Optical fibre with a thin tin wire in the centre of the core

M. Hässig, W. Lüthy, Th. Feurer
Institute of Applied Physics, University of Bern, Sidlerstrasse 5, CH-3012 Bern, Switzerland
myrtha.haessig@iap.unibe.ch

Abstract

An optical step index fibre is manufactured with a 1.9 μm tin wire in the centre of the core. The core with a diameter of 100 μm is made from Schott 8252 glass with a refractive index of n = 1.538, the cladding with an outer diameter of 155 μm is made of Duran glass with n = 1.473.

Introduction

When a preform is drawn to a fibre, its diameter is reduced by a factor of hundred or more. Thereby the proportions of inner structures such as core or cladding are generally maintained. According to Taylor [1] it is therefore interesting to incorporate a metal wire in the preform since it can be expected to be reduced in its diameter when drawn to a fibre in the same way as the silica-glass surrounding. In principle it should be feasible, at least with multiple drawing steps, to produce wires with nm diameters and arbitrary length.

Experiments have been performed at our institute with wires of gold, platinum and lead [2]. As yet it had not been possible to reach wire diameters below 2.25 µm. In the experiments of [2] it turned out that drawing of Taylor wires is favoured with metals of low surface tension.

Platinum with a surface tension of σ = 1.865 Nm^{-1} [3, F-32] transforms to small droplets when the fibre is drawn. Gold with σ = 0.731 Nm^{-1} [3, F-24] at the melting point often shows droplets but also wires with diameters down to few microns can be found. Better results have been achieved [2] with lead (σ = 0.451 Nm^{-1} [3, F-32]). With lead a diameter as low as 2.25 µm has been reached. Experiments are also reported with a lead-tin alloy [4-5]. In [4] wire diameters as low as 10.5 µm are reported.

It is now interesting to compare the promising results of lead with Taylor wires of pure tin. Literature values of the surface tension of tin vary considerably depending on purity and atmosphere [3, F-32]. With an average surface tension of tin of $\sigma \sim 0.54$ Nm^{-1} that is not much higher than that of lead it should also be possible to draw thin wires. Further it is interesting to confine the central wire in a core-cladding structure of a light guiding fibre.

In the present paper we report on the fabrication of an optical step index fibre with a thin central core made from tin. The resulting fibres are characterized with optical microscopy and electron microscopy.

Experimental

In a first experiment tin was cast into a Duran capillary of 0.6 mm by 9 mm diameter. The composition of Duran (in wt %) is 81 SiO_2; 13 B_2O_3; 4 Na_2O/K_2O; 2 Al_2O_3 [6]. The surface tension of Pyrex that is similar to Duran is given in [7] as $\sigma = 0.15238\ Nm^{-1}$. This is unfortunately considerably smaller than the surface tension of tin. The tin was "high purity" 99.99 % (Goodfellow LS313731 SJP SN 005120/5). The tin-filled capillary was the preform to be drawn to a fibre. After preheating to 410 °C for 30 minutes, the fibre was drawn at a furnace temperature of about 1000 °C. An example of the fibre is shown in Fig. 1:

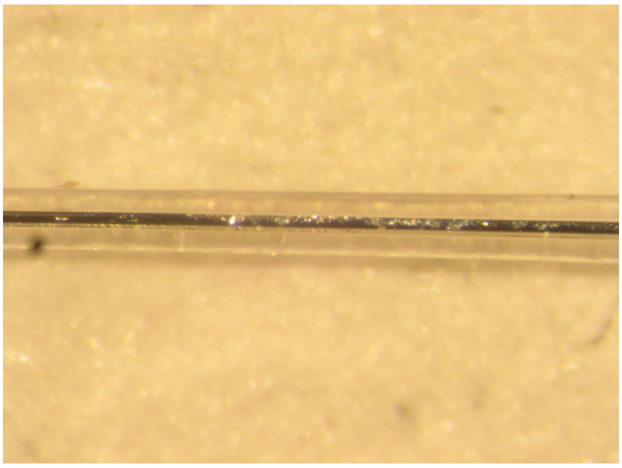

Fig. 1: 200 µm diameter Duran glass fibre with a core of tin.

