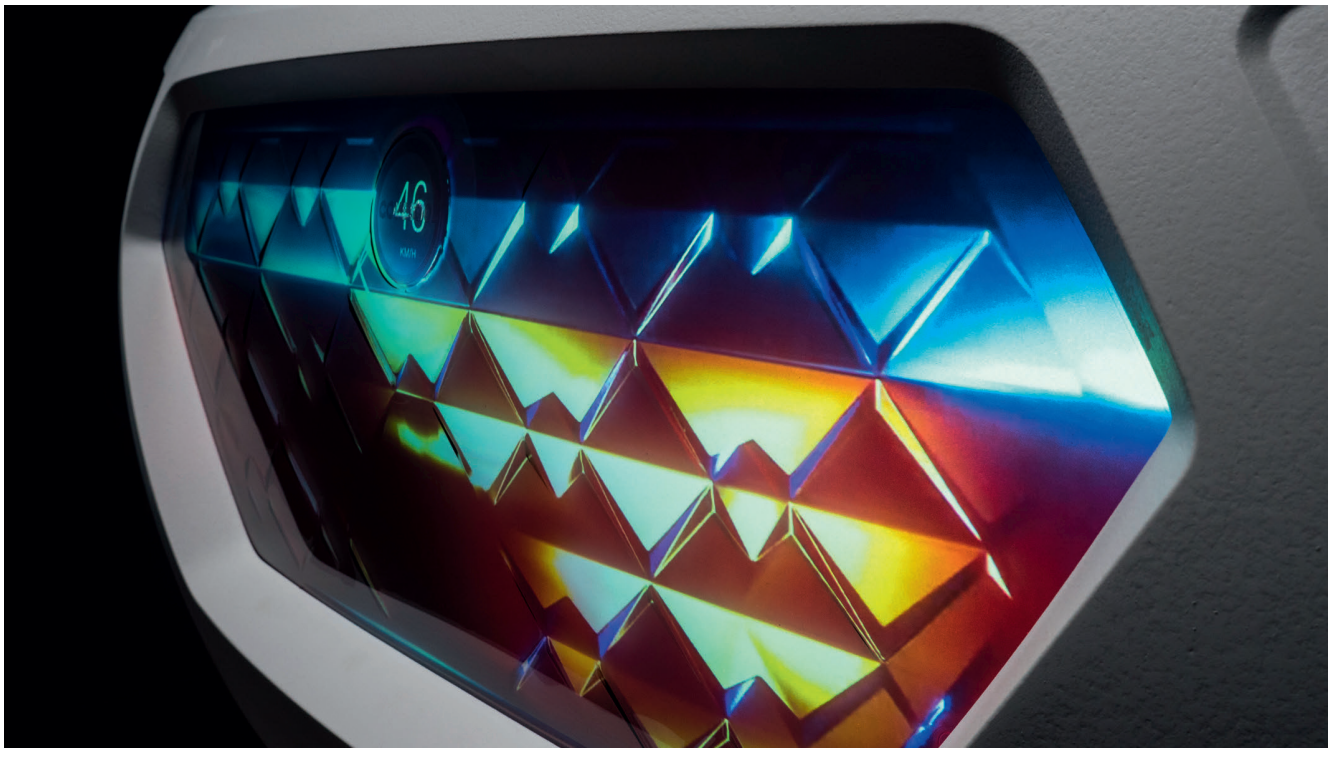
Present in a Multitude of Trends

Polycarbonate (PC)

Lightweight construction, functionality and design are characteristic of material development in all areas of application for PC compounds, composites and films. The range of materials has enormous opportunities when it comes to the mobility of the future, lightweight structural construction with continuous fiber-reinforced composites, 5G technology and medical technology.



