Trends in Smartphones

Since the launch of the first iPhone in 2007, Smartphones seen a huge growth, but have recently matured and start to enter commoditization. The OEM landscape has drastically changed over the past few years. Well-known brands such as Nokia, Motorola, RIM have disappeared, while brands such as Vivo or OPPO that are still somewhat unknown in many countries, based on their strong position in China are now among the top 5 global Smartphone manufacturers and competing with Huawei, towards the third place after Samsung and Apple. In terms of performance, design and features there are large similarity between the players. While due to the expected commoditization, the Electronics OEMs are increasing focus to look after new market such Wearables or Connected Home, the industry is gearing up for some major technology changes in smartphones allowing OEMs to differentiate in a fierce competitive environment. 2017 and 2018 will be very exciting years for the Mobile industry, with not only incremental improvements in performance but in specific also in new hardware technologies such as flexible displays or software breakthroughs such as artificial intelligence enabling the Smartphone to become an even closer companion.

Where do Smartphone OEMs innovate?

In the following, a few focus areas are discussed, where OEMs gear up to differentiate with 2017 and 2018 models incorporating their latest innovations.

New Charging and Data port

While 2016 was important for the first launches of devices based on the new USB-C port, this year will make USB-C mainstream especially on Android devices. The advantages of USB-C are extreme versatility, quick charging and data speed. It offers a single solution for multiple interconnects, to HD monitors, headphones, memory storage and power banks. The data transfer speed is a factor 10 increase over previous generation micro USB2.0 and 3.0.

Faster Chips

Naturally, semiconductor chips will see an ongoing increase in speed resulting from a combination of multicore processor approach as well as faster transistor switching time due to smaller feature sizes. As consequence, Smartphones will increasingly be able to run applications faster and even smoothly play complex games, with high-resolution graphics and support more virtual/augmented reality applications. During CES 2017 Qualcomm announced its latest Snapdragon 835 processors. In terms of speed and power consumption, it sets the new benchmark. The speed increases by 27% based on latest Samsung 10nm lithography. It's 40% lower power consumption over previous generation Snapdragon 820 will notably extend battery life. It's incredible 30% smaller footprint allows manufacturer to design thinner devices and enlarge battery size further. Very probably, the upcoming Samsung S8 will be the first smartphone using the Snapdragon 835 processor.

Outsmarting the Smartphone

Increasing speed combined with high-resolution graphics enables smartphones to run high performance demanding applications such as Virtual Reality (VR). The smartphone can be easily plugged into VR headsets to immerse into artificial 3D worlds or Augment Reality (AR) to access useful information or morph into new gaming options. Objects can be recognized, rooms mapped out and relevant information can be displayed next to the objects. The global success of Pokémon Go demonstrated that Consumers are ready to embrace such new technology. Deep-learning combined with voice recognition, facial recognition and lip reading can increase user convenience a lot and change smartphone into a natural personal assistant. The success of Amazon's Echo platform in the US indicates the broad user acceptance despite some concerns on privacy. The NVIDIA keynote speech at the opening of CES 2017 gave an impressive sneak pre-view into an amazing future and was characterized by various announcements linked to the Google Assistant, Microsoft's Cortana and Amazons Alexa assistants with lots of OEMs having signed deals with the Silicon Valley IT companies.

Faster Wireless Connectivity

While the upcoming telecom 5G network dominates the media with strong showcases at CES among others by Ericsson, Nokia, Qualcomm the current 4G LTE speeds can still be increased significantly by advanced modems. Currently, high-end Smartphones such as the Samsung Galaxy S7 and Apple iPhone 7 have download data rates of 600Mbps and upload rate at of 150Mbps. Depending on the network carrier capability, the newly announced modems with Snapdragon can further boost these download speeds to an incredible 1Gbps speed in early 2017, ahead of the actual 5G prototype roll-out.

