Claims

1. A waveguide, comprising:

a substrate, the substrate having a substrate thickness distribution defined by a top surface of the substrate and a bottom surface of the substrate, wherein substrate thickness distribution varies along a first length parallel to the top surface and a second length perpendicular to the first length of the waveguide;

an index layer disposed on the bottom surface of the substrate, the index layer having an engineered thickness distribution defined by an exterior surface of the index layer and the bottom surface of the substrate, wherein the engineered thickness distribution varies along the first length and the second length perpendicular to the first length; and

an input coupling grating and an output coupling grating each having optical device structures disposed over the top surface of the substrate.

2. The waveguide of claim 1, wherein the substrate has a first refractive index and the index layer has a second refractive index, wherein the second refractive index matches the first refractive index or a difference between the first refractive index and the second refractive index is between about 0 and about 0.1.

3. The waveguide of claim 1, wherein the engineered thickness distribution varies in a first direction parallel to the top surface and a second direction perpendicular to the first direction.

4. The waveguide of claim 1, further comprising an anti-reflective layer disposed over the exterior surface of the index layer.

5. The waveguide of claim 4, wherein the anti-reflective layer includes an alternating low index layer and high index layer, wherein the low index layer has a refractive index of between about 1.4 and about 1.7 and the high index layer has a refractive index of greater than about 2.0.

6. The waveguide of claim 1, further comprising a low index layer disposed over at least one of the input coupler grating or the output coupler grating.

7. The waveguide of claim 6, wherein the low index layer has a refractive index of about 1.4 to about 1.7.

8. The waveguide of claim 1, wherein a portion of the optical device structures are angled relative to the bottom surface of the substrate.

9. The waveguide of claim 1, wherein the index layer is polymer material or a nanoparticle based material.

10. A method of forming a design thickness distribution in an optical device, comprising:

measuring a substrate thickness distribution of a substrate defined by a distance between a top surface of the substrate and a bottom surface of the substrate along a first length parallel to the top surface and a second length perpendicular to the first length;

disposing an index layer on the bottom surface of the substrate; and

etching the index layer to have an engineered thickness distribution to form a design thickness distribution, wherein the design thickness distribution is defined by the engineered thickness distribution and the substrate thickness distribution, wherein the design thickness distribution varies along the first length and the second length.

11. The method of claim 10, wherein the etching includes at least one of ion implantation, ion beam etching (IBE), reactive ion etching (RIE), directional RIE, plasma etching, and thermal atomic layer etching.

12. The method of claim 10, further comprising disposing an anti-reflective layer over the index layer.

13. The method of claim 10, further comprising disposing a low index layer over a plurality of optical devices disposed on the top surface of the substrate.

14. A method of forming a design thickness distribution in an optical device, comprising:

measuring a substrate thickness distribution of a substrate defined by a distance between a top surface of the substrate and a bottom surface of the substrate along a first length parallel to the top surface and a second length perpendicular to the first length;

generating a phase map from the substrate thickness distribution across the bottom surface of the substrate;

measuring a non-uniformity of pitch between adjacent optical device structures of a plurality of optical device structures disposed on the top surface of the substrate;

generating an engineered phase profile by subtracting the phase map and the non-uniformity of pitch from a design phase map corresponding to a phase to be formed at each location of the optical device;

converting the engineered phase profile to an engineered thickness distribution; and

disposing an index layer on the bottom surface of the substrate to have the engineered thickness distribution to form a design thickness distribution, wherein the design thickness distribution is defined by the engineered thickness distribution and the substrate thickness distribution, wherein the design thickness distribution varies along the first length and the second length.

15. The method of claim 14, wherein the index layer is disposed via an inkjet printing process to have the engineered thickness distribution.

16. The method of claim 14, wherein the substrate has a first refractive index and the index layer has a second refractive index, wherein the second refractive index substantially matches the first refractive index.

17. The method of claim 14, further comprising removing an anti-reflective layer from the bottom surface of the substrate before disposing the ~~index-matched~~ index layer.

18. The waveguide of claim 1, wherein the index layer is a film comprising silicon nitride, titanium, tantalum oxide, niobium oxide, or zirconium oxide.

19. The waveguide of claim 18, wherein the film further comprises embedded nanoparticles.

20. The method of claim 10, wherein the substrate has a first refractive index and the index layer has a second refractive index, wherein the second refractive index matches the first refractive index or a difference between the first refractive index and the second refractive index is between about 0 and about 0.1.