In electric vehicles, the original function of the radiator grille, namely to supply air to the engine, is no longer needed. It can therefore be used entirely as a design element, for example by integrating luminous logos and fade-out effects © Covestro

During the course of 2018, the high demand for polycarbonate (PC) had already slowed down considerably in comparison with the strong previous years. This trend intensified in 2019. As a result, the market volume including the PC share for blends of 4.5 million t in 2018 rose only moderately in following year 2019 and was noticeably below the usual annual growth rate. The price level dropped significantly, leading to declining margins in the PC industry. The cause of this could be attributed to increased competitive pressure as well as economic and geopolitical uncertainties such as the weakening economy in China and the rest of the world, the crisis in the automotive industry and the Chinese-American trade conflict. At the beginning of 2020, the corona pandemic caused demand for PC to collapse successively in Asia, Europe and the USA. For instance, nearly all global car manufacturers temporarily ceased production. PC manufacturers then cut back their production. The decline in demand was mitigated by higher PC requirements in the medical, construction, electrical, electronics and household appliance industries. In addition, many retailers are replenishing their warehouses with PC in order to prepare a good starting position for the period after the pandemic.

Covestro AG, Leverkusen, Germany, assumes that, despite the current situation, global demand for PC will grow by around 4 % per year in the medium term. It is anticipated that global capacities will increase in the next ten years from »

5.5 million t in 2019 to almost 9 million t. This is driven primarily by the disproportionately high increase in PC demand in China, which is consequently at the center of the capacity expansion. This will be driven by established, globally positioned PC manufacturers such as Covestro or Sabic, Riyadh, Saudi Arabia, local producers such as Luxi Chemical, Liaocheng City, China, and Wanhua Chemicals, Yantai, China, and a burgeoning number of local newcomers such as Zhejiang Petroleum and Chemical, Zhoushan, China. Should the currently announced expansion in terms of capacity take place, around 50 % of global capacity would be installed in China from 2025. This is a massive increase compared to 2019, when it only accounted for 25 % of global capacity. However, the expansion could slow down in the medium to long term because the Chinese government removed PC from the Guidance Catalogue of Industry Restructure in early 2020. As a result, investments in local PC systems will therefore no longer be given preferential treatment. Some Chinese PC manufacturers have accordingly withdrawn or postponed planned capacity increases. For instance, Luxi Chemical has abandoned a major project planned in Liaocheng with a capacity of 1 million t/a.

Despite the large local capacities, China imported approx. 1.6 million t/a of PC in 2019. This was offset by exports of only about 260,000 t – an increase of about 12 % over the previous year. There are a number of reasons for the high import volume in relation to the locally installed capacities. For some local manufacturers, for example, full capacity utilization of their new systems is still uncommon. There is also a high demand for special PC and PC blend types that are not yet being produced locally. Nevertheless, it is anticipated that within a few years the Middle Kingdom will transform into a major net PC exporter, which will significantly change the global trade structure. China's rapidly growing significance in the global plastics market is also reflected in the fact that more and more Chinese compounders are becoming involved in overseas markets. They frequently focus on business with the automotive industry. However, Japanese and above all Korean market players are also gaining ground in Europe and the USA.

