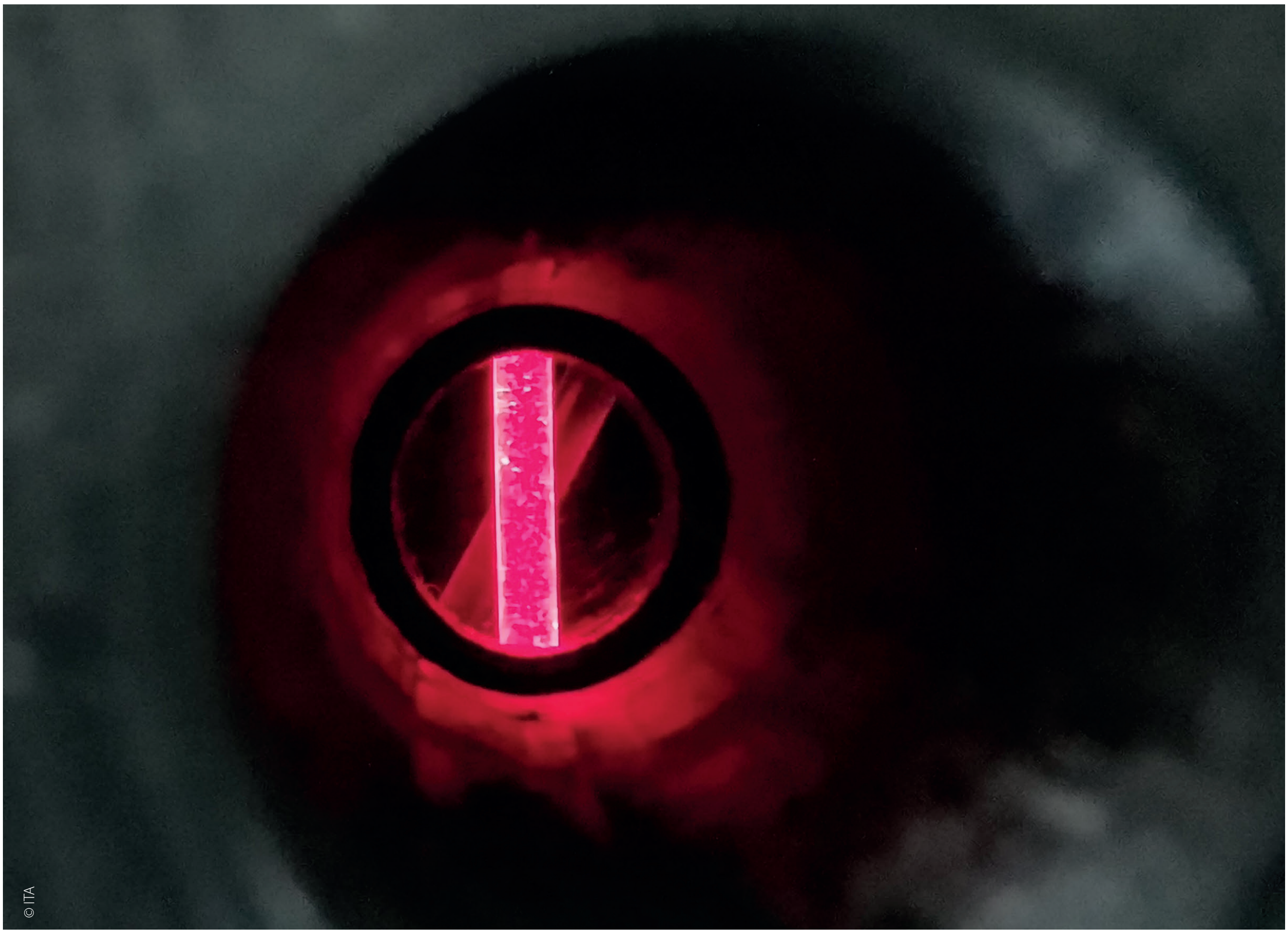
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Polymer Optical Fibers Increase the Reliability of MRI Images

Motion Sensing Light Guides

Patient movements can severely affect the quality of MRI and CT images. A new approach detects the movements and subsequently incorporates them into the image evaluation by means of correction algorithms. This significantly improves the image quality. For the detection of the patient's movements, the use of polymer optical fibers is suitable.

