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Multifunctional Advanced Material

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ABSTRACT: Multifunctional materials are the materials that perform multiple functions in a system due to their specific properties. Multifunctional materials can be both naturally existing and specially engineered.For example, some traditional materials that provide, for instance, high mechanical strength can be modified at the nanoscale to attain other properties such as energy absorption, self-healing, etc. The applications of such new "smart" materials include energy, medicine, nanoelectronics, aerospace, defense, semiconductor, and other industries.Numerous examples of multifunctional materials can be found in nature. Bio-materials routinely contain sensing, healing, actuation, and other functions built into the primary structures of an organism. For example, the human skin consists of many layers of cells, each of which contains oil and perspiration glands, sensory receptors, hair follicles, blood vessels, and other components with functions other than providing the basic structure and protection for the internal organs. Through biological evolution, these structures were seamlessly integrated into the body to serve their functions.The ability for materials to respond to their environment in a useful manner has broad technological impact. Such "smart" systems are being developed in which material properties (such as optical, electrical, or mechanical characteristics) respond to external stimuli. Materials of this kind have tremendous potential to impact new system performance by reducing size, weight, cost, power consumption, and complexity while improving efficiency, safety, and versatility. The multifunctionality of materials often occurs at scales from nano through macro and on various temporal and compositional levels .Innovative advanced materials make a direct and positive impact on economic growth, the environment, and quality of life. They allow for improved processes and products and create several avenues to increasing sustainability.

KEYWORDS: multifunctional, advanced, materials, industries, evolution, nano, macro, economic growth

I. INTRODUCTION

Multifunctional Material is defined to be any material or material-based system which integrally combines two [or possibly more] properties, one of which is normally structural and the other functional, e.g. optical, electrical, magnetic, thermal etc... The integration of multifunctional values in such a common material has become a special area of interest in recent years. Smart Textile represents the next generation of textiles anticipated for use in several fashion, furnishing and technical textile applications.[1] The term smart is used to refer to materials that sense and respond in a pre-defined manner to environmental stimuli. The degree of smartness varies and it is possible to enhance the intelligence further by combining these materials with a controlling unit Improvement of existing properties and the creation of new material properties are the most important reasons for the functionalization of textiles[2]. Polymer nano composites offer the possibility of developing a new class of nanofinishing materials for textiles with their own manifold of structure property relationship only indirectly related to their components and their micron and macro-scale composite counterparts. Functionalisation of textiles is an approach to improve the native properties as well as to impart new functions in the textile products. The functional finishes impart new properties such as UV resistance, photo-catalytic activity, flame retardency, antibiotic , antistatic, antimicrobial activity and wrinkle recovery to the fabrics.[3]

Examples of advanced materials studies

The following are several examples of sustainable solutions through improved materials chemistry or using alterative innovative materials.

A. Power-generating structural composites

"Researchers at ITN Energy Systems and SRI International have integrated a power-generating function into fiber-reinforced composites. Individual fibers are coated with cathodic, electrolytic, and anodic layers to create a battery. The use of the surface area of fibers as opposed to that of a foil in a thin film battery allows greater energy outputs, measured on the order of 50 Wh/kg in a carbon fiber-reinforced epoxy laminate. These batteries may be deposited on various substrates, including glass, carbon, and metallic fibers."[4]

B. Thermostructural materials for gas turbines

Gas turbines are a core technology in aero-propulsion and industrial power generation. Technological progress in this area depends on advances in thermo-structural materials. The requirements to reduce emissions, increase fuel flexibility, and resist environmental attack call for development of new material systems with multifunctional properties. University of California Santa Barbara researchers employ a holistic approach that embraces and integrates all critical aspects of materials technology, including alloys, coatings, and composites, processing, and simulations to create the thermostructural materials that combine mechanical strength and exceptional thermal stability. [5]Materials issues relevant to the high-pressure turbine include higher temperature single crystal alloys that act in concert with coatings, advanced bond coat alloys for environmental protection with improved thermo-chemical and thermo-mechanical compatibility with the load-bearing alloy, and thermal barrier oxides with new compositions that enhance temperature capabilities. Ceramic matrix composites (CMCs) and associated environmental barrier coatings are also incorporated in next generation engines, especially for combustors.[6]