To optimize Smartphone performance, having materials with Low Dielectric surrounding the antenna would help to improve Power Consumption and Antenna Radio Performance. In addition, besides the material dielectrics, any devices that offer a high dB Gain in antenna performance would also be advantageous, especially in indoor environment, where building material such as brick or cement would affect the radio frequencies (esp. for high frequencies bandwidth) and that would affect the antenna performance.

Wireless Charging

The global wireless charging market is forecasted to triple from about $4.5Billion in 2016 to more than $15Billion in 2020. In addition to increased Consumer convenience, a key driver behind wireless charging in mobile devices is a better water and dustproof design. There are two major types of wireless charging concepts: radiative charging (RF or microwave based) and non-radiative charging based on inductive coupling. In radiative wireless charging transfer energy through an emitted electric field. Given radiation exposure concerns, radiative wireless charging is typically operating in lower power ranges up to about 10-15mW. Non-radiative charging is based on the coupling of the magnetic field between two coils where the magnetic field of a transmitting coil induces a magnetic field in a receiving coil which in return leads to a current flow. As magnetic fields attenuate much faster than electric fields, the distance to transmit power is much lower compared to radiated charging. Given the lower body impact of inductive charging, this concept has been widely adopted by various manufacturer and has been optimized by coupling coils in resonant mode. Seeing also an increasing spread of public wireless charging stations e.g. at airports, restaurants or coffee shops, we can expect a rapid spread of wireless charging in the near future.

The end of Earphone Cables in Mobile

Apple started a new wave in Thinnovation by obsoleting the 3.5" AudioJack. While initial Consumers' feedback was lukewarm, Consumers will get used quickly to wireless audio. It eliminate needs to carry two sets of headphones and hassle with unwinding earphone cables. Lenovo/Motorola and LeEco already followed Apple in 2016 with first models. We can expect a strong further expansion of wireless audio during 2017 and 2018. The next generation Bluetooth 5.0 will facilitate this growth strongly. A benchmark vs existing lower powered Bluetooth 4.0 reveals an incredible doubling of speed, quadrupling of range while data broadcasting capacity will increase by factor 8 allowing better indoor and outdoor communication through walls. This increased capacity will attract many true audio geeks towards wireless.

The end of switches and buttons

Removal of physical buttons makes waterproof Smartphones easier in manufacturing and reduces hardware complexity. While a few common buttons like home, open and back have already been replaced by touch buttons, it can be expected that soon also volume switches and power buttons will be replaced by 3D-touch and pressure sensitive buttons within the display or body of the phone.

Integrated Electronics

a) Rigid Substrates   b) Flexible Substrates   c) Stretchable Substrates

Figure 1 shows the span of opportunities to integrated electronics directly into a plastic substrate or housing. a) shows the traditional LDS process where electronics circuitries can be transferred onto rigid substrates. b) and c) show a Silver printing technique where circuitry can be printed on flexible or even stretchable substrates.

LDS (Laser Direct Structuring) is an established technology since many years and being applied in various applications, covering a wide range from mobile to automotive to medical, and many more. Manufacturers interested in LDS technology can obtain newest Bio- based compounds from DSM, suitable for low temperature applications as well as applications that require highest peak temperatures, where additional components need to be assembled onto these "3D plastics PCBs" through lead-free reflow soldering. ForTii and ForTii Eco LDS compounds set new benchmarks in high stiffness and good process ability, enabling shortest cycling times and reducing plating time significantly. As such, it is an ideal solution for high performing designs and offers total cost reduction compared to traditional materials such as Polycarbonate. Various grades are available, ranging from UL94-V0 to UL94-HB flammability rating.

To offer designer integration of circuitry such as an antenna onto flexible substrates, DSM has developed compounds and the required technology to apply silver printing techniques and to transfer circuitry onto flexible substrates, based on its Arnitel compounds (Thermoplastic Copolymer).

Samples are available for customer testing. To support OEMs also in their longer term technology roadmaps, DSM has also supports transfer of circuitry onto stretchable substrates based on Arnitel VT films as shown in Figure 1.

Design Innovations

What comes next after metallic Smartphone Casing?