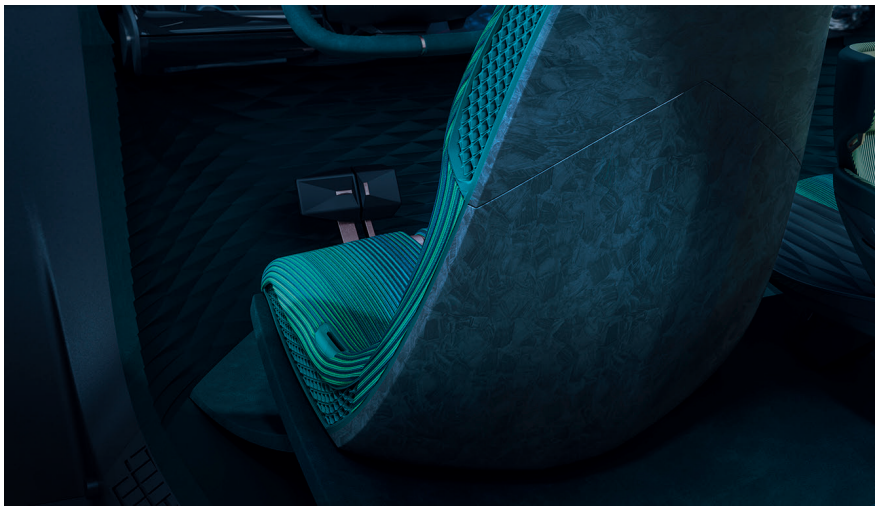


Fig. 1. The aim of the new lightweight design concept for the seat backs is to reduce the weight of the ENO.146 concept vehicle. Compared to previously used backrests, the development from PC is up to 50 % lighter © GAC

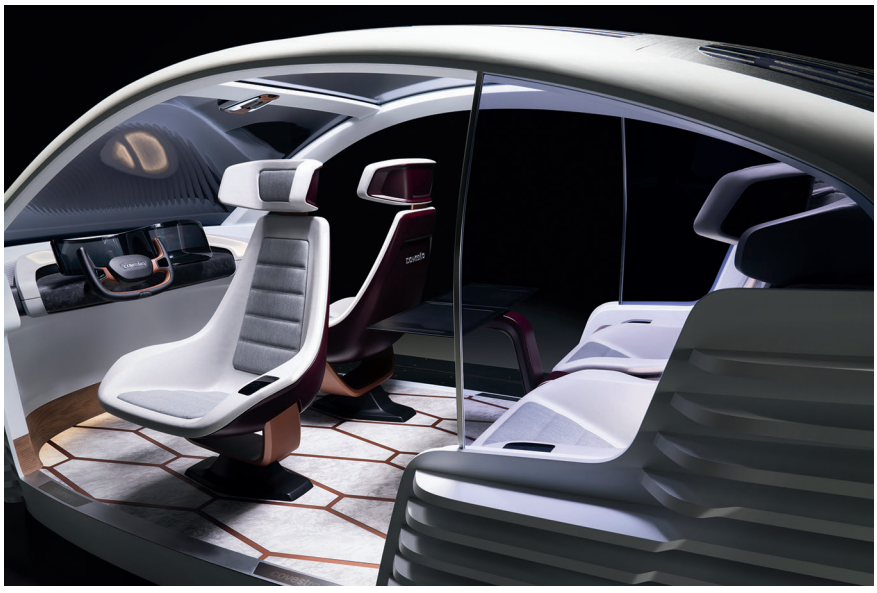


Fig. 2. The car interior of the future will feature a variety of operating, service and infotainment displays as well as integrated ambient lighting systems © Covestro

Besides the growing relevance of China and Asia, the focus on a sustainable circular economy will significantly influence the plastics industry and thus also the PC industry in the years to come. Among other things, the focus on durable and reusable plastic products, sustainable sources of raw materials and the avoidance of waste are the fundamental goals. At present, Covestro is heavily engaged in a long-term program to establish material cycles and thus also intends to develop new business opportunities across the value chain of its products. To this end, the company cooperates globally with numerous partners. For example, it recently launched a strategic cooperation with Neste, Espoo, Finland. It aims to replace several thousand metric tons of fossil raw materials for the production of PC with raw materials that are synthesized with predominantly bio-based hydrocarbons. The latter are derived entirely from renewable sources such as used and residual oils and fats. The more sustainable PC raw materials are added to the existing PC production as a drop-in replacement. The resulting PC products have the same quality as virgin PC and can therefore be used directly by processors in existing processes.

Bio-Based Raw Materials for PC

A current example of a recyclable material cycle based on used plastics is the recycling of PC from 5-gallon water bottles (equivalent to 19 l) within the framework of a cooperation with two Chinese companies, the beverage producer Nongfu Spring, Hangzhou, and the recycling company Ausell. The recovered, single-variety PC features consistently high quality and is processed by Covestro with virgin material into high-quality post-consumer recyclates (PCR) based on PC and PC blends. These materials are in high demand in the electrical and electronics industry, for example, because they satisfy industry standards such as Ecolabel "Blue Angel" or the environmental seal "EPEAT". The material is also suitable for the automotive industry, for example as blends of PC and acrylonitrile butadiene styrene (ABS) for car interiors.

