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SMART LIGHTING TECHNOLOGIES. (Possible Applications of the Light Emitting Apparatus Inventions with the Additional Use of Composite Materials and the Integration of Artificial Intelligence and Artificial Neural Network Technologies)

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Abstract

This article examines current trends in the development of intelligent lighting technologies based on Light Emitting Apparatus designs. Particular attention is given to the application of composite materials incorporating synthetic diamonds in combination with advanced light-emitting diode (LED) technologies, as well as to the integration of artificial intelligence (AI) and artificial neural networks (ANNs) into intelligent lighting control systems. The paper presents prospective applications of these innovative engineering solutions aimed at improving energy efficiency, thermal management, operational reliability, and the functional performance of next-generation smart lighting systems. The proposed technological approaches may serve as a foundation for the development of advanced energy-efficient lighting solutions for industrial, transportation, architectural, and smart city infrastructure applications.

Keywords: Laser; Laser Diode; Light-Emitting Diode (LED); Light-Emitting Apparatus; Composite Ceramics; Artificial Diamonds Embedded in Composite Ceramics; LED Luminaires with Optical Lenses; LED Luminaire Configurations Incorporating Miniature Lenses.

Introduction

1. Machine Vision

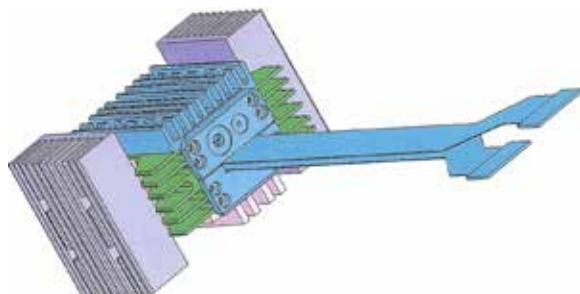
Lasers generate characteristic optical structures resulting from the mutual interference of coherent light waves. These structures, commonly referred to as **speckle patterns**, are random interference patterns formed by the interaction of coherent waves exhibiting

random phase shifts and/or random intensity distributions. Such patterns typically consist of bright speckles separated by dark regions, producing non-uniform illumination.

For automated manufacturing processes and industrial machine vision applications, the operational area must be illuminated with highly uniform monochromatic light to

ensure reliable image acquisition, measurement accuracy, and object recognition.

Figure 1. *Laser diode module with a cooling system based on composite materials incorporating synthetic diamonds*



Conventional laser sources are unsuitable for many machine vision applications because the speckle phenomenon introduces undesirable intensity fluctuations and image artifacts. Light-emitting diodes (LEDs) do not generate speckle and therefore eliminate this limitation; however, LEDs generally exhibit lower optical brightness and produce non-uniform radiation distributions in the far field.

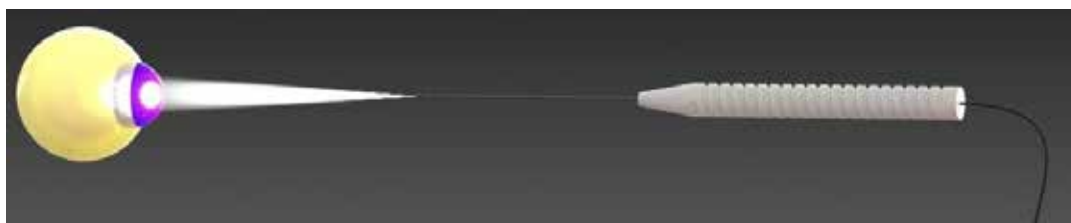
The proposed **Light Emitting Apparatus** overcomes these limitations through the implementation of the patented design incorporating a phosphor microdroplet deposited on the end face of an optical fiber. In this configuration, the effective size of the emitting region is determined either by the phosphor droplet diameter, approximately **100–150 μm** , or by the diameter of the **optical fiber core**, typically **30–50 μm** .

This emitting area is approximately three times smaller than that of a conventional LED while simultaneously providing significantly greater spatial uniformity of the emitted light. These characteristics make the proposed technology particularly suitable for high-precision machine vision systems requiring compact, homogeneous, and high-quality illumination.

The cost of commercially available industrial machine vision lighting systems typically ranges from USD2,000–3,000 for standard configurations to USD25,000–50,000 for advanced integrated solutions. According to preliminary engineering estimates, the proposed Light Emitting Apparatus is expected to reduce system cost by approximately 35–50%, depending on the selected configuration and system architecture.

