3. *Stankowska J., Peter E., Czarnecka A. The effect of D-phenylalanine admixture on dielectric properties and domain structure of TGS crystals, Ferroelectrics.*

4. *Shi W., Wang M., Sun X., Fang C. Properties of LUTGS crystal grown above Curie temperature // Ferroelectrics 1999, vol. 221, pp. 123–127.*

5. *Gunyakov V.A., Parshin A.M., Khrustalev B.P., Shabanov V.F. Determining the orientation of the director of a nematic liquid crystal on the surface of a ferroelectric crystal // Optiko-Mekhanicheskaya Promshlennost 1997, vol. 64, no. 5, pp. 96–98.*

6. *Trybus M., Kalita W., Proszak W. Relation Between Domain Structure Distortion and Spontaneous Polarisation in l-lysine Doped TGS Single Crystals // ICSS Zakopane 2002.*

7. *Łapsa K., Trybus M., Runka T., Proszak W., Drozdowski M. Brillouin scattering studies of the ferroelectric phase transition in L-lysine doped TGS single crystals // Journal of Molecular Structure – in press.*

8. *Trybus M., Proszak W. Simple Theoretical Model of Domain Structure Morphology Against Observations of Domains in Doped TGS // XXV International Conference IMAPS - Poland 2001, Rzeszów - Polańczyk, 26-29 September, s.145–148, 2001.*

J. Wójcik, L. Czyżewska, A. Walewski, P. Mergo
Marie Curie-Sklodowska University,
Laboratory of Optical Fibers Technology,
Lublin, Poland

PREPARATION AND POLARIZING PROPERTIES OF THE SIDE METAL PIPE OPTICAL FIBERS

Technology and basic characterization of new kind of side hole optical fiber with silver layers in the holes named side metal pipe optical fiber is presented. The static deposition method of several hundred nm thickness silver layers from liquid phase was used. Polarization properties of the side metal pipe optical fibers were found.

1. Introduction

Introduction of metal elements into the optical fibre's structure creates new possibilities of waveguides' parameters' modification. A known solution is introducing of molten metal into a hole situated along a single-mode fibre's core in order to obtain a polarising waveguide [1]. The alternative manner is deposition of metal layers on the internal surface of those holes [2, 3].

The known methods of metal layers' producing on non-metallic surfaces may be divided into several groups including chemical and physical vapour-deposition and liquid-phase-deposition processes.

Silver seems to be the most attractive metal because it is the best electricity conductor [4].

This paper presents the basis of technology of new type of optical fibers named side metal pipe SMP optical fiber. Its structure is similar to that of the side-hole optical fiber [5] but the internal surface of the two open holes placed on the both sides of the core is covered with silver. These fibers have circular cores.

The paper presents the technology of production of the optical fiber substrate (optical fiber with two open holes and circular core) and the static method of preparation of silver layers by liquid phase deposition including influence of temperature, time, reagents concentration, number of deposition stages on the chemical reaction efficiency.

We produced several fibers with different distances between the core and inner surface of holes interface and 500 nm thick metallic sliver layers.

We measured parameters of silver layers especially their geometrical parameters and electrical resistance.

Properties of these fibers in a point of view of light beams propagation with different polarization were initially measured too.

2. Preparation of silver layers

On the basis of our previously research, we chose silver as a metal and liquid-phase-deposition method in which redox reactions were applied [2,6]. After adding a complex compound of silver to a reducer solution, metallic silver is formed and it forms a deposit on the inner surface of a silica-glass capillary. We previously employed the dynamic method, in which deposition efficiency depends on the flow of reagents through capillary at high temperature [2].

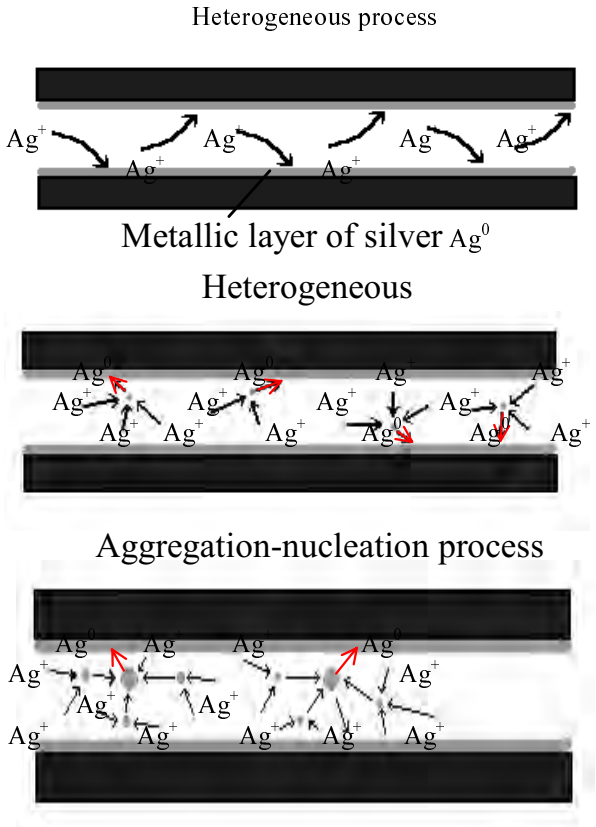

Fig. 1. Hypothetical schemes of the process [2]

According to the general rules of colloid chemistry and our earlier experiments connected with silica-glass preparation with sol-gel method, a silver liquid-phase-deposition process may occur via various mechanisms, which are hypothetically presented in figure 1.

Unfortunately, preparation of silver layers wasn't repeatable. Layers had different thickness along the capillary and they had relatively high electrical resistance. Probably the reason of it was that the process proceeded with nucleation – aggregation mechanism [2].

Also the investigations of nickel deposition by thermal decomposition of nickel carbonyl were terminated negatively [3].

Therefore we make investigations of deposition silver layers by static method. It depends on realization of cycle: filling capillary with reagents in room temperature, heating capillary to reaction temperature and in this manner deposition on inner surface silver layer, remove of needless products of reaction in room temperature with simultaneous its filling with new portion of reagents.

In our research we have used an ammonia solution of silver nitrate and a water solution of ammonium tartrate. We have applied the following reactions:

$$AgNO_3 + NH_4OH \Rightarrow Ag(NH_3)_2NO_3 + H_2O$$
$$Ag(NH_3)_2NO_3 + (NH_4)_2C_4H_4O_6 \Rightarrow [Ag(NH_3)_2]_2C_4H_4O_6 + NH_4NO_3 \Rightarrow$$
$$\Rightarrow 2Ag + 2(COONH_4)_2 + N_2O_3 + 2\,NH_3 + H_2O$$
$$N_2O_3 \Rightarrow NO_2 + NO$$

The investigation of deposition process we made using capillaries with different inner diameter. When the optimal process conditions were determined, we made preliminary preparation metal layers in holes of side metal pipe fiber.

3. Results of investigations of the silver depositions inside capillaries

Figures 2–5 present selected results of investigations of silver layers deposition process into silica capillaries. In the experiments type IV silica glass capillaries with internal diameter from 45 to 500μm and 2m lengths was used.

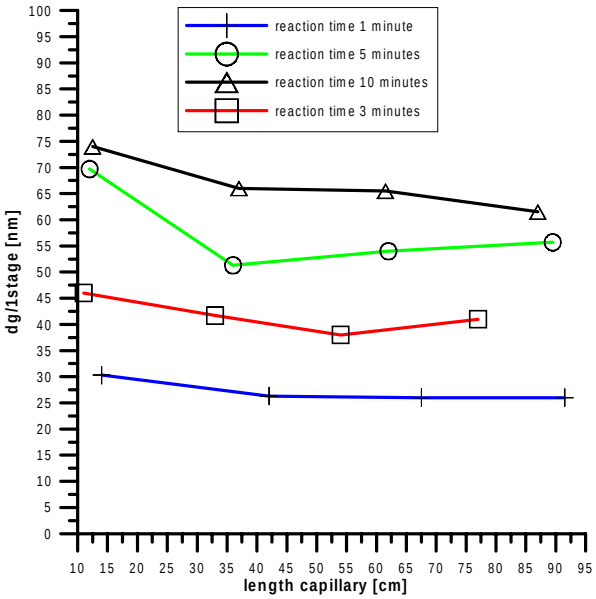

Fig. 2. Sliver layer thickness distribution along the capillary. Inner diameter of capillary 250μm, reaction temperature 90^{0}C, $AgNO_3$ concentration 0,1g/cm^3