Light-guiding materials such as optical fibers fulfil important functions not only in data communication, but also in medical technology. Polymer optical fibers (POFs) made of special plastics have a number of advantages over optical fibers made of silicate glass, both in short-distance communication and in illumination and sensor technology. The first POFs were developed as early as 1967 by DuPont from polymethyl methacrylate (PMMA) [1]. More recently, a number of other polymers have been used in addition to PMMA for manufacturing. Of particular note are polycarbonate (PC) and thermoplastic polyurethane (TPU), but also various block copolymers such as the fluoroplastic Cytop from AGC Chemicals and the cyclo-olefin copolymer Zeonex from the American manufacturer Zeon [2].

Due to the lower elastic modulus compared to optical glass fibers, POFs are more flexible even with large fiber diameters and can therefore be easily integrated into textiles. In addition, they enable easier light coupling and better light capture. They are also cheaper, easier to handle and offer high electromagnetic immunity (EMI) [3]. Because of these advantages, POFs are predestined for short-range communication in motor and rail vehicles, electronic devices and building networking, among other applications. They are also suitable for measuring and monitoring a range of environmental parameters such as pressure, temperature, pH values, body move-

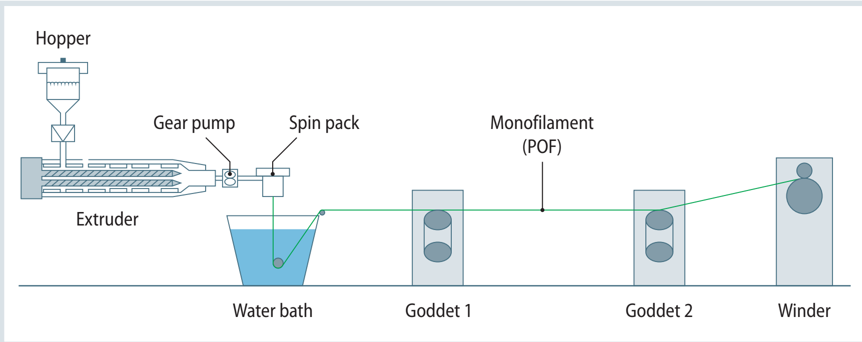

Fig. 1. POFs with different fiber diameters and cross-sections can be produced using the melt spinning process. Source: ITA; graphic: © Hanser

ment, velocity, oxygen saturation and friction [4 – 9].

Melt Spinning Enables Adaptation of Different Fiber Properties

Besides production by hot drawing and extrusion, melt spinning (**Fig. 1**) is one of the most suitable processes for the production of POFs [10]. Melt-spun fibers with adjustable fiber attenuation and degree of hardness or flexibility can be produced from the aforementioned polymers. By adjusting the process parameters and the nozzle geometry, different fiber cross-sections (circular, square, trilobal, etc.) and different fiber diameters are possible.

In addition to the mentioned fields of application, POFs can also be used for medical applications such as health monitoring and motion analysis due to their pressure sensitivity. The Institut für Textiltechnik of RWTH Aachen University (ITA), Germany, and the Stimulate research campus led by Siemens are currently working on such an application in a joint project funded by the German Federal Ministry of Education and Research (BMBF). In the Stimulate project, the two development partners are investigating the possibility of body movement monitoring during medical imaging, such as magnetic resonance imaging (MRI) or computer tomography (CT), using melt-spun POFs. Patient movement during imaging results in significant artefacts and thus unusable scans. However, with precise knowledge of the body movements during the measurement, it is possible to implement appropriate countermeasures to restore the image quality. Thus, a repeat performance of the time-consuming and cost-intensive examination can be avoided.

