Claims

1. A hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss, comprising an outer cladding and an inner cladding, wherein the inner cladding is composed of nested structural elements that are arranged along a circumferential direction of an inner wall of the outer cladding and are connected to the inner wall of the outer cladding, and a central cavity surrounded by the inner cladding forms a core, characterized in that each nested structural element comprises three or more layers of nested glass tubes with different radii, wherein at least one inner nested glass tube of at least one layer of inner nested glass tubes deflects to one side relative to an outer nested glass tube adjacent thereto, with a deflection angle of 5 to 55 degrees.

2. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1, characterized in that the deflecting inner nested glass tube is comprised in one or two layers of inner nested glass tubes.

3. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 2, characterized in that each nested structural element comprises three layers of nested glass tubes with different radii, comprising, from outside to inside, an outer nested glass tube, a first inner nested glass tube and a second inner nested glass tube, wherein the first inner nested glass tube deflects to one side relative to the outer nested glass tube, or the second inner nested glass tube deflects to one side relative to the first inner nested glass tube.

4. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 2, characterized in that each nested structural element comprises three layers of nested glass tubes with different radii, comprising, from outside to inside, an outer nested glass tube, a first inner nested glass tube and a second inner nested glass tube, wherein the first inner nested glass tube deflects to one side relative to the outer nested glass tube, and the second inner nested glass tube deflects to one side relative to the first inner nested glass tube.

5. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 3 or 4, characterized in that the first inner nested glass tube deflects to one side relative to the outer nested glass tube, that is, a deflection angle is formed between a connecting line L2 between a curvature center $O_2$of the first inner nested glass tube and a curvature center O_1 of the outer nested glass tube, and an extending line L1 of a connecting line between the curvature center O_1 of the outer nested glass tube and a geometric center O of the core; or the second inner nested glass tube deflects to one side relative to the first inner nested glass tube, that is, a deflection angle is formed between a connecting line L3 between a curvature center O_3 of the second inner nested glass tube and a curvature center O_2 of the first inner nested glass tube, and an extending line of a

connecting line L2 between the curvature center O_2 of the first inner nested glass tube and a curvature center O_1 of the outer nested glass tube.

6. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1 or 2, characterized in that the inner cladding comprises four to six nested structural elements; or the nested structural elements are evenly distributed at intervals along the circumferential direction of the inner wall of the outer cladding; or both the outer cladding and the inner wall are circular.

7. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 3 or 4, characterized in that the nested glass tubes comprise circular nested glass tubes with different radii, wherein the circular nested glass tubes are tangent to each other, and the outer nested glass tube is tangent to the inner wall of the outer cladding; or the nested glass tubes comprise arc-shaped nested glass tubes and circular nested glass tubes with different radii, wherein each arc-shaped nested glass tube intersects the inner wall of the outer cladding or the adjacent outer nested glass tube, the circular nested glass tubes are tangent to each other, or each circular nested glass tube is tangent to the inner wall of the outer cladding; or the nested glass tubes comprise arc-shaped nested glass tubes with different radii, wherein each arc-shaped nested glass tube intersects the inner wall of the outer cladding.

8. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1 or 2, characterized in that all inner nested glass tubes of one layer of inner nested glass tubes deflect to a same side relative to the outer nested glass tube adjacent thereto, with a same or basically same deflection angle.

9. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 3, characterized in that all the first inner nested glass tubes deflect to a same side relative to the outer nested glass tube, with a same or basically same deflection angle, and none of the second inner nested glass tubes deflect relative to the first inner nested glass tubes.

10. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 4, characterized in that all the first inner nested glass tubes deflect to a same side relative to the outer nested glass tube, with a same or basically same deflection angle, and all the second inner nested glass tubes deflect to an opposite side relative to the first inner nested glass tubes, with a same or basically same deflection angle; or all the first inner nested glass tubes deflect to a same side relative to the outer nested glass tube, with a same or basically same deflection angle, and all the second inner nested glass tubes deflect to a same side relative to the first inner nested glass tubes, with a same or basically same deflection angle.

11. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss

according to claim 3 or 4, characterized in that the second inner nested glass tube is a circular nested glass tube, the first inner nested glass tube is a circular nested glass tube or an arc-shaped nested glass tube, and the outer nested glass tube is an arc-shaped nested glass tube; or the second inner nested glass tube is an arc-shaped nested glass tube, the first inner nested glass tube is an arc-shaped nested glass tube or a circular nested glass tube, and the outer nested glass tube is an arc-shaped nested glass tube.

12. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1 or 2, characterized in that the deflection angle is 15 to 55 degrees; or the deflection angle is 25 to 50 degrees; or the deflection angle is 35 to 45 degrees; or substrate materials of both the outer cladding and the nested structural elements are pure silica glass; or the inner and outer nested glass tubes have a wall thickness of 0.3 to 1.5 μm.

13. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 3 or 4, characterized in that a ratio of outer diameters of the outer nested glass tube to the first inner nested glass tube is 1: 0.5 to 1: 0.65, and a ratio of outer diameters of the first inner nested glass tube to the second inner nested glass tube is 1: 0.3 to 1: 0.5.

14. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1 or 2, characterized in that a region of the core and other inner cavity regions of the outer cladding are filled with a gas; preferably the gas is argon, nitrogen, helium, air, or a mixture of multiple gases.

15. The hollow-core anti-resonant fiber with high single-mode performance and ultra-low loss according to claim 1 or 2, characterized in that a fundamental mode loss of the fiber is 0.05 to 0.5 dB/km; or a fundamental mode loss of the fiber is less than 0.15 dB/km; or a higher-order mode loss of the fiber is 3 to 20 dB/m; or a higher-order mode loss of the fiber is greater than 8 dB/m.