牲层 620，其配置在基底例如晶片 610 之上或上方 ；外延材料 630，其配置在牺牲层 620 之上或上方 ；及多层支撑柄 670，其配置在外延材料 630 之上或上方。在一个实例中，多层支撑柄 670 包含 ：硬性支撑层 640，其配置在外延材料 630 上方 ；软性支撑层 650，其配置在硬性支撑层 640 上方 ；及柄板 660，其配置在软性支撑层 650 上方。多层支撑柄 670 配置在外延材料 630 之上并维持其压缩。

[0109] 在一些实例中，硬性支撑层 640 可包含聚合物、共聚物、低聚物、其衍生物或其组合。在一个实施方案中，硬性支撑层 640 包含共聚物。在一个实例中，共聚物可为乙烯 / 乙酸乙烯酯 (EVA) 共聚物或其衍生物。用作硬性支撑层 640 的 EVA 共聚物为晶片夹紧 (WAFER GRIP) 粘膜，其在商业上可从位于 Santa Rosa，CA 的 Dynatex International 购得。在其他实例中，硬性支撑层 640 可包含热熔性粘合剂、有机材料或有机涂层、无机材料或其组合。

[0110] 在一个实施方案中，硬性支撑层 640 包含无机材料，其具有多个无机层，例如金属层、介电层或其组合。在另一实例中，硬性支撑层 640 可包含复合材料或图案化复合材料，例如有机 / 无机材料。复合材料可包含至少一种有机材料和至少一种无机材料。在一些实

例中，无机材料可包含金属层、介电层或其组合。复合材料可用于优化器件性能，例如，增加反射率、电导率和 / 或产量。在另一实施方案中，硬性支撑层 640 可包含蜡或其衍生物，例如黑蜡。

[0111] 在另一实施方案中，软性支撑层 650 可包含弹性体，例如橡胶、泡沫或其衍生物。可选地，软性支撑层 650 可包含材料，例如氯丁橡胶、胶乳或其衍生物。软性支撑层 650 可包含单体。举例来说，软性支撑层 650 可包含乙烯丙烯二烯单体或其衍生物。

[0112] 在另一实施方案中，软性支撑层 650 可包含液体或流体，其包含在膜内部。可选地，软性支撑层 650 可包含气体，其包含在膜内部。膜可包含材料，例如橡胶、泡沫、氯丁橡胶、胶乳或其衍生物。在一个实例中，膜为橡胶或胶乳气球。

[0113] 在另一实施方案中，柄板 660 可包含材料，例如塑料、聚合物、低聚物、其衍生物或其组合。在一个实例中，柄板 660 可包含聚酯或其衍生物。柄板 660 可具有在从约 50.8μm 至约 127.0μm 的范围内的厚度，例如，约 23.4μm。

[0114] 在一个实施方案中，该方法进一步包括移除牺牲层 620，以分隔外延材料 630 与基底，例如晶片 610，如图 6A 所示出的；及随后通过在其间使用粘合剂接合以形成粘合层 690 而将外延材料 630 黏合或附接至支撑基底 680，如图 6B 所示的。支撑基底 680 可以使用粘合剂接合至外延材料 630 的暴露表面。在一个实例中，粘合层 690 可由光学粘合剂和 / 或紫外线固化型粘合剂形成或包含光学粘合剂和 / 或紫外线固化型粘合剂，例如，在商业上可购得的 Norland 紫外线固化型光学粘合剂。在一些实例中，粘合剂可包含巯基酯化合物。在其他实例中，粘合剂可进一步包含材料，例如邻苯二甲酸丁辛酯、甲基丙烯酸四氢糠酯、丙烯酸酯单体、其衍生物或其组合。

[0115] 如图 6B 所示的，在一个实例中，提供 ELO 薄膜堆栈 600B，其包含：支撑基底 680，其配置在外延材料 630 的第一表面上方；及多层支撑柄 670，其配置在外延材料 630 的另一表面上方。粘合层 690 可配置在外延材料 630 和支撑基底 680 之间。多层支撑柄 670 包含：硬性支撑层 640，其配置在外延材料 630 上方；软性支撑层 650，其配置在硬性支撑层 640 上方；及柄板 660，其配置在软性支撑层 640 上方。

