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LASER TECHNOLOGY AND INTEGRATED TECHNICAL SYSTEMS. (Laser Technology and Integrated Technical Systems for Ophthalmic Devices and Instruments Utilizing Artificial Intelligence Elements Associated with Artificial Neural Networks)

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Abstract

This article examines the potential applications of the invention “Light Emitting Apparatus with Integrated Emitter” in medical technologies, machine vision, and related automated systems. The distinctive technical features of the proposed invention can provide significant technical and economic benefits across a wide range of applications. One of the prospective applications considered in the article is machine vision. A number of medical procedures, therapeutic processes, and automated manufacturing operations require uniform illumination of the operating or working area with monochromatic light. Under certain operating conditions, conventional laser systems produce localized and distorted light patterns and therefore are not suitable for generating a uniform monochromatic light flux across an operating or working area. Light-emitting diodes (LEDs) do not produce such distorted structures; however, they generally provide lower brightness, while their radiation may also exhibit non-uniformity in the far field. To provide a comprehensive solution to these technical limitations, the article considers a configuration of the “Light Emitting Apparatus with Integrated Emitter” incorporating a phosphor droplet at the end face of an optical fiber. In this configuration, the dimensions of the light-emitting region are determined either by the diameter of the phosphor droplet, approximately 100–150 μm , or by the diameter of the fiber core, approximately 30–50 μm . The proposed apparatus also incorporates a combination of engineering solutions intended to extend the operational lifetime of the laser diode, including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and protective coatings, including synthetic diamond films. The combined implementation of these technical solutions is expected to provide a laser diode operational lifetime of approximately 10,000 hours or

more, while enabling stable and uniform monochromatic illumination for medical, machine-vision, and automated industrial applications.

Keywords: *Laser Technology; Integrated Technical Systems; Light-Emitting Diodes (LEDs); Monochromatic Light; Laser Diodes; Standard Lasers; Monochromatic Light Flux; Machine Vision; General Technical Specifications of Microscopes; Modified Mounting Module; Laser Diode Lifetime*

Introduction

A wide range of medical technologies, as well as a number of technologies related to them to varying degrees, can benefit from the

distinctive features of the above-mentioned invention, providing a significant technical and economic effect.

Figure 1. *The figure shows an integrated laser illumination system for ophthalmic applications, implementing a product that utilizes artificial intelligence elements associated with artificial neural networks, under the general name “Light Emitting Apparatus with Integrated Emitter”*



Potential Applications of the “Light Emitting Apparatus with Integrated Emitter” Invention.

1. Machine Vision

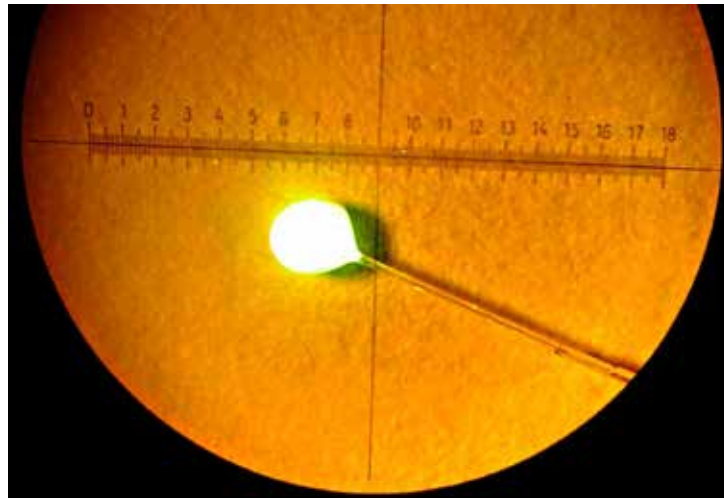
A wide range of processes, including medical treatment procedures and various automated manufacturing processes, require uniform illumination of the operating area with monochromatic light.

Under certain conditions, conventional lasers produce localized, distorted light patterns and are therefore unsuitable for generating a uniform monochromatic light flux within an operating area.

Light-emitting diodes (LEDs) do not produce such distorted patterns; however, they provide lower brightness. In addition, LED radiation is non-uniform in the far field.

