coatings

Editorial

The Engineerization of Physical and Chemical Phenomena

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There are a number of concepts in materials science that are only ambiguously described in the literature and/or are not completely understood. A logical analysis of these concepts may allow a better understanding, correct dissemination, and a progression in knowledge in this area of science. This sort of in-depth philosophical analysis can be very easily approached and potentially applied to a number of scientific concepts, thus becoming a novel important tool for the progression of knowledge in this scientific field. For instance, let us consider the possibility of developing a definition of functional materials that is an alternative to that currently used definition in the literature. It is not easy to provide a general and strict definition for these types of materials. Materials are typically distinct in terms of structural and functional types. Structural materials are comprehensively defined as materials capable of bearing loads. In contrast, accurately defining a functional material class is much harder than distinguishing the structural counterpart. Overtime, different definitions have been formulated for functional materials [1]; for example, they have been defined as: "those materials able to respond to magnetic, optical or electrical stimuli". However, such a form of definition can be perfectly adopted for sensing devices, but it is quite limiting for a more general case. In a device, the functional material is the "active material" that imparts the functional behavior to the device as a whole, while the exact response of the device is determined by the structure and how the functional material is integrated with the rest of the structure. Functional materials have been also defined as "those materials which possess particular native properties and functions of their own". Again, they have been referred to as: "materials that can undergo controlled transformation through physical interactions", or also as: "materials whose 'function' is associated with their electric, magnetic and/or optical properties". Surprisingly, there are also definitions based on what they are not, such as a "material which is not primarily used for its mechanical properties, but for other properties such as physical or chemical". As observed, these definitions are not really general and the formulation of an alternative definition for the functional material that is more satisfactory, clear, and universal is pivotal.

The word "engineerization" is currently used in the literature, and it can be usefully adapted to develop an alternative definition for the functional material class. Although this word has been coined in chemistry and in chemical engineering to indicate the industrial scale-up of a chemical or biochemical process (that is, the conversion of a laboratory-scale chemical or biochemical process to the pilot scale and finally to the production scale), the same word can be extended to all physical and chemical phenomena, comprising a meaning of industrially (technologically) exploiting these processes. With this preface, a novel definition of functional materials can be proposed. Functional materials are technologically useful materials based on the engineerization of some physical or chemical phenomenon. The engineerization of all physical/chemical phenomena is potentially possible for producing a functional material. This novel definition can be clarified by a few examples. Among many chemical processes, let us consider, for example, the ability of zeolites to react with gaseous acid. This reaction is known as deallumination. Therefore, zeolites nano-powders can be used as irreversible molecular traps for gaseous acids such as acetic acids [2] because of their high surface development and the ability to chemically react with acid molecules.

Nano-sized zeolites powders represent a functional material of natural origin since it allows the simultaneous engineerization of the following phenomena: (i) deallumination reaction, (ii) high surface development, and (iii) fast adsorption kinetics (due to the small size of grains). A further example could be based on magnetite: This mineral is not a functional material, but it corresponds to a magnetic substance. In contrast, a magnetite-polymer microcomposite (dispersion of micrometric magnetite powder in a polymeric matrix) is a functional material (plastic magnet) since it is based on the engineerization of the magnetism phenomenon characterizing the filler. Functional materials do not identify with the physical (or chemical) property but with the engineerization of that physical (or chemical) property, which is the fabrication of a hybrid material, and its working principle is based on that physical phenomena. A magnetic and transparent magnetite-polymer nanocomposite is a multifunctional material because it results in both optically transparent and magnetic properties. In particular, when the same functional material is adequate for more than one application, it can be defined as "multifunctional" since it has different characteristics that are potentially useful for technological applications. In this case, more than one physical–chemical phenomenon undergoes engineerization in the same material. Multifunctional materials are usually considered as superior to unifunctional materials. However, is this idea really correct? A multifunctional material should be a material optimized at the same time for two, three, or more properties. Can a single material be really the optimal one for more than one application? The high specialization of materials, which is desirable for the industrial applications, clashes with the concept of multifunctionality. Too many compromises are needed in multifunctionality; consequently, unifunctionality should be better than multifunctionality. The availability of selective sensors, monochromatic light sources, specific rapid tests, etc., prove that unifunctionality should be a fundamental factor for most high-performance materials.

It must be pointed out that this definition developed for the functional material class can also be applied to the structural material class. In fact, it is possible to say that all technologically useful materials are based on the engineerization of certain phenomena that, when they are of a mechanical type (e.g., high tensile resistance, excellent surface hardness, high toughness, high wear resistance, etc.), provide origins to a structural material; on the other hand, if they are of a physical or chemical type, they should produce a functional material. For example, nanostructures, such as carbon nanotubes (CNTs), can be technologically used both for their mechanical and physical properties. Depending on which property is involved in the engineerization process, a structural or a functional material results. If, for example, engineerization involves the high mechanical resistance of carbon nanotubes, similarly to the case of CNT-polymer composites, a structural material is achieved.