Predominantly organic-based raw materials also play a key role in the circular economy in plastics production and help to reduce the CO_2 footprint of plastics and the products that are manufactured from them. For instance, Covestro has recently launched Makrofol EC, a partially bio-based PC film whose carbon content is derived from starch and thus from plant biomass by more than 50 %. It features similarly favorable properties to comparable standard PC films and offers improved chemical and weathering resistance as well as high abrasion resistance. Potential applications are labels, device housings, 3D packaging and operating and decorative strips.

Besides the circular economy, continuous fiber-reinforced thermoplastic composites (CFRTP) with PC matrix will also assume a more important position in the PC sector in the future. The tapes or plate-shaped semi-finished products exhibit extremely high strength and stiffness of up to 100 GPa combined with very low weight. Due to these properties, they serve as a viable alternative to metals such as »

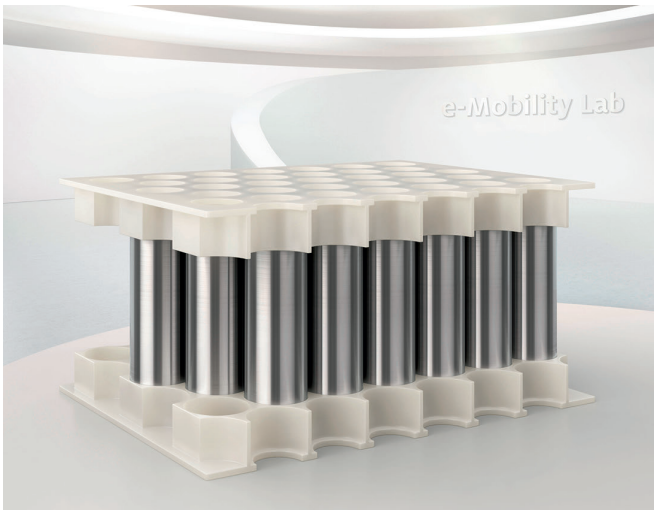


Fig. 3. The cylindrical cells can be bonded in just 5 s in the carrier made of a PC+ABS blend © Henkel, PR082

Fig. 5. Fiberglass-filled PC grades are particularly suitable for medical components that must be very rigid and strong, such as handles for laparoscopic surgical instruments © Covestro

sheet steel or die-cast aluminum in lightweight construction where space is limited. There are numerous automated processes available for their economical and large-scale processing, such as automatic tape laying (ATL), automatic fiber positioning (AFP) or hybrid molding. The latter integrates the forming of composites into injection molding, enabling the direct functionalization of a component, for instance with fastening elements, guides and fixtures. This makes it possible to produce complex components in a one-shot process. As thermoplastic systems, PC-based CFRTPs are easy to recycle, which, along with their lightweight construction potential, makes them exceptionally sustainable. Unlike most CFRTPs with a different matrix, they can also be put to use to produce lightweight components with high load-bearing capacity in a high-quality and aesthetic design. This is because of the transparency of PC, the high quality of the surface finish of PC components (Class A) and the wide scope for coating and surface design. Glass-like effect coatings, for instance, can be used to enhance the carbon look that comes from the fibers. Graining and even textile effects can also be achieved. In addition, the surfaces can be coated with scratch-resistant polyurethane hardcoats (PU) or self-healing PU coatings using in-mold coating. The range of applications for CFRTP with PC matrix extends from automotive and mechanical engineering to the electrical, electronics and consumer goods industries as well as the production of sports and leisure fashion.

