Interdisciplinary Approach to Nanomaterial Based Coatings

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1. Introduction

Coatings with special properties play an increasingly important role in science and technology. The surface properties of materials or components in many cases strongly define a great deal of the application properties as well as the areas where these components can be used. In addition to this, very often the specific functions attributed to the components only can be obtained by an appropriate coating. For example, simple window glass, the basic function of which is to separate indoor and outdoor, obtains their different functionalities only through special coatings, such as anti-reflective, heat reflective or self-cleaning coatings. In the area of glass, vacuum or gas phase deposition techniques are widely used. Fully automated coating lines like magneton sputtering are mounted on line to the float glass line. That coating technology providers in this case are companies which develop, produce, and maintain these lines for the user companies. Due to the fact that large-scale/large area coatings are produced by these technologies, the material providers (target materials) business is sufficient for him to develop the needed ultra pure materials. Other typical examples for large-scale coatings are automotive and architectural paints and lacquers. The situation changes completely for low-volume or low area applications, which in general are resulting in low material consumption. In this case, the material provider has a problem to obtain a sufficiently high return of invest by the material sales, facing high development and production costs. Nevertheless, there exist many highly interesting applications based on low material volumes. Especially, innovative and flexible small and medium-size enterprises, in general, need highly specialized coating materials for the competitiveness of their products: But not only the availability of the material, but also the existence of an appropriate application technology very often is the bottleneck for coating material users. A second large area for the utilization of special coatings are large companies, if they need high-performance coatings on special products, which at the end do not sum up to large material volumes. In addition to this, very often these companies either don't have the skills or are not willing to build up the facilities for special coating applications. Again, the competitiveness of systems or end-user products of these companies are affected by the non-availability of the specific coating in question.

Whereas the materials question is not so stringent if the needed added value is obtained through the coating system (e.g. vacuum coating), the situation changes completely if the scale of the material has to bring in profit. Due to the fact that selling material means operating on the lowest value-added level, small volumes of materials are just not developed by the classical material providers, which to a great deal is represented by the chemical industry. It never has been the business of chemical industry to develop and provide small amount of materials, to develop the specific coating technology or to carry out the coating procedure.

2. The role of materials

Materials, directly or indirectly, are the basis of over 70% of all important technologies. Each innovation in materials has a tremendous effect on technological developments, too. In addition to this, approximately 70% of the materials users in industrialized nations are small and medium-sized enterprises. As a rule, these companies neither have skills nor the financial backing to take over the burden of 10 years coating material developments in order to bring the new product to the market. This means that a gigantic bottle neck opens up in supplying tailor-made coating materials for thousands of specific applications.

Innovation in materials needs tools. Chemical synthesis is able to provide a great deal of these tools. This is documented by the scientific literature very clearly. A new and fascinating tool for property tailoring is provided by nanostructures in materials. Nanostructured materials are accessible through nanoparticle technology. Nanoparticle fabrication can be carried out by various means, such as gas phase reactions or liquid phase reactions. Due to their very high surface area, the chemical behavior of the surface is dominating all other processing steps. Appropriate chemical surface modification advantageously can be carried out in liquid phase. Liquid phase technology can be carried out easily in closed systems, a technology to be widely used in chemical industry. Any contamination can be avoided through these technologies, which is a very important issue for the acceptance of these new technologies. This means, if the described approaches can be combined with the needed interdisciplinary new routes to application, high-tech coating materials can be provided for industry on a wide scale.

3. The interdisciplinary approach

The bottlenecks caused by the market requirements in supplying low volume coating materials are facing an abundance of scientific results, where many new materials with fascinating properties are developed day by day by many brilliant researchers. These materials in most cases lead to scientific publications, but only in a few cases to patents. Patents, however, are necessary in order to make use of the developed materials in industry. Without patent protection, copying of material based technologies is easily possible, being a very serious obstacle for commercialization. This means, if one thinks to improve routes to the market, the existing scientific career structures aren't very helpful, since they force researchers to publish their results as fast as possible. But even patent application, an indispensable first step, not necessarily leads to improved materials utilization, since the problems coming from market requirements and the technology development not automatically are solved through this. The question arises whether, academia, beside the scientific part, can take over a part of the development of material based coating technologies. For this, a series of different technologies are required, which have to be organized in the well-managed way. These disciplines, as a rule, are chemistry, physics, materials science, chemical engineering, materials engineering, processing, molding and shaping, mechanical engineering, production technology, modeling and quality assurance. The problems of academia to fulfill these requirements in a well-managed way become obvious: Appropriate structures are the real exception, even in large development centers (such as national laboratories or R&D centers of large research organizations). This never will change, if we don't change something in the carrier motivations of the researchers: researchers should have the choice between the pure scientific career and the application oriented carrier, where he participates in the benefits generated on the basis of his work.

In order to improve the figure of merit of material science and development (ratio between financial input and industrial output), we have to build up appropriate organizations, having so-called vertical interdisciplinary structures (fig. 1). In the world with an increasing number of unsolved problems (e.g. energy, nutrition, health), we cannot afford to leave important scientific results to the publication of wonderful papers only.