For a comprehensive solution to this problem, a configuration of the above-mentioned invention incorporating a phosphor droplet at the end face of an optical fiber can be used. In this configuration, the size of the light-emitting region is determined either by the diameter of the phosphor droplet, approximately 100–150 μm , or by the diameter of the fiber core, approximately 30–50 μm .

Figure 2. *The figure shows a droplet of phosphor mixed with a transparent optical coating applied to the end of an optical fiber inserted into a microscope. The system is shown at the lasing threshold with the microscope illumination lamp switched on*



The application of the distinctive features of the above-mentioned invention makes it possible to fundamentally improve the existing technical configuration.

The dimensions of the phosphor droplet are approximately three times smaller than those of an LED (light-emitting diode). In addition, the resulting light output is expected to be more uniform and stable.

The cost of a conventional machine vision system typically ranges from approximately USD2,000–3,000 to USD25,000–50,000.

According to preliminary estimates, the proposed Light Emitting Apparatus is expected to be approximately 35–50% less expensive, regardless of its specific design or configuration.

The operational lifetime of the proposed apparatus is primarily determined by the operational lifetime of the laser diode.

Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime can be estimated at approximately 10,000 hours or more.

2. Illumination Systems for Microscopes

This application primarily concerns illumination systems for microscopes used in

various medical and biomedical laboratories.

First, it is necessary to compare the complexity and labor intensity involved in manufacturing the proposed technical system with those associated with conventionally used technical systems.

The proposed technology, when integrated into a larger technical system, is sufficiently flexible and adaptable to enable the incorporation of highly efficient and advanced local technical subsystems. These may include high-speed electronic circuit boards (so-called RITM boards) and advanced structural materials, including composite materials and, in particular, carbon–carbon composites produced by vacuum pyrolysis using viscose fabrics, as well as synthetic diamond films.

The implementation of these innovative subsystems makes it possible to obtain significant technical advantages arising from the specific characteristics of laser diodes.

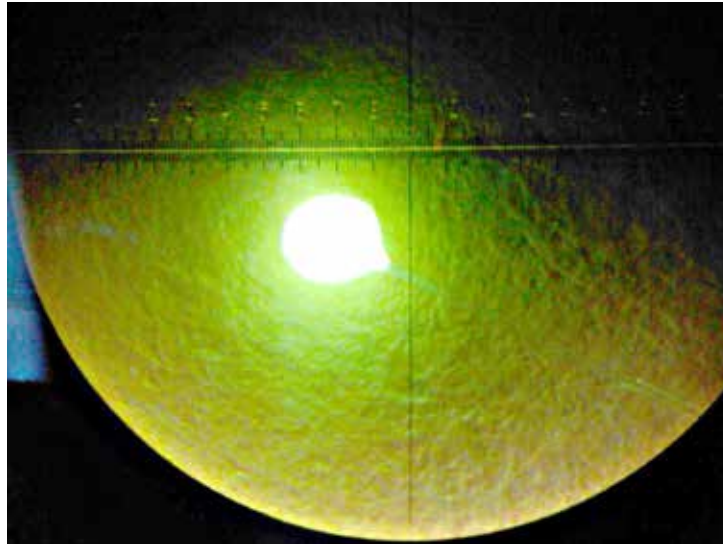
The monochromatic nature of the emitted light generated through the proposed invention makes it possible to reduce or eliminate chromatic aberration and thereby increase optical resolution.

At present, the cost of illumination systems used in various types of microscopes may reach approximately USD2,000–3,000.

When the proposed invention is implemented, energy consumption associated with illumination is expected to be reduced

by approximately 85–95%, while the cost of the proposed configuration is expected to be at least 50–60% lower than that of existing systems.

Figure 3. *The figure shows a droplet of phosphor mixed with an optically transparent coating, attached to the end of an optical fiber inserted into a microscope. The system is shown at the lasing threshold with the microscope illumination lamp switched off*

