Nano-enhanced automotive plastic glazing

Driven by the need to reduce vehicle weight, the desire for more design freedom, and for higher levels of safety, the automotive industry has been investigating the substitution of mineral glass windows by polymers (more specifically polycarbonate) glazing for decades. However, until recently some key performance specifications had not been reached; scratch resistance and long term ultraviolet (UV) resistance remained challenges. Recent advances involving nanotechnology are helping polycarbonate (PC) window developers to overcome these challenges. Due to these advances the automotive sector expects that in 2020, 20% of automotive glazing will be produced from PC. Hence, global PC revenues are expected to experience exponential growth in the automotive sector given market indications from 2008. This BRIEFING explains how advances in nanotechnology using nanoscale additives to create compounds with new properties can improve the abrasion resistance and weatherability of PC glazing, and therefore contribute to the penetration of PC glazing in the automotive industry.

Polycarbonates (PC) are transparent, hard, strong and tough thermoplastics that can maintain stiffness up to 140°C. However, limited chemical and scratch resistance and a tendency to yellow upon long term exposure to UV light have been constraints to the use of PC in automotive glazing.

Nano-enhanced functionalities

By utilising ultra-hard nano-scale silica particles embedded in a coating matrix material, scratch-resistant coatings that are transparent can be obtained even though the particles themselves are not transparent. Other nanoparticles offer similar combinations of functional protection and transparency. Exploiting this effect (and other nano-effects related to surface behaviour), nano-coatings for automotive glazing applications can offer hydrophobic/anti-smudge, UV and infra-red (IR) shielding, and anti-fogging functionalities (the usual basis of these coatings is an organic modified siloxane filled with nano-scaled silica particles).

Figure 1 illustrates the presence of nanoparticles within the automotive glazing coating. Nano-enabled coatings in PC have a thickness of around 1mm that usually, but not always, combine an external anti-scratch/easy-to-clean nano-scaled coating with an internal coating that prevents fogging and visible condensation on PC. All coatings incorporate UV stabilization components[1]. The additional functionalities offered by such nanotechnologies are summarised in ***Table 1***.

Plastic glazing is now taking off, after several false starts, due to increasingly strict CO_2 emissions legislation in all leading industrial nations. Materials such as PC are up to 50% lighter than glass; this can lead to a 50% reduction in the weight of panorama roofs and windows resulting in significant reductions in fuel consumption and CO_2 emissions. Weight saved in the upper sections of the vehicle allows for reductions in the weight of other vehicle parts due to the centre of gravity moving closer to the road. Therefore windows, and especially panorama roofs, are interesting candidates for the use of such nano-enabled lightweight materials. In parallel to this increasing market pull, continuous R&D

