Optical fibre with a submicron silver wire in the centre of the core

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Abstract

A preform is fabricated consisting of a silver-coated capillary from 8252 glass for the core and a Duran wrapping for the cladding. The silver-coating is produced by wet chemistry using $AgNO_3$ chemically reduced with glucose. After drying and evacuation the preform is drawn to a fibre with a furnace temperature of about 1000 °C. The silver coating is transformed in a series of wires with micron-size diameter and typical lengths of hundred µm. They are characterized by lateral observation of the fibre with an optical microscope and measured in a scanning electron microscope. It is shown that submicron diameter silver wires can be produced.

Introduction

When metal wires are integrated in a fibre preform upon fibre drawing the diameter of these wires is reduced in the same way as the fibre from the preform [1,2]. It has been shown [2] that in our fibre drawing tower wire diameters of few microns can be fabricated from gold and lead. Taylor wires in the centre of an optical fibre can be used to force the light to propagate in a given mode [2, 3]. Finally, the method of Taylor wire production is interesting because it might be a useful step in the direction of manufacturing nanowires.

In our experiments performed with gold and lead as yet, however, it has not been possible to reach submicron wire diameters. It is therefore interesting not to use a wire integrated in the preform but a thin metal coating in the glass capillary forming the future core. A simple procedure to obtain a thin metal coating is the deposition of silver from $AgNO_3$.

In our letter we report on the manufacturing of a step-index fibre with a submicron silver-wire in the centre of the core. The produced fibre is characterized by optical microscopy and by scanning electron microscopy. The obtained wire diameter of about 900 nm is only about one order of magnitude larger than that of a real nanowire [4].

Experimental

In a first experiment a capillary of glass 8252 [5] with diameters of 6.5 mm by 0.5 mm was silver coated on the inner side. The silver coating was manufactured using wet chemistry [6]. The recipe given in [6] was slightly modified by omitting the use of NaOH and tartaric acid and by further replacing saccharose by glucose. 0.84 g of silver nitrate $AgNO_3$ (Sigma-Aldrich 204390-10G, purity 99.9999%) was dissolved in 50 ml of distilled water. When ammonia solution (25 % NH_3 in H_2O) is added, the solution turns brown due to the formation of Ag_2O. When more ammonia is added, Ag_2O is dissolved by forming a $2[Ag(NH_3)_2]^+\ 2OH^-$. By careful titration the solution becomes just transparent again when about 0.84 ml are added.

The transparent solution was then drawn up 15 cm into the capillary with the aid of a syringe and then blown out again. Thereby a thin wet layer is formed on the inner side of the capillary. In a next step, a solution of 4 g glucose (Sigma-Aldrich D – (+) – Glucose G8270-100G) dissolved in 20 ml H_2O was drawn up. This leads to deposition of a silver metal layer on the inner side of the glass capillary. When this procedure is repeated four times a homogeneous silver mirror results. The capillary was then dried and sealed at its lower end.

The preform is finished by filling the coated capillary into a Duran [7] glass tube of 10 mm by 6.9 mm diameter that is also sealed at its lower end. This preform is evacuated and preheated at 410 °C for half an hour and then drawn to a fibre at a furnace temperature of about 1000 °C.

The given furnace temperature can be controlled if drop formation is compared with pure SiO_2. When SiO_2 preforms are drawn the drop formation is reached at about 1950 °C when SiO_2 has a viscosity of about $10^{5.5}$ Poise [8]. This temperature has repeatedly been controlled with a quotient-pyrometer operating simultaneously at 970 nm and 1030 nm. Considering the working points of glass 8252 of 1240 °C and of Duran at 1260 °C that are defined at a viscosity of 10^4 Poise, it has to be expected that the drop formation already occurs at higher viscosity of about $10^{5.5}$ Poise similar to SiO_2. This would correspond to a preform temperature of about 1050 °C when glass 8330 is taken for comparison [9, Fig. 6].

Results and discussion

Visual inspection of the preforms neck shows the transition from the homogeneous silver mirror to wire fractions. An example is shown in Fig. 1:

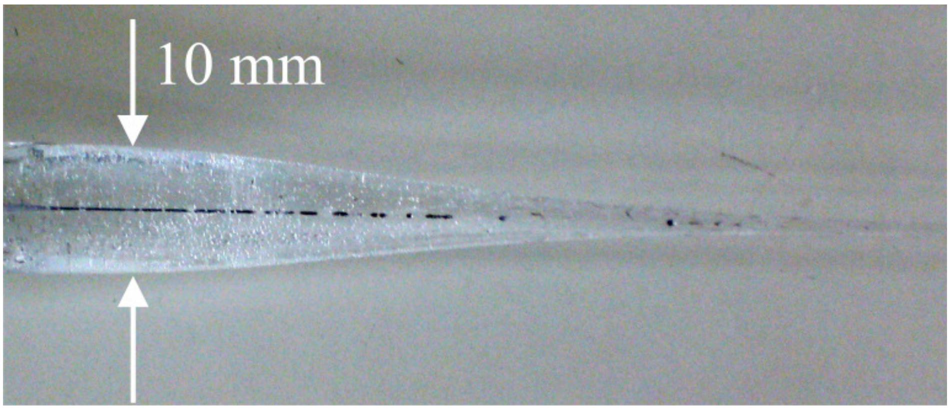

Fig. 1: Neck of the preform after fibre drawing.

In the drawn fibre numerous fragments of Ag wire are found separated by hollow regions or collapsed regions. Hollow regions indicate evaporation of contaminants. In the drawn fibre the typical length of the fragments is in the order of 100 µm.
An optical micrograph of such a fragment is shown in Fig. 2:

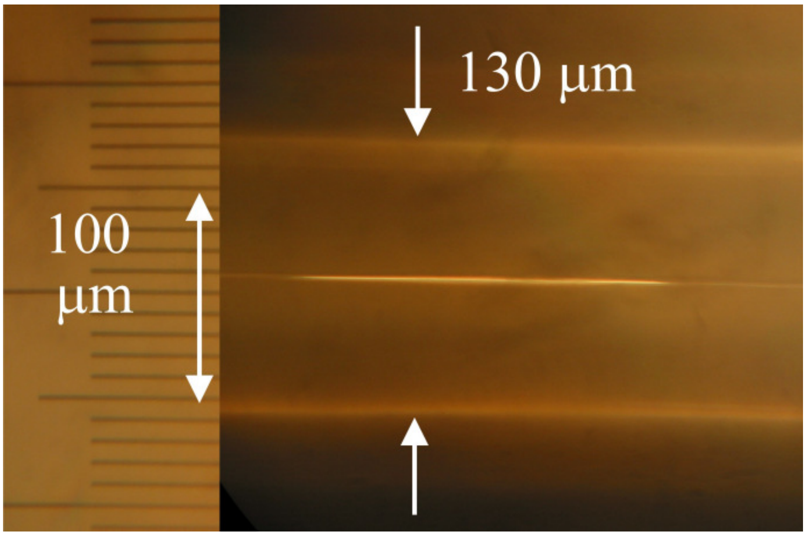

Fig. 2: Optical micrograph of a short silver wire in the optical fibre

The total length of these fragments has been measured over a fibre length of 24.2 cm. 309 fragments were measured with a total length of 14.7 mm. This results in a filling factor of f = 0.06.

The thickness of the metal wire is in the order of 900 nm as shown in the electron micrograph of Fig. 3.

With the volume of the silver per m of fibre, and the reduction of the diameter between preform and fibre, the thickness D of the deposited silver film can roughly be estimated according to (1):

$$D = \frac{1}{2 \cdot r_i} \cdot \left(\frac{r_o}{r_f} \right)^2 \cdot f \cdot r_w^2 \qquad (1)$$

With r_i = 250 μm the inner radius of the preform, r_o = 5000 μm, the outer radius of the preform, r_f = 65 μm, the radius of the fibre, and r_w =0.5 μm the radius of the silver wire. With these assumptions a value of D of about 180 nm results. With the data of [10] κ_0 = 3.638 @ λ = 589.3 nm and α, the absorption coefficient

$$\alpha = \frac{1}{d} = \frac{\kappa_0 \cdot 4 \cdot \pi}{\lambda} \qquad (2)$$

the 1/e transmittance of silver at λ = 589.3 nm is reached at a layer thickness of d = 12.9 nm. For a completely opaque layer the estimated thickness of 180 nm is reasonable.

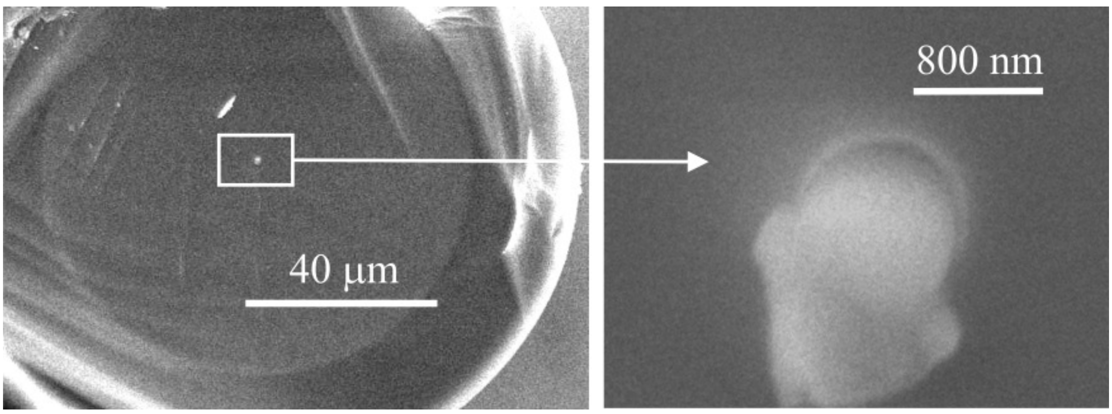

Fig. 3: Electron micrograph of the silver wire. Left side: overview, right side the central wire in detail. Upon cleaving the fibre, the wire is somewhat deformed and pulled out of the fibre. Its diameter is about 900 nm.

Conclusion

In summary a preform has been fabricated consisting of a silver-coated capillary from 8252 glass for the future core and a Duran wrapping for the future cladding. The silver-coating has been produced by wet chemistry using $AgNO_3$ chemically reduced with glucose. After drying and evacuation the preform has been drawn to a fibre with a furnace temperature of about 1000 °C. The silver coating is transformed in a series of short wires with micron-size diameter and typical lengths of hundred µm. Since the characterisation of the wires by lateral observation through the cladding and the core with an optical microscopy is at its resolution limits, the fibres have been cleaved and measured in a scanning electron microscope. It is shown that submicron diameter silver wires could be produced.

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