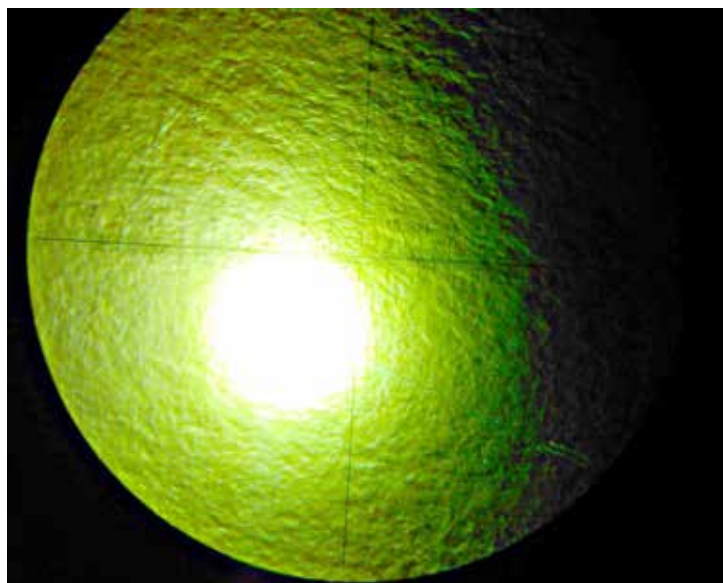


The application of the proposed invention fundamentally changes and improves the overall technical characteristics of microscopes, thereby expanding their potential applications across various fields of engineering

and technology, and particularly in medical applications.

The operational lifetime of the proposed configuration of the apparatus is also primarily determined by the operational lifetime of the laser diode.

Figure 4. *The figure shows a phosphor droplet at the end of an optical fiber inserted into a microscope, operating in a state equivalent to 2 mW of laser output, with the microscope illumination lamp switched off*



Since the proposed apparatus incorporates a comprehensive range of technical

solutions intended to extend the operational lifetime of the laser diode – including

intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime of the laser diode can be estimated at approximately 10,000 hours or more.

3. Application of the Proposed Apparatus in Medicine, Medical Technologies, and Medical Equipment

One of the primary areas of application of the proposed apparatus is endoscopy of various types.

An optical fiber equipped with a phosphor droplet makes it possible to illuminate the surrounding space in multiple directions, since the emitted light is distributed in all directions around the light-emitting region.

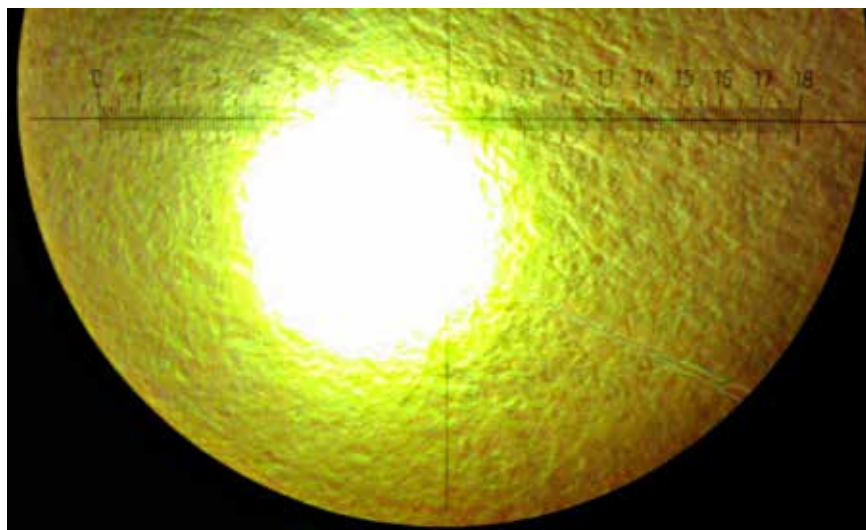
In conventional systems, one of the existing limitations is that only a relatively narrow area is illuminated, with the illuminated region being determined by the divergence of the radiation emerging from the optical fiber. In the proposed configuration of the invented apparatus, illumination can be generated in different spectral ranges and colors, includ-

ing white light. This also provides the possibility of performing, for example, photodynamic therapy and ultraviolet irradiation, thereby offering additional capabilities for both diagnostic and therapeutic procedures.

According to preliminary estimates, the cost of an endoscope illumination system designed in accordance with the proposed invention is expected to be approximately 35–45% lower, while the efficiency of the endoscope and the overall endoscopic procedure is expected to increase significantly.

The operational lifetime of the proposed configuration of the apparatus is primarily determined by the operational lifetime of the laser diode. Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime of the laser diode can be estimated at approximately 10,000 hours or more.

