A novel technique for active fibre production

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Received 12 January 2006; accepted 9 February 2006

Abstract

Active fibre devices are conventionally manufactured using MCVD technique. Recently it has been shown that nearly equivalent results can also be obtained with sol–gel technology. Now we present a novel technique allowing simplification of the manufacturing process even more. The required constituents are mixed in the form of dry micro- and nano-sized particles. A silica glass tube forming the future core region of a fibre preform is filled with a powder mix of SiO$_2$, 1% Nd (as Nd$_2$O$_3$) and 10% Al (as Al$_2$O$_3$). This tube is mounted in the centre of a larger tube forming the future cladding. The empty space between the two tubes is filled with SiO$_2$ powder. After preheating, the evacuated preform is drawn to a fibre. A length of 45 cm, cladding-pumped with a diode laser at 808 nm as well as a core-pumped fibre of 5.1 cm length showed laser action between 1.05 and 1.1 μm.

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Keywords: Preform manufacturing; SiO$_2$ powder; Fibre drawing; Active fibres; Nd fibre laser

1. Introduction

Fibres for telecommunication as well as rare earth-doped active fibres are commonly manufactured with modified chemical vapour deposition (MCVD). They are characterized by excellent quality especially by very low losses such as 0.154 dB/km at 1.55 μm [1]. In view of the complex apparatus that is required for MCVD a much simpler way has been found to produce active fibres. This is sol–gel technology which typically starts with an aqueous solution of tetraethoxysilane (TEOS) that can be doped with rare earths. The liquid is used for dip coating of silica glass tubes to produce fibre preforms. After gelation and drying this material forms a network of SiO$_2$ that can be vitrified in a furnace and finally be drawn to a fibre. Laser action has been achieved with fibres produced with this technique [2–4].

Sol–gel technique, however, starts from aqueous solutions and it is therefore very difficult to obtain fibres with a low content of OH-groups. These undesirable OH-groups lead to strong absorption at wavelengths corresponding to the OH-stretching vibration at 2.8 μm or its first harmonic at 1.4 μm. This can suppress laser action at wavelengths exceeding about 1.3 μm. This problem can be relaxed if fibre preforms are manufactured with starting materials that are basically free of water. Therefore we propose to manufacture laser fibres from silica glass tubes filled with granulated silica, rare-earth oxide and alumina as a solvent for rare earth ions and to enhance the refractive index of the core.

In our letter we describe the manufacturing of a Nd$^{3+}$(1 at%):Al$^{3+}$(10 at%):silica glass fibre made from commercially available products in an extremely simple way. Even with the first attempt a fibre could be drawn that shows laser action around 1.06 μm.

2. Experimental

The schematic assembling of the fibre preform is shown in Fig. 1. The future core consists of a silica glass tube of 5
by 3 mm diameter filled with the mixture of silica powder
[5], alumina (Al₂O₃ from Sigma–Aldrich “99.99% purity”) and
neodymium oxide (Nd₂O₃ from Riedel-de Haën “>99.9% purity”). This tube is introduced coaxially into
a larger tube of 19 by 16 mm diameter. The free space is
filled with silica powder. An electron micrograph of the
starting oxides is shown in Fig. 2. Despite of the relatively
large grains of silica (typically 400 µm diameter) and alu-
mina (typically 200 µm diameter) no preceding melting or
vitrification is performed. Melting occurs only during the
fibre drawing process. The only preparation step was dry-
ing by evacuation and heating in the drawing furnace at
a temperature of 1400 °C.

The dried preform was then drawn to fibres at a furnace
temperature of 1750 °C. Different fibres were drawn with
cladding diameters ranging from 70 µm to 230 µm. No
plastic coating was applied. The cladding to core diameter is maintained in the drawing process and the ratio corre-
sponds to the preform (19:3). The melting temperature of
Nd₂O₃ is 2320 °C [6] and the melting temperature of
Al₂O₃ is 2054 °C [6]. These temperatures are far above
the furnace temperature during fibre drawing. Dependent
on the solubility of Nd₂O₃ and Al₂O₃ in SiO₂ scattering or clustering of the dopant may occur.