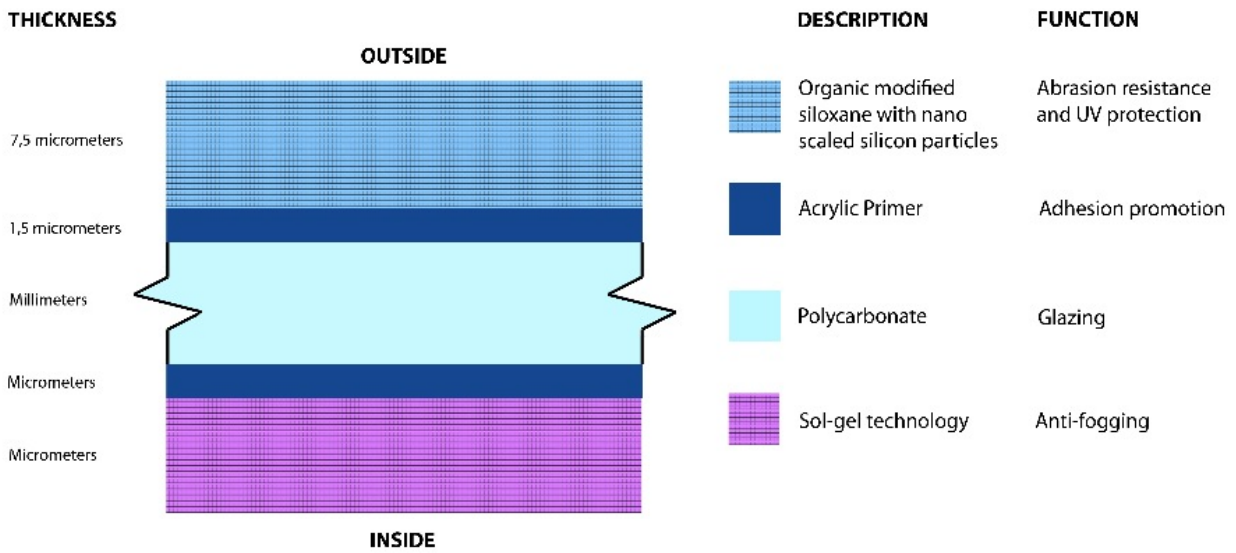

Figure 1: *Cross section depicting nano-enhanced layers in automotive glazing coatings*

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Function	Typical technologies	Nano-components
Abrasion resistance	Physical vapour deposition, chemical vapour deposition, others	Coating filled with nano-scaled anti-scratch ultra hard particles (various metal oxides including TiO_2, SiO_2, Al_2O_3 or mixtures thereof)
UV-protection	Silicon Hard Coating	Zinc oxide (ZnO) and titanium dioxide (TiO_2) nano particles.
Anti-fogging	Sol-gel technology and others	Surface tension due to nanoscale surface geometries based upon titanium oxide (TiO). Others coatings have been developed by alternating layers of silica nanoparticles and polyallylamine hydrochloride.
Easy-clean	Various metal oxides made available to the air	Nano-particles (TiO_2) with photo-catalytic behaviour in air when exposed to UV rays
Decoration	Inks and pastes	Not significant in most cases, some advanced optical effects may require nanoscale coating layers or particles

Table 1: *Summary of desirable properties for automotive glazing and corresponding nano components*[2]

and upscaling advances have resulted in the technologies involved reaching the level of maturity required to move from smaller niche applications to full mass commercialisation.

Although automotive windows are by far the largest potential market for nano-enhanced PC windows, they are by no means the only application area. Vehicles for any mode of transport (marine, road, air, rail, or military) could be expected to increasingly incorporate polymer windows.

Impacts

Economic/Industry

Global PC demand in 2008 is estimated at around 3 million tonnes; global capacity in that same year was some 4.3 million tonnes. Despite this overcapacity, large industries are planning further expansion of their production capacity, particularly in Asia where the largest market growth is expected. In other parts of the world demand is also expected to grow, leading to an expected demand of 4.6 million tonnes by 2013.[3]

The automotive industry only constitutes 13% of the global nano-enhanced PC demand; in fact the biggest markets are for flat screens and CD's (CD, DVD, CD-ROMs, Blue-Ray disks, etc). At present the automotive market for nano-enhanced PC is mainly represented by tail- and headlights, with some applications also found in transparent interior parts. Up to now, nano-enhanced PC glazing is of only anecdotal importance, with first applications in Seat Leon, Smart Fortwo, and Alfa 156-159 models. However, industry leaders predict that global nano-enhanced PC demand for automotive glazing could reach between 100,000 tonnes and 200,000 tonnes by 2014[3]; an exponential growth given the current estimated consumption in this particular application of only around 3000 tonnes/year (2010). This growth will be driven by a wider adoption of existing solutions (rear side windows for example) but also by PC entering into applications previously not found in the market (such as panorama roofs, truck rear windows and others). Indeed, glass manufacturers see the nano-enhanced PC material as a threat to the current global market for automotive glass estimated to be worth around € 4.8 billion annually[4].

To reach quality and cost requirements of the automotive industry, new techniques that go beyond the conventional in machinery, moulds, materials, and processing methods were required. To address these needs, several PC market leaders have created subsidiaries that cover the step from PC raw material to that of a finished, ready-to-be installed PC window.