Measure Patient Movements with POFs

Developments in the field of POF and advances in sensor technology have pushed the application boundaries for human motion analysis [9]. For example, POFs are currently being investigated for motion analysis in smart carpets and as strain gauges [15]. By combining a defined pressure sensitivity and targeted light coupling, they enable measurements of dynamic patient movements [9]. In addition, the electromagnetic interference immunity makes POFs ideal candidates for medical applications, especially in MRI, which are highly susceptible to such interference.

The development of POFs that have the necessary pressure sensitivity and the integration of the fibers with regard to the required light coupling is the focus of the Stimulate project. The technological principle is based on the so-called cross-coupling between two POFs. Within the framework of the project, a textile grid is being developed that provides the foundation for patient movement monitoring and image correction in MRI or CT scans.

Textile Grid as the Central Element

The textile grid is made of two different POF systems. The first fiber system is connected to a light source and consists of flexible, soft POFs. They are not conventionally available on the market »

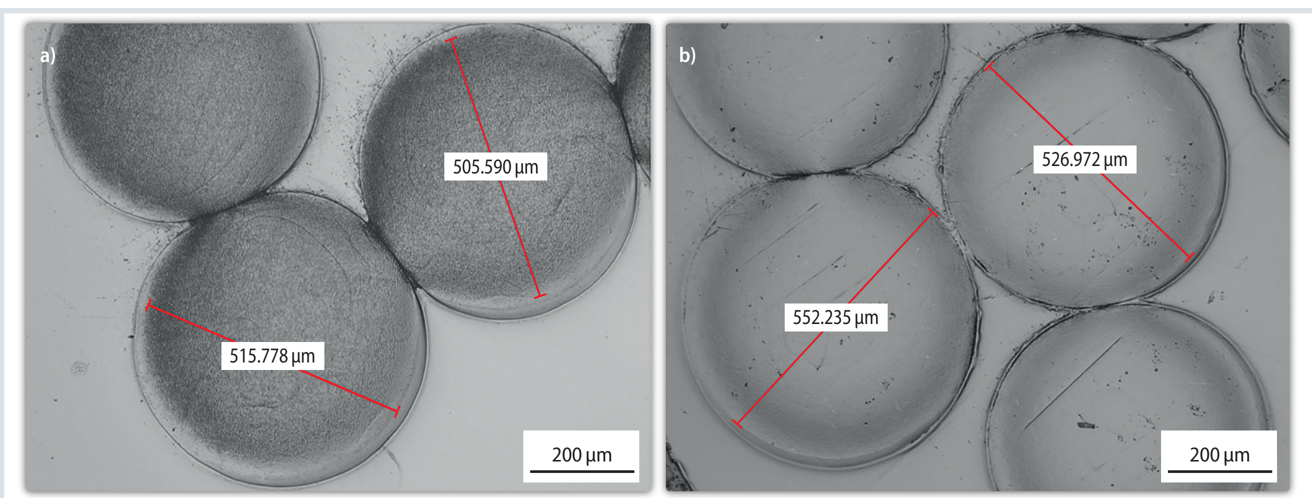

Fig. 2. Light microscope images of the cross-section of melt-spun POFs made of TPU: the melt-spun POFs made of Elastollan 1180 from BASF (left) have a density of 1.08 g/cm^3 and were produced at a polymer throughput of 5.6 g/min using a spinneret with a capillary diameter of 1.5 mm, a draw ratio of 1 and a winding speed of 23 m/min. The melt-spun POFs of Covestro's Desmopan 9385 has a density of 1.18 g/cm^3 and was produced at a polymer throughput of 4.8 g/min using a spinneret with a capillary diameter of 1 mm, at a draw ratio of 2 and a take-up speed of 23 m/min. © ITA