In a second experiment, the goal was to achieve a core-cladding structure.
For the preparation of a preform leading to a step index fibre again, the tin was cast into a capillary of 0.6 by 9 mm made of Duran glass with a refractive index of 1.473 [6]. This capillary was then centred in a larger silica tube of 21mm by 17 mm made from pure silica glass 300HSQ with a refractive index of 1.45847 @ 587.56 1.45637 @ 656.27 [9]. Free space between the tubes was filled with granulated SiO_2 with 200 µm to 400 µm grain size. After preheating to about 600 °C and evacuation for half an hour, the preform was intended to be drawn to a fibre at an oven temperature of 1950 °C. It turned out that Duran glass is not stable at this high temperature; the preform was inflated and blocked in the furnace.
In a third experiment a capillary of glass 8252 (Schott) with a diameter of 0.5 by 6.5 mm was used as the core. Glass 8252 has a composition (% by weight

rounded) of 60 SiO_2; 4.5 B_2O_3; 14.5 Al_2O_3; 2 MgO; 10 CaO; 9 BaO [10]. This glass has a refractive index of n_{8252} = 1.538 @ λ = 587.6 nm [8] and is therefore suitable as a core in a Duran cladding with n_{Duran} = 1.473 @ λ = 587.6 nm [6]. The working temperature of glass 8252 is 1240 °C [8] that of Duran is 1260 °C [6] so that the whole preform can be drawn at a moderate temperature. The cladding is made with a Duran glass tube of 10 mm by 6.9 mm diameter.

The capillary was filled with 10 cm of the high purity 0.5 mm diameter tin wire. The wire was molten with the aid of a vertical furnace at a temperature of up to 400 °C.
The assembled preform was mounted in the drawing furnace and, again preheated to 410 °C and evacuated for one hour. Fibre drawing occurred at a temperature of 1000 °C. A result of the produced wire is shown in Fig. 2:

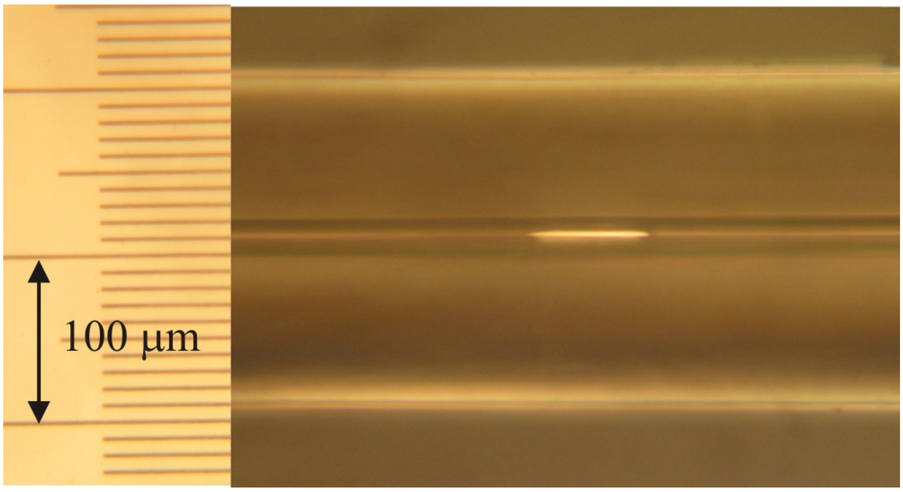

Fig. 2: Optical micrograph of the drawn fibre. The fibre diameter is 195 µm. The diameter of the tin wire is about 10 µm.

