The term "substantially" should herein be taken to mean that ordinary product variances and tolerances are comprised.

The term "about" is generally used to include what is within measurement uncertainties. The term "about" when used in ranges should herein be taken to mean that what is within measurement uncertainties are included in the range.

It should be emphasized that the term "comprises/comprising" when used herein is to be interpreted as an open term, i.e. it should be taken to specify the presence of specifically stated feature(s), such as element(s), unit(s), integer(s), step(s) component(s) and combination(s) thereof, but does not preclude the presence or addition of one or more other stated features.

Throughout the description or claims, the singular encompasses the plural unless otherwise specified or required by the context.

Diameters, thickness and other structural values are seen in a cross sectional view of the hollow core PCF unless otherwise specified or clear from the context.

The hollow core photonic crystal fiber (PCF) according to an aspect of the invention comprises an outer cladding region and 7 hollow tubes surrounded by the outer cladding region each of said hollow tubes having an average outer diameter d2 and an average inner diameter d1. Each of the hollow tubes is fused to the outer cladding to form a ring defining an inner cladding region and a hollow core region surrounded by the inner cladding region. The hollow tubes are not touching each other and wherein at least one of said hollow tubes is free of a nested sub tube having an average outer diameter smaller than the average inner diameter d1 of said hollow tube and arranged in the hollow structure of the hollow tube and fused to the hollow tube. It has been found to be advantageous for suppressing of undesired higher order modes that the hollow tubes each has an average outer diameter which is referred to as d2 and an average inner diameter which is referred to as d1. The ration d1/d2 is equal to or larger than about 0.8.

The average outer diameter d2 and/or the average inner diameter of the respective hollow tubes may be equal or different from hollow tube to hollow tube

In an embodiment d1 and/or d2 is/are substantially identical for at least three of the hollow tube, such as for all of the seven hollow tubes.

According to embodiments of the invention and against all teaching of prior art hollow core PCF it has surprisingly been found that a hollow core PCF with a non-touching inner cladding structure where there are seven non-touching tubes may provide a highly increased suppression of higher order modes (HOMs) than the above described hollow core PCF with six 6 non-touching inner cladding tubes. In particular – and as shown in the example – it has been found that the hollow core PCF of the invention with seven non-touching tubes has an increased suppression of HOMs with azimuthal number above 1, such a third order HOMs while simultaneously having low loss in the fundamental mode of at least a transmission band below 2 μm, preferably below 1.5 μm.

The term "transmission band" is herein used to mean a band with a bandwidth of at least about 10 nm, such as at least about 25 nm and preferably at least about 50 nm or even at least about 100 nm of transmission wavelength.

The term "low loss transmission band" means a transmission band for light in its fundamental mode with a transmission loss of less than about 100 dB/km, preferably less than about 60 dB/km and more preferably less than about50 dB/km.

It has further been found that by increasing the ration d1/d2 the low loss transmission band may be achieved at even lower wavelengths such as a low loss transmission band comprising wavelengths below 1200 nm, such as below 1 μm, such as below 800 μm, such as below 600 my. Advantageously the ration d1/d2 is equal to or larger than about 0.85, such as equal to or larger than about 0.9.

The outer cladding comprises solid cladding material and is preferably entirely of solid material.

PATENT CLAIMS

1. A hollow core photonic crystal fiber (PCF) comprising an outer cladding region and 7 hollow tubes surrounded by said outer cladding region, each of said hollow tubes having an average outer diameter d2 and an average inner diameter d1, wherein each of said hollow tubes is fused to said outer cladding region to form a ring defining an inner cladding region and a hollow core region surrounded by said inner cladding region, wherein said hollow tubes are not touching each other and wherein at least one of said hollow tubes is free of a nested sub tube having an average outer diameter smaller than the average inner diameter d1 of said hollow tube and arranged in the hollow structure of the hollow tube and fused to the hollow tube.

2. The hollow core PCF of claim 1, wherein d1/d2 is equal to or larger than about 0.8, such as equal to or larger than about 0.85, such as equal to or larger than about 0.9.