Recyclable and 3D Printed

More and more additive manufacturing processes are being applied in the production of complex and individualized plastic parts. They also represent promising opportunities for establishing closed material cycles. This is illustrated, for example, by the lamp manufacturer Signify, Eindhoven, Netherlands, who uses 3D printing to produce lamps made of PC on an industrial scale. Owing to their transparency, impact resistance, thermal stability and freedom of design, the compounds developed by Covestro for this purpose meet the requirement profile of the lamps. As thermoplastics, they are also recyclable. The lamps could therefore be designed specifically for the circular economy. Nearly all of their components can be reused or recycled.

© Signify

New Designs for Vehicle Interiors

ENO.146, an electric concept car from the Chinese automaker Guangzhou Automobile Group, demonstrates the opportunities PC-based CFRTP opens up in terms of lightweight construction, production efficiency, design and sustainability. The backrests of both front seats of the vehicle are made of Covestro's PC-based CFRTP Maezio (**Fig. 1**). In comparison to conventional metal constructions, the composite seat back is up to 50% lighter. Savings in terms of weight are particularly significant as they are achieved on one of the heaviest parts of the car interior. The injection molding process used makes it possible to incorporate functional structures into the shape of the backrests, reducing the number of components and materials and thus reducing the complexity of production and assembly processes. The design of the interior of the ENO.146 replicates the atmosphere of a lake with lotus flowers. The backrest adapts to this design with its natural look and feel, imparting a strong aesthetic appeal. It can also be recycled into injection molding compounds.

Future car interiors will be strongly influenced by the trend towards autonomous vehicles. The interior will be transformed into a multifunctional space with a large number of large 3D displays that are seamlessly embedded in their surroundings (**Fig. 2**) and integrate numerous elements such as ambient lighting, touch and operating functions as well as haptic effects. As a result, the tasks that 3D displays and their covers have to perform are increasing.

Films for Scratch-Resistant Surfaces

PC is particularly suitable for the design of such displays because, unlike glass, for instance, it has a greater freedom of shape, offers a wide range of options for designing surfaces in terms of color and structure, and is shatterproof in the event of a crash. In addition, there are various manufacturing processes available that

have great potential for the cost-reducing integration of functions. With the Film Insert Molding (FIM) process, display surfaces can be made scratch- and abrasion-resistant, UV-resistant and insensitive to media such as skin creams using specially additive and coated films. The films can be printed conductively on the back in order to integrate multi-touch functionalities and other electronic functions into the display. The injection compression molding process can be used to produce particularly large display covers with high transparency, whose birefringence is reduced so that the passenger is able to see a very sharp image. For such highly integrated, large-scale 3D displays, Covestro has developed the Makrolon-Ai series, which makes it possible to create high-gloss surfaces with highest optical purity, and the formable, UV-curing films of the Makrofol HF series, which are designed for large-area components with deep gloss.

The exterior of vehicles is also undergoing quite some changes. Electric vehicles, for example, no longer have any need for the classic radiator grille to supply air to the engine. The front of the vehicle is thus developing into a formative design element with new functions, some of which also result from autonomous driving. The FIM process with PC compounds and films has great potential for use in the design and construction of seamless, large-area 3D front modules, because it facilitates the economical integration of decorative elements and numerous functions, especially in terms of pedestrian and passenger protection. These include, for instance, metallized and glass-like surfaces, high-resolution infrared light laser scanners (IR) for autonomous driving (LiDAR sensors), ambient lighting elements in black panel technology, cleaning spray nozzles and display elements for communication, for example with pedestrians. Covestro has developed the black films and compounds Makrofol ST and Makrolon ST especially for the integration of LiDAR sensors. They offer high transmission for the IR light of the sensors and are designed for FIM processing.

Fig. 4. The "Bird" concept for a 5G antenna housing based on PC should not only enable technology to function flawlessly, but also blend in well with the cityscape © Covestro

Combining Design and Functions

One example of a front module concept that Covestro has developed on the basis of PC is the "5D-FIM design" (**Title figure**). It combines an injection-molded 3D substructure with a 2D cover film that can be printed with a multi-dimensional, colored decoration. It can incorporate sensors, illuminated logos and fade-out effects as well as a defroster function. In the future, there are plans to additionally form the film and incorporate this deformation into the injection molding process (FIM One Step Process).