[0116] 在一个实例中，粘合层 690 可由粘合剂形成，粘合剂已在固化工艺期间暴露于紫外线辐射。一般说来，粘合剂可在一段时间内暴露于紫外线辐射，这段时间在从约 1 分钟至约 10 分钟的范围内，优选地从约 3 分钟至约 7 分钟，例如约 5 分钟。粘合剂可在从约 25℃至约 75℃的范围内例如约 50℃的温度下固化。

[0117] 在其他实例中，粘合层 690 的粘合剂可为有机硅粘合剂，或可包含硅酸钠。在这些实例中，粘合剂可在一段时间内固化，这段时间在从约 10 小时至约 100 小时的范围内，优选地从约 20 小时至约 60 小时，且更优选地从约 30 小时至约 50 小时，例如约 42 小时。粘合剂可在从约 25℃至约 75℃的范围内例如约 50℃的温度下固化。粘合剂也可在从约 1psi（每平方英寸磅）至约 50psi 的范围内的压力下固化，优选地是从约 3psi 至约 25psi，且更优选地从约 5psi 至约 15psi。在一个实例中，压力可为约 9psi。

[0118] 牺牲层 620 可暴露于蚀刻工艺，以从基底移除外延材料 630。在一些实施方案中，牺牲层 620 可在蚀刻工艺期间暴露于湿蚀刻溶液。湿蚀刻溶液包含氢氟酸，并可包含表面活性剂和 / 或缓冲剂。在一些实例中，牺牲层 620 可以按约 0.3 毫米 / 小时或更大的速度被蚀刻，优选地是约 1 毫米 / 小时或更大，且更优选地是约 5 毫米 / 小时或更大。在一个可

选实施方案中，牺牲层 620 可在蚀刻工艺期间暴露于电化学蚀刻。电化学蚀刻可为偏压工艺或电镀工艺。同样地，在此处所述的另一实施方案中，牺牲层 620 可在蚀刻工艺期间暴露于蒸汽相蚀刻。蒸汽相蚀刻包括将牺牲层 620 暴露于氟化氢蒸汽。蚀刻工艺可为光化学蚀刻、热增强蚀刻、等离子体增强蚀刻、应力增强蚀刻、其衍生物或其组合。

[0119] 在此处的实施方案中，外延材料 630 可包含砷化镓、砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。外延材料 630 可具有矩形几何形状、正方形几何形状或其他几何形状。外延材料 630 可包含一层，但通常包含多层。在一些实例中，外延材料 630 包含具有砷化镓的一层及具有砷化铝镓的另一层。在另一实例中，外延材料 630 包含砷化镓缓冲层、砷化铝镓钝化层和砷化镓活性层。砷化镓缓冲层可具有在从约 100nm 至约 500nm 的范围内的厚度，例如，约 300nm ；砷化铝镓钝化层具有在从约 10nm 至约 50nm 的范围内的厚度，例如，约 30nm ；且砷化镓活性层具有在从约 500nm 至约 2000nm 的范围内的厚度，例如，约 1000nm。在一些实例中，外延材料 630 进一步包含第二砷化铝镓钝化层。

[0120] 在此处的其他实施方案中，外延材料 630 可包含晶胞结构，其包含多层。晶胞结构可包含砷化镓、n 掺杂砷化镓、p 掺杂砷化镓、砷化铝镓、n 掺杂砷化铝镓、p 掺杂砷化铝镓、磷化铟镓、其合金、其衍生物或其组合。在许多实例中，砷化镓为 n 掺杂或 p 掺杂。

[0121] 在一些实施方案中，牺牲层 620 可包含砷化铝、其合金、其衍生物或其组合。在一个实例中，牺牲层 620 包含砷化铝层，并具有约 20nm 或更小的厚度，优选地在从约 1nm 至约 10nm 的范围内的厚度，且更优选地从约 4nm 至约 6nm 的厚度。基底例如晶片 610 和 / 或支撑基底 680 通常包含砷化镓或其衍生物，并可为 n 掺杂或 p 掺杂。