Fig. 2 shows that the inner diameter of the capillary has not collapsed. This shows that pressure has been developed during the drawing process. The occurrence of evaporation has to be assigned to insufficient purity of the material. Evaporation led to a complete disruption of the tin wire. Most of the fibre is empty, only short pieces such as the one in Fig. 2 can be found.
The experiment was repeated with nearly identical parameters. The capillary was sealed at its lower end, and a 10 cm length of tin wire was inserted. Then melting of the tin wire in the capillary was performed with a hand held hot air blower. Beginning

at the bottom the capillary was slowly moved through the hot air zone with a speed of about 2 mm/min. As a result the tin wire tightly filled the capillary. The following preparation of the preform as well as fibre drawing occurred in the same way as in the former experiment. The inspection of the drawn fibre again showed a lot of empty capillaries with, however also mm length pieces of thin wire. The thinnest tin wire with a diameter of about 2 µm is shown in Fig. 3.

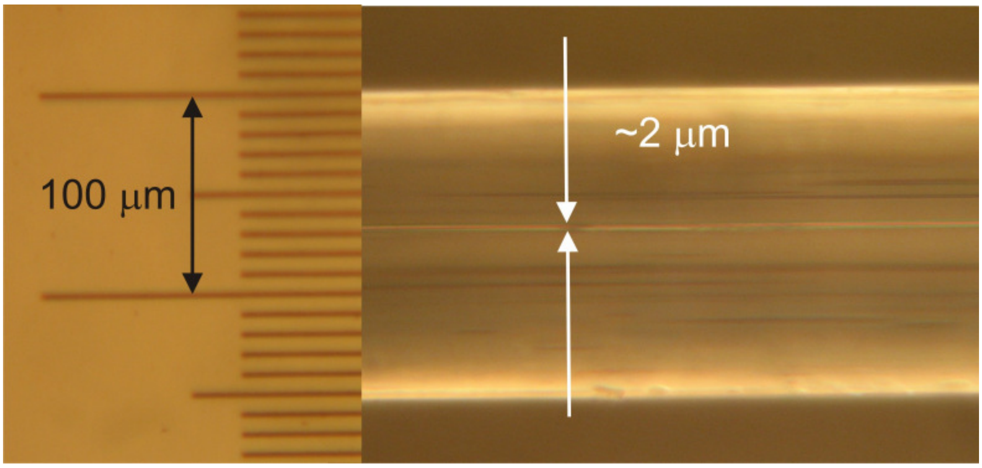

Fig. 3: Optical micrograph of the drawn fibre. The fibre diameter is 155 µm, the diameter of the tin wire is about 2 µm.

Since the optical microscope is at its limit, the sample is also tested in a scanning electron microscope. For this purpose the sample shown in Fig. 3 was cleaved. Since the cleave had to be very well defined in position with a tolerance of about 10 µm, it was not possible to use a standard cleaver. Cleaving was therefore performed under the optical microscope with a razor blade. The cleaved fibre was mounted in an aluminium holder with conductive silver glue and slightly gold sputtered. The gold layer is only about 2 nm thick to reduce charging without shielding the material properties. Fig. 4 shows the cleaved fibre end.