PC and above all its blends with ABS also have enormous potential for applications in Li-ion batteries in electric vehicles. In these applications, they are employed for components such as cell holders, end plates, module walls, covers, spacers, frames for pouch cells and crash absorbers. The material properties sought after here are characteristics such as high dimensional stability, low-temperature impact strength and fire resistance (UL 94 V-0) as well as electrical properties such as high tracking resistance and good thermal conductivity. Battery developers also prefer thermoplastics such as PC because of the high degree of freedom in terms of shaping and low-cost injection molding in mass production. The breakthrough of the Li-ion battery in vehicle drive systems not only demands a long lifespan, operational safety and reliability, but also automated mass production at low cost. The suitability of PC compounds in combination with »

Fig. 6. The packaging of breast implants as well as other types of implants must protect them from damage and contamination. PC films provide the necessary toughness and stiffnes © Covestro

The Authors

Frank Schnieders is Senior Manager Market Insights and Solutions.
Jochen Hardt is Global Marketing Manager Mobility.
Dirk Wurster is Head of Polycarbonates for Electrical, Electronics & Appliances in the EMEA region.
Dirk Pophusen is Global Segment Manager Consumer & Industrial Solutions, Covestro Specialty Films.
Maximilian Hemgesberg is Head of Business Development Coated Films, Covestro Specialty Films.
Florian Stempfle is Head of Business Development Specialty Films in the EMEA and LATAM regions.

All authors work at Covestro Deutschland AG in Leverkusen or Dormagen, Germany. For further information please contact Dr. Frank Rothbarth, Covestro Deutschland AG, frank.rothbarth@covestro.com

Database and Sources

All market information is based on Covestro's own surveys and estimates, as well as additional information on investments and technical developments from Covestro or from press releases from the companies mentioned.

Service

Digital Version

- A PDF file of the article can be found at ***www.kunststoffe-international.com/2020-8***

German Version

- Read the German version of the article in our magazine ***Kunststoffe*** or at ***www.kunststoffe.de***

other materials is clearly demonstrated by a joint development by Henkel AG & Co. KGaA, Düsseldorf, Germany, and Covestro. Cylindrical Li-ion cells are attached to a carrier made of the flame-retardant PC+ABS Bayblend FR3040 EV with the one-component acrylic adhesive Loctite, which cures rapidly and dimensionally stable under UV light, in cycle times of only 5 seconds (**Fig. 3**). Conventional curing times, by contrast, are usually several minutes to hours.

Like electromobility, the associated charging infrastructure is also evolving into a true growth market. Components that are manufactured from technical thermoplastics such as PCs can now be found in virtually all commercial and domestic charging stations. In this context, typical applications of PCs are housings, technical components and structural parts such as front panels, covers, charging sockets or plug holders. Covestro has developed a wide range of PC and PC blend types for charging stations. They feature flame-retardant additives and satisfy the UL 94 flame retardancy test for thin wall thicknesses, usually with the best classification V-0. Compounds featuring UL-f1 listing are also available for charging stations that are exposed to UV light and water in outdoor use. Thanks to the high impact resistance of PC, the components are permanently functionally reliable and resistant to vandalism. The transparency and good colorability of PC allow for the easy incorporation of colored LED indicator lights, for example. Material examples from series production are Makrolon 6487 and 6557. ChargePoint, Campbell, CA/USA, uses these PC grades in its level-2 charging stations, for example for plug holsters and front panels.

There is an increasing demand for injection-molded electronic 3D structural components in vehicle interiors, but also in electronics or household appliances. These components are very lightweight, thin, highly integrated and functional and replace multi-part, space-consuming superstructures. IMSE (Injection Molded Structural Electronics) technology is one way to produce these seamless miniature components economically. PC films and compounds developed by the Finnish company TactoTek, Oulunsalo, in combination with FIM technology have excellent prospects in this process. These films can therefore be employed to create multifunctional surfaces. They can be printed with circuit diagrams for the integration of capacitive control surfaces, for example for LEDs, and with decorative elements on the side that is subsequently overmolded. PC compounds are also used as FIM back-injection material to produce geometrically complex structures, provide functions such as LEDs and stabilize the entire component. Due to their high transparency, they ensure low light loss when integrated LEDs are used.

Well Suited for 5G Infrastructure

5G technology is at present one of the key innovation drivers in networking all areas of daily life and the economy to the Internet of Things (IoT). The close connection of devices such as cell phones, vehicles, household appliances and industrial plants requires a wide range of base stations with antennas, both indoors and outdoors. A large number of PC manufacturers are currently working on material solutions for the housings of these so-called small cells and antennas as PCs and their blends are well suited to the requirements profile. For example, PC is consistent even at high transmission rates for radio frequencies of up to 50 GHz. It is robust, lightweight, heat-stable, resistant to cold and can be processed economically in high volumes in injection molding. Depending on the additives used, it is thermally conductive and resistant to weathering and UV light. It can be injection molded into 3D circuit carriers and equipped with high-resolution circuit diagrams by laser direct structuring.

Small cells and antennas will be omnipresent in the future. Therefore, besides functionality, an attractive design is also an extremely important factor. Covestro,

Deutsche Telekom AG, Bonn, Germany, and the Swedish Umeå Institute for Design at the University of Umeå therefore have recently developed creative designs for the housings of base stations and antennas based on the PC Makrolon in a pilot project (**Fig. 4**). A particularly impressive proposal is designed in the shape of a bird and can be mounted on street lamps, for instance.

PC is also used for various applications in medical technology. Material development in this area is influenced by the increasing use of wearables and the trend towards self-medication. The systems for self-medication, also known as drug delivery devices, must function with low effort and dose precisely. To achieve this, they must be, for example, low-friction. Corresponding raw material developments for auto-injectors and injection pens, among others, are Makrolon M204 LF, M402 LF and M404 LF from Covestro. The PC compounds eliminate the need for lubricants thanks to their low coefficients of friction.

There is an increasing demand for fiberglass-filled PC grades in the design of load-bearing components for delivery systems, but also for handles, for example for minimally invasive surgical instruments (**Fig. 5**). For this purpose, Covestro has developed two product series that are biocompatible pursuant to the ISO 10993–1 standard with different filling levels, which have high rigidity and strength and enable high-gloss surfaces. The Makrolon M-800 series is principally intended for components subject to high mechanical stress, while the more easy-flowing M-400 series is intended for larger, thinner and geometrically more filigree components subject to mechanical stress.

Good Signal Transmission

Wearables are increasingly being used to monitor vital functions such as pulse, blood pressure and sugar directly on the body. PC and its blends are ideally suited as raw materials for housings of these devices. However, the requirements are manifold, complex and vary greatly depending on the device. Characteristics that are in demand are features such as rigidity, materials that protect the interior of the device from external mechanical stress even with thin wall thicknesses and materials that are also easy to process. In addition, good chemical resistance, e. g. against skin lotions, disinfectants or perspiration, high dimensional stability over a wide temperature range and good flame retardance are often of great significance. For devices interacting with smartphones, for example, low dielectric constants must ensure signal transmission. All these requirements can be met with PC and its blends. In addition, PC offers numerous possibilities in terms of design freedom – from high-gloss surfaces and the integration of LED lamps to displays that are not visible when inactive and appear as a flawless black surface (black panel technology).

Packaging for high-quality, sensitive medical products such as implants or medical tools is also a rapidly growing area of application for PCs in medical technology. One of our products in this area is Makrofol MA507. The film is used, for example, for the packaging of breast implants (**Fig. 6**). Its high level of toughness and stiffness protects the contents from damage. It is also able to withstand temperatures of up to 163 °C in pressure autoclaves when the packages are sterilized with steam. ■