Claims

1. A hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss, comprising:

an outer cladding; and

an inner cladding which is formed by nested structural elements arranged circumferentially at an interval along an internal surface of the outer cladding and connected to the internal surface of the outer cladding and clads a central cavity to form an equivalent circular fiber core cavity, the nested structural element comprising two or more layers of nested glass tubes having different radii, wherein an auxiliary inner cladding is disposed along a circumference of the internal surface of the outer cladding and comprises auxiliary nested structural elements, the auxiliary nested structural elements are arranged at an interval along the circumference of the internal surface of the outer cladding in an alternate manner with the nested structural elements and are connected to the internal surface of the outer cladding, and an equivalent circular mode-filtering cavity, tangent to an auxiliary nested structural element and nested structural elements on two adjacent sides, is formed between the auxiliary nested structural element and the nested structural elements on two adjacent sides.

2. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1, wherein the auxiliary nested structural element comprises one or more layers of nested glass tubes having different radii.

3. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the nested glass tubes comprise an outer nested glass tube and an inner nested glass tube from outside to inside.

4. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein there are one or more auxiliary nested structural elements, each of which is located between two adjacent nested structural elements.

5. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the auxiliary nested structural element is arranged symmetrically between two adjacent nested structural elements such that a geometric centerline of the auxiliary nested structural element coincides

with a geometric centerline of the two adjacent nested structural elements.

6. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the inner cladding comprises three to five nested structural elements, and the auxiliary inner cladding correspondingly comprises three to five auxiliary nested structural elements; preferably the nested structural elements are arranged at an interval circumferentially and uniformly along the internal surface of the outer cladding.

7. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the nested structural element comprises three layers of nested glass tubes having different radii, comprising an outer nested glass tube, a first inner nested glass tube, and a second inner nested glass tube from outside to inside; preferably the nested structure element comprises three layers of nested glass tubes having different radii, wherein the outer nested glass tube and the first inner nested glass tube are circular glass tubes having different radii, and a support pad is disposed at a connection between the outer nested glass tube and the first inner nested glass tube; and preferably there are one or more support pads distributed along a circumference; and a cross section of the support pad is approximately circular, oval, rhombic, or rectangular.

8. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the outer cladding and the internal surface are both circular.

9. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the nested glass tubes comprise circular nested glass tubes having different radii, respective circular nested glass tubes are tangent, and the outer nested glass tube is tangent to an inner cavity surface of the outer cladding.

10. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the nested glass tubes comprise circular-arc nested glass tubes having different radii and circular nested glass tubes having different radii, wherein respective circular-arc nested glass tubes intersect with the internal surface of the outer cladding or intersect with adjacent nested glass tubes on the outside, and respective circular nested glass tubes are tangent to respective circular nested glass tubes or tangent to the internal surface of the outer cladding.

11. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein the nested glass tubes comprise circular-arc nested glass tubes having different radii, and respective circular-arc nested glass tubes intersect with the internal surface of the outer cladding, or a base material of the outer cladding, a base material of the inner cladding, and a base material of the auxiliary inner cladding are all pure silica glass.

12. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 3, wherein single-side wall thicknesses of the inner nested glass tubes and the outer nested glass tubes constituting the nested structure elements and the auxiliary nested structure elements are consistent or have a difference of less than 20%; or single-side wall thicknesses of the inner nested glass tubes and the outer nested glass tubes constituting the nested structure elements and the auxiliary nested structure elements and a single-side wall thickness of the outer cladding are from 0.3 μm to 1.5 μm.

13. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein a ratio of a diameter of the equivalent circular fiber core cavity to a diameter of the equivalent circular mode-filtering cavity is 1:0.4 to 0.7; preferably a loss of a fundamental mode of the optical fiber is less than 0.1 dB/km, or an attenuation of a higher-order mode of the optical fiber is greater than 10 dB/m.

14. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 3, wherein a ratio of a diameter of a circular fiber core to a diameter of the outer nested glass tube of the nested structural element is 1:1.2 to 1.5; or a ratio of a diameter of the outer nested glass tube of the nested structural element to a diameter of the first inner nested glass tube of the nested structural element is 1: 0.55 to 0.75; or a ratio of a diameter of the first inner nested glass tube of the nested structural element to a diameter of the second inner nested glass tube of the nested structural element is 1: 0.4 to 0.7.

15. The hollow-core anti-resonant optical fiber with a single-mode and an ultra-low loss according to claim 1 or claim 2, wherein a fiber core cavity region and other cavity regions in the outer cladding are filled with a gas, and the gas is argon, nitrogen, helium, air or a mixture of multiple gases, or a loss of a fundamental mode of the optical fiber is less than 0.5 dB/km; or a loss of a higher-order mode of the optical fiber is greater than 6 dB/m.