The operational lifetime of the proposed apparatus is primarily determined by the service life of the laser diode. The proposed design incorporates multiple engineering solutions intended to maximize laser diode longevity, including an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Figure 2.



2. Illumination Systems for Microscopes

The monochromatic light generated by the proposed Light Emitting Apparatus provides significant advantages for microscopic imaging. The use of monochromatic illumination substantially reduces chromatic aber-

ration, thereby improving image quality, optical resolution, and measurement accuracy. These characteristics are particularly important for high-resolution optical microscopy and precision analytical applications.

The cost of illumination systems currently employed in various types of micro-

scopes typically ranges from approximately USD2,000 to USD3,000, depending on the microscope configuration and optical performance requirements.

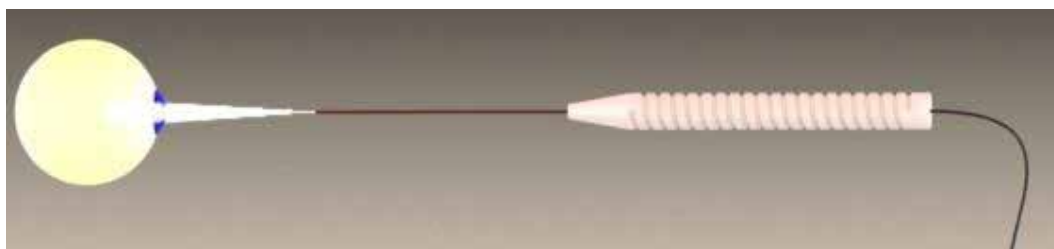
Implementation of the proposed invention is expected to reduce illumination-related energy consumption by approximately 85–95%. Furthermore, the projected manufacturing cost of the proposed illumination system is estimated to be at least 50–60% lower than that of existing commercial solutions while maintaining or improving optical performance.

The application of the proposed Light Emitting Apparatus is expected to significantly improve the overall technical characteristics of modern microscopes, including optical efficiency, illumination uniformity, energy efficiency, and operational reliability. These improvements considerably expand

the potential applications of microscopy across scientific research, medicine, industrial inspection, materials science, biotechnology, and advanced manufacturing.

The operational lifetime of the proposed apparatus is primarily determined by the service life of the laser diode. To maximize durability, the proposed design incorporates multiple engineering solutions, including an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Figure 3.



3. Medical Applications of the Proposed Light Emitting Apparatus

One of the most promising medical applications of the proposed Light Emitting Apparatus is endoscopy.

The proposed optical fiber design incorporating a phosphor microdroplet at the fiber tip enables uniform omnidirectional illumination, allowing light to be emitted in all directions around the distal end of the endoscope. Conventional endoscopic illumination systems are generally limited by the divergence angle of the optical fiber, resulting in illumination of only a relatively narrow field of view.

In contrast, the proposed invention provides substantially improved illumination of the surrounding tissue while supporting the generation of multiple wavelengths, including full-spectrum white light. Furthermore, the apparatus enables operation at specific wavelengths required for specialized medical procedures, including photodynamic ther-

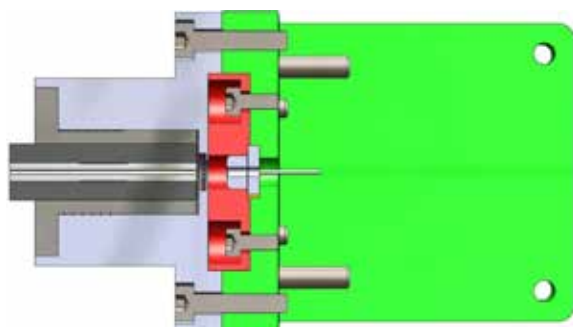
apy (PDT) and ultraviolet (UV) irradiation, thereby expanding both the diagnostic and therapeutic capabilities of modern endoscopic systems.

According to preliminary engineering assessments, an endoscopic illumination system based on the proposed invention is expected to reduce manufacturing costs by approximately 35–45% compared with existing technologies. At the same time, the improved optical performance is anticipated to significantly enhance endoscopic visualization, diagnostic accuracy, procedural efficiency, and overall clinical effectiveness.

The operational lifetime of the proposed apparatus is primarily determined by the service life of the laser diode. To maximize durability, the proposed design incorporates multiple engineering solutions, including an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in

the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Figure 4.



4. Application of the Proposed Light Emitting Apparatus for Surgical Field Illumination

Another important medical application of the proposed **Light Emitting Apparatus** is the illumination of the surgical field during operative procedures.