[0122] 虽然以上内容涉及本发明的实施方案，但可设计本发明的其他和另外的实施方案而不偏离本发明的基本范围，且本发明范围由所附权利要求确定。

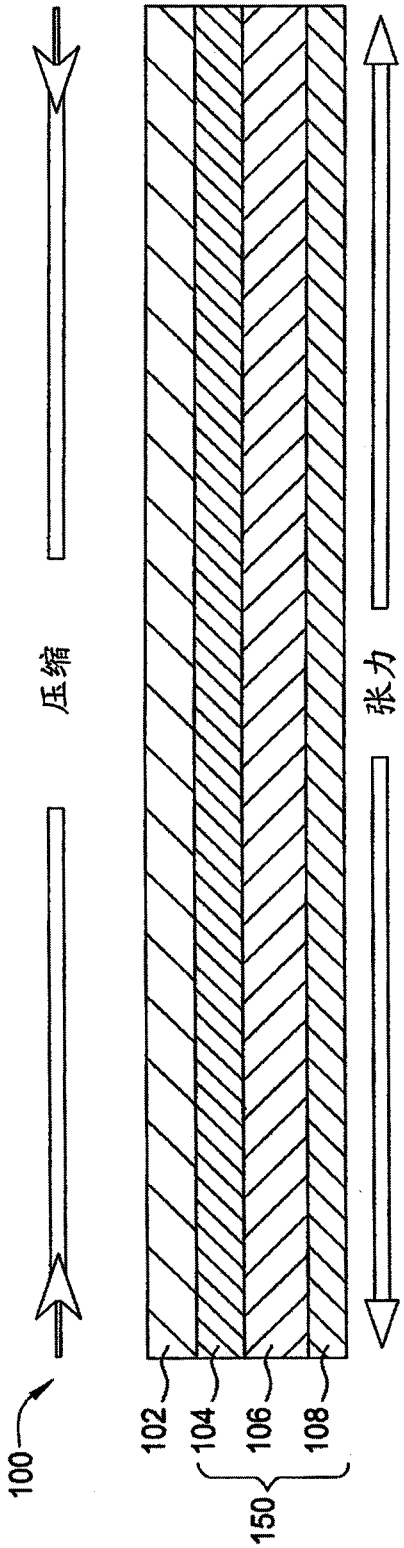

图 1

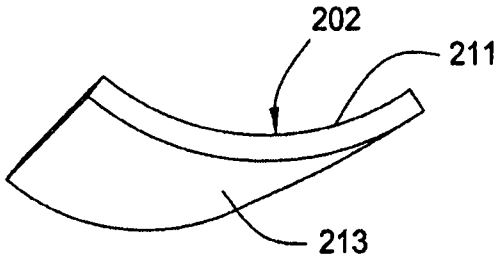

图 2A

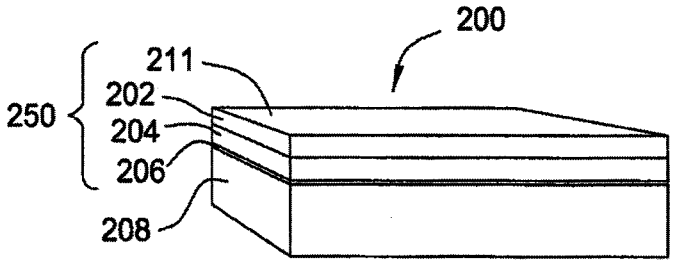

图 2B

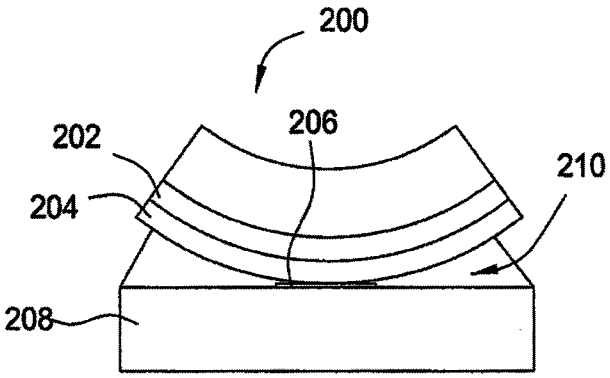

图 2C

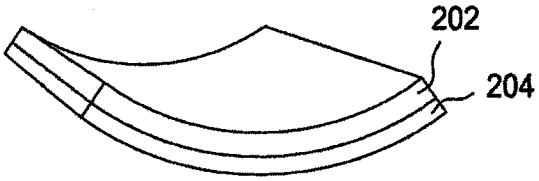

图 2D

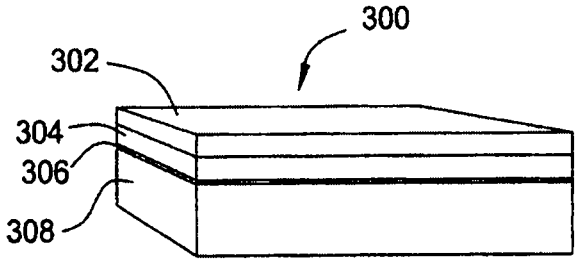

图 3A

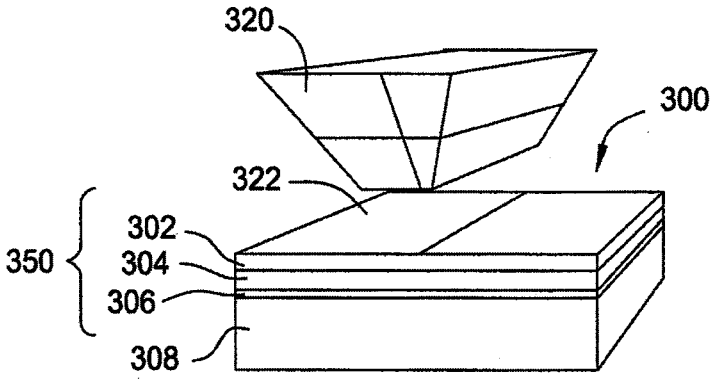

图 3B