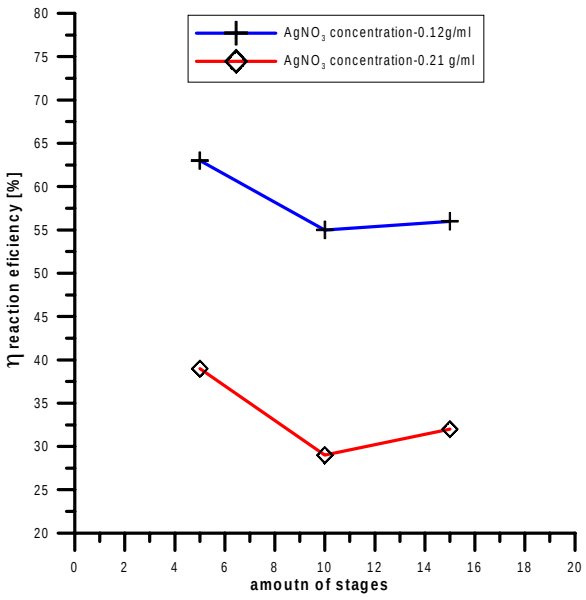

Fig. 3. Influence of the amount stages on the reaction efficiency. Inner diameter of capillary 115μm, capillary length – 2m, reaction temperature 900C

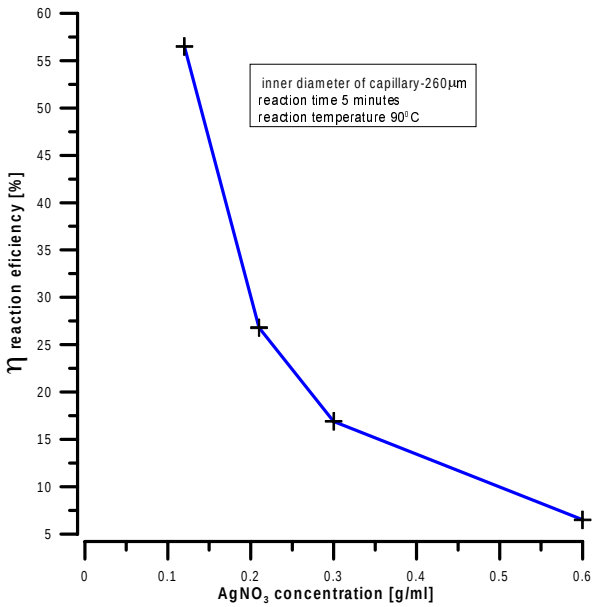

Fig. 4. Influence of AgNO3 concentration on the reaction efficiency. Capillary length 2m

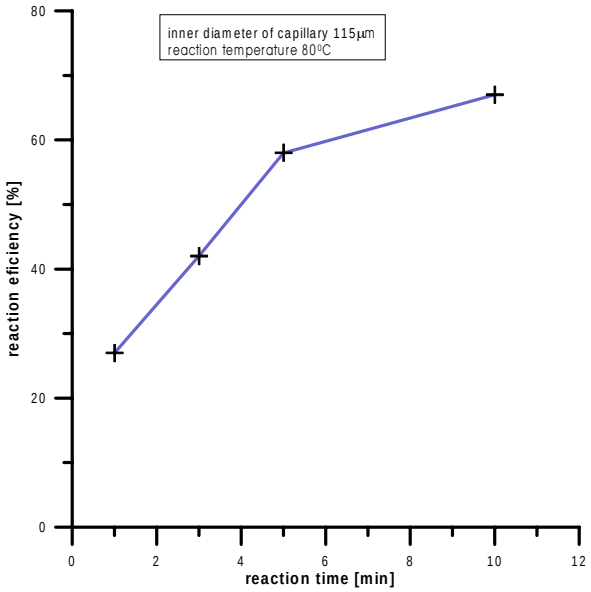

Fig. 5. Influence of reaction time on their efficiency. Capillary length 2m

In final experiments capillaries with internal diameter equal to 45 μm was used. Obtained results permits on choice of conditions of silver layers deposition at the SMP fiber preparation.

4. Construction and preparation of the SMP fiber

Figure 6 presents structure of the side metal pipe optical fiber.

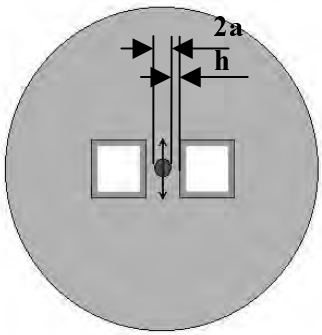

Fig. 6. Schema of the side metal pipe optical fiber

We manufactured series of the SMP fiber. Figure 7 presents refractive index profile of the manufactured fiber. Figure 8 presents microscopic photo of substrate of SMP fiber – fiber without sliver layers (figure 7a) and SMP fiber – fiber with silver layers (figure 7b).

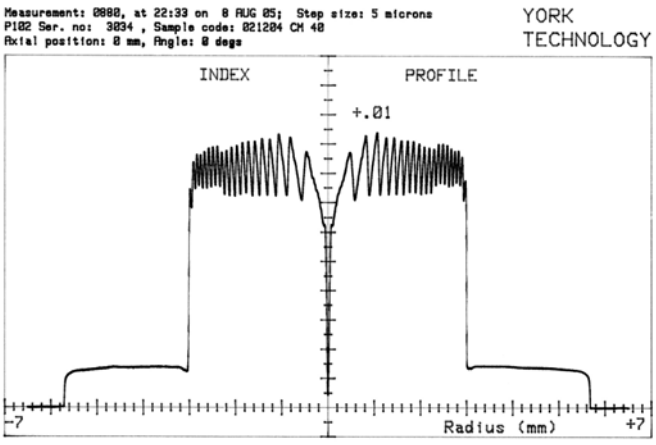

Fig. 7. Refractive index profile of the SMP fibers

a *b*

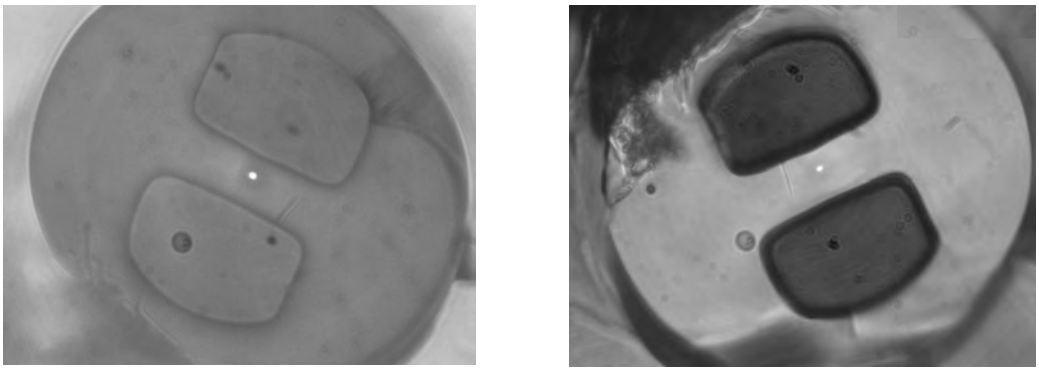

Fig. 8. Microscopic photo of the substrate of SMP fiber – without silver layers – figure (a) and SMP fiber – fiber with silver layers (b)

The some measurements of geometrical and optical parameters of the substrate of SMP fiber were done. Results are presented in table.

Geometrical and optical characteristics of the substrate of SMP fiber

2a [μm]	h [μm]	External diameter [μm]	Cut-off wavelength λ_c [μm]
4	3	125	0,72
4	6	125	0,71
4	8	125	0,71
4	10	125	0,7
4	12	125	0,69
4	14	125	0,67

In all fibers thickness of the silver layers was equal to 0,5μm. Electric resistance of silver layers of 1cm of fiber is equal to 2,3 Ohms. Theoretically calculated electric resistance of 0,5μm thick silver layer form melting silver is equal to 1,2 Ohms. For 1m fiber length with h = 3μm the polarizing efficiency is equal to 25% for 633nm wavelength. For the rest fibers we did not observe the polarizing effect.

5. Summary and conclusions

Preparation of silver layers deposition on inner surface of capillaries from liquid phase with static method was elaborated

The layer thickness was controlled by amount of stages. In one stage the layer 34nm thick was obtained during SMP fiber preparation.

The resistivity of obtained layers is only two times bigger then the melting silver, what means that the structure of layers is good enough

The substrates of SMP optical fiber with different distances between holes and core and cutoff wavelength equal to 700nm were manufactured

The SMP optical fiber was obtained by deposition of silver layers 500nm thick.

For only one SMP optical fiber the weak polarization effect for wavelength 633nm was found

Probably the measurements of polarization properties of the SMP fibers for longer wavelength then cutoff wavelength give completely different results

Also the polarization properties will be better when the distance between holes and core will be decrease.

The next technological investigations should concern optimization of the layer thickness in relation to its distance from core for specified wavelength in relation to cutoff wavelength

1. *Eickhoff W., Electronic Letters, vol. 16, pp 762 – 764, 1980.*
2. *Wójcik J. at all. SPIE Proceedings, vol. 5028, pp 35 – 40, 2003.*
3. *Wójcik J. at all, SPIE Proceedings, vol. 5576, pp 94 – 102, 2004.*
4. *Rabii Ch.D. Applied Optics, vol. 38, pp 4486 – 4493, 1999.*
5. *Wójcik J. at all, SPIE Proceedings, vol. 3731, pp 88 – 94, 1999.*
6. *Mergo P., PhD thesis, 2003.*