Functional composite materials (FCMs) represent a very powerful solution for many modern technological problems. The most recently developed functional micro- and nanocomposites, based on the incorporation of nanostructures and advanced artificial materials in a powdered form such as graphene, carbon nanotubes, fullerenes, metal nanoparticles, perovskites, etc., in matrices of different nature (i.e., ceramics, polymers, metals) belong to this important material class. Currently, an increasingly large number of scholars are involved in the development of new types of FCMs; consequently, the development of this special material class constitutes a very broad and fruitful field of research. FCMs are complex multicomponent solid systems. The different components are both molecular and solid (eventually nano-sized) in nature. The functional materials contain a structural component, usually consisting of a polymer (thermoplastic or thermosetting resin), that has the function of making a self-supporting and easy to handle material. One or more molecular or solid (particulate) components with precise functionality are also required to allow this complex system to work. Typically, a few phenomena are exploited together to produce useful FCMs; however, it is possible to take simultaneous advantage of a number of phenomena in the working mechanism of FCMs (in some cases, the functional properties are achieved synergistically by combining two or more components). Let us consider some examples of how a functional material is achieved by combining several physical phenomena. In the preparation of an optical filter or an UV-limiter, at least three physical properties need to be combined together: (i) perfect optical transparency (i.e., an amorphous polymer matrix that does not produce light-scattering phenomena because of an absence of crystallites); (ii) high solubility for the functionalizing organic molecule (dye) (i.e., in order to have high solubility of the functionalizing dye, non-bonding interactions acting among the polymeric macromolecules must be similar to those acting among the organic molecules; in addition, when organic compounds are molecularly dispersed in the polymeric matrix, they absorb independently each other and the required transparency is maintained); (iii) strong optical absorption (i.e., the organic molecule must contain a chromophoric group characterized by a high extinction coefficient value). In the case of color filters based on the surface plasmon resonance of noble metal nanoparticles (e.g., gold, silver, etc.), high dispersibility replaces the solubility requirement. All cited properties are strictly required and the lack of even only one of these properties surely compromises the operation of such a device. A further example is represented by a fluorescent varnish. In this case, the required properties are as follows: filmability, adhesiveness, optical transparency, high solubility of the fluorescent dye in the optical-grade matrix, and high quantum efficiency of the fluorescent group. FCMs can be considered as a type of molecular machine that is highly specialized in the execution of special operations. These "molecular machines" have a working principle (the phenomenon on which they are based) that can be theoretically modelled. Therefore, an FCM design is an attractive and very important area of research in materials science that is strictly required for the optimization of these useful materials.

The paper collected in this Special Issue titled "Recent Advances in Carbon/Graphite Coatings" describes the development and the characterization of functional polymeric microcomposites, functional materials of natural origin, functional materials of different molecular types, and other types of carbon-based functional materials. As observed, the developed general definition of functional materials can be conveniently applied to each one of these cases. A first example is represented by the article titled "Electrical method for the in vivo testing of exhalation sensors based on natural clinoptilolite". In this paper, a sensing device for breath detection and measurement has been fabricated by using a nature-made functional material, which is the zeolite mineral named clinoptilolite. In this case, the engineerization of three physical phenomena was synergistically exploited: (i) the physical adsorption of water molecules on the clinoptilolite extra-framework cations by ion–dipole interactions; (ii) the possibility for the extra-framework cations to act as charge carriers in an electrical transport mechanism based on cation hopping; and (iii) the increase in the charge carrier's mobility as a consequence of the water molecule adsorption on cations. A second example of functional material is described in the article, titled: "Functional polymeric coatings for CsI(Tl) scintillators", which presents a polymeric microcomposite coating developed by embedding a high reflective white powder in an epoxy matrix. In this case, the functional material is based on the engineerization of light-scattering phenomena with some micron-sized barium sulfate ($BaSO_4$) particles or Teflon (PTFE) particles that are generated in the visible spectral range. Again, an electrically conductive coating has been studied in the article titled "Influence of the thermomechanical characteristics of low-density polyethylene substrates on the thermoresistive properties of graphite nanoplatelet coatings". In this case, the electrically conductive coating is a functional material based on the engineerization of the electrical transport phenomenon characterizing the percolative structure of a graphite–polymer microcomposite deposited on a polyethylene substrate. Analogously, the graphite oxide (GO) paper coating, for which its preparation is described in the article titled "Green solid-state chemical reduction of graphene oxide supported on a paper substrate", is a type of functional material. This functional material is based on the engineerization of the physical phenomenon of the electrical transport in graphene-containing structures supported on a dielectric substrate. Finally, the developed definition can be applied to all types of functional materials described in the articles collected in this

Special Issue, although they have completely different natures, thus proving the absolute generality of the developed considerations.

In conclusion, an alternative universal definition for the functional material class has been developed. This definition is based on the word "engineerization", and its meaning involves scaling up a chemical process or, equivalently, industrially exploiting a chemical phenomenon. Functional materials are materials based on the engineerization of a physical or chemical phenomenon. However, all technologically useful materials (both of functional and structural type) can be similarly defined as "materials based on the engineerization of one or more physical, chemical or mechanical phenomena", with the intention of technologically exploiting these phenomena. Such logical analysis, corresponding to a sort of in-depth rational (philosophical) study of still confused concepts in material science, could be an important tool for the progression of knowledge in this field.

Conflicts of Interest: The author declares no conflict of interest.

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