The nano-enhanced PC value chain (***Figure 2***) runs from the raw material supply (bulk containers of

Figure 2: *Polycarbonate glazing value chain*

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PC pellets) through to the distribution of a ready-to-install finished window that includes functional layers, printed-on masking and, if applicable, defrosting circuits. Substantial economic added value is generated in the coating process and trading chain steps; the total mark-up of the nano-enhanced PC is around 50-100% on top of the raw material cost. Most nano-enhanced plastic glazing European companies buy the PC as raw material (at present the price is around 2.70 €/kg) and sell the added value parts to the automotive industry; covering within their organization all the steps between raw material supply right down to delivery just-in-time to the automotive assembly plant.

Technology Readiness Levels

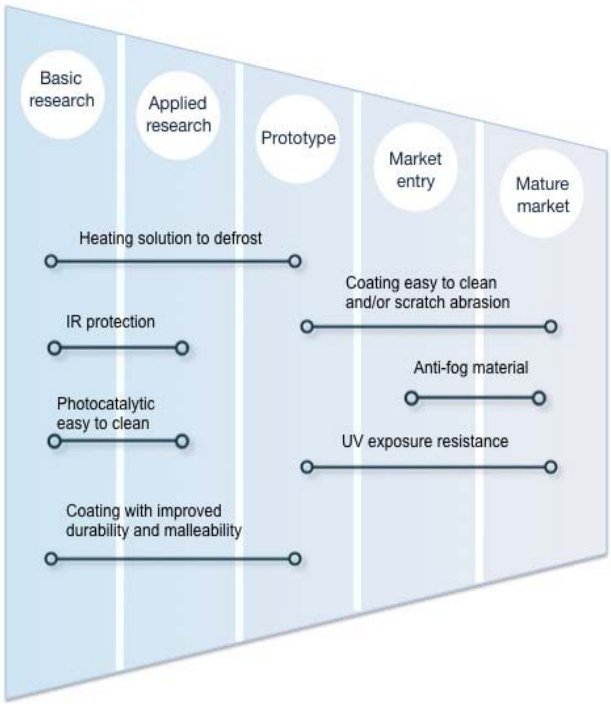

Figure 3: *TRL for nano-enhanced glazing materials*

Challenges

One of the remaining limitations of PC windows is the level of scratch and impact resistance obtained with the current nano-enhanced coatings. Therefore one of the key challenges to be overcome is that of improving abrasion resistance, which would allow for PC windows to also be applied in windscreens and main side windows.

This performance level at present allows for PC to be applied in windows that are not subject to active abrasion (not moving up and down) and are not exposed to windscreen wipers. Therefore, the most achievable applications, at this time, are for rear (and full front) side windows, panorama roofs, and small rear windows not exposed to rear window wipers.

This application barrier is not just a technological one. Based on the common perception of performance limitations of PC windows especially in windshields, European regulations and standards explicitly forbid the use of PC in such windows. PC window manufacturers are working with EU standardization bodies to explore adaptation of such standards if and when proof can be provided of PC nano-enabled windows meeting the required specifications. However, an amendment to EU standard ECE43R is expected at the end of 2010, which would allow PC to be used in front windscreens.

There are a number of other important barriers for nano-enhanced PC to overcome before it can overtake glass in automotive applications:

- The performance of the glass over time is stable. It maintains the same properties almost 'forever', whereas the performance of nano-enhanced PC decreases.
- The industry structure and established partnerships of the automotive industry (glass industry, headlamps industry…) does not facilitate easy introduction of new technologies in cars.
- The nano-enhanced PC industry competes against the glass industry, which is also making big efforts in terms of weight reduction, design freedom, and crash behaviour in order to maintain their market share in the automotive sector.
- Plastic glazing (contrary to mineral glazing, made with sand) is produced with oil. European oil dependency is already greater than desired and causes price instability.
- A key disadvantage of PC remains the cost; a material based on oil tends to be more expensive to manufacture than sand-based glass even if glass production is highly energy intensive.
- The total CO_2 footprint and Life Cycle Assessment (LCA) of PC windows (being sourced from fossil fuel) still needs to be objectively compared with the footprint and LCA of glass windows.

Impacts

Societal/Impact on European citizen

Replacement of glass with PC windows can reduce car weight by up to 20 kg, depending on the car. Taking into account knock-on effects caused by centre of gravity advantages the cumulative weight reduction could be some 20-25% higher than the direct impact.[5] This weight reduction leads to a reduction in fuel consumption and CO_2 emissions during its lifetime. The automotive industry estimates that a 10% weight reduction can lead to a 6-8% improvement in fuel usage and thus a 20 Kg of CO_2 per kilogram of weight reduction over the vehicle lifetime.[6]

TRANSPORT: Nano-enhanced automotive plastic glazing

Reducing weight, especially in the upper sections of the vehicle, also facilitates better braking behaviour, reduces collision impact, and offers a superior driving experience. In addition to performance, safety is a main driver in transport applications; crash injuries involving plastic glazing are substantially reduced when compared to glass. Anti-fog and easy (self) cleaning properties can further increase safety and comfort for the user.

Ethical and societal aspects

As in other industries applying engineered nanomaterials, employees' safety is a concern to which the precautionary principle should be applied. There is current political and stakeholder debate on how to put this principle in practice while uncertainty remains concerning the health and environmental risks of such nanomaterials to employees and the consumer.

Other than the issues discussed, no information has been identified on any other currently debated ethical or societal issues specifically related to the nanotechnologies and applications highlighted. General issues including the need for responsible sustainable development of the technologies, products and processes, and furthering social and global justice also apply in this case.

EU Competitive Position

EU headquartered Bayer is in a leading position both in terms of production volumes as well as in terms of connections to the automotive value chain. On top of that, several main research institutions and highly innovative smaller companies are based in Europe (such as GXC-Coatings). Additionally, some large PC suppliers with headquarters outside of the EU do have substantial EU based research, production, and marketing activities and thus further enhance the European capability to bring the results of such research to the market. Finally, the presence of innovative car makers provide opportunities for strategic collaborations such as those between Bayer and Daimler.

Outside Europe, and especially in Asia, players like Mitsubishi Chemical Corporation (JP) and Teijin Chemicals Ltd (JP) have increased their interest in these applications and have developed their own new nano-enhanced plastics.

Several industry inventories have identified companies such as Exatec and its mother company Sabic Innovative Plastics, Bayer Materials Science under the Bayvision brand (DE), Mitsubishi Chemical Corporation (JP), Momentive Performance Materials (US), Teijin Chemicals (JP), Schott HiCotec (DE), Freeglass (DE), INGlass Group (IT), Clever-Glass (CZ) WebastoAG (DE), Dynamit Nobel Kunstoff (DE), GXC Coatings (DE), LeyBoldOptics GmbH (DE) as global industry leaders.[7]

Summary

- Vehicle glazing can be made from PC, rather than glass, to produce lighter weight panoramic roof, side and rear windows.
- Advanced glazing is projected to have significant energy saving potential; however, several technological and market barriers are slowing down market introduction and penetration.
- Vehicle designers are increasing the glazing area of cars; using glass, the result is increased vehicle weight. Plastic glazing opens up new possibilities in the light weighting of vehicles, styling, and part integration.
- Nano-enhanced PC is already used in side windows, rear windows and panoramic sunroofs (current regulations do not allow PC windshields and moveable windows, as they could be damaged by the wipers and moveable windows may scratch)
- Promising functionalities of nano-enhanced PC glazing include abrasion-resistance, weatherability, and anti-fog properties.
- Anti-fog and hydrophobic coating for PC glazing can also improve the safety of the car; the crash behaviour of PC windows is superior to that of most mineral glass windows
- Barriers remain to be overcome; the performance of glass is still better and maintains the same properties over time. In addition, glass windows can add stiffness to the car body. Moreover glass industry innovations in new laminated glass windows also offer improved crash performance and reduced weight.

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