The optical fiber incorporated in the proposed system can be easily attached to a surgeon's finger or integrated directly into surgical instruments such as scalpels, forceps, or other microsurgical devices, providing localized, highly uniform illumination precisely at the operative site.

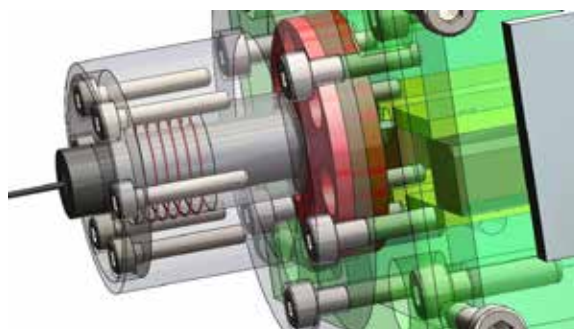
This technology is particularly valuable in ophthalmic surgery, where homogeneous illumination of the sclera is essential for achieving optimal visualization and surgical precision. The optical fiber employed for this application has an extremely small diameter of approximately 100 μm , allowing it to be introduced into the eye with minimal tissue trauma while providing uniform omnidirectional illumination of the scleral region. Such illumination is considered an important factor contributing to improved visualization, enhanced surgical accuracy, and successful clinical outcomes.

The estimated cost of the proposed localized surgical illumination system is expected to be approximately USD3,000, depending on the specific configuration and intended clinical application.

The operational lifetime of the proposed apparatus is primarily determined by the

service life of the laser diode. To maximize durability, the proposed design incorporates multiple engineering solutions, including an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Figure 5.



5. Online Inspection System for Nuclear Reactor Containment Structures and Adjacent Nuclear Facility Components

Another potential application of the proposed Light Emitting Apparatus is its integration into online inspection systems for monitoring the condition of nuclear reactor containment structures and critical components located in the vicinity of nuclear reactors.

The proposed technology may be incorporated into advanced optical inspection and monitoring systems designed to support continuous or periodic assessment of reactor infrastructure, enabling high-quality illumination for visual inspection, defect detection, and structural condition monitoring under demanding operating environments.

According to preliminary engineering estimates, the cost of a complete inspection system based on the proposed invention may reach several hundred thousand U.S. dollars, depending on the configuration, level of automation, and integration requirements.

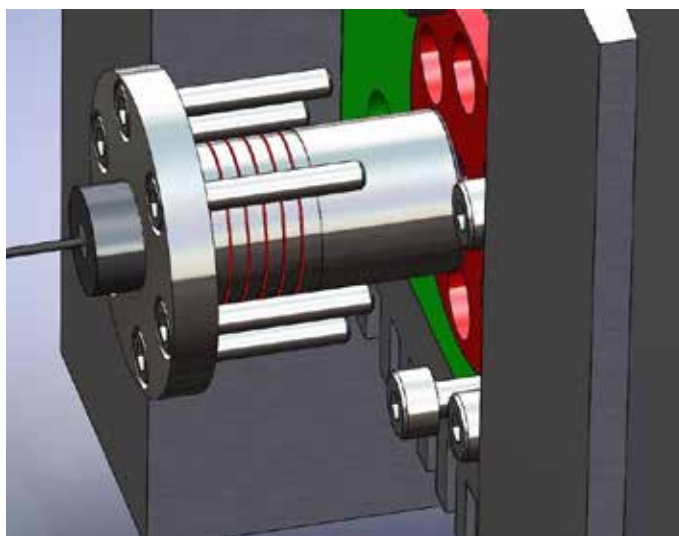
The anticipated market demand includes several hundred systems worldwide for monitoring commercial nuclear power plants.

In addition, several hundred comparable systems may be required for inspection and maintenance of nuclear reactors installed aboard submarines and other platforms equipped with nuclear propulsion systems.

The operational lifetime of the proposed apparatus is primarily determined by the service life of the laser diode. To maximize durability, the proposed design incorporates multiple engineering solutions, including

an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Figure 6.



6. Underwater Illumination Systems for Submersibles and Professional Diving Applications

Another promising application of the proposed **Light Emitting Apparatus** is the development of advanced underwater illumination systems for **submersibles, bathyscaphes, remotely operated underwater vehicles (ROVs), autonomous underwater vehicles (AUVs), and professional diving equipment.**

The proposed technology offers the potential to provide high-intensity, energy-efficient, and highly reliable illumination under extreme underwater operating conditions, where optical performance, thermal stability, and long-term operational reliability are of critical importance.