For a long time, Apple is favoring aluminum body designs, a high-end device concept largely acquired from Japan Sony Corp. in late 1980s (e.g. Walkman). Given the high popularity of iPhones, metallic cases of Aluminum, Stainless Steel, Titanium or Magnesium have become a new big trend, which offers a highly valued esthetical touch and feel, combined with superior mechanical performance. Meanwhile in most of the mid to high end models metallic cases has largely replaced plastic housings. While the intrinsic thermal conductivity of metals helped to spread the increasing heat generated by ever more powerful processors, the electrical conductivity of metals caused RF attenuation leading to weaker radio transmission and reception. Grounding the metallic casing and making it an extension of the antenna which radiates itself is a way to overcome the EMI shielding issues of metallic casings. Modern smartphones have multiple antennas: Cellular (GSM / EDGE / 3G / 4G LTE), GPS, Wi-Fi and Bluetooth. In order to achieve good reception independent on the absorption of the hand that is holding onto the smartphone, there are typically two cellular antennas, the primary at the top part of the phone and a secondary cellular antenna, usually located at the bottom of the phone. Depending which of the two cellular antennas has the better reception, the phone can switch between these two cellular antennas. To support such design with good reception efficiency, the metallic casing is typically separated in three parts (see Figure 2 below): the upper metallic back part is connected to the top antennas which double as an antenna amplifier. The main body part is grounded, which the bottom metallic part of the back enclosure is connected the secondary cellular antenna, again double as an amplifier for the cellular antenna.

Figure 2: Different generations of iPhones showing the evolution of antenna separators (Source: manually cut and paste from various internet pictures, logos manually deleted)

The top and bottom antennas need to be electrically isolated from each other. This is the main purpose of the insulating plastic antenna separator, which can be distinguished due to their different color from the metallic enclosure.

At the same time, the latest iPhone 6 and 7 have increased the width of these insulating separators. This is to increase reception efficiency further by using these separators as RF transparent windows so that RF signals can be transmitted to and/or from antenna(s) inside the enclosure. The increased separator thickness also helps to reduce capacitive leakage through the separator. The insulation of the separators has both electrical resistance and capacitance and it can conduct current through both paths. Such separators therefore should have a high electrical resistance. Given the high resistance of insulation, very little current should actually leak. But the capacitive path however is frequency dependent. With the increased data rates of latest smartphones, the increase in separator width directly contributes to lower leakage currents though the insulator.

However, despite all these sophisticated engineering, the physical presence of a metallic enclosure remains non optimum for RF design, especially if frequencies increase further. As metallic enclosures have become more common in smartphone design, it no longer serve as a differentiator among OEMs. Thus new material and design been developed to differentiate among OEMs. 2017 will probably bring a stronger shift towards glass front and back covers. In December 2016 Huawei launched a beautifully designed Honor Magic which was also a highlight during CES 2017. It shall be noted that also the touch and feel in the supplied entirely halogen free USB-C cables is really magic on this phone. There is a very distinct and nice silky feeling in the brilliant white cables.

Glass covers naturally support wireless charging as contrary to metal enclosures. Glass does not absorb any magnetic resonances. At the same time OEMs push the boundaries further, to design esthetic smartphones which are getting ever thinner. Currently the world's thinnest phone is the Vivo X5 with a record thickness of only 4.75mm as shown below in Figure 3.

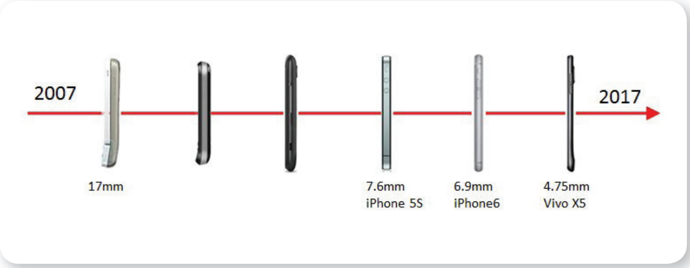

Figure 3: ThInnovation in Smartphone thickness during the last 10 years since the initial launch of the iPhone

