Silica fibres with a metallic core

Stefanie Scheidegger, Loredana Di Labio, Valerio Romano, Willy Lüthy, Thomas Feurer Institute of Applied Physics, University of Bern, Sidlerstrasse 5 CH-3012 Bern, Switzerland

stefanie.scheidegger@iap.unibe.ch

Abstract

Experiments are performed with the goal to incorporate a gold wire in the centre of a silica preform and to drawn it to a fibre. Wire diameters in the nm range are aspired. After a first drawing step fibres of 20 μ m diameter with lengths of several cm are found. After a second drawing step, fibres as thin as 2 – 4 μ m with mm lengths can be produced. The fibres are analyzed by optical and electron microscopy. It can be shown that the silica tube did not collapse completely. This is assigned to a local overpressure of evaporated silver contained in the gold wire. Together with the high surface tension of gold this prevents the generation of nm-sized gold wires.

Introduction

Metal wires molten in glass have a long tradition in applications such as incandescent lamps, radio valves, and many other. Elements of metal-to-glass bonds are commercially available (see e.g. http://www.schott.com/epackaging) and their properties have widely been investigated [1].

Only little information, however, can be found on metal wires integrated inside an optical fibre. Metallic coatings in a hollow-core fibre are described [2] in literature. A preform containing a metal wire is expected to allow the production of extremely thin metal wires when it is drawn to a fibre. This would open the possibility to generate nanowires [3 - 5] with arbitrary length. Such a thin wire inside the core region of a fibre can influence the mode of guided waves or can be used to generate a high electric field. The thinner the wire can be manufactured, the higher will be the electric field that can be generated. This could open a possibility to influence the energy levels of dopant ions by Stark effect. All the mentioned possibilities are a strong motivation to study the feasibility of nanowires incorporated in a silica glass fibre.

In the present report we describe experiments to produce thin gold wires incorporated in the core of an optical fibre.

Experiment and Discussion

In a first experiment a gold wire of 0.5 mm diameter was inserted into a silica capillary of 0.6 mm inner diameter. The filled capillary was placed into a Herasil WG silica tube of 19 mm by 16 mm diameter. All empty space was filled with granulated silica. The filled silica tube was used as a preform and drawn to a fibre. For fibre drawing the preform was evacuated. The furnace temperature was about 1850°C. With a melting temperature of gold of 1064.43 °C [6, B-93] the wire is completely molten before the viscosity of silica is sufficiently low for fibre drawing. After drawing, the fibre was examined with an optical microscope.

The core of the drawn fibre contained several pieces of thin gold wire with a total length of 11.5 cm (Fig. 1), as well as a series of small droplets. The main length of the fibre showed an empty core or was completely collapsed.



Fig. 1: Micrograph of a drawn gold wire in the core of a silica fibre.



Fig. 2: Micrograph as in Fig. 1 with a ~2mm empty gap between two wires.

A piece of a fibre with an empty core has been investigated in a scanning electron microscope (ISI DS 130 S). The resulting micrograph is shown in Fig. 3.



Fig. 3: Electron micrograph of an empty core region.

With the goal to further reduce the diameter of the gold wire a length of 11.5 cm of the fibre shown in Figs. 1 and 2 was prepared for a second drawing. Both ends are sealed off by melting in the beam of a CO_2 -laser. Then, it is inserted in the centre of a 19mm by 16mm diameter silica tube. The space between the fibre and the silica tube is filled with granulated SiO₂. After evacuation the preform is drawn to a fibre.

The fibre shows a series of gold droplets (Fig. 4) as well as thin wires, typically of about 2 mm length (Figs. 5, 6).



Fig. 4: Gold globules in the drop of the fibre.



Fig. 5: Optical micrograph of a fibre with gold core after the second drawing step.



Fig. 6: Electron micrograph of a section through the fibre of Fig. 4. The diameter of the hole is $4.2 \,\mu\text{m}$, the diameter of the gold wire is $3.6 \,\mu\text{m}$.

The thermal expansion of gold is $14.2 \cdot 10^{-6}$ at 25°C [6, D-152]. Assuming temperature independence of this value, heating up to 1850°C would result in a linear expansion of 2.6 %. This is clearly not sufficient to explain the hole diameter with respect to the wire diameter in Fig. 5. Further it does not explain the hollow parts in the fibre as seen e.g. in Fig. 2. Therefore it has to be assumed that evaporation of gold or an alloying component such as copper or silver is responsible for the generation of a pressure in the order of some 10 mB. This would be sufficient to prevent the fibre from collapsing.

It can be assumed that even fine gold of 99.9 % gold content contains a sufficient contamination of silver that reaches a pressure of some 10mB at 1850°C. This pressure prevents the voids from collapsing and the high surface tension of gold in the range of about 1.1 N/m @1100°C – 1600°C [7, 8] of 0.731 N/m @ mp [6, F-24] or 1.339 N/m @ 1373 K [9].



Fig. 7: Vapour pressure of silver [6, D-152]



Fig. 8: Vapour pressure of gold [10]

From Figs. 7 and 8 it can be concluded that a contamination of Silver should be avoided.

Since the drawing temperature for silica fibres is about 1850°C only a limited list of metals is suitable to be incorporated in a glass fibre. Possible candidates with their melting points, boiling points, expansion coefficients, vapour pressures and surface tensions are listed in Tab. 1.

Metal	Melting	Boiling	Linear Exp.	Temperature	Surface
	point	point	Coeff. @	at $p = 1 mB$	Tension
			25°C		@mp
	[°C]	[°C]	[°C ⁻¹]	[K]	[Nm]
Aluminum	660.37	2'467	25.10-6	1'782	0.865 [11]
Cobalt	1495	2870	12.10-6	2.167	1.880
Copper	1083.4	2567	16.6.10-6	1'862	1.150
Gold	1'064.43	2'807	14.2.10-6	2'023	0.731
Iron	1'535	2'750	12.10-6	2'093	1.700
Nickel	1453	2732	13.10-6	2.156	1.725
Platinum	1'772	3'827	9.10-6	2'817	1.865
Silicon	1410	2355	3.10-6	2.340	0.875
Silver	961.93	2'212	19.0.10-6	1'582	0.785
Titanium	1'660	3'287	8.5.10-6	2'405	1.460
Vanadium	1890	3380	8·10-6	2.525	1.950

Tab. 1: Melting points, boiling points, expansion coefficients, vapour pressures and surface tensions of selected metals.

With their high melting points that are, however, still below the drawing temperature and their low vapour pressures platinum and titanium seem to be the most promising candidates for future experiments.

Conclusion

In conclusion we have incorporated a gold wire in the centre of a silica preform and drawn to a fibre in two subsequent steps. After the first drawing step, fibres of 20 μ m diameter with lengths of several cm could be produced. After the second drawing step, fibres as thin as 2 – 4 μ m with mm lengths could be produced. The fibres have been analyzed by optical and electron microscopy. It could be shown that the silica holes did not collapse completely. This is assigned to a local overpressure of

evaporated silver contained in the gold wire. Together with the high surface tension of gold this prevents the generation of nm-sized gold wires.

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