Fig. 1 illustrates the vertical versus the horizontal interdisciplinary. The mostly employed model for interdisciplinary collaboration is the horizontal model. The horizontal collaboration is of high importance for the generation of new basic results. It only can be brought to the market place through collaboration with very large material oriented companies having the vertical interdisciplinarity in-house. But there are only a limited number of them around the world. The vast majority are materials users without own development capacities. The vertical interdisciplinarity is hardly practiced in academia. Important reasons are, as already mentioned, carrier problems as well as important, structural and organizational problems.

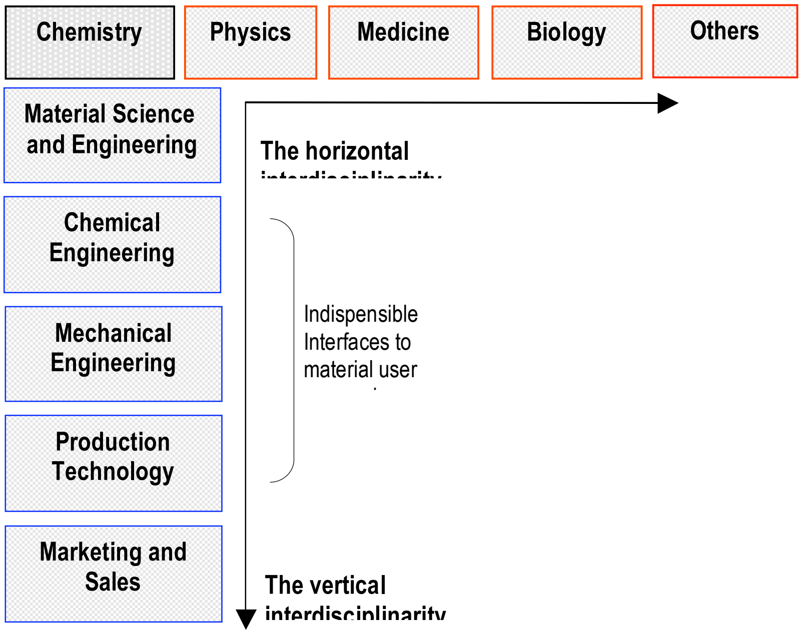

Fig. 1. Sketch of horizontal versus vertical interdisciplinarity in the area of material development as an example

In order to improve the above-mentioned figure of merit, it is necessary to develop R&D structures being able to provide flexible interfaces to all types of industrial levels, to companies which are able to utilize basic results as well as to companies which only can use already developed technologies or even turnkey technologies. These are more or less uncritical technology areas with only one or a few disciplines, necessary to reach the marketplace, for example in software development.

4. Development Examples Using The Vertical Approach

4.1 The Nanoglass Coating For Moldable Stainless Steel Surfaces

Coatings with glass-like materials on metals are well known in form of enamels. They are known to be brittle, inflexible and not at all impact resistant. Moreover, due to the necessity to adapt the thermal coefficient of extension to the substrate, fillers have to be used which make the coating nontransparent. This may be alright on mild steel, but stainless steel by itself has a very nice-looking and shiny surface. However, the surface is scratch sensitive, not tarnish resistant at higher temperatures and, most important, not fingerprint resistant. in order to overcome these problems a thin glass film coating technology has been developed with a glass structure consisting of silica nanoparticles surrounded by the network modifiers. A model of the structure is shown in fig. 2. The conventional silicate glass structure is based on SiO_4^{4-} tetrahedrons (fig 2 b), the corners of which are either linked to another tetrahedron or to a network modifier. This structure leads to the typical glass-like properties, that means a high brittleness and a strongly reduced softening point compared to fused silica.

The high brittleness makes it impossible to bend or to deep draw glass coatings. In the nanostructured type (fig. 2 a) the silica network structure is present in form of nanoparticles, linked together by the ionic type of network modifiers surrounding the nano-particles. It was expected that this interface would be plastically deformable, leading to a deformable coating, too. Based on these considerations a coating technology has been developed using a multicomponent nanostructured glass.

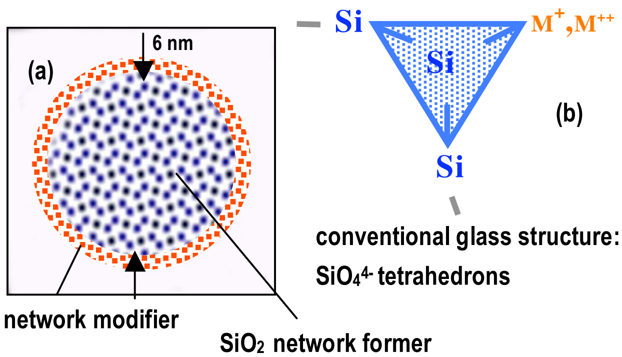

Fig. 2. Comparison between a nanotype and a conventional glass structure

The coating was used for stainless steel iron plates. After coating and curing, the plates are fixed to the construction by a bending and molding step. The new coating is highly abrasion resistant and does not change the appearance of the stainless steels surfaces. The coating thickness is in the range of about five micrometers, hardly visible and was introduced into the market by one of the worldwide largest suppliers of household goods. To build up the project, a period of about five years of basic research has been carried out, investigating the processing and properties of materials based on silica, MTEOS and TEOS and alkaline metals for nanoparticulate binder and coatings. These investigations were carried out by INM within the frame of various projects focused on coatings on steel and glass. As a result INM was approached by the world leader in household goods who was interested in utilizing these systems for the coating of iron plates. After clearing up the patent questions, a new company (EPG) was founded in order to build up the production technology for the plates. EPG placed an R&D order to INM, and was permitted to rent INM facilities to carry out pilot and test production as well as the quality assurance procedure. After a nine-months development period a production technology for the coating of 35.000 plates per week has been established.

Fig.3. Iron plate as it is available on the market

Meanwhile, the technology of making stainless steel resistant against fingerprints, tarnishing and scratching is built up for many other areas by EPG. This is an example, how through a close collaboration between a public institution, a global player and a new development company new products can be brought onto the market in a short time to a mutual benefit.

4.2 Highly Scratch Resistant Polyurethane Clear Coats

The need for new coatings with superior scratch resistance is still large for many applications, such as automotive coatings and coatings of any type of plastic. In most cases highly transparent coatings are required. Polyurethanes are of high interest for their high environmental stability. However, despite many attempts, no really satisfying solution has been developed, so far. For this reason, a new type of polyurethane has been developed in a Ph.D. thesis [1]. The structure of this star type polyurethane is shown in fig. 4. In order to connect the silica nanoparticles strongly to the polyurethane backbone, the surface is modified by an epoxy silane as diol source and a blocked isocyanate is used. By hydrolytic ring opening of the epoxy and the deblocking of the isocyanate the polyurethane bonds is formed starting from the silica nanoparticles as shown in fig. 4. For the commercialization of this technology, a strategic partnership has been formed by a global player dealing with the mechano-chemical fabrication of surface modified nanoparticles and an automotive coating supplier. Depending on this silica content, the abrasion resistance determined by the taber abrader method measuring the weight loss, the new coating is up to 40 times more abrasion resistant then conventional clear coats. The technology transfer model: four years of basic research based on basic funds of INM, exposition of the results at Hanover fair, acquiring customers and starting the technology work in form of projects for commercialization with global players.

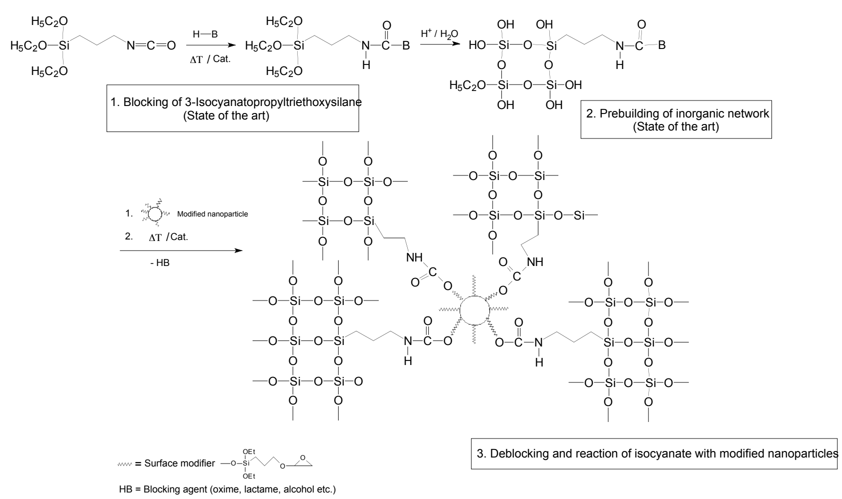

Fig. 4. Scheme of the preparation of the new star type transparent and abrasion resistant polyurethane clear coat [patent pending]

4.3 Antimicrobial Coatings

The third example relates to the fabrication of anti-microbial coatings on top of in-ear hearing aids. In-near hearing aids become very common due to their almost complete invisibility. However, due to the formation of a “closed system” in the year, generating a moist atmosphere, inflammations are very common, too. For this reason, an anti-microbial coating has been developed by INM based on a nanoparticulate controlled release silver system. In order to make the system more efficiently, the surface of the coating has been equipped with an antiadhesive property, automatically developed by the formation of a gradient during the curing step. At INM, based on its interdisciplinary vertical structure, the whole technology has been developed. The production technology for the coating material has been developed by EPG, which now is the producer and supplier. The new in-ear hearing aids are very successful on the market and sold worldwide.

5. Summary

In summary, it is to say that using new strategic approaches for development and commercialization, global new technologies can reach the market place which otherwise never would. The close collaboration between public and private institutions on the basis of a mutual benefit is an important basis. This only can come into action on a broader scale, if appropriate career, management and vertical structures are established in public research.

6. References

[1] Ph. D. thesis of Mr. Martin Kluke (in print)