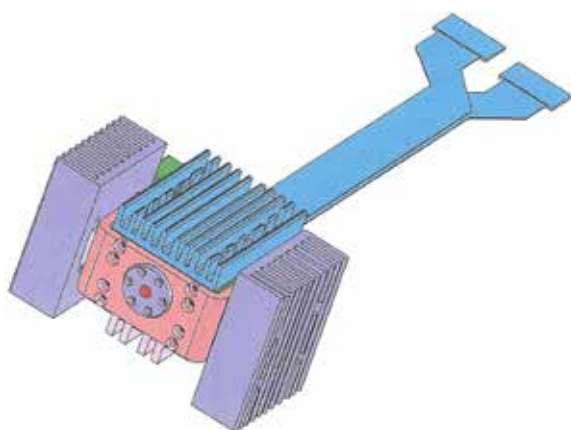
Depending on the system configuration and intended application, the estimated cost of a complete underwater illumination system may reach up to USD100,000.

The overall service life of the proposed apparatus depends on multiple engineer-

ing components; however, the operational lifetime of the illumination system itself is primarily determined by the durability of the laser diode. To maximize service life, the proposed design incorporates multiple engineering solutions, including an advanced high-efficiency cooling system, a modified mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for enhanced thermal management. Based on these design features, the expected operational lifetime of the apparatus is estimated to be 10,000 operating hours or more.

Should there be specific commercial or technical interest, the proposed underwater illumination system can be further developed, optimized, and engineered in greater detail to meet the requirements of particular marine, scientific, industrial, or defense applications.

Figure 7.



7. Underwater Optical Communication Systems

Another promising application of the proposed **Light Emitting Apparatus** is underwater optical communication between divers, surface vessels, submersibles, and submarines.

The proposed system may utilize green wavelengths for communication in coastal and shallow-water environments, where green light provides superior propagation characteristics, while blue wavelengths are more suitable for deep-ocean applications due to their lower attenuation in seawater.

According to preliminary engineering assessments, the proposed technology may provide reliable communication over distances of up to 100 meters between divers. Communication between a surface vessel and a bathyscaphe or other underwater vehicle may potentially reach distances of up to 10,000 meters, depending on environmental conditions, optical system configuration, and communication protocols.

The estimated cost of a fully integrated underwater optical communication system is expected to be approximately USD1 million, particularly for specialized applications in defense, emergency response, underwater rescue operations, and the management of technological disasters.

The overall operational lifetime of the proposed apparatus depends on multiple engineering components; however, the service life of the optical communication subsystem is primarily determined by the durability of the laser diode. To maximize reliability, the proposed design incorporates advanced ther-

mal management, an enhanced mounting module, intelligent control and regulation electronics operating in the radio-frequency range, optimized material selection, specialized protective coatings, and synthetic diamond-based thin-film technologies for superior heat dissipation. Based on these engineering solutions, the expected operational lifetime of the apparatus is estimated to exceed 10,000 operating hours.

Should specific commercial or governmental interest arise, the proposed underwater optical communication system may be further optimized and engineered to satisfy the requirements of particular industrial, scientific, maritime, or defense applications.

Potential Applications of the Proposed Light Emitting Apparatus

The proposed **Light Emitting Apparatus** represents a next-generation intelligent lighting platform that combines advanced laser-based illumination, phosphor-conversion technology, composite materials incorporating synthetic diamonds, and artificial intelligence-driven control systems.

Unlike conventional LED luminaires employing optical lenses or micro-lenses, the proposed technology provides enhanced optical efficiency, superior illumination uniformity, improved thermal management, and significantly greater flexibility in controlling the spectral and spatial characteristics of the emitted light.

These characteristics enable its application across a broad range of sectors, including:

- intelligent industrial lighting and machine vision systems;
- microscopy and scientific instrumentation;
- medical imaging, endoscopy, and surgical illumination;
- underwater lighting and optical communication systems;
- nuclear facility inspection and monitoring;
- transportation and autonomous systems;
- architectural and urban lighting;
- defense and aerospace technologies;

- smart manufacturing and Industry 4.0 infrastructure;
- Smart City lighting networks integrated with artificial intelligence and sensor technologies.

The integration of artificial intelligence, artificial neural networks, advanced compos-

ite materials, and intelligent optical control enables the proposed technology to significantly improve energy efficiency, operational reliability, illumination quality, and functional adaptability compared with conventional LED lighting systems.

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