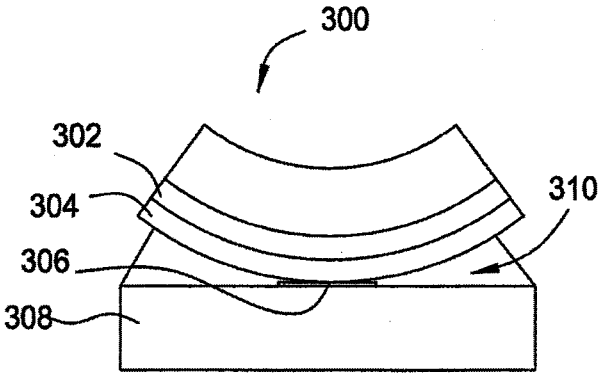

图 3C

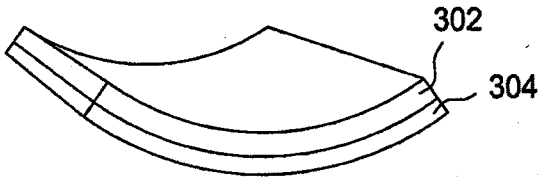

图 3D

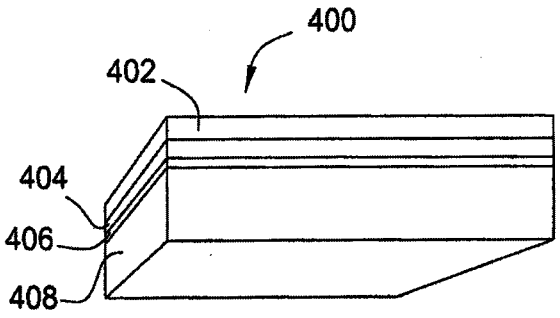

图 4A

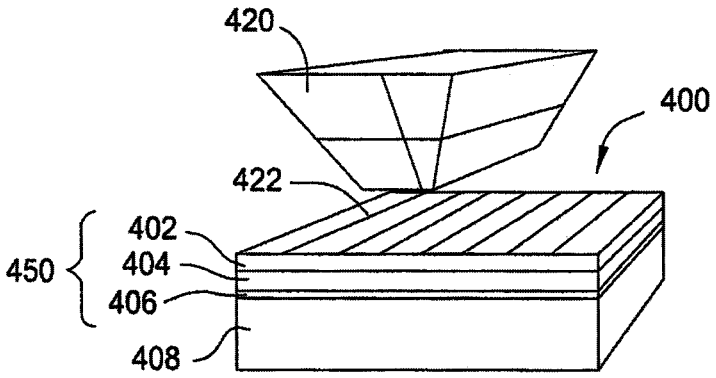

图 4B

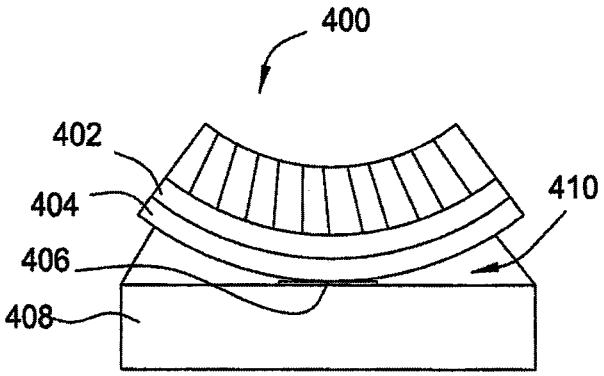

图 4C

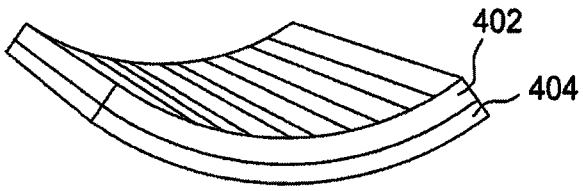

图 4D

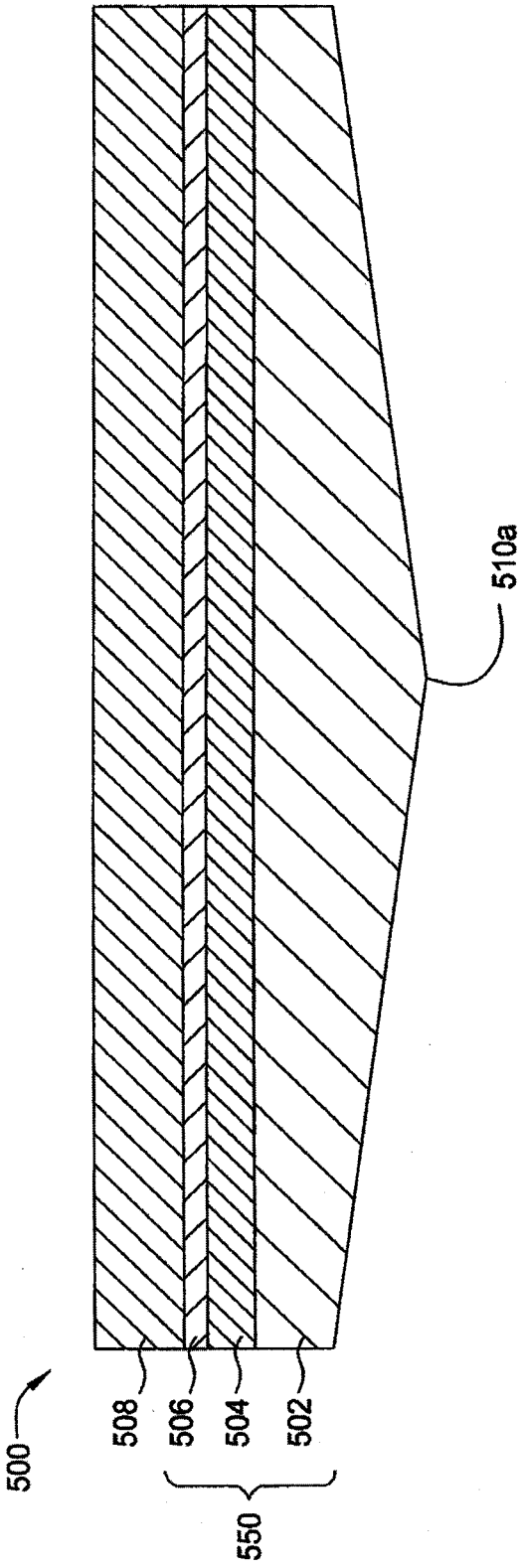

图 5A

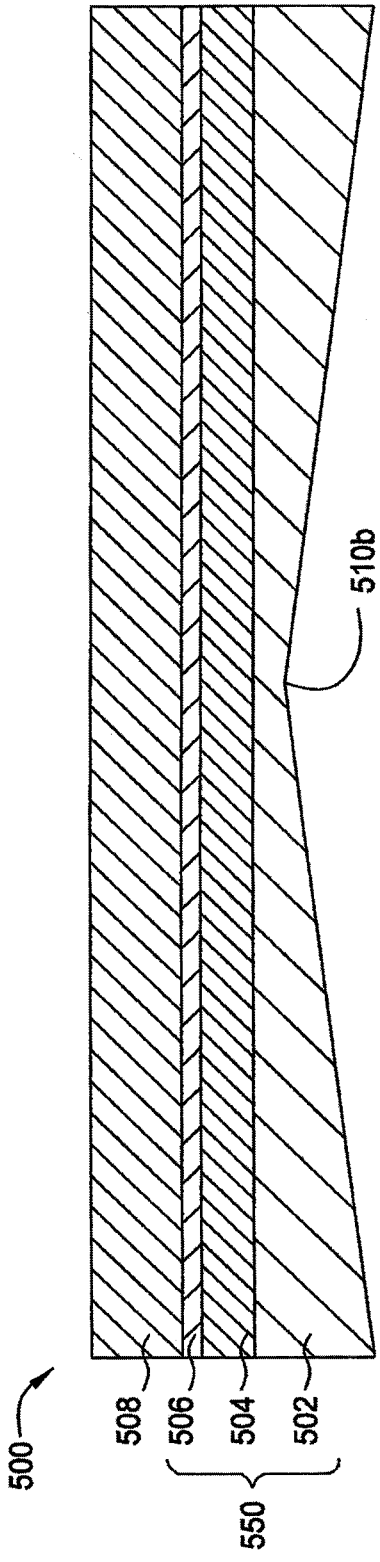

图 5B

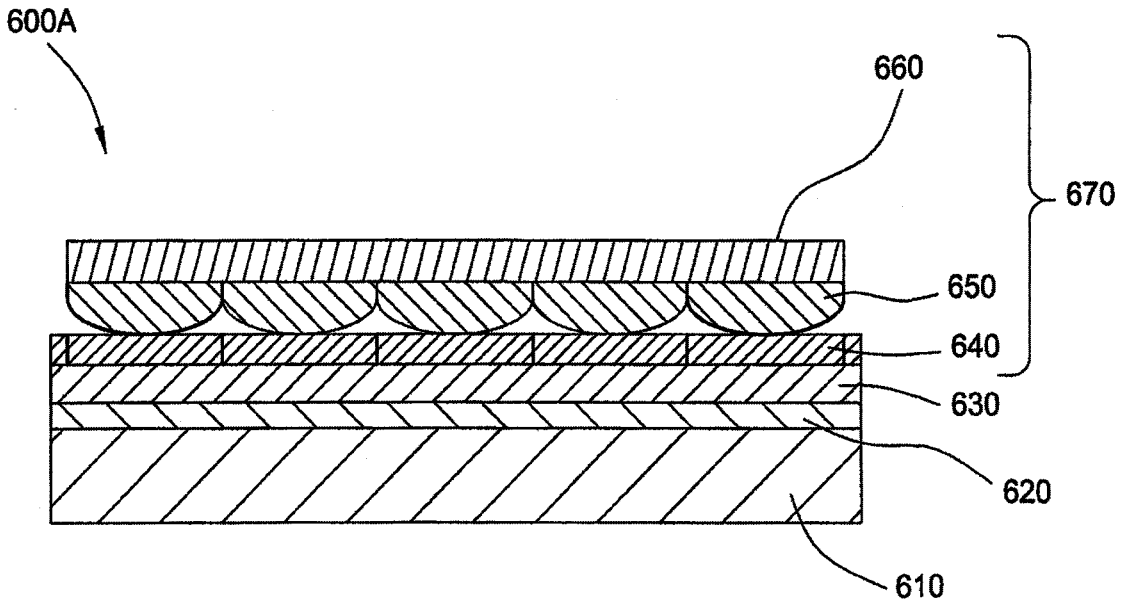