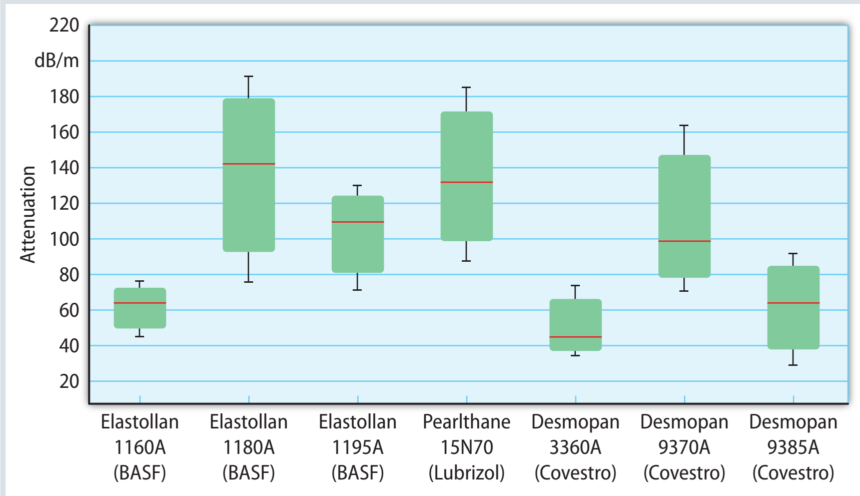

Fig. 3. The attenuation measurement reveals large differences in the materials. Materials 1160 (BASF) and 3360 (Covestro) are selected for their lower attenuation and smaller deviations. Source: ITA ; graphic: © Hanser

and are therefore produced by the researchers themselves as part of the project. The first fiber system is referred to as the driving fiber in the following. The second fiber system consists of a PMMA POF (hereafter referred to as sensing fiber), which has a low attenuation, is dimensionally stable and is connected to a photodiode. The main requirement for the POF is thus, in addition to light conduction, primarily the pressure force-induced cross-coupling of light between the driving fiber and the sensing fiber. The dependence of the optical properties on the compressive stress of the textile grid plays the decisive role in the underlying operating principle.

Several internal and external influencing factors (raw materials, processing conditions and fiber properties such as diameter, cross-section, crystallinity, etc.) must be taken into account in the development of the POF and the textile grid. For this purpose, ITA and the Hochschule für Telekommunikation Leipzig, University of Applied Sciences (HfTL) in Leipzig, Germany, have recently produced titanium dioxide (TiO_2)-doped POFs with a trilobal cross-section by compounding and melt-spinning PMMA [13, 16]. Radiation patterns within the cross-section of the melt-spun fibers were also investigated using ray tracing simulation [17, 18].

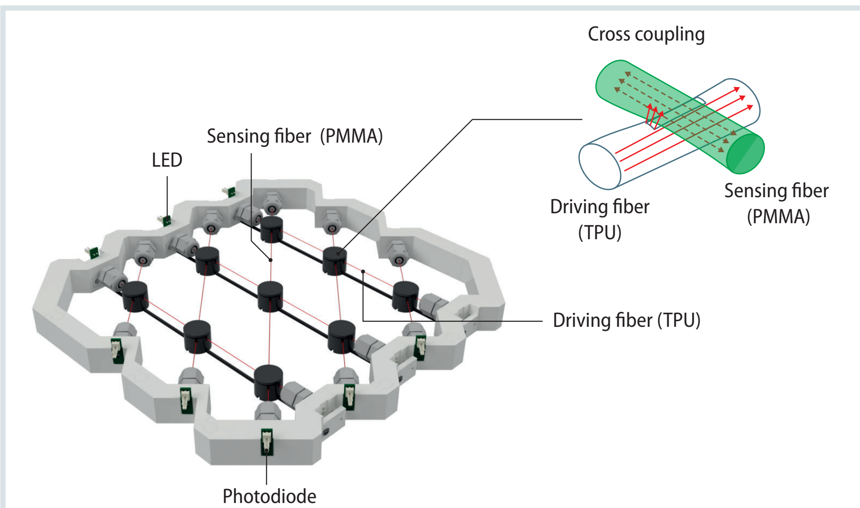

Fig. 4. Schematic view of the 3D-printed demonstrator: important for a correct measurement result are the pressure sensitivity of the driving fiber and the light coupling into the sensing fiber as well as the sensitivity when measuring the captured light intensity. Source: ITA ; graphic: © Hanser

