Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 15 (2014) 129 – 137

Procedia Technology

2nd International Conference on System-Integrated Intelligence: Challenges for Product and Production Engineering

In-line production, optronic assembly and packaging of POFs

Bechir Hachicha[a]*, Ludger Overmeyer[a]

[a]Institute of transport and automation technologies, Leibniz Universität Hannover, an der Universität 2, Garbsen 30823, Germany

Abstract

The importance of optical technology as a key technology is constantly increasing. In application areas, where the conventional use of electrical solutions for signal generation, signal transmission or signal reception is limited due to data transfer rates as well as electromagnetic compatibility, optical waveguide technologies are developed and applied. Optical waveguides, essentially fibre systems, are also used as sensors in many applications for measuring physical properties like temperature and elongation. Using multimode fibres, the variation of light intensity is measured to determine the applied changes on its physical properties. Multimode fibres have an average core diameter of 50 µm and are easier to handle than single mode optical fibres but they have less sensitivity and a lower measurement range. Three main steps separate production and use of polymer single-mode optical fibres. The first one includes fibre manufacturing methods. Then the necessary length for the sensor application is selected and the ends of the fibre are prepared and polished. The last step involves optronic assembly and packaging, which consists of integrating the optical fibre onto the surface of the element to be measured and coupling it with optronic devices such as the transmitter and receiver of the light signals. In this paper an approach is presented for a production unit, which combines all these three steps together.

Peer-review under responsibility of the Organizing Committee of SysInt 2014.

Keywords: Polymer; optical; assembly; packaging; fibers; waveguides; single mode

1. Introduction

Polymer optical waveguides are, compared to electrically conductive structures, resistant to ambient conditions like high electromagnetic fields or chemical products. They offer light weight and low raw material costs. Polymer

* Corresponding author. Tel.: +0049-511-762-18321; fax: +0049-511-762-4007.
E-mail address: bechir.hachicha@ita.uni-hannover.de

2212-0173
Peer-review under responsibility of the Organizing Committee of SysInt 2014.
doi:10.1016/j.protcy.2014.09.064

optical waveguides enable also significantly higher communication bandwidth and data rate than conventional electrical systems. Considering the sensitive characteristics they have low maintenance requirements and high durability. In particular, single mode polymer optical fiber has as sensor high measurement precision. In a single mode waveguide only one light mode can be propagated through it, that eliminates modal dispersion and allows a 10^{-6} *rad* exact measurement of phase shifting and accordingly an elongation of 10 nm. The measurement can be realized with high resolution along the fiber, so that beside the elongation value, detection of the elongation's location is possible with *1 mm* accuracy [1], [2], [3].

The packaging and assembly of the optical waveguides are the steps in the production chain with the lowest degree of automation. Especially by the coupling, alignment and mounting of beam receiving and sending elements manual or semi-automated strategies based on “fit into place” or “pick, measure and place” are used in separated steps as described in [4], [5].

The Collaborative Research Centre 653 of the Leibniz Universität Hannover has the approach to realize gentelligent components. These elements are parts of machine construction and are able to independently measure changes in their physical properties like elongation or temperature variation. The measurement occurs during the application without restriction of the conventional process and is communicated and saved online. For this purpose a production unit is being developed for an in-line production, assembly and packaging of polymer optical waveguides onto different surface geometries. Fig. 1 illustrates an example of a wheel carrier, which has an integrated polymer optical waveguide. A detailed view is given in Fig. 1 Cross-section A-A [6].

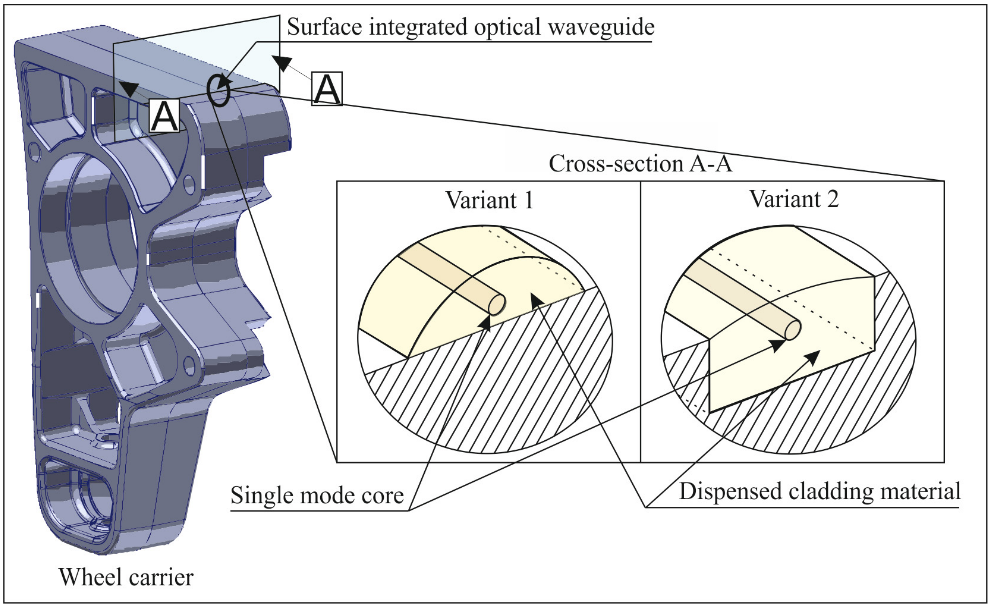


Fig. 1. Wheel carrier with integrated polymer optical waveguide.

The single mode core is produced in the unit using a combination of heat-drawing and extruding process. The cladding material is dispensed and also used as adhesive for the attachment onto the surface. The first variant in fig. 1 is a direct attachment onto the surface. The second variant shows an alternative using a trench in the surface.

In the production unit the dispensing process is also controlled to realize coupling taper structures between the end of the waveguide and other optronic devices, as illustrated in fig. 2. In this way, a complete combination of the production, integration and coupling of optical waveguides in the same unit is possible. This enables a continuous in-line process, which can be automatically adapted to the desired functionality of the polymer optical waveguide and its requirements. In section 2 the used strategy to realize the production unit is presented followed by a conclusion and discussion in section 3.

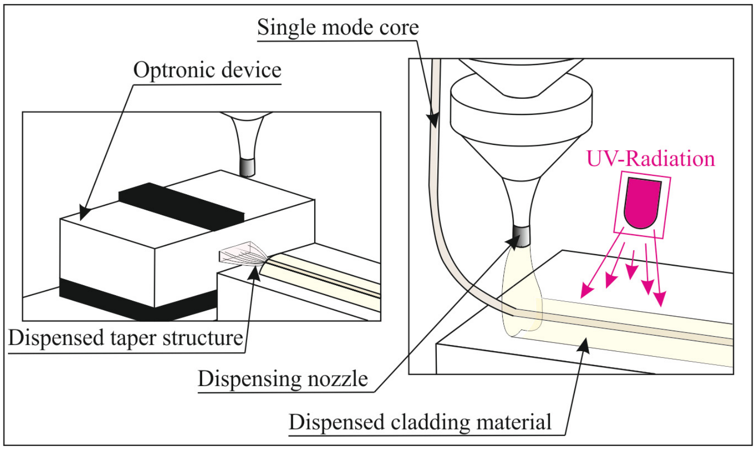


Fig. 2. Dispensing the cladding and subsequently the taper structure.

2. Inline production, optronic assembly and packaging of single mode fibers onto 3 dimensional substrates

The different stages from the polymer material processing to coupling functional optical waveguides are nowadays carried out separately. This results in manufacturing an optical waveguide, which is not directly applicable before its position and length are adapted and the right coupling device for the desired product has been selected and attached [7].

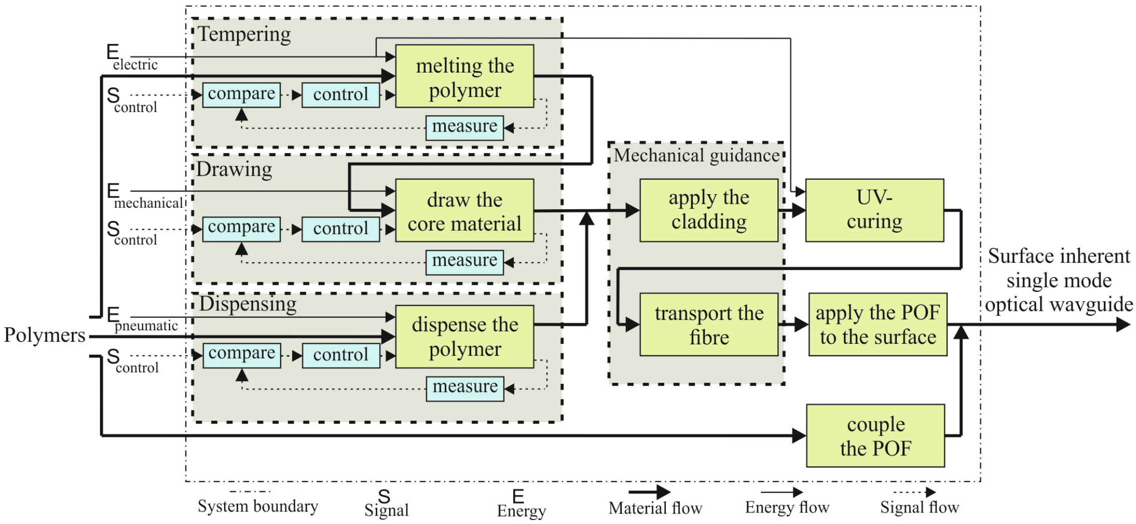


Fig. 3. Functional diagram of the production unit.

A unit with integrated production, optronic assembly and packaging allows a combination of the discrete steps to a continuous in-line process. The input material of this production unit is the polymer for the core and the cladding, as well as for the coupling structure. The output is an optical waveguide, which with the aid of a computer numerically controlled (CNC) manipulator, will be directly integrated onto a 3-dimensiunal surface. The functional diagram of the production unit is presented in fig. 3.

Principally 3 main functions can be distinguished in the production unit. The first function is producing the optical fiber core with the desired diameter. For this purpose a control of the tempering is necessary to achieve an adequate temperature for the polymer processing. Then the melted polymer is drawn to the desired diameter. The second function includes realizing the cladding with the aid of a dispensing process. The third function is the exact positioning and attachment of the produced optical waveguides, as well as the optical coupling with the optronic devices. An additional function involves the effective transport of the produced optical fiber from inside the unit onto the surface where it is applied.

2.1. Production of the optical core

A combination of the heat-drawing and the extrusion process was chosen to realize the waveguide core and was integrated in the production unit. In this way optical fibers can be produced and their diameter can be controlled using the drawing speed as well as the flow rate from the extruder. Fig. 4 shows the principle of this combination. To control the flow rate, it is necessary to control the piston speed and the heating temperature according to the rheometric properties of the used polymer. An image processing system is used for continuous monitoring of the optical fiber diameter.

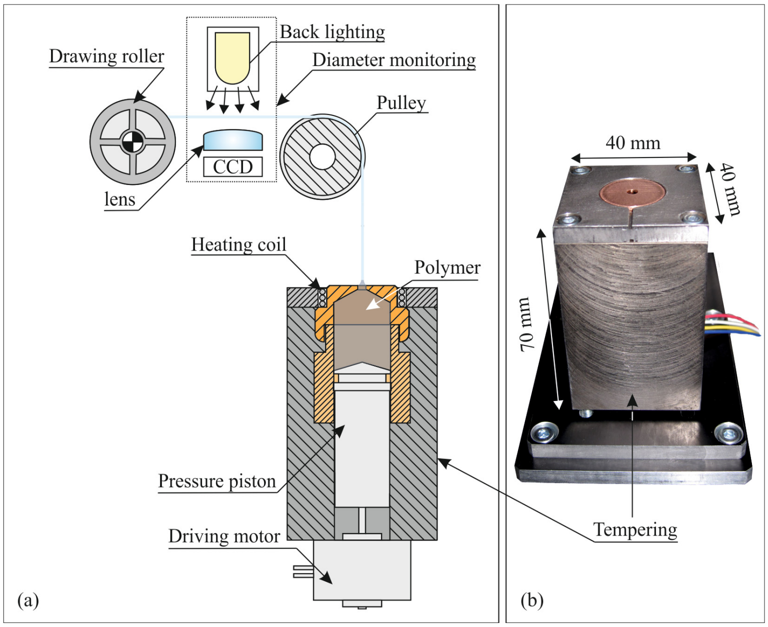


Fig. 4. (a) Combination of the heat-drawing and extrusion process (b) realized tempering system.

Optical waveguides transmit light waves in the range of *400-2000* nm and the number N of modes inside depends on the structure constant V. The output parameters are the core radius d, the light wavelength λ and the numerical aperture A_N. This relation is described with eq. 1 as in [8].

$$V = \frac{\pi \cdot d}{\lambda} \cdot A_N \tag{1}$$

While $V < 2.405$ only one mode is allowed to propagate through the waveguide. The resultant diameter for a single mode waveguide is expressed with eq. 2 as in [8].

$$d \leq \frac{V \cdot \lambda}{\pi} \cdot \frac{1}{A_N} \tag{2}$$

Fig. 5 represents the relation between the single mode diameter and the numerical aperture for different wavelengths. The numerical aperture is the sinus of the maximal angle of incidence Θ_{max} and it depends on the index of refraction n_{core} of the core and $n_{cladding}$ of the cladding material. The relation is described with eq. 3 as in [8].

$$A_N = \sin \Theta_{\max} = \sqrt{n_{core}^2 - n_{cladding}^2} \tag{3}$$

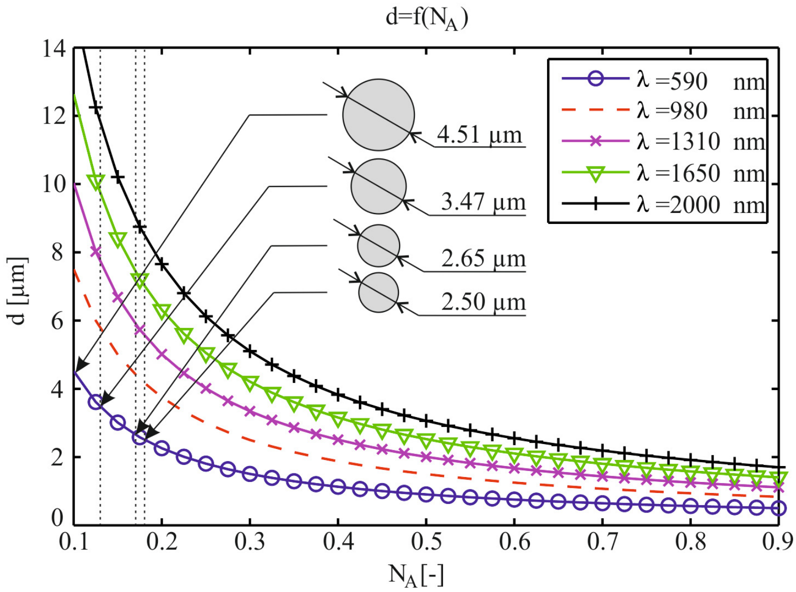


Fig. 5. The diameter of single mode fibre core as a function of numerical aperture.

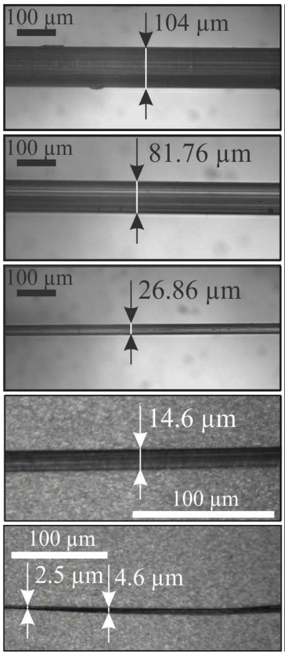
Polymethylmethacrylate (PMMA) is used as core material with a *1.49* index of refraction at *590 nm* wavelength. UV-cured liquid polymers are foreseen for implementing the cladding. Fig. 5 illustrates the resulting maximum single mode fiber diameter based on eq. 2 and 3. Moreover, the index of refraction of these polymers at *590 nm* wavelength and the resulting numerical aperture are given in table 1.

Microscopy pictures of the first results at *225°C* and under variation of the drawing speed are shown in fig. 6. The manufacture of diverse constant diameters from *100 µm* up to *2.5 µm* was possible with the presented method for short lengths. The manufacture of constant diameters of less than *3 µm* for longer lengths is not yet feasible due to an insufficient measuring precision of the image processing system and the transparency of the optical core.

Table 1. Numerical aperture and single mode core diameter depending from the used cladding polymer

Polymer	Index of refraction at 590 nm	Numerical aperture	Max. single mode core diameter
UV 390119	1.48625	0.10	4.51 µm
UV 391568	1.48430	0.13	3.47 µm
UV 390120	1.48375	0.13	3.47 µm
UV 391629	1.48000	0.17	2.65 µm
UV 391628	1.47850	0.18	2.50 µm

Ongoing research focuses on determining the appropriate combination of a charge couple device sensor (CCD-sensor), a telecentric lens and incident lighting for measurement precision under *1µm*. The image processing system is necessary to close the control loop and to achieve a continuous monitoring of the produced optical fiber core. Controlled parameters like temperature, piston and drawing velocity are adjusted based on the measured and the target diameter, as well as the rheometric properties of the used polymer. Sufficient controlling of the production process allows a realization of an optical fiber core with a selective variation of the diameter. This is advantageous for coupling the optical fibers with different optronic devices featuring individual geometrical dimensions. This point will be discussed in subsection 2.3.



Polymer: PMMA	Melting point: 140 °C	Process temperatur: 250 °C	Drawing velocity: 0.2 mm/s
			Drawing velocity: 0.3 mm/s
			Drawing velocity: 0.8 mm/s
			Drawing velocity: 1.5 mm/s
			Drawing velocity: 4 mm/s

Fig. 6. Polymer optical fibers realized with PMMA.

2.2. Production of the optical cladding

At the Institute of Transport and Automation Technology a dispensing process for multimode polymer optical waveguides was previously developed [9], [10]. In this process liquid inorganic-organic hybrid polymers from Micro Resist Technology are used, OrmoCore for the core and OrmoClad for the cladding. These liquid polymers are dispensed along the surface and polymerized with UV radiation. Methods and results of this process are discussed in [9], [10], [11].

For the herein presented production unit, the dispensing process will be adapted for producing the cladding of the single mode optical fiber. Liquid polymers presented in table 1 are used for this purpose. The liquid polymer is applied simultaneous to the core material and to the substrate surface (see Fig. 2). In this way a wetting is realized in the boundary surface between core and cladding, as well as between cladding and substrate surface. After polymerization with UV radiation the cross-linking is done and the adhesion in the boundary surfaces is provided. An optimal combination of surface tension between core and cladding as well as between cladding and substrate surface has to be defined to achieve sufficient wettability and correspondingly a high adhesion. The wettability influences also the roughness of the boundary surface. Roughness higher than *10%* of the transmitted wavelength increases the absorption and transmission in the boundary surface, which causes extrinsic attenuation [12].

An image processing system is furthermore needed for the control loop of the dispensing process. The guidance of the polymer optical core and its cladding along the desired route is necessary to have an exact positioning on the geometrical surface. Fig. 7 shows the two examined integration methodologies, either inside a trench structure or directly along the surface. In the variant with a trench structure illustrated in fig. 7a, the viscosity of the liquid polymer and the surface tension should be considered to achieve optimal integration of the first cladding part inside the trench. Fig. 7b shows the steps for the variant with a direct integration onto the surface. In this case however, to avoid propagation losses due to in-homogeneities at the contact region between the bottom cladding and the fiber, it is foreseen that the fiber should be coated with cladding material previous to integration.

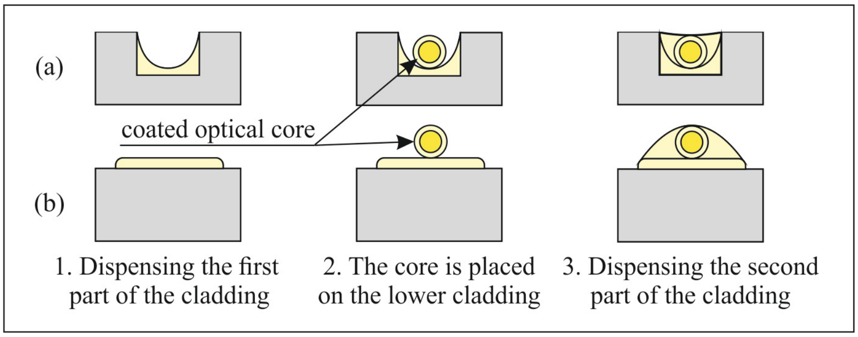


Fig. 7. Steps for an integration of the optical waveguide (a) directly onto the surface and (b) inside a trench.

The main challenge for realizing an affective cladding dispensing process is to match an optimal surface energy between the core, cladding and substrate materials thus achieving high geometrical accuracy of boundary surface structure. Good adhesion in the boundary surfaces will provide mechanical and thermal stability.

2.3. Realization of coupling structures

The coupling of optical waveguides with other waveguides or optronic devices is an important step in the optronic assembly and packaging. To realize an in-line process, a solution is needed for attachment directly after the integration of the optical waveguides onto the surface or simultaneously while the cladding material is applied. The idea is to adapt the dispensing process as well as the drawing process to achieve an in-line optronic coupling (see fig. 2). There are 2 principles for coupling optical waveguides: The cross-sectional coupling and the longitudinal surface coupling. For the cross-sectional coupling methods the optical waveguides are faced directly to each other or to an extra coupler structure. If both cross sections have different diameters, a waveguide taper also called waveguide transformer is used. The waveguide taper is a coupling structure between two waveguides or a waveguide and an optronic device with different cross-sectional geometries. The different field distribution of the guided light wave within the coupling parts must be adapted to each other, so that the coupling efficiency is maximized (see fig. 8a) [13].

Specific controlling allows the dispensing of a taper structure. The first results of dispensed taper structures are shown in fig. 8b. In this figure a cross-section of a bare-die laser diode is shown, which was coupled with a dispensed optical waveguide on an aluminum surface. Another possibility to realize a cross-sectional coupling is to control the drawing process. The end of the polymer optical fiber is drawn with a bigger diameter than the single mode core diameter and in this way adapted to the geometry of the optoelectronic device.

For the longitudinal surface coupling two waveguides structures are coupled along a definite distance. Along this distance a lateral contraction of the waveguides is realized. The effect can be improved, if the core materials of the both polymer optical fibers (POF) are in direct contact. The length of the coupling distance defines the degree of efficiency [7]. Longitudinal coupling is also possible by adapting the dispensing process. Two optical fiber cores have to be placed conterminously to each other and then the cladding material is dispensed and the waveguide is fixed to the surface.

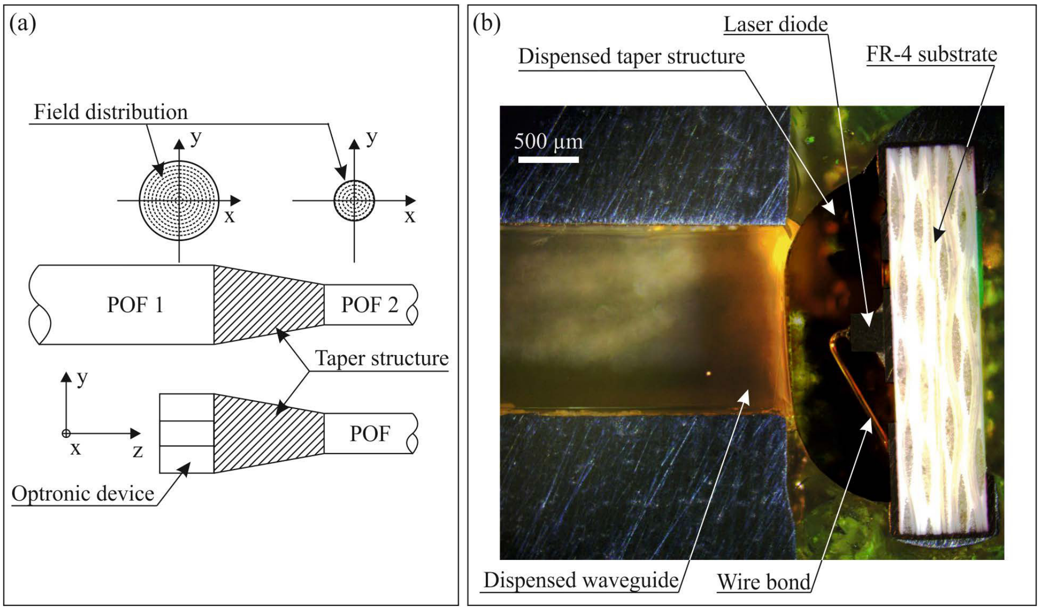


Fig. 8. (a) Taper structure to adapt the light field distribution from the emitting to the receiving optronic partner
(b) Example of a dispensed taper structure.

The possibility of direct coupling of optical waveguides is advantageous and the high selectivity and flexibility of the dispensing process offers a solution to realize it in-line and directly on the substrate surface. The discrete steps in the conventional optronic assembly are combined inside the same production unit. Investigations have to be conducted on the power losses due to the different presented coupling alternatives. In this way a characterization of the process will be possible compared to conventional methodologies.

3. Conclusion and discussion

Combining the drawing, extruding and dispensing process in a single production unit can provide for an in-line manufacture, optronic assembly and packaging of polymer optical fibers onto different geometries. The preliminary results show the feasibility of controlling the drawing and extruding process to produce single mode fibers.

The dispensing process supports the function of the intended production unit by making the cladding part of the polymer optical fiber, but also by fixing and integrating the sensor to the desired geometrical surface. Furthermore, the dispensing process offers the possibility of adapted taper structures for cross-sectional coupling, as well as longitudinal coupling between two optical fibers.

Controlling the single function in the intended unit, as well as the combined functionality poses a big challenge. For this purpose image processing systems are needed for monitoring the accuracy of the core diameter and the position on the surface of the produced optical fibers. The single mode diameter is $< 5\mu m$; therefore measurement accuracy under 0.5 μm is needed. For this reason selecting a suitable image processing system is required. A boundary surface with low roughness between core and cladding material is also necessary for avoiding propagation losses. Therefore, adaptation of chemical properties of the core and the cladding material is necessary, as well as characterization of the adhesive force in boundary area.

The in-line combination of production, optronic assembly and packaging of polymer optical fibers is a research topic with many challenging aspects. The approaches in this direction support the increasing application of optronic systems and offer new perspectives for their use in automated production lines. The produced single mode fiber allows high bandwidth communication within integrated systems and can moreover be used as a precise sensor with high sensitivity and spatial resolution along its complete length.

Acknowledgements

This research project is part of the Collaborative Research Centre program SFB 653 - Gentelligent Components in their Lifecycle - Utilization of Inheritable Component Inherent Information in Production Engineering (www.sfb653.uni-hannover.de).

The authors want to thank the German Research Foundation (DFG) for the supporting and funding this research project.

References

[1] Hering E, Martin R. Photonik: Grundlagen, Technologien und Anwendung. Springer Verlag. 2006.

[2] Li B, Xing X. Polymer Nanowires. State key laboratory of optoelectronic materials and technologies. School of physics and engineering, Sun Yat-Sen University. 2010.

[3] Samiec, D. Verteilte faseroptische Temperatur- und Dehnungsmessung mit sehr hoher Ortsauflösung. Photonik 2011;6: 34-37.

[4] Böttger G, Schröder H, Jordan R. Active or passive fiber-chip-alignment: Approaches to efficient solutions. Optoelectronic Interconnects XIII. 2013

[5] Zimmermann L, Preve G, Tekin T, Rosin T, Landles K. Packaging and assembly for integrated photonics – a review of the ePIXpack photonics packaging platform. IEEE Journal of Selected Topics in Quantum Electronics. 2011;17(3):645-651.

[6] Denkena B, Litwinski K M, Brouwer D, Boujnah H. Desigh and analysis of a prototypical sensory Z-slide for machine tools. Production Engineering Research and Development (WGP). 2012.

[7] Brückner V. Elemente optischer Netze. 2nd ed. Wiesbaden: Vieweg Teubner; 2011.

[8] Scheel W. Optische Aufbau- und Verbindungstechnik in der Elektronischen Baugruppenfertigung. Templin: Verlag Dr. Markus A. Detert; 2002.

[9] Overmeyer L, Dumke M, Heiserich G, Franke S, Schulz L. Power Transmission by Optical Fibers for Component Inherent Communication, Journal of Systemics, Cybernetics and Informatics 2010; 8:55-60.

[10] Dumke M, Overmeyer L, Rieske R, Craiovan D. Dispensing and Printing of Polymer Optical Waveguides. World of Photonics Congress 2011. 2nd EOS Conference on Manufacturing of Optical Components. München: European Optical Socitey; 2011.

[11] Lorang D, Tanaka D, Spadaccini C, Rose K, Cherepy N, Lewis J. Photocurable Liquid Core-Fugitive Shell Printing of Optical Waveguides. Journal of Advanced Materials 2011; XX:1-4.

[12] Ziemann O, Krauser J, Zamtow PE, Daum W. POF-Handbuch. 2nd ed. Berlin, Heidelberg: Springer Verlag; 2007.

[13] Sautter D, Weinerth H. Lexikon: Elektronik und Mikroelektronik. 2nd ed. Berlin, Heidelberg: Springer Verlag; 1993.