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INTEGRATIVE MODULES FOR ELECTRONIC SYSTEMS. (Integrative Modules for Electronic Systems, Including Laser Diodes, with an Intensive Cooling System Based on Diamond–Copper Composite Materials)

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Abstract

The article examines integrative modules for complex electronic systems, particularly those incorporating laser diodes, with a focus on reliable and efficient thermal management. As demonstrated by practical developments in recent years, effective cooling remains one of the key challenges affecting the performance, reliability, and operational efficiency of such electronic devices.

Particular attention is given to the development of integrative technical solutions aimed at minimizing energy losses and increasing useful energy output, especially in various lighting systems. The proposed approach focuses on achieving efficient cooling without introducing additional structural elements or requiring additional energy consumption for thermal management, including through the application of diamond–copper composite materials.

The article also considers technical solutions intended to increase the output optical power of lighting devices while maintaining a compact and structurally simple design. The objective is to achieve higher light output at relatively low operating power and, consequently, reduced energy consumption, while providing the thermal conditions required for the stable operation of laser diodes and other electronic components.

Keywords: *Integrative Modules; Electronic Systems; Laser Diodes; Optical Power; Diamond Spheres; Ductile Material; Composite Material; Pseudo-Porous Structure; Optical Cable; Laser Radiation; Lamp with a Flat Light-Emitting Element*

Introduction

In order to minimize energy losses and increase useful energy output, particularly

in various lighting systems, considerable attention is currently being devoted to the development of integrative technical solutions

that provide efficient cooling without requiring additional structural elements or additional energy consumption for thermal management.

In parallel, research and development efforts are focused on technical solutions that make it possible to increase the output optical power of lighting devices while maintaining a compact, simple, and efficient design. Such solutions are intended to achieve higher light output at relatively low operating power and, consequently, reduced overall energy consumption.

Figure 1.



The image shows one of the innovative developments designed to convert laser radiation into light within conventional and commonly used spectral ranges.

The author of this publication considers the integrated solutions proposed in the scientific and technological publications and books by Aleksandra Efimova, a recognized innovation specialist in this field, to be among the most suitable approaches.

One of the principal features that distinguishes Aleksandra Efimova's proposals and developments from similar solutions presented by other authors is the extensive platform for experimental computer modeling. This platform has emerged from her broad and in-depth knowledge of the fundamental techniques and methods of systemic and combinatorial computer modeling applied to related innovation processes, including those at the intersection of fundamental scientific and technological disciplines.

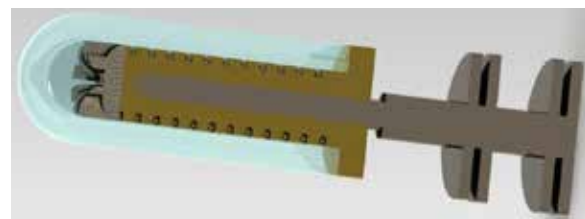
In analyzing the innovative technologies proposed in her publications, Aleksandra Efimova advances a concept of particular importance for addressing the problem

under consideration: the combinatorial structure of each solution, understood as a harmonious combination and mutual complementarity between conventional technologies and materials, on the one hand, and innovative technologies and materials – primarily composite materials – on the other.

Of particular significance in Aleksandra Efimova's proposals is the tendency toward the integration and comprehensive adaptation of new materials and technological approaches within the environment and operating conditions of existing, well-established technologies and materials. This approach creates a foundation for transforming their properties and capabilities and bringing them to a new level of technological innovation.

The following image presents an axial cross-sectional view of such a device, providing a more convenient representation for its detailed examination and analysis.

Figure 2.



As can be seen, the design of the innovative lamp integrates the functions of several basic structural elements within a single system.

The lamp holder incorporates a **vortex-type heat sink**, the shaft and discs of which are manufactured from a **diamond–copper composite material** that constitutes one of the key components of the lamp's cooling system.