Laser experiments have been performed with a 45 cm
length of fibre with a cladding and core diameter of
170 µm and 27 µm respectively. The fibre is cladding-
pumped with a fibre-coupled diode-laser pump-module
(LIMO HLU10F100-808). The output of the pump-fibre
(NA = 0.22, rₕ = 50 µm) is imaged onto the front face
of the fibre through a butt-coupled resonator mirror
(T₈₀₉ nm = 94.11%, T₁₀₆₄ nm = 0.31%) with two lenses.
These lenses with f = 6.5 mm and f = 14.5 mm (Melles
Griot) are coated for minimum Fresnel losses @ 830 nm.
The rear mirror is butt-coupled with a reflectance of
97.7%. With such a short piece of fibre, cladding-pumping is extremely inefficient and therefore the laser threshold was very high (5 W of launched power).

A 5.1 cm length of fibre with cladding and core dia-
teters of 70 µm and 11 µm respectively is also core-pumped with a Ti:sapphire laser operated at 808 nm. Pump light is coupled into the fibre core with the f = 14.5 mm lens. The mirrors are the same as in the experiment with the cladding-pumped fibre.

3. Results and discussion

In this core-pumped arrangement the threshold is reached with a pump power of 228 mW.

In view of the completely new technique of manufactur-
ing, an analysis of this high threshold for a neodymium fibre laser and the correspondingly low output is not yet in the scope of this work.

The lifetime of the ⁴F₃/2 upper laser level has been deter-
mined with a chopped excitation. The arrangement of chopper and photomultiplier has a temporal resolution <10 µs. The measured fluorescence decay was about 300 µs. This value has to be compared with 409 µs mea-

In this comparison the measured lifetime is clearly at the lower end of the range. This is an indication of a distorted core and possibly considerable clustering.

The losses of the fibre are determined with a cut-back measurement using the beam of a He–Ne–laser at
633 nm. The experiment is performed with a fibre of 24 m
length (Fig. 3). The resulting extinction length of 5.8 m
@1/e corresponds to losses of 0.75 dB/m @ 633 nm.

Fig. 1. Schematic assembling of the Nd³⁺(1 at%):Al³⁺(10 at%):silica glass fibre preform.

Fig. 2. Electron micrographs of (a) silica sand, (b) alumina powder, and (c) neodymium oxide the width of the bars is 800 µm for (a) and (b) and 100 µm for (c).
Assuming scattering losses following a $\lambda^{-4}$ law, this results in 0.1 dB/m at 1.06 $\mu$m. In view of the simple manufacturing process, the losses are unexpectedly low and therefore very encouraging for future experiments.

According to the high alumina content and its probably high concentration fluctuation a very broad spectrum extending to 1100 nm can be expected [2]. Laser action covers a broad spectral range from 1050 nm to 1100 nm. An overlap of 9 different spectra is shown in Fig. 4.

4. Summary

A novel technique is proposed that allows extremely simple manufacturing of active fibre preforms. The required constituents are mixed in the form of dry micro- and nano-sized particles and filled in silica-glass tubes. A preform is made with a core formed by a powder mix of SiO$_2$, 1% Nd (as Nd$_2$O$_3$) and 10% Al (as Al$_2$O$_3$). After preheating, the evacuated preform is drawn to a fibre. A length of 45 cm, cladding-pumped with a diode laser at 808 nm as well as a core-pumped fibre of 5.1 cm length showed laser action between 1.05 and 1.1 $\mu$m.

Acknowledgments

We thank V. Romano, Th. Feurer and F. Sandoz for helpful discussions. H.J. Weder we are grateful for technical assistance. This work is supported in part by the Swiss NCCR program “Quantum Photonics”, Subproject 5c “Coherent Control of Matter in Photonic Crystal Fibers”.

References


[5] The silica was kindly made available from Dütwyler Fiber Optics SA, CH-Boudry.