C. Nanoparticle assembly using DNA strands

"Scientists at the U.S. Department of Energy's Brookhaven National Laboratory have developed a general approach for combining different types of nanoparticles to produce large-scale composite materials with special properties. The approach takes advantage of the attractive pairing of complementary strands of synthetic DNA—based on the molecule that carries the genetic code in its sequence of matched bases known by the letters A, T, G, and C. After coating the nanoparticles with a chemically standardized "construction platform" and adding extender molecules to which DNA can easily bind, the scientists attach complementary lab-designed DNA strands to the two different kinds of nanoparticles they want to link up. The natural pairing of the matching strands then "self-assembles" the particles into a three-dimensional array consisting of billions of particles. Varying the length of the DNA linkers, their surface density on particles, and other factors gives scientists the ability to control and optimize different types of newly formed materials and their properties.[7]"

D. Organic batteries provide better recyclability

A typical battery consists of two electrodes - anode and cathode, electrolyte layer, separator, and current collectors. Most of traditional battery technologies use metals or metal oxides as electrode-active materials, and metals are not renewable resources. This study describes the use of organic materials as electrodes. The advantage of such organic-based batteries over Li-ion batteries in terms of sustainability is improved recyclability, safety, adaptability to wet fabrication process, and extraction of starting material from less limited resources. One recently developed type of organic battery is based on organic radical polymers - "aliphatic or nonconjugated redox polymers with organic robust radical pendant groups as the redox site". The organic batteries have lower energy density compared to Li-ion technology, but this limitation is expected to be overcome in the near future.[8]

II. DISCUSSION

Multifunctional materials are designed so as to meet specific requirements through tailored properties. Smart materials can be considered as multifunctional ones that have the ability to react upon an external stimulus, simulating, in this way, the behavior of nature's materials. Furthermore, the introduction of biomemetics in the material science, allows the designing of materials with similar processes as nature does: building from molecules to complete structures. This article focuses on the presentation of the various multifunctional materials reported in the literature and the processing means developed.[9]The Panel on Structural and Multifunctional Materials focused on emerging materials and the processes used for their fabrication, with special attention to the types of multifunctionality that could be designed into a material. An example might be a composite material in which both the matrix and filaments serve several functions: The matrix might contain microcapsules sensitive to mechanical stress that, upon breaking, would highlight the damaged area by changing color. The strengthening filaments might have two different compositions which, when imbedded in a conducting polymer matrix, would produce a galvanic current. Such a material might be the basis for a new generation of lightweight, long-service electric vehicles.[10]

This article discusses DoD structural materials development approaches and goals. It highlights the importance of lighter, stiffer, and stronger materials, and the need for materials to operate for long periods at high temperature with predictable degradation. These materials are necessary to improve vehicle mobility, maneuverability, transportability, and survivability.Once all the data were presented, the panel identified four areas of R&D opportunity. In priority order these are Materials design assisted by computation,Service-induced material changes,Composite materials design and development, and Integration of nondestructive inspection and evaluation into the original design.[11] These four opportunities are expanded upon, with special emphasis on the design of structural materials that are truly multifunctional.Investments in these research areas should result in advances that would yield many of the necessary new DoD materials. Such advances will Reduce development time and costs,Modernize design criteria,Predict and verify functionality,Continuously monitor in-service health, and Predict residual life.[12]

Since the fractions of fibers comprising a composite material may be varied over a wide range, these materials may be designed with a broad range of density, stiffness, and strength values, because the filaments used are very strong and have large elastic moduli. Many filamentary materials also have lower density than metals, so metal matrix composites, for example, can be less dense than the parent metal but have greater strength and stiffness, increasing both specific strength and specific stiffness. These points are especially relevant for polymer matrix composites where very high specific properties can be obtained for nominal temperature applications. Thus, “composite materials design and development” is a compelling approach that merits study and refinement, because reduced weight is a primary design criterion in many structures.In addition to extensive composite material development efforts, this panel believes that opportunities exist for “integrating non-destructive inspection and evaluation into the original design” of both materials and structures. This would allow for continuous monitoring of the health of all newly designed structures. Integrating sensors into the structure requires that they be very small, so many new types of sensors must be created. In addition, small portable advanced sources, such as X-ray and neutron sources, will be needed to allow field evaluation of structures and some sources should be incorporated into the internal structure in places that would be difficult to examine with an outside source.[13]