Each component of this system is multifunctional. In addition to performing heat-transfer and heat-accumulation functions, the structure of these components, formed from numerous composite microglobules, simultaneously performs the essential function of dissipating heat flows. This effect is achieved due to the **pseudo-porous structure of the composite material**.

Particular attention should be given to the innovative structure of the diamond–copper composite.

The original manufacturing process for the composite globules begins with the formation of synthetic-diamond spheres with a diameter of 5–7 microns. This dimension may vary depending on the profile and dimensions of the component, as well as its operating conditions.

The spheres are subsequently coated with copper using specialized equipment and an original innovative technology (Appendix 2).

The thickness of the copper coating is selected so that, during the formation of the lamp component in a mold, a sufficient amount of ductile material remains on the diamond spheres to enable the metal to flow and fill the spaces between the synthetic-diamond spheres.

As a result, a pseudo-porous structure is formed in which diamond spheres are uniformly distributed throughout the material. Diamond provides exceptionally high thermal conductivity while remaining electrically non-conductive.

This structure enables heat to be rapidly dissipated and uniformly distributed across the cross-sectional area of the heat-sink discs.

An optical cable is positioned within the spiral grooves of the lamp housing and receives a laser beam from the laser module. The optical cable is arranged in a spiral and positioned within the housing grooves at a diameter that causes the cable to emit light across its entire cylindrical surface. This configuration is significantly more efficient than light emission transmitted solely through the end face of the cable.

In order to separate the laser radiation from the lamp's output radiation, a phosphor layer designed for a specific emission spectrum is applied to the optical cable.

As a result, the final radiation emitted by the lamp is completely non-toxic. Furthermore, because the emitting surface area is thousands of times greater than the area of the optical cable end face, a 1–2 W laser diode provides a lamp output equivalent to approximately 60–75 W.

The presented models demonstrate that, based on the general principles of innovative design proposed by Aleksandra Efimova, it is possible, within a conventional form and structural configuration – for example, that of an ion-exchange filter – to

use natural and completely safe materials to achieve an almost ideal final result characterized by unusual parameters and properties:

- complete elimination of chemical reagents from the process;
- use of naturally occurring ion-exchange properties;
- exceptionally high potential ion-exchange capacity, including the capacity required for the purification of liquids contaminated with radioactive substances.

Under such design approaches, the requirements imposed on the design process itself also change fundamentally. This makes it possible to extensively incorporate computer modeling methods and techniques, as well as methods and techniques aimed at achieving the ideal final result, into the development process.

Figure 3.



Figure 4.

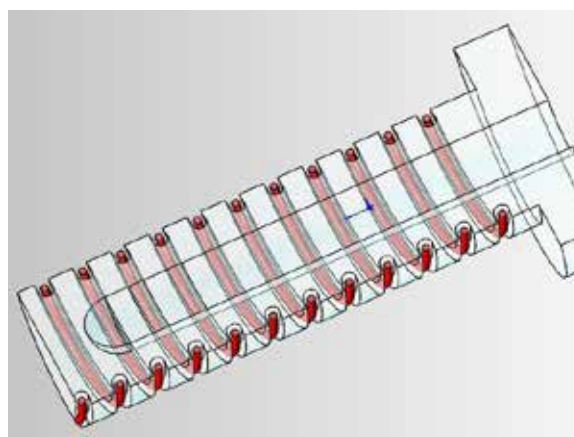
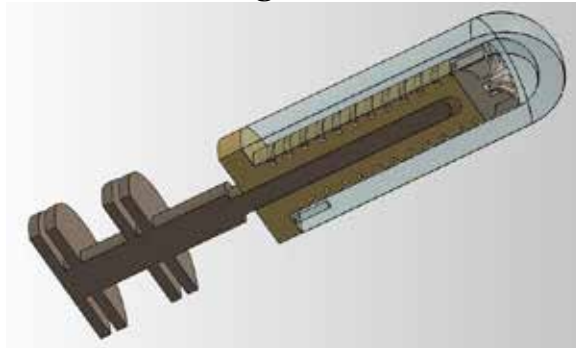
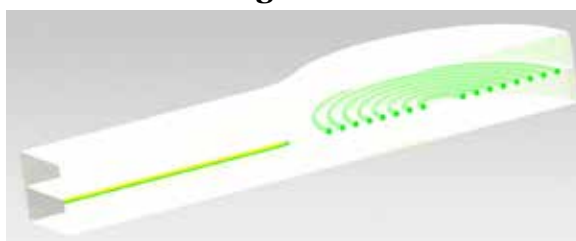


Figure 5.