Figure 5. *The figure shows a formed phosphor droplet at the end of an optical fiber inserted into a microscope, operating in a state equivalent to 2 mW of laser output, with the microscope illumination lamp switched on*



4. Application of the Invention for Surgical Field Illumination

Another potential medical application of the proposed invention is illumination of the surgical field.

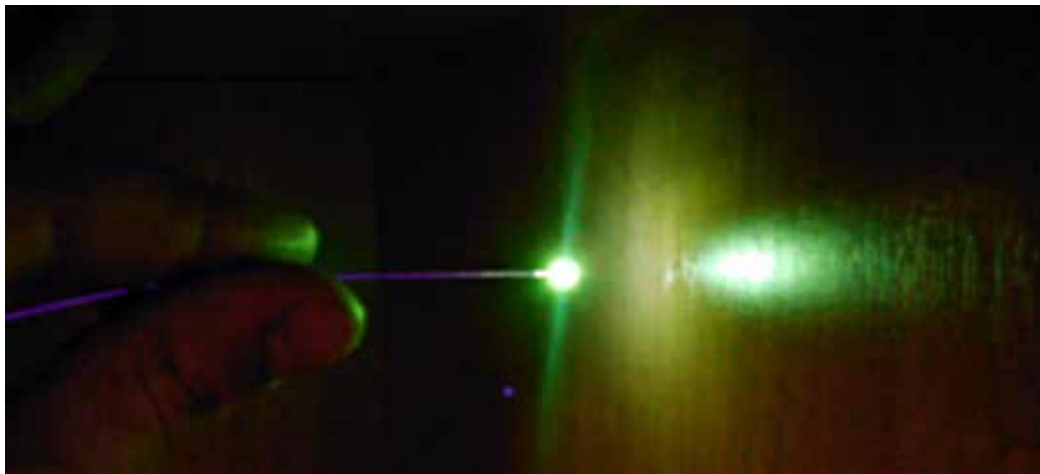
The optical fiber can be readily attached to a surgeon's finger or to a surgical instrument, such as a scalpel or clamp. This capability is of particular importance in ophthalmology.

In ophthalmic procedures, uniform illumination of the sclera of the eye is required. The optical fiber used for this purpose is very thin, with a diameter of approximately 100 μm . Its small diameter allows it to be introduced into the eye with minimal tissue trauma and to provide multidirectional illumination of the sclera. This is considered an important factor contributing to the successful performance of the surgical procedure.

The estimated cost of the proposed local surgical field illumination system may be approximately USD3,000.

The operational lifetime of the proposed configuration of the apparatus is primarily determined by the operational lifetime of the laser diode. Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime of the laser diode can be estimated at approximately 10,000 hours or more.

Figure 6. *The figure shows the characteristic light emission of the technical subsystem in a darkened environment*



As demonstrated by the initial experiments, even a module assembled from standard components operates effectively and confirms the initial theoretical and calculated assumptions.

The optical-to-optical conversion efficiency is very high, even when using a phosphor of relatively low quality that has not been selectively optimized for the specific application.

The image presented in Figure 6 immediately suggests a number of additional applications based on the obviously low weight and compact dimensions of the light-emitting unit, particularly illumination in hard-to-reach locations and localized illumination of specific areas. One of the primary fields for such applications is, once again, medicine.

In dentistry, the proposed technology can be used for illumination of the oral cavity by means of compact light-emitting units

integrated into standard medical and dental instruments. Such a localized illumination system can be incorporated into a dental mirror, saliva suction system, and other dental instruments and devices.

In laboratory and medical examinations, the technology can be used to provide illumination during endoscopic procedures. It can also be combined with fluorescence-based diagnostic techniques, including methods used for vascular examination. Localized procedures involving photochemical reactions can be performed by delivering illumination at the required wavelength.

In surgery, the technology can also be applied to illuminate poorly illuminated or otherwise difficult-to-access areas during diagnostic laparoscopy.

Furthermore, when developing new applications of the proposed technology, it should be taken into consideration that phosphors

can retain their luminescent properties at temperatures of approximately 600 °C. This makes it possible to develop applications for localized or specialized illumination of high-temperature areas. For example, an optical fiber incorporating a phosphor-based emitter could be integrated into the tip of a heated soldering iron to provide visual feedback and real-time monitoring of soldering conditions and soldering quality.

The developers subsequently obtained additional photographs of the same module using the same phosphor. In this configuration, a phosphor-containing droