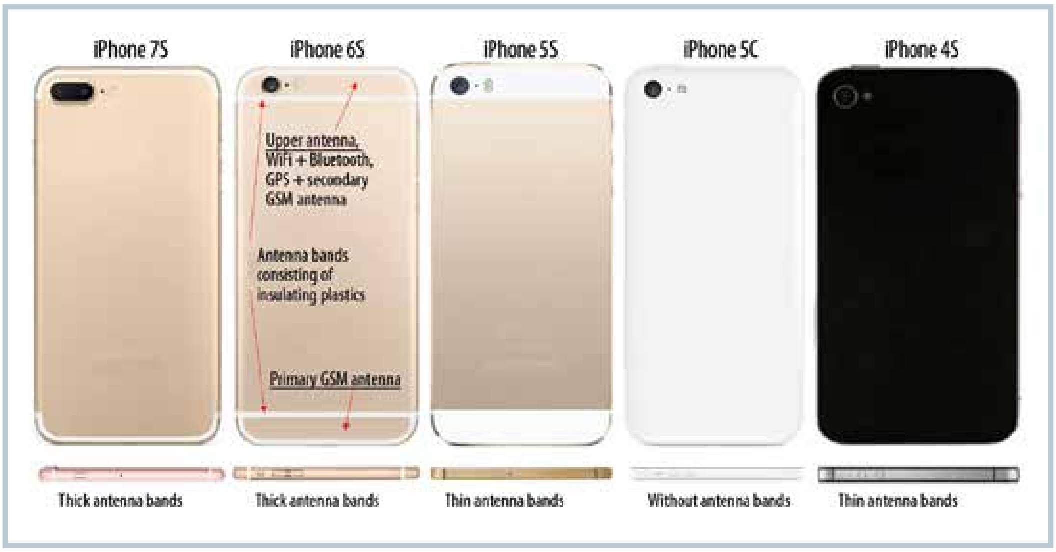
Icons of the Modern Era

Polyphthalamides for Hybrid Connections in Metallic Smartphone Housings

Nothing defines the current generation more than the smartphone. Premium, classy metal devices are the current trend. In order for the numerous integrated antennas to work notwithstanding the conductive housings, they must be electrically insulated against each other. Two newly developed polyphthalamides that join especially well with titanium and stainless steel alloys are suited for this purpose.



The antenna separation in the course of various iPhone generations (© DSM)

Apple introduced the first iPhone in 2007 and created a new market segment. Smartphones have been highly successful ever since but now the market is approaching saturation. There have been tremendous changes among OEMs in the meantime. Formerly familiar global brands such as Nokia, Motorola, and Research in Motion have disappeared. Brands like Huawei, Vivo, and Oppo are now among the world's five largest smartphone manufacturers thanks to their strong market position in China. Huawei is expected to oust Apple from 2nd place among smartphone manufacturers as early as the end of 2017. There are hardly any significant differences between the various manufacturers in terms of performance, functions, and design anymore. Technically the smartphone is increasingly becoming a commodity.

Manufacturers are exploring progressive fields of application and new technologies to set themselves apart from the mass of smartphones. Aside from the usual performance improvements, new hardware technologies such as flexible displays and special artificial intelligence chips will be seen in the mobile communications industry during the next year. They allow the corporations to penetrate even deeper into the lives of customers via the smartphone, expanding their presence.

Advantages and Disadvantages of Metal Housings

Apple has long offered a smartphone with aluminum housing – a concept for high quality devices that was largely adopted of the Sony Corporation with its Walkman in the late 80s. The popularity of the iPhone turned metal housings into a trend. Housings made of aluminum, stainless steel, titanium, or magnesium (**Table 1**) are available today. These materials combine robust construction with a high quality appearance and elegant design.

While the metal's intrinsic thermal conductivity supports heat distribution and dissipation for the ever more powerful processors, electrical conductivity weakens the transmission of RF signals for numerous integrated antennas. Other components in the smartphone housing like printed circuit boards, EMI shielding, and metallic coatings also dampen the RF signals. These unwanted shielding characteristics can be prevented among other things by grounding a certain housing component, so that the housing ultimately serves as an extension of the antenna.

Modern smartphones have various integrated antennas: For mobile communication (GSM, EDGE, 3G, 4G, LTE), navigation (GPS), local wireless networks

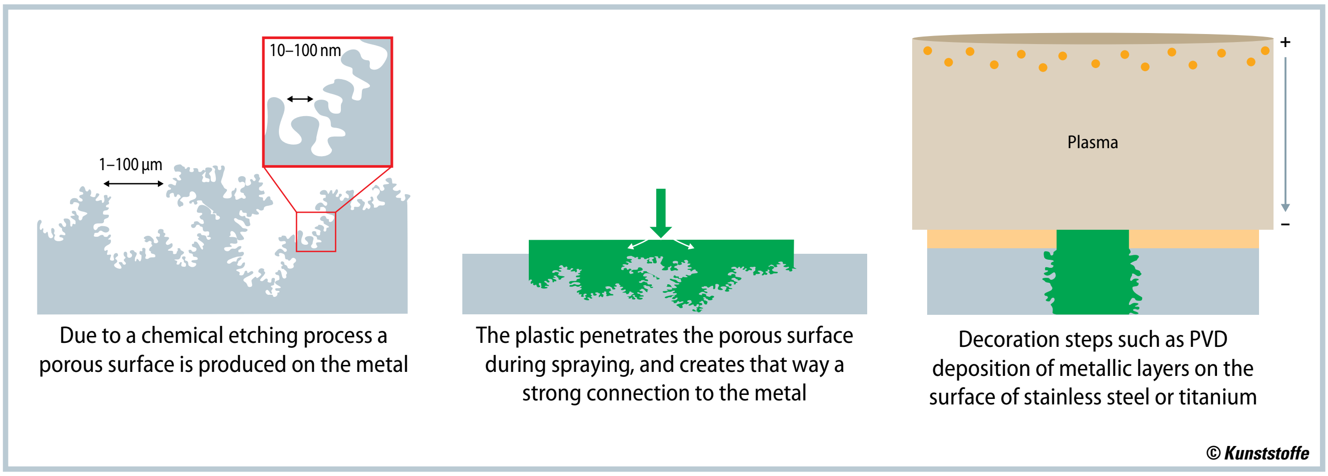


Fig. 1. Nano-molding technology (NMT) creates strong connections without adhesives or primers. The process can be divided into three steps (source: DSM)

(WLAN), and data transmission between devices over short distances (Bluetooth). They also have two mobile radio antennas in order to enable good reception notwithstanding signal absorption, for example by a hand holding the device.

The metal housing is typically divided into three zones in order to combine an attractive design with good RF reception (**Title figure**). Serving as an additional antenna booster, the upper section is connected to the upper antenna on the back. The main body of the device is grounded. On the back, the lower section is connected to the additional antennas and once again serves as an antenna booster. In order for this to work from a technical perspective, the individual metal elements have to be electrically insulated against each other at the top and bottom.

Antenna separation has become broader in the housings of the most recent full metal iPhone generation (6/7). The reception is better since the RF signals pass through the plastic antenna separation, allowing reception and transmission by the antennas in the housing. Broader separation with plastic compared to previous models reduces capacitive leakage currents. The polymer however must have a high electrical resistance for this purpose. All engineering skills notwithstanding, the metal housing is anything but ideal for RF signals, especially since the frequencies are going to increase considerably in the coming mobile radio generation (5G) with data rates of up to 10 gigabit per second.

Since the metal housing has become the design standard in the meantime, it no longer serves as a distinguishing feature for OEMs.

Glass Housings

A front and back made of glass can be increasingly expected in the industry going forward. Huawei already introduced the Honor Magic smartphone with a glass housing in December of 2016 and presented it at the CES 2017 consumer electronics trade fair in Las Vegas. In contrast to metal housings, the glass housing makes wireless charging of the smartphone possible and does not absorb any RF signals. Increasingly thin smartphones are another trend. Currently the thinnest mobile device of this kind is the Vivo X5 with 4.75 mm.

A smartphone housing made entirely of glass is the dream of many industry designers. However, it is unlikely to have the required mechanical strength, for example to pass drop and impact tests. That is essential in order to ensure the reliability in everyday use. Metallic frames therefore continue to be used until completely flexible displays become possible sometime in the future.

Choosing the material used for the frame affects the bending strength, weight, durability, and possible processing methods. Aluminum is used due to its low density, recycling characteristics, low raw material and manufacturing costs. However, aluminum alloys are susceptible to corrosion with extended use in metal housings. Compared to these, the surface of stainless steel alloys offers more design possibilities such as matte and glossy versions, polished or brushed metal, and various textures. Stainless steel alloys can be subsequently treated with vacuum metallization, physical vapor deposition (PVD), or electrocoating.

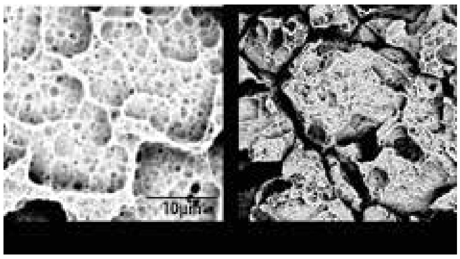


Fig. 2. Scanning electron microscope images of substrate structures made of aluminum (left) and stainless steel (right) that are suitable for an NMT connection (© DSM)

PVD is a possible alternative to nickel coatings in order to address the risk of nickel allergies and avoid environmental law restrictions in waste processing. Switching from aluminum to stainless steel does, however, increase the weight of the smartphone. The latter can be partially compensated by thinner wall thicknesses thanks to the better mechanical properties. Titanium will also be increasingly considered as an alternative to stainless steel in the future.

Nano-Molding as the Joining Technology of Choice

Hybrid joining structures made of metal and plastic are required for smartphones and numerous other applications. The application and component design are often decisive for the choice of the corresponding joining technology. Para- »

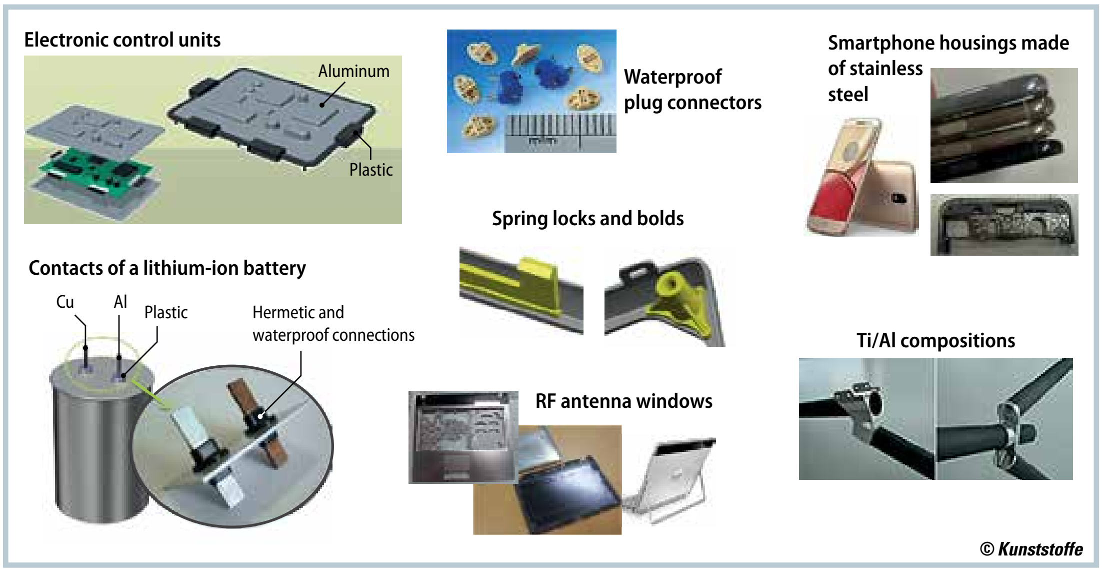


Fig. 3. Overview of some application examples where metal-plastic composites were joined to each other in the NMT process. The process is used in aviation and aerospace, automotive engineering, and the electrical and electronics industry (source: DSM)

meters such as dielectric properties, temperature resistance for subsequent process steps, ongoing resilience in application, leak tightness, and the possible outgassing of adhesives and primers play a crucial role here.

Nano-molding technology (NMT) is a highly resilient joining method for metal and plastic (**Fig. 1**). A porous metal surface with small hollows in the micro and nanorange is produced in a multi-stage, wet chemical etching process (**Fig. 2**). Once the metal surface has been adequately etched and cleaned, the plastic is injection molded on. A very strong bonding between the metal and plastic is created since the plastic penetrates deep into the porous surface structure. The connection can be influenced by the surface of the metal, the processing conditions, and the characteristics of the polymer.

Adhesives and primers are not necessary with NMT. This is a major advantage for applications where the possible outgassing of additives is undesirable. The resulting connections are gas and water tight, which is advantageous for sensitive electronics applications. Subsequent processing steps such as anodizing or PVD for surface refinement can follow the NMT process. The sturdy metal-plastic composite systems are used in various industries such as aviation and aerospace as well as the automobile industry (**Fig. 3**).

Smartphones with stainless steel instead of aluminum housings harbor additional challenges in the selection of plastics. Aluminum is typically anodized to protect the soft surface against scratches and corrosion. This makes it possible to color the product according to the design. Since anodizing takes place after the NMT process, the polymers that are used have to stand up to this treatment. Polybutylene terephthalate (PBT), mixtures of PBT and polyethylene terephthalate (PET), polyphenylene sulfide (PPS), and polysulfone (PSU) are for example suitable here.

Anodizing is very well suited for aluminum but not for other metals such as stainless steel and titanium. These two are, however, popular materials for new

Property	Aluminum	Stainless steel 304	Titanium
Density [kg/m^3]	2700	8030	4540
Melting temperature [°C]	660	1399	1668
Tensile strength [MPa]	72	290	400
Elongation [%]	60	55	27
Modulus of elasticity [GPa]	70	286	116
Corrosion resistance	very well	excellent	excellent

Table 1. The stainless steel alloy SUS 304 is currently used most frequently as an alternative to aluminum (source: DSM)

The Authors

Dr. Tamim P. Sidiki is Global Marketing Director Electronics at DSM Engineering Plastics; Tamim.Sidiki@DSM.com
Julie Liong is Marketing Manager for structural components at DSM Engineering Plastics.
Dr. Michelle Seitz and **Dr. Li-Dong Zheng** are Senior Researchers at DSM Materials Science.

Service

Digital Version

- A PDF file of the article can be found at *www.kunststoffe-international.com/4781580*

German Version

- Read the German version of the article in our magazine *Kunststoffe* or at *www.kunststoffe.de* smartphones. Polymers that can be joined with these metals in the NMT process and also withstand higher temperatures for processing techniques such as PVD are needed. PVD processing takes about three hours at temperatures between 180 °C and 240 °C. The higher the temperature is during coating, the better is the quality. Polymers generally used for NMT processing are unusable here. PPS, for example, is not a suitable material for visible housing components due to weak UV resistance and colorability.

OEMs are therefore choosing high-temperature plastics such as polyether ether ketone (PEEK). A novel polyphthalamide (PPA) with a glass transition temperature (T_g) of 160 °C and properties similar to PEEK serves as an alternative.

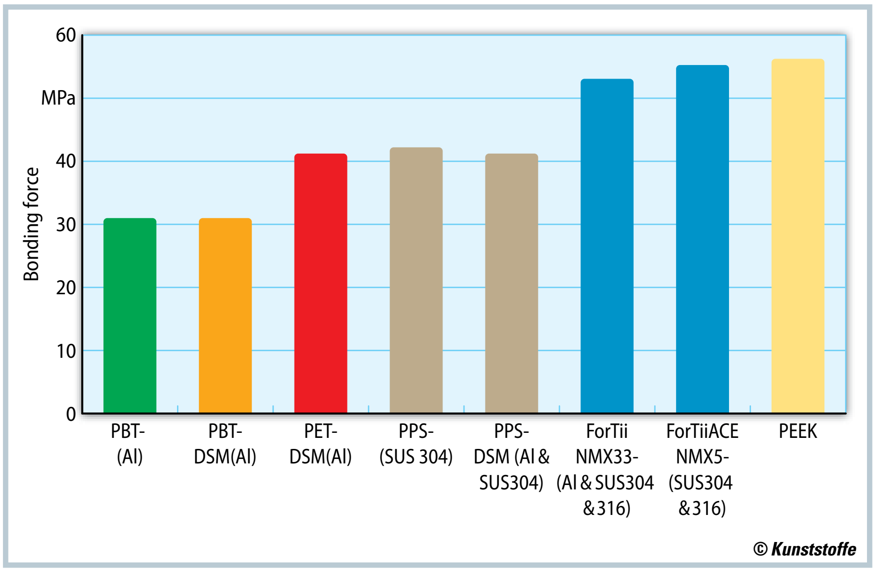


Fig. 4. In a comparison of the bonding strength of various plastics on stainless steel after NMT processing, the new materials stand out with high values (Al = aluminum, SUS 304 and SUS 316 = steel alloys) (source: DSM)

High-Temperature Plastic with Highest Glass Transition Temperature

The quality of the NMT connection is primarily influenced by three factors: The quality of the metallic surface, the defined porosity in combination with the subsequent coating with plastic, and the plastic used in the process. Koninklijke DSM N.V., Herleen/Netherlands, has developed a plastic material that is very well suited for NMT processing with the PPA ForTii Ace presented at K 2016. The chemistry of the C4 molecule permits better crystallization, so that it has the highest glass transition temperature (T_g) in its material class compared to other PPA materials. The high proportion of aromatic compounds also leads to a high T_g of 160 °C. This results in temperature and chemical resistance that is comparable to PEEK. The stiffness at high processing temperatures actually exceeds that of PEEK. Furthermore, the molecular structure of ForTii Ace offers a very high mechanical strength.

The PPA can achieve very high NMT bonding forces with titanium or stainless steel alloys thanks to its polymer structure in combination with the good processing characteristics (**Fig. 4**). In order to adequately coat the micro/nano-pores, the flow and crystallization characteristics of the polymer are of great importance. As soon as the surface structure of the metal is sufficiently filled, the onset of polymer crystallization makes the high bonding forces possible along with a rigid and solid connection.

DSM developed two NMT varieties especially for connections with titanium and stainless steel alloys: ForTii NMX33 and ForTii Ace NMX5. They exhibit peak performance in the bonding strength with stainless steel and titanium (**Fig. 4**). With a melting temperature of 320 °C and 340 °C respectively, connections with these polymers are highly temperature resistant and compatible with subsequent PVD processing. ForTii Ace is suitable for applications where dimensional stability, heat and UV resistance for light colors, or dielectrics are the main concerns. Both varieties are commercially available already. PBT and PPS types for the NMT process are also offered by DSM (**Fig. 5**).

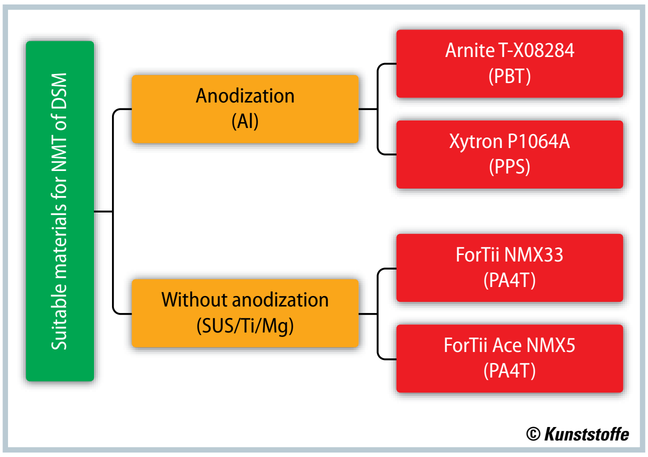


Fig. 5. In addition to the two polyphthalamides that were presented, DSM has other plastics for the NMT process in its portfolio (source: DSM)

Outlook

OEMs currently want to develop new markets including wearables and smart homes. Mobile applications as well as new developments in the connected home and smart cities fields, voice control devices, and drones are leading to numerous new devices that need robust metal-plastic hybrids.

While PBT, PBT/PET, and PPS are commonly used as standard materials in the NMT process today, ForTii Ace polymers from DSM offer characteristics that could previously be achieved only with PEEK. Their chemical, mechanical, and thermal resistance is comparable to PEEK. They simultaneously offer very good dimensional stability and bonding strength with metals, along with a higher mechanical strength. ■