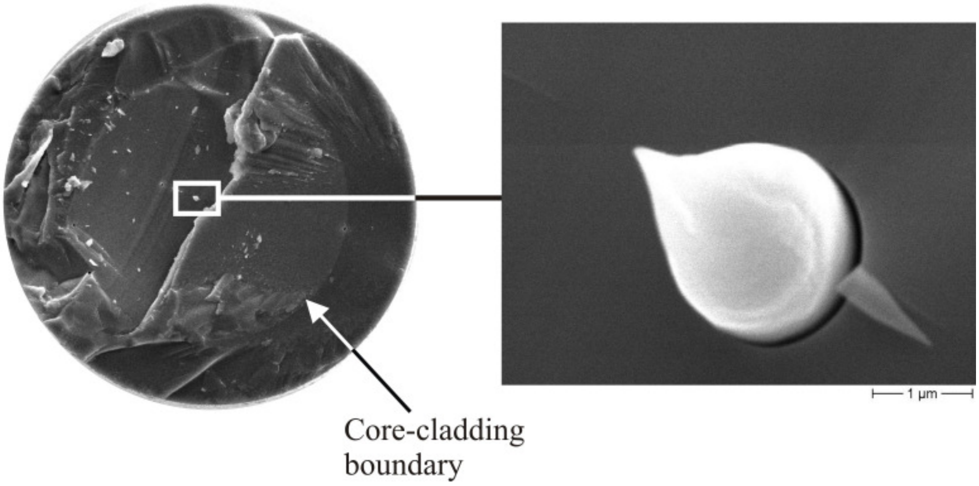

Fig. 4: Electron micrograph of the cleaved fibre. Left: Overview of the fibre with a diameter of 155 µm. Right: Magnified tin wire of 1.9 µm diameter.

In Fig. 4 the core-cladding transition can easily be seen. The core appears brighter than the Duran cladding. This is possibly due to the 9 wt % content of barium. Barium with an atomic weight of 137.34 is considerably heavier than aluminium or silicon and is expected to produce more backscattered electrons and secondary electrons in the scanning electron microscope.

Results and discussion

As in former experiments with gold and lead also the minimum diameter reached with tin was in the order of 2 µm.

Besides the surface tension, the main problem seems to be purity. Evaporation of contaminations leads to rupture of the wire and hollow core regions. When the fibre contains only short pieces of tin the search of these pieces under the optical microscope becomes very difficult and laborious when long fibres have to be inspected. Even with a microscope of 0.3 µm resolution a thin wire can only hardly be identified when observed through the core-cladding structure of a fibre.

Once a thin wire is localized then electron microscopy can easily give the required information.

Conclusion

In summary we have manufactured an optical step index fibre with a 1.9 μm tin wire in the centre of the core. The core with a diameter of 100 μm is made from Schott 8252 glass with a refractive index of $n = 1.538$ @ $\lambda = 587.6$ nm, the cladding with an outer diameter of 155 μm is made of Duran glass with $n = 1.473$ @ $\lambda = 587.6$ nm.

Acknowledgments

We thank L. Di Labio, M. Neff and V. Romano for helpful discussions and for their help in the drawing tower.

References

[1] **G.F. Taylor**
"A method of drawing metallic filaments and a discussion of their properties and uses"
Phys. Rev. 23 655-660 (1924)

[2] **Stefanie Scheidegger**
"Optical fibres with a central metal wire"
Diploma work IAP 11.12. 2008 (ID 3036)

[3] **R.C. Weast editor**
"CRC Handbook of Chemistry and Physics"
55th edition (1974/75)4

[4] **Yu. S. Skibina, L.A. Melnikov, P. Glas, D. Fischer, N.B. Skibina, V.I. Belaglazov, R. Wedell**
"High-quality microstructure glass and metal-glass fibers"
Conference on Lasers and Electro-Optics, 2003. CLEO '03.
ISBN: 1-55752-748-2, INSPEC Accession Number: 8158625,
Baltimore-USA, CtuL7, (2003)

[5] **L.A. Melnikov, Yu. S. Skibina, P. Glas, D. Fischer, N.B. Skibina, V.I. Belaglazov, R. Wedell**
"glass and metal-glass holey fibers with high quality hexagonal structure"
CLEO-2003-Europe-Munchen-Germany-CL2-3-THU (2003)
ISBN: 0-7803-7734-6

[6] **Schott – Rohrglas GmbH**
"Schott Duran" Röhren, Kapillaren und Stäbe aus Borosilicatglas 3.3
Datasheet, 28.02.2007

[7] **M. Sato**
“Studies of the Wetting effect and the surface tension of solids“
Proceedings of the Japan Academy 30 (3) 193-198 (1954)

[8] **Schott –Rohrglas GmbH**
“Glass 8252, technical data“
Business Segment Tubing 9/2003

[9] **N.N.**
“Hanauer Quarzglas und Quarzgut“
Heraeus Schott Q-A1/111 p. 26

[10] **K. Naumann, O Franz**
“Earth-alkaline aluminoborosilicate glass for lamp bulbs“
United States Patent 6074969 Publication Date: 06/13/2000