In general, the military needs materials that are lighter, stronger, stiffer, and usable at higher temperatures. This allows equipment to be more mobile, maneuverable, transportable, and to last longer. For the military’s air arms, the goals have always been to fly higher, farther, and faster. Recently, DoD has emphasized the total life-cycle cost of all types of equipment and materials of construction. There has been great interest in “smart materials”—e.g., materials that will monitor and report on their own health. This requires the development of many new sensors, some of which must be an integral part of the material. New instruments to activate and query these sensors are also required. Finally, there have recently been demands for multifunctional materials, e.g., a composite with high strength and stiffness in which the strengthening filaments can supply battery power.[14]

The cost of materials is a relatively small fraction of the fabricated cost of a structure, typically 10 to 20 percent. Thus, combining these fabricated costs of the structure with the value of a pound saved gives the average maximum cost that can be tolerated in a particular application. For the automobile example, where the value of a pound saved is $2.00 times a 20 percent material cost as a fraction of total cost, the upper limit is $0.40 per pound for the primary structural material of the automobile, which is about the cost of automobile-quality steel. It is also possible to conclude that aluminum will not be a cost-effective substitute for steel in automobiles until gasoline costs $4.00 per gallon.2 As noted in Appendix C, these calculations must be fine-tuned to align with factors such as the speed at which the object moves and the complexity of the structure fabricated. For example, the value of a pound saved in the rotating part of the gas turbine in an airplane is 10 times the value of a pound saved in the fuselage. Also, materials costs for complex composite structures are as little as 2-5 percent of the total fabricated cost.[15]

The cost of a gallon of fuel, transported halfway around the world, stored and transported to forward fuel depots, and finally delivered by air to vehicles at the battlefront may be as much as $400 per gallon, although the more usual price was between $13 and $30 per gallon (DSB, 2001). Weight reduction coupled with strength increase is doubly important for vehicle or engine weight and for allowable engine size. For rotating or oscillating components, both mass and strength are important, but the impact of reducing rotating or oscillating mass cannot be minimized. In any engine, reduction of moving mass makes it possible to reduce the mass of shafts, bearings, and bearing support structures; thus a simple weight reduction in moving mass can cascade through the engine to a dramatic total weight decrease. These same factors apply to flywheel-type energy storage systems and to rail-gun systems.[16]

Material stiffness is a property that is especially important for extensive structures that must hold their shape and in tube and sheet structures where buckling propensity is directly related to the elastic modulus (Seely and Smith, 1955). Specific modulus, a performance index of a material, is defined as the elastic modulus divided by density. In many sheet or column structures where the material has a low modulus, to ensure sufficient component rigidity the thickness of the structure must be increased above that required to achieve the specified design strength. In the design of these structures, the most important quantity is the elastic modulus. The structural stresses may not be the significant quantities—that is, the stresses may not limit the loads that can be applied to the member without causing structural damage, and hence the strength properties of the material (such as yield stress) are not of primary importance. Note that the specific moduli of Fe, Al, and Mg are almost identical, so simply substituting one material for another does not change this (ASM, 1961).One area where elastic modulus is critical is in the design and construction of gun tubes. High stiffness allows the propellant charge to expand and accelerate a projectile to maximum velocity, but does not allow the expanding gases to leak past the projectile and thus undermine efficiency. New high-energy propellants require that gun tubes be stiffer; this can be achieved using a composite reinforced by filamentary windings. These propellants also demand that the refractory interior surfaces of the gun tube be resistant to erosion and corrosion at temperatures higher than those that are currently encountered.[17]

In monolithic materials, stiffness is very difficult to change by alloying and is hardly affected by microstructure. In fact, alloying and heat treatment work better to decrease stiffness than to increase it. Thus, designers of new monolithic materials have only two options: The material must be made lighter so that structural efficiency is improved or it must be made stronger. These, then, are the most promising directions for monolithic materials research.[18]

In the design of composite materials, however, density, stiffness, and strength are almost independent quantities (Schaffer et al., 1995). The filaments used are quite strong and often have elastic moduli about twice the modulus of metals, so increasing stiffness is a real design opportunity. Many filamentary materials also have low density; incorporating them into a metal or alloy will both decrease density and increase strength, thus increasing both the specific strength and the specific stiffness. It is these qualities that make new composite materials compelling opportunities for the future. Because ceramic or polymer matrix materials can produce very strong, lightweight structures, research on these materials is of primary importance.[19]

The drawbacks are that the fabrication costs of composite materials often exceed those of metals and alloys, and their ductility and fracture toughness are usually lower. Where cost is not of primary importance and low ductility and global toughness are not the primary causes of failure, composite materials are prime candidates for structural design. However, R&D on composite materials must proceed in many directions simultaneously. The most important needed advances are in the processing and scale-up of multiple material combinations. Current processing methods are slow, involving hand lay-up of binder-impregnated composite sheets or the processing of only small batches of material. Other needed advances include adequate exterior coatings for nonoxide composites, fiber coatings to prevent fiber-matrix chemical diffusion at high temperatures, and control of the interface between filaments and matrix to optimize properties.[20]

It is also essential to understand the mechanics of fracture in each type of material. Especially in the design and manufacture of composite materials, there are opportunities for integrating nondestructive investigation and evaluation sensors into the original design of both materials and structures. This would allow for continuous health monitoring of all newly designed structures. The integration of sensors into the structure requires that they be very small, so many new types of sensors will be needed.[21]

III. RESULTS

The application of wearable devices is promoting the development toward digitization and intelligence in the field of health. However, the current smart devices centered on human health have disadvantages such as weak perception, high interference degree, and unfriendly interaction. Here, an intelligent health agent based on multifunctional fibers, with the characteristics of autonomy, activeness, intelligence, and perceptibility enabling health services, is proposed. According to the requirements for healthcare in the medical field and daily life, four major aspects driven by intelligent agents, including health monitoring, therapy, protection, and minimally invasive surgery, are summarized from the perspectives of materials science, medicine, and computer science. The function of intelligent health agents is realized through multifunctional fibers as sensing units and artificial intelligence technology as a cognitive engine. The structure, characteristics, and performance of fibers and analysis systems and algorithms are reviewed, while discussing future challenges and opportunities in healthcare and medicine. Finally, based on the above four aspects, future scenarios related to health protection of a person's life are presented. Intelligent health agents will have the potential to accelerate the realization of precision medicine and active health.[22]

- The **Structures and Composites Laboratory (SACL)** has led the design of integrated structures, development of smart structures, quantification of the damage tolerance of composite structures and development of advanced multifunctional materials. It has played a key role in the realization of new materials and structures in actual aerospace and transportation systems.

- The **EXtreme Environment Microsystems Laboratory (XLab)** is developing MEMS sensors, nanoelectronics and nanostructured materials that can withstand high temperatures, radiation exposure and chemical attack. It leverages the Stanford Nanofabrication Facility and the Stanford Nano Shared Facilities to create and examine nanomaterials, MEMS sensors and radiation-hardened, temperature-tolerant electronics. It has played a key role in the development of next-generation sensors and electronics for space exploration, combustion, satellites and subsurface well bores.
- The **Reconfigurable & Active Structures Lab** investigates structures that do more than carry loads. They study the connection between a structure's performance and form allowing us to change geometry, mechanics, and multi-physics response (e.g. electromagnetic, self-sensing, optical) of a structure. The ultimate goal is the realization of reconfigurable spacecraft structures and scientific instruments with on-demand performance, helping reduce weight and energy use.
- The **Morphing Space Structures Lab** develops deployable spacecraft structures, novel flexible composite structures, and origami-inspired structures.

Together, our SACL and XLab laboratories are examining the high-strength and lightweight properties of nanomaterials and nanoelectronics to advance aerospace systems and subsystems. They are also embedding robust piezoelectric sensors in composites to monitor the structural health of aircraft systems. At the fundamental level, their research focuses on the following areas in advanced materials and structures:

- Smart structures
- Multifunctional materials
- Structural health monitoring[23]
- Damage tolerance of composite materials
- High-temperature piezoelectric transducers
- Nanocomposite materials
- MEMS sensors and electronics
- Nanoscale sensors for harsh environments
- Nanoceramic materials for harsh environments
- Radiation-hardened electronics

Intelligent and nanoscale materials

Our success in these areas leverages our core competencies in design manufacturing and experimental characterization of advanced structures and materials. Ultimately, the maturity and scalability of nanomaterials and the advancement of structural health monitoring approaches will change the way we engineer aircraft, automobiles, spacecraft, satellites and planetary rovers.

Progress in science and industry needs the knowledge, production and utilization of newly customized materials such as laminated composites, nanocomposites, porous and functionally graded materials. Smart material solutions are developed while incorporating self healing, active piezoelectric and shape memory characteristics. At ARL-MLS, we focus on developing the aforementioned solutions while providing resilient, eco-friendly and biocompatible solutions to industries. Advanced material exploration and investigative methodologies such as atomistic, micromechanics, multiscale modelling are enacted towards characterization and improvement of material properties for applications in aerospace, biomedical and engineering structures. Our goals are to overcome the following challenges such as:

- Structurally efficient polymers and elastomers for lightweight structures with functionality.
- Industry specific material identification and selection.
- Sustainable eco-friendly materials for advanced structures and devices
- Discovering new materials for bioengineering applications.
- Identification and selection of replaceable fillers for high performing composites and nanocomposites.
- Characterizing the lifecycle of newly developed materials.
- Mapping effective processes for easy manufacturability and utilization of advanced materials.[24]

To overcome the many global challenges in the field of Materials Engineering, ARL – MLS has been actively developing cutting edge solutions such as:

- Physical characterization of new materials tailored towards industrial applications.
- Discovering Multi dimensional properties of materials for additive manufacturing (4D Printing / 5D Printing).
- Developing tailored multifunctional materials for sophisticated engineering applications (porous, nanocomposites, piezoelectric and flexoelectric materials).

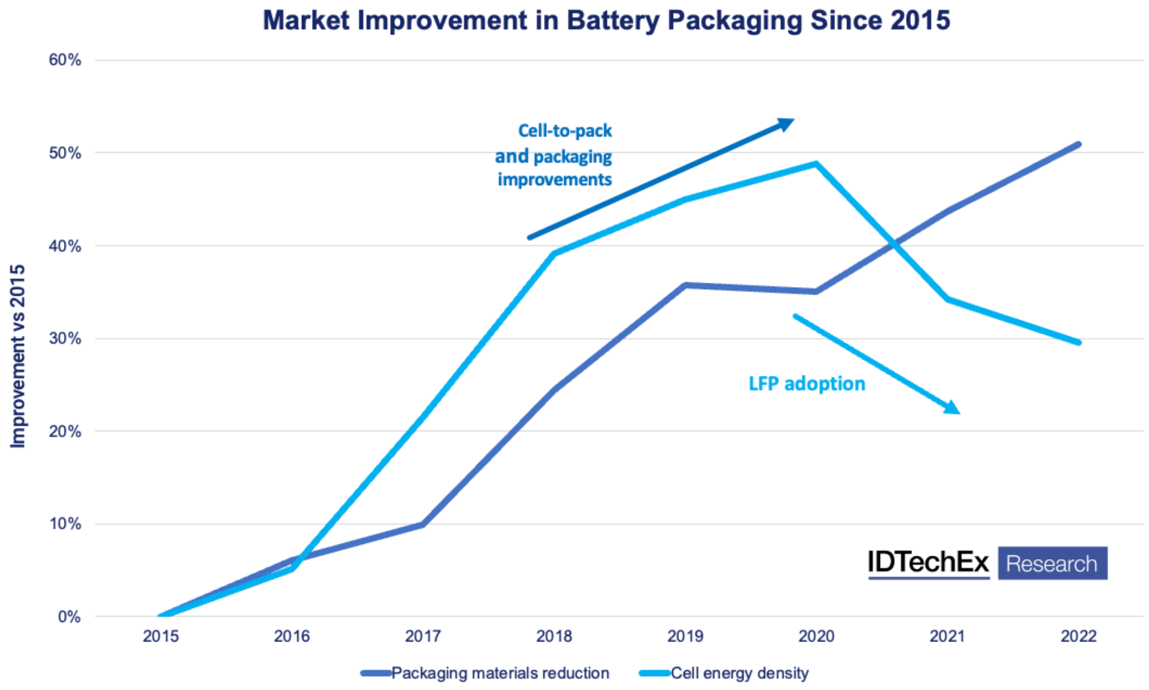
- Resilient and robust material solutions to withstand extreme environments.
- Cost effective self-healing material alternatives for extending structural life.
- Development of composite based fillers to accentuate performance of conventional materials.
- Developing customized functionally graded materials for lightweight multifunctional structures.
- Generating new material alternatives for shock absorbance and damping of projectile impacts.

IV. CONCLUSIONS

Thermal management is critical in several industries, and the trends in emerging technologies are driving material innovation. Electronics in markets from personal devices through to cars are seeing increased integration, densification, and hence an increased focus on thermal management. As these components have less and less free space to utilize, the use of materials that provide more than one function is on the rise.[23]

Electric Vehicle Battery Evolution

The electric vehicle (EV) market has continued its trend toward higher energy-density battery designs. While the average market energy density has decreased slightly since 2020 due to the resurgence of LFP batteries, the percentage of the battery that is taken up by the cells has been increasing, somewhat mitigating the hit from adopting the lower energy density cell chemistry.



The increasing share of LFP has decreased average cell energy density, but the efficiency of packaging has continued to increase rapidly, helping offset this at a pack level. Source: IDTechEx

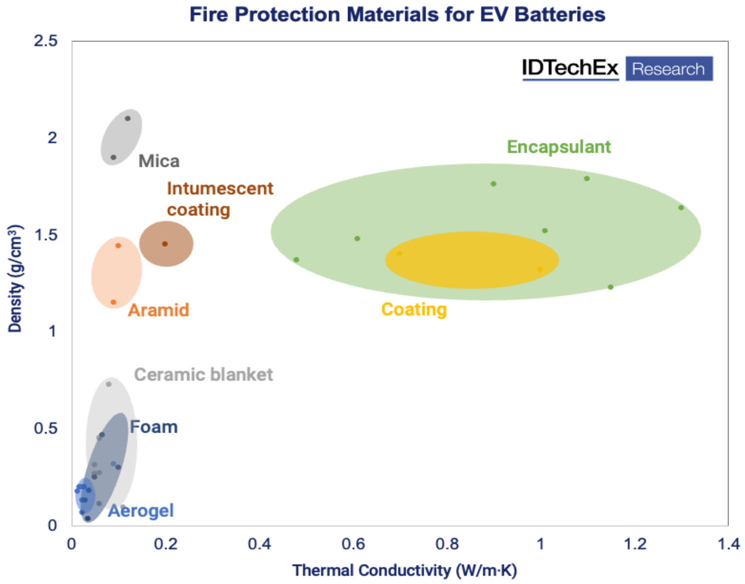
The trend of increasing packing efficiency is partly due to incremental improvements but also greater adoption of cell-to-pack and cell-to-body designs that have been seen in 2022. BYD's Blade battery has seen a greatly increased deployment in 2022, with BYD's market share in China's EV market reaching approximately 25% in the first half of 2022. This cell-to-pack design has each prismatic cell take up the entire width of the pack. In 2022, Tesla has also deployed its first vehicles using the fabled 4680 battery cells and a structural pack design where the seats are attached directly to the lid of the battery. These design changes greatly improve energy density by removing ancillary materials that do not directly contribute to the battery's operation. Several OEMs have announced plans for cell-to-pack or cell-to-body designs to be deployed within the next few years, including groups like VW, Stellantis, and several others.[22]

Fire Protection in Future Battery Designs

Despite the removal and reduction of materials in EV batteries, there are several materials that will always be required in an EV battery design for it to function optimally. These include the thermal management strategy (cold plates, coolants, etc.) and, critically, in 2022, fire protection materials. Similar to 2021, EV fires have been prominent in news outlets but, now more than ever, a driver for material innovation. While fires are a rare event and less likely to occur than in a combustion engine vehicle, Li-ion batteries, regardless of chemistry or cell format, present a non-zero risk of thermal runaway and subsequent fire. 2021 saw several recalls relating to battery fire risks from major OEMs, including GM, Hyundai, VW, and others. In 2022, India has seen a large focus on battery fires in electric two-wheelers, which has prompted the adoption of specific safety standards relating to several battery design factors.[21]

With the public focus and impending implementation of thermal runaway safety regulations in various regions, OEMs are forced to consider materials used for fire protection more carefully. The previously discussed trend towards cell-to-pack and higher energy density packs presents a challenge in fire protection. As energy density increases, there is less space for added materials, leading to suppliers focusing on multifunctional materials. For example, aerogels are gaining traction in the market thanks to their ability to provide thermal insulation, fire protection, and compressibility. In 2022, Aspen Aerogels was named as the supplier for GM's Ultium platform, and its PyroThin material reported revenue of US$18.4 million in the first half of 2022 compared to US$6.7 million for all of 2021. Rogers Corporation, a prominent player in providing compression foam pads for pouch cell battery packs in 2022, announced its EV ProCell Firewall materials that provide both fire protection and compression management (critical for pouch cell battery packs). An acquisition of Rogers by DuPont was announced in late 2021 as one of the largest acquisitions in the materials space in recent history. However, this acquisition was terminated at the end of 2022 after DuPont failed to obtain clearance from all the required regulators[23]

Several other material options can be used depending on the cell format and whether an inter-cell and/or a pack level solution are required. In 2023 and beyond, with the rapidly expanding EV market, several of these materials will experience rapid growth in demand, and IDTechEx is predicting a 13-fold increase in fire protection material demand by 2033. IDTechEx's latest report, "Fire Protection Materials for Electric Vehicle Batteries 2023-2033", analyzes trends in battery design, safety regulations, and how these will impact fire protection materials. The report benchmarks materials directly against each other and for applications within battery packs. The materials covered include ceramic blankets/sheets (and other non-wovens), mica, aerogels, coatings (intumescent and other), encapsulants, encapsulating foams, compression pads, phase change materials, and several others. 10-year market forecasts are included by material and vehicle category.



Many materials are applicable for fire protection, each with its own pros and cons depending on battery design. Source: IDTechEx - "Fire Protection Materials for Electric Vehicle Batteries 2023-2033"

The Evolution of Thermal Interface Materials in EV Batteries

Thermal interface materials are a critical component in the vast majority of modern EV battery designs. These help to dissipate heat from the cells towards the cooling structure (module housings, cooling, channels/cold plates). The most common applications currently have the battery cells sit on a gap-filling TIM inside a module; several of these modules then sit on another gap-filling TIM to contact the liquid-cooled cold plate below. This approach has changed in some more recent designs, especially cell-to-pack designs.

The concept is to have the cells contact the cold plate directly through a single TIM, reducing the number of interfaces and hence improving heat transfer. Due to less interfaces, the thermal conductivity of the TIM can be reduced, and less TIM is required. Initially, this can reduce the weight and cost of the TIM and make for easier dispensing. However, with the removal of module housings (or similar structures), the TIM must now provide a structural component. Therefore, this is a great opportunity for thermally conductive adhesives.[22]

While (as above) materials around battery cells are being removed from the pack to enable greater energy density, the TIM is one that will largely remain and provide multifunctional properties to aid in both thermal management and structure of the battery pack. With larger form factor cells, the area for TIM to be applied may reduce somewhat for certain designs, but IDTechEx is predicting over 2TWh of liquid or refrigerant-cooled batteries by 2031, providing huge growth for TIMs along with several other thermal management components and materials. IDTechEx's report "Thermal Management for Electric Vehicles 2023-2033" details the OEM strategies, trends, and emerging alternatives around the thermal management of Li-ion batteries, electric traction motors, and power electronics. IDTechEx also provides a report titled "Thermal Interface Materials 2021-2031: Technologies, Markets and Opportunities" that considers TIM application in EV batteries, but also 4G/5G infrastructure, LEDs, data centers, and consumer electronics.