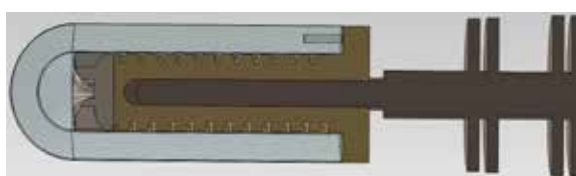
The formation of light emission resulting from the luminescence of an optical cable bent to a specific radius can be achieved through a variety of alternative configurations. One such example is the emitter shown in cross-section in the following image, in which the cylindrical surface of the optical cable begins to emit light when the cable is bent to a predetermined radius.

Figure 6.



The following image presents a structural diagram of the lamp in longitudinal cross-section, clearly illustrating its individual technical components. Each of these components has a specific functional and technical purpose and performs defined technological and conceptual functions within the overall design of the device.

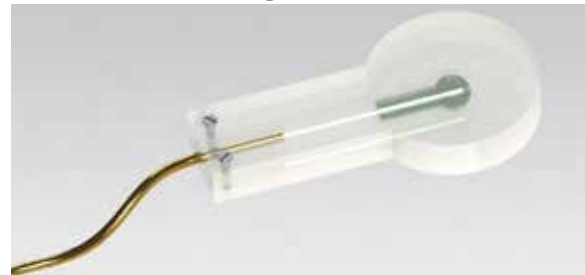
Figure 7.



The proposed design incorporates numerous innovative elements and, most importantly, is fully prepared for serial and mass production. Furthermore, the particular configuration of the lamp, together with the combination of technological principles

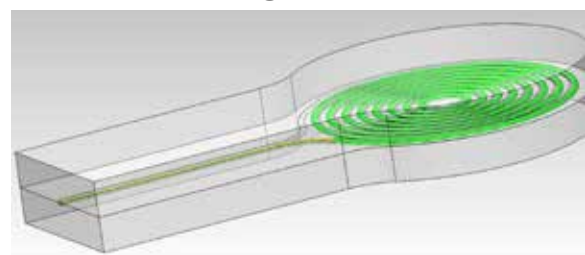
and structural materials employed in its design, provides significant potential for further technological development. The design allows new technical solutions to be integrated into the innovative product as they emerge through the continued advancement of laser technologies, composite-material technologies, and new energy-efficient control and cooling systems.

Figure 8.



The following image shows a miniature lamp in which a phosphor mixture is applied to the end of the optical cable according to a specific geometry within a three-dimensional coordinate system. This configuration provides light emission within the white region of the visible spectrum. The diameter of the optical cable is only 120 microns, making it possible to create micro-miniature light sources for use in highly compact optoelectronic systems.

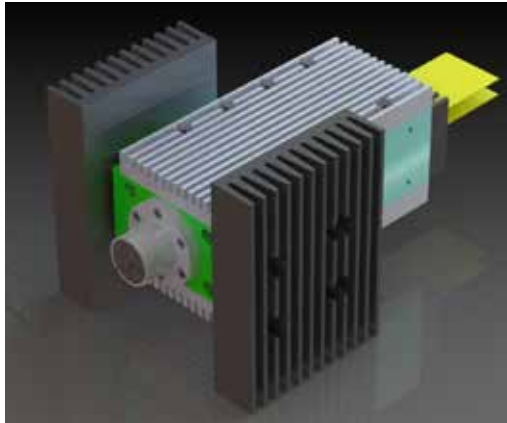
Figure 9.



The following image shows a lamp with a flat light-emitting element connected to a single optical cable. In addition to its overall energy efficiency, this system makes it possible to achieve the required level of illumination over a specified area with minimal resource requirements and maximum structural simplicity. The same system also allows virtually any combination or mixture of phosphor materials to be applied to the flat spiral section at the end of the optical cable,

thereby making it possible to obtain the required spectral and optical characteristics of the emitted light.

Figure 10.



The following image shows a laser diode module designed on the basis of active cooling principles utilizing the heat-dissipation effect of components manufactured from a pseudo-porous diamond–copper composite material.

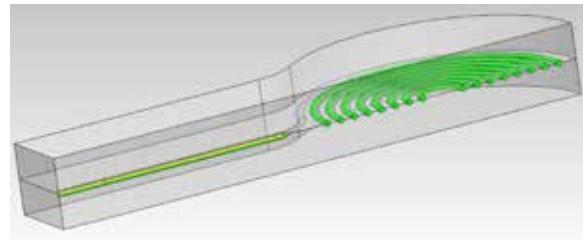
One of the innovative integrative features of the proposed design is the use of **thermo-electric coolers** in combination with the thermally conductive and heat-dissipating structural elements of the module housing.

The thermoelectric coolers are positioned between the external heat sinks and the module housing. The thermally conductive structural elements transfer heat from the printed circuit board (PCB) to the housing walls on which the thermoelectric coolers are mounted. The base surfaces of the heat sinks are, in turn, pressed against the thermoelectric coolers. Where necessary, additional module components requiring continuous cooling may also be mounted on these heat sinks.

Practical experience has demonstrated that reliable cooling makes it possible to achieve a high degree of stability in the output parameters of laser radiation. This, in turn, significantly expands the range of possible module output configurations and, where required, enables the laser radiation to be distributed among several optical cables, each of which supplies light to an individual lighting device.

The most important consideration remains the primary removal of heat directly from the laser diode.

Figure 11.



The image shows models of such devices.

Figure 12.

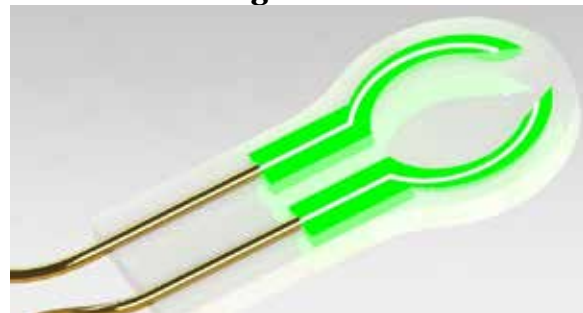
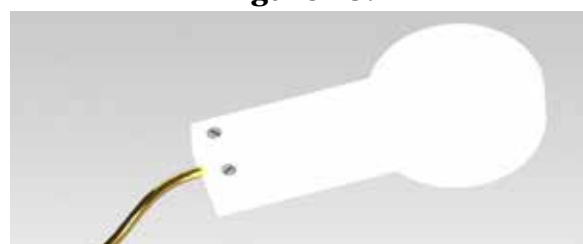


Figure 13.



The presented three-dimensional models show the thermally conductive structural elements that simultaneously serve as the primary mounting components for securing the laser diode within the module housing.

As can be seen from the models, despite its structural simplicity and manufacturability, the laser-diode support disc (highlighted in red in the models) provides comprehensive protection of the laser diode against overheating through a combination of thermal-management factors. As noted above, this significantly improves the operational stability of the module while reducing the amount of energy required for lighting.

The models also illustrate a coding and decoding system that makes it possible to identify the optical cables and corresponding lighting devices connected to the module.

In addition to its primary operating functions, such a system provides a platform for the implementation and control of various

computer-based models for energy management and distribution.

These functions depend entirely on the intended application and operating conditions of the module. Of particular importance for the further development of the proposed concept is the possibility of integrating the software component of the system directly at its most critical functional point.

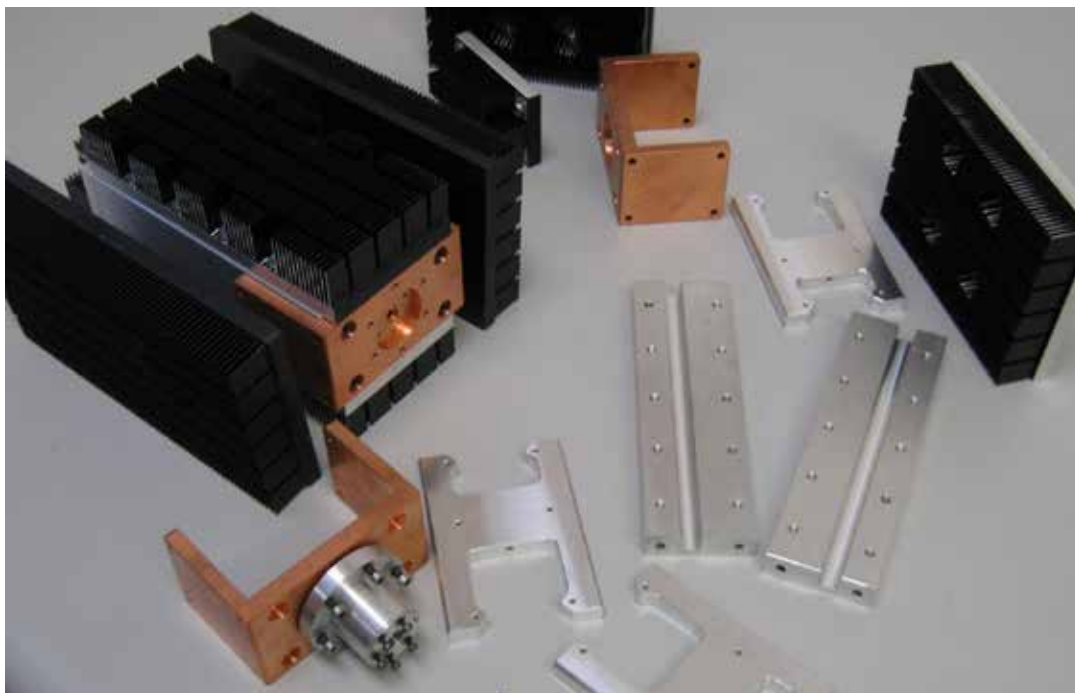
Furthermore, this fundamental approach to the application of new composite materials in novel applications, characterized by unconventional properties and performance characteristics, makes it possible to develop new lighting devices and instruments with parameters that meet the requirements of modern technologies.

It should also be noted that, in addition to advanced composite materials, nature

provides exceptionally valuable natural materials. The application of the approaches described in the publications of Aleksandra Efimova therefore makes it possible to establish a harmonious combination of long-established natural materials with proven engineering and manufacturing techniques.

The conceptual solutions proposed by Aleksandra Efimova also provide opportunities for further technological development. One example is the advancement of carbon – carbon composites, initially produced in fabric form, into solid components manufactured by compressing such fabrics. Components produced in this manner may exhibit highly unusual properties and open up new innovative possibilities in lighting technology and related technological processes.

Figure 14.



The image shows the actual structural components of the innovative laser diode module, including its cooling system and a laser diode holder manufactured from a diamond–copper composite material.

As can be seen from the image, all other components of the housing and cooling system of the laser module are manufactured from standard profiles and conventional materials and do not require any specialized materials or dedicated technological equip-

ment. The components can also be manufactured using standard cutting and measuring tools.

This design can be considered an example of the integration and combination of innovative technical solutions aimed at the efficient and safe conversion of laser diode radiation into safe, high-intensity phosphor emission, while providing virtually complete heat dissipation and minimizing both thermal and optical losses.

All principal output parameters of this integrated lighting system fully comply with the applicable standards and safety requirements.

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