While esthetically, an all glass smartphone housing would be an Industrial Designers' ambition, its mechanical integrity may not pass the required product testing, such as drop and tumble, necessary to ensure sufficient reliability when the Smartphones are used by the Consumers'. Combined with the ongoing ThInnovation, we can therefore expected for some of the upcoming high-end models with all glass designs to continue the use of a metallic frame, as long as a fully flexible display is not implemented. At the same time, such a metallic frame can continue to support, acting as an antenna amplifier since there will still be RF attenuation source linked to parts in the smartphone housings (PCB, EMI shields, metallic coatings…).

The selection of metals for frames has implications for mechanical integrity, weight, durability, and finishing processes and effects achievable. Aluminum's low density, recyclability, and low raw material and fabrication cost are attractive. When used in a metal frame, Al-alloys exhibit corrosion during long term usage. Compared to Al, Stainless Steel Alloys could achieve a wider selection of finishing: from matte to high gross finishing; from polished to brushed metal or even fine hairline finishing. Its surface could be treated with Vacuum Metallization (VM), Physical Vapor Deposition (PVD) or even Electrodeposition (ED). PVD could also be considered as an alternative to Ni plating as some consumers are sensitive to nickel and the waste treatment has environmental restrictions. Increased weight (due to higher density factor) could be a concern but the higher mechanical properties also allow for reduced wall thickness. Thus, the net increase in weight for each device might be negligible or perhaps metal such as Titanium (Ti) could be considered instead.

Property	Aluminum	Stainless Steel 304	Titanium
Density	2700 kg/m³	8030 kg/m³	4540 kg/m³
Melt temperature	660 ºC	1399 ºC	1668 ºC
Tensile strength	72 MPa	290 MPa	400 MPa
Elongation	60 %	55 %	27 %
Modulus of Elasticity	70 GPa	286 GPa	116 GPa
Corrosion resistance	Very good	Excellent	Excellent

Nano Mold Technology (NMT) is used to provide direct metal to polymer bonding and is an important secondary processing step which happens before the decoration processes such as anodization or PVD. In NMT, a specially textured metal surface is overmolded with polymer to generate a strong bond. The strength of the bond can be influenced by the metal surface, the processing conditions, and the properties of the compound. Different substrates require different treatments to achieve a suitable surface texture, but the key feature of the surface texture is a multiscale roughness containing but micron and nano features to allow optimum polymer infiltration and interlocking. An overview of the NMT process is shown below as well as an examples of a suitably textured substrate surfaces are shown in the figures below. A strong bonding which avoids trapped airgaps and prevents delamination when conditions or under stress is important.

Moving from Aluminum to Stainless steel poses additional challenges for polymer selection for NMT. For Aluminum, anodization is commonly applied to protect the soft Aluminum surface from scratches and, depending on design, also give it different colors. As anodization occurs after NMT, polymers such as PBT, PBT/PET blends, or PSU have been used as they must survive the chemical process. While anodization is ideal for Aluminum, it does not work for other higher mechanical strength metals such stainless steel or Titanium. As these alternative alloys are very hot candidates to provide structural integrity for next generation smartphones, polymers suitable for NMT which are compatible for alternative higher temperature processing techniques such Physical Vapor Deposition (PVD) are required. As PVD processes typically require 3 hours at temperatures of 150 ºC to 180 ºC the commonly used polymers for NMT are no longer suitable due to the high temperatures. PPS is not an ideal material for external parts which also need to comply to high esthetic requirements due to it spoor UV resistance and poor color-ability. Manufacturers therefore must select from higher temperature plastics such as PEEK or the newest, specialized high Tg & HDT PPAs which compete with PEEK in performance.

The NMT process can generally be described in the following steps:

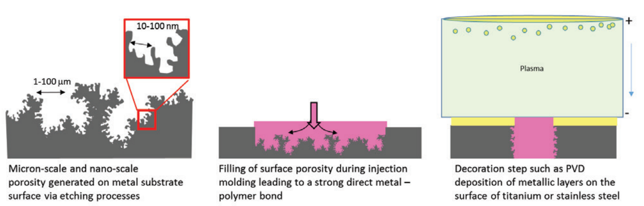

Figure 4 shows the different process step in NMT

a) After substrate cleaning, generation micron and nano-scale porosity on the metal substrate surface. For aluminum, a multi-step wet chemical etching process is used.
b) Once the metal is suitably etched and cleaned, it is overmolded with a plastic compound resulting in a strong, direct metal to polymer bond due to polymer filling of the surface texture.
c) After overmolding, the part may undergo decoration processes such as PVD of metallic layers.

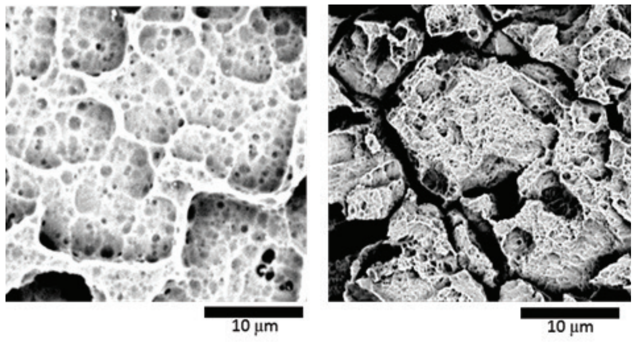

Figure 5 shows scanning electron microscopy images of (left) an aluminum and (right) stainless steel substrate surface suitable for NMT bonding.

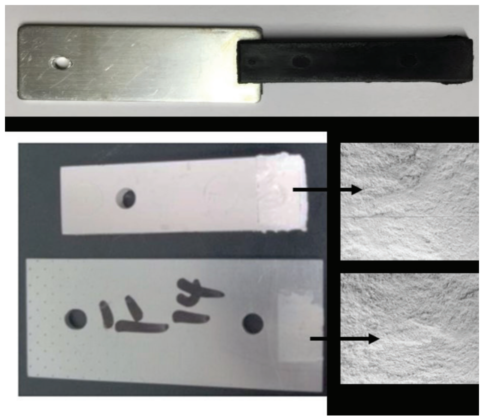

Figure 6: Above is a shear specimen produced with NMT to join the polymer to the metal substrate. Below is a specimen after testing showing that performance was not limited by the interface leading to excellent bond strength.

DSM has developed a new material suitable for NMT based on its high performing ForTii Ace polymer. The uniqueness of ForTii Ace with the highest Tg amongst all PPAs, lies in the chemistry of the C4 molecules, which enables superior crystallization behavior compared to other PPAs. Furthermore, its high glass transition temperature (Tg), driven by high aromatic content, brings the temperature and chemical resistance at levels of PEEK, while outperforming PEEK in stiffness at high processing temperatures. The high polymer/molecular strength of ForTii Ace gives it the highest mechanical strength among all PPAs. ForTii Ace is able to achieve exceptionally high NMT bonding forces with titanium as well as stainless steel and related alloys. This is because of its high polymer strength as well as excellent process ability. Essential for good bonding via NMT is control over flow and crystallization to allow sufficient filling of the micro/nano pores. Once the metal surface structure is sufficiently filled, crystallization ensures excellent bond strength and high stiffness and strength of the compound. Specifically, for bonding to Titanium or stainless steel alloys DSM has developed two dedicated NMT grades ForTii NMX33 and ForTii Ace NMX5. For applications where dimensional stability, light colors resistance to heat and UV or dielectrics are playing an essential role, the ForTii Ace polymer is an ideal candidate. Both grades are commercially available, enabling designers to realize next generation all-glass casings or other creative metal to plastic bonds that require highest performance and esthetics.

NMT as an elegant technology to bond metal to plastic being used in various applications and many different industries such as industrial, aerospace or automotive. It should be noted that DSM is offering a full NMT portfolio to our customers covering specifically also PBT and PPS compounds. This broad portfolio enables manufacturers to obtain material and application support for various designs and industries through one focal point.

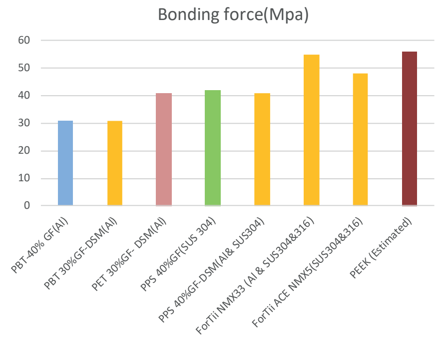

Figure 7: Bonding strength of different plastics to stainless steel through NMT process

Figure 7 shows the bonding strength of some common plastics used in NMT process to stainless steel. The ForTii NMX33 and ForTii Ace NMX5 compounds showing the highest performance in bonding strength to stainless steel as well as Titanium. Moreover, with a melt temperature of 320 and 340°C, respectively. These compounds show the highest temperature resistance being fully compatible to the extreme temperature conditions during the PVD process. Bond force for PEEK is an estimate while the others are measured values.

Customizing Smartphones

A trend already now has been customizing smartphones. Dutch company Fairphone and well-known Alphabet's Google Ara project set the direction to more OEMs looking into modularity to offer not only customization but also easy replacement and upgradability of certain components while still keeping performance, quality and esthetics of the smartphone at a high level. Phones like to the Moto Z or LG G5 were the latest entrants in this arena.

Eliminating the Display Bezel

Figure 8: Xiaomi Mi Max

The Mi Mix, designed by French designer Philippe Starck, is distinguished by its ceramic body and the near-edgeless display that covers 91 per cent of the phone's front surface area. The user sees almost no bezel surrounding their screen. The Mi Mix handset is made in polished black ceramic. To allow the screen to extend to the top edge of the phone, Mi Mix's front-facing camera is located on the bottom bevel, and the usual phone speaker is replaced by a piezoelectric ceramic driver that sits behind the display.

From Edge to Bend to Flex

In 2017 we could see new designs based on flexible OLED displays rather than the traditional rigid LCD panel. While initial concepts of Samsung and LG enables some minor bending of the phone and cool designs with a curved edge, the actual desire is to have real flexibility in the display such as showcased by Samsung or lately also by Lenovo during its Tech World 2016. Both the Samsung as well as Lenovo models are not yet commercially launched, but they give a preview about what is in the pipeline.

Conclusions

Since the Smartphone as an application is maturing, the push to innovate in design and features is rapidly increasing. From small Startups to global multinationals, huge effort is put into new design concepts allowing differentiating in a lucrative multibillion dollar market. 2017 will bring many new models with a clear trend going away from Aluminum enclosures to glass or ceramic with metal frames of higher mechanical strength such as stainless steel or Titanium. Such designs can rely on proven plastic to metal bonding techniques based on high performing DSM engineering plastics which are proven in some first advanced concepts just being launched in 2017. While standard NMT technology is widely available on PBR, PBT/PET and PPS base, the new ForTii Ace compounds of DSM raise the bar to the level of PEEK with comparable chemical, mechanical and thermal resistance, while offering very good dimensional stability and excellent bonding strength in specific developed towards higher mechanical strength metals. ForTii Ace allows designers to go beyond current material capabilities to realize the next innovation jump in Smartphones.

For 2018 we can even expect some real "Star-Trek" technology making its way from laboratories to the mass market. Bendable or flexible displays will further enrich the design space and pave the way towards holographic displays such as prototyped in the Holoflex concept of researchers from the Human Media Lab at the University of Kingston in Canada. For the time being the required additional grid of micro lenses on top of the display pose some resolution limitations, it is however a perfect proof of the concept. Other techniques based on nanotechnology have been shown by the Californian start-up Leia 3D prototyping 3D displays with the extra need of special glasses. Soon we can see first commercial models opening an entirely new user experience.