Info

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References & Digital Version

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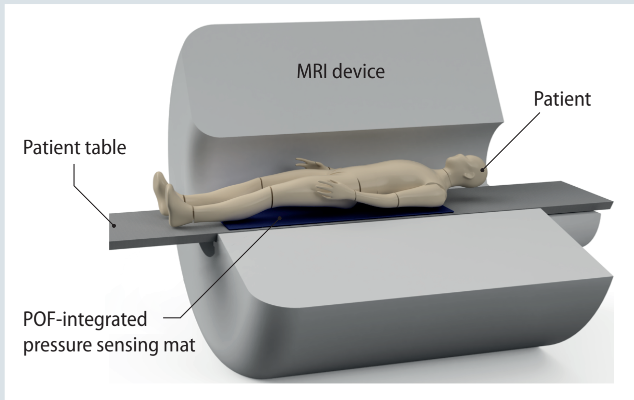

Fig. 5. Final approach of the project for image correction: via the POF pressure measurement mat integrated into the MRI, the patient's movements can be precisely recorded. © ITA

What Is the Effect of Different Fiber Properties?

In some previous work on this project, the researchers developed a 2D pressure sensing device by cross-coupling between a driving fiber and a sensing fiber [17,19,20]. TPU and PMMA fibers were fabricated for the experiments. It was shown that the differences in the degrees of hardness between the two fiber systems are decisive parameters for increasing the contact area under pressure. Various influencing variables such as the fiber cross-section, the crossing angle and the influence of pressure on the sensitivity of the structure were also investigated [17–20]. The researchers found that smaller crossing angles result in higher cross-coupling efficiency, while the increase in pressure also increases the sensitivity. The prototype structure developed with these findings was subsequently presented as a sensitive 2D multitouch system [17].

Melt-spinning tests on eight types of transparent TPU from BASF, Covestro and Lubrizol enabled the production of monofilament driving fibers with different diameters from 0.2 to 1 mm (**Fig. 2**) for coupling with commercially available PMMA fibers with a diameter of 0.5 mm. Process parameters such as polymer throughput, drawing ratio and winding speed were varied in the process. A spinning system from Fourné Maschinenbau and spinnerets from Sossna with an L/D ratio of 4 and a capillary diameter of 1 to 2 mm were used to produce the driving fibers.

Appropriate Combination of Driving and Sensing Fibers

The attenuation measurements on a plastic sheet showed considerable differences between the raw materials (**Fig. 3**). Nevertheless, some of the driving fibers are suitable as counterparts for the PMMA sensing fiber in terms of attenuation coefficients and flexibility. The integration of selected fibers into a 3D-printed demonstrator (**Fig. 4**) at the Stimulate research campus by Otto-von-Guericke University in Magdeburg, Germany, showed that the pressure sensitivity of the driving fiber and the light coupling into the sensing fiber are crucial for the development goal.

A very important factor in the system is also the sensitivity when measuring the captured light intensity. Therefore, the driving fiber should have a high light emission, while the sensing fiber must capture as much of the emitted light as possible in order to guide it into a transparent and safe medium. This allows the photodiodes to detect and measure the light intensity. The necessary optomechanical connections are designed to have minimal light absorption and sufficiently high power. A suitable approach for pressure detection and image correction in MRI is shown in **Figure 5**.

Conclusion and Outlook

The knowledge gained in the Stimulate project paves the way for using POFs in medical imaging. The development is based on the flexibility of transparent POFs and the pressure-induced light emission from a driving fiber into a sensing fiber through cross-coupling. By capturing the light signals with photodiodes, this leads to a visual image in a 3D-printed demonstrator. These pressure-induced measurements are the input data for image correction algorithms in medical imaging devices such as MRI or CT, as they reflect the patient's body movement during imaging. In the future, this approach will be tested in application-oriented tests on medical imaging devices using a prototype of the developed textile grid. ■