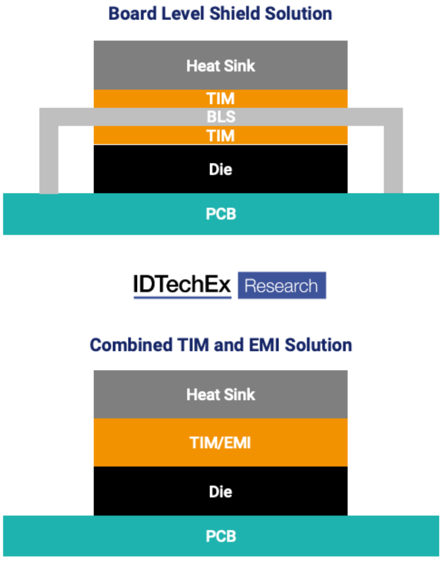
Combining Thermal Management and Electromagnetic Shielding in 5G and ADAS

Several industries are moving towards higher frequency. Two key examples of this are 5G telecommunications for higher data transfer rates and automotive radar to enable higher resolution detection. At higher frequencies, electromagnetic interference (EMI) shielding becomes more challenging with traditional methods. Combine this with increasing component density and power, and materials that can provide both thermal management and EMI shielding become an increasingly interesting proposition.

5G rollout is well underway, but the highest frequency, mmWave (>24GHz) infrastructure, is still in its infancy. The vast majority of 5G infrastructure in 2022 is still in the lower frequency bands below 6GHz. However, IDTechEx predicts a 70-fold increase in mmWave small cell rollout by 2033. mmWave infrastructure presents a host of challenges around signal propagation, but also, the higher frequency leads to smaller, more densely packed antenna where both thermal management and EMI shielding are a challenge.[24]

Automotive radar is one of the key components of advanced driver-assistance systems (ADAS) and an enabling technology for future autonomous vehicles. Previous automotive radar units were largely utilizing 24GHz. Since then, the market has largely transitioned to >77GHz. This helps increase the resolution but also creates a more compact antenna and hence radar unit. These higher-frequency radars will be the dominant technology in the future. IDTechEx estimates that over 90% of automotive radar will be in the 77GHz region by 2030. In these designs, the compact nature of the device with higher frequency signals once again provides challenges to both thermal management and EMI shielding.

Traditional EMI shielding typically consists of a metal board level shield (BLS) placed over the component with a thermal interface material (TIM) used between the component and the shield and then another between the shield and a heat sink. These shields often have holes in to help with heat dissipation, but at higher frequencies (shorter wavelengths), this greatly reduces the EMI effectiveness of the shield. Additionally, having multiple interfaces between the component and the heat sink means that heat transfer is much less efficient. Several material companies have presented a solution to these problems, where a TIM is provided that also has EMI shielding properties.[24]



A combined EMI shield and TIM can replace multiple TIMs and a board-level shield (BLS). Source IDTechEx

Several players, such as Henkel, Kitagawa, and Schlegel, have all released TIM pads that also function as EMI shields. An option that stands out in 2022 is the announcement of Laird's CoolZorb D. Like others, this is a combined EMI shield and TIM but differs as it comes in the form of a 1-part dispensable material. The material provides a thermal conductivity of 3.5W/m×K and high attenuation, especially above 20GHz. The dispensable nature means it is potentially better suited to larger volume manufacturing to help automate the production process. While these combined EMI/TIM options are more expensive than a similar TIM, the ability to remove the EMI absorbing material can lead to a lower cost of device overall in addition to a simpler manufacturing process.

5G and automotive radar are both rapidly growing markets with a transition to higher frequencies. IDTechEx is predicting over 12 million 5G stations in 2032 that will require thermal management and that the yearly market value for TIMs in ADAS will increase 11-fold over the next ten years.[23]

IDTechEx's report "Thermal Management for Advanced Driver-Assistance Systems (ADAS) 2023-2033" covers trends in ADAS sensor and computer evolution with a focus on thermal interface materials and die attach with additional chapters on combined EMI and thermal materials and radar radome materials. The IDTechEx report on "Thermal Management for 5G 2022-2032" addresses the trends in 5G deployment and how this impacts the antenna design, choice of semiconductor technology, die attach materials, and thermal interface materials. Both technological aspects and market forecasts are included for the next ten years. Additionally, it considers many smartphones and how the incorporation of 5G is impacting thermal materials (interface and heat spreaders).[24]

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