图 6A

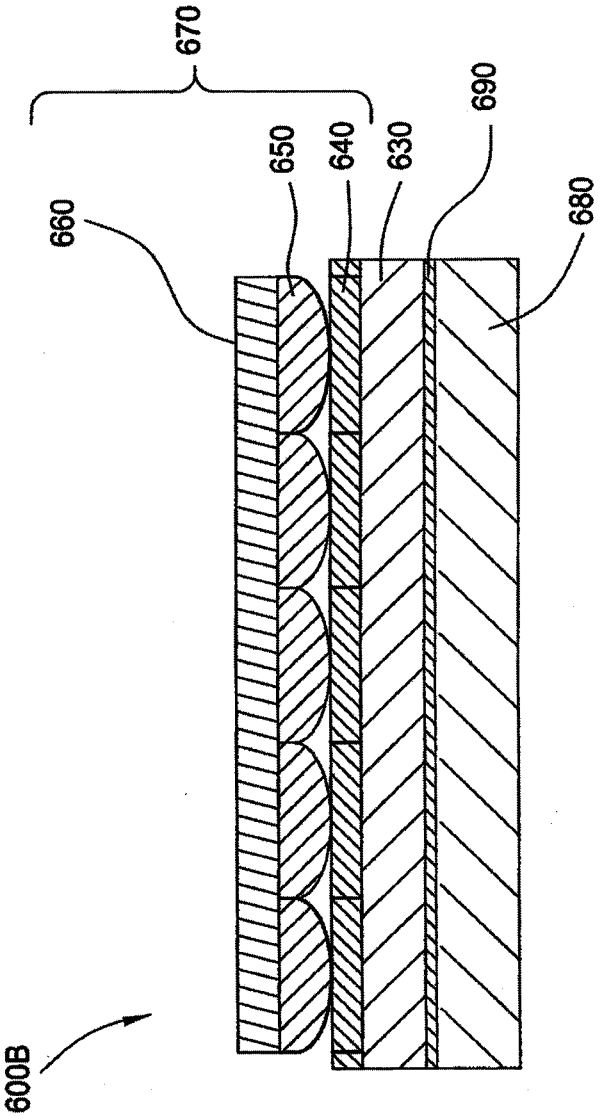

图 6B

Abstract

Embodiments of the invention generally relate to epitaxial lift off (ELO) thin films and devices and methods used to form such films and devices. The ELO thin films generally contain epitaxially grown layers which are formed on a sacrificial layer disposed on or over a substrate, such as a wafer. A support handle may be disposed on the opposite side of the epitaxial material than the substrate. The support handle may be used to stabilize the epitaxial material, such as by providing compression to the epitaxial material. Furthermore, the support handle may be used to grip and hold the epitaxial material during the etching and removal steps of the ELO process. In various embodiments, the support handle may include a pre-curved handle, a multi-layered handle, a non-uniform wax handle, and two shrinkage-induced handles which universally or unidirectional shrink to provide compression to the epitaxial material.

摘要

本發明的實施方案通常涉及外延遷移(ELO)薄膜和器件，以及用來形成這類膜和器件的方法。ELO 薄膜通常包括外延生長層，其在配置於基底例如晶片之上或上方的犧牲層上形成。支撐柄可配置在除了基底外的外延材料的相對側上。支撐柄可例如通過給外延材料提供壓縮來穩定外延材料。此外，在 ELO 工藝的蝕刻和移除步驟期間，支撐柄可用於抓緊以及支撐住外延材料。在不同實施方案中，支撐柄可包括預先彎曲的柄、多層柄、非均勻蠟柄和兩個收縮誘發柄，其普通地或單向地收縮，以給外延材料提供壓縮。