3. The hollow core PCF of claim 1 or claim 2, wherein said hollow tubes have a center to center distance Λ between adjacent hollow tubes which is between about 1.01*d2 and about 1.5*d2, such as between 1.05*d2 and 1.2*d2.

4. The hollow core PCF of any one of the preceding claims, wherein said hollow core region has a core diameter D of from about 10 µm to about 100 µm and said average outer tube diameter relative to the core diameter d2/D is from about 0.5 to about 0.75, such as from about 0.65 to about 0.72.

5. The hollow core PCF of any one of the preceding claims, wherein each of said hollow tubes comprises a core center facing region with a wall thickness t, wherein said wall thickness is up to about 2.1 µm, such as up to about 1 µm, such as in the range from about 150 to about 350 nm or in the

range from about 650 to about 850 nm or in the range from about 900 to about 2.1 µm.

6. The hollow core PCF of claim 5, wherein at least one of the hollow tubes has a different wall thickness t than at least one other of the hollow tubes, preferably 3 of the hollow tubes have a wall thickness and the remaining 4 hollow tubes have another wall thickness.

7. The hollow core PCF of any one of the preceding claims, wherein the minimum distance between adjacent hollow tubes is at least about 0.1 µm, such as at least about 1 µm, such as at least about 2 µm, such as at least about 5 µm.

8. The hollow core PCF of any one of the preceding claims, wherein the hollow core region and said hollow tubes independently of each other comprise gas selected from air, argon, nitrogen or mixtures comprising any of the mentioned gasses, optionally said hollow core region and said hollow tubes independently of each other are vacummated or filled with pressurized gas.

9. The hollow core PCF of any one of the preceding claims, wherein the outer cladding region has an outer diameter of at least about 125 µm, 150 µm, such as at least about 200 µm.

10. The hollow core PCF of any one of the preceding claims, wherein the outer cladding region and/or the hollow tubes comprise a solid glass material, preferably said solid material is of silica, optionally doped with refractive index modifying dopant.

11. The hollow core PCF of any one of the preceding claims, wherein the outer cladding region comprises a photonic bandgap structure surrounding said inner cladding region.

12. The hollow core PCF of any one of claims 9-11, wherein the outer cladding region comprises an outer background material having a refractive index N_{oc} and a plurality of inclusions having a refractive index different from the refractive index of the background material, said plurality of inclusions in the outer background material is preferably arranged in a cross-sectional pattern comprising at least two rings of inclusions surrounding the inner cladding region, such as at least 3 rings, such as at least 4 rings of inclusions.

13. The hollow core PCF claim 12, wherein said plurality of inclusions have an average diameter (d_{inc}) of up to about 2.5 µm, such as up to about 2 µm, such as between about 1.1 µm and 1.8 µm, such as between about 1.15 µm and about 1.7 µm, such as between about 1.2 µm and about 1.5 µm, such as about 1.3 µm.

14. The hollow core PCF of any one of claims 12-13, wherein said plurality of inclusions are arranged at a pitch (Λ_{inc}) of up to about 6 µm, such as up to about 5 µm, such as up to about 4 µm, such as between about 2 µm and 4 µm.

15. A laser system for delivering laser light to a user apparatus, said laser system comprising a laser light source and a fiber delivery cable for delivering light from the laser light source to the user apparatus, wherein said fiber delivery cable comprises a hollow core PCF according to any one of the preceding claims.

16. The laser system of claim 15, wherein said laser light source has a pump duration of from about 30 fs to about 30 ps and a peak power determined at the exit of the laser light source which is at least about 5 kW, such as at least about 10 kW, such as at least about 30 kW, such as at least about 50 kW.

17. The laser system of any one of claims 15-16, wherein said hollow core PCF has a first fiber end which is adapted for being connected to said user apparatus and a second fiber end optically connected to an output fiber of said laser light source via a fiber coupling structure, wherein said fiber coupling structure comprises at least one of

a focusing lens,

a graded-index element (GRIN),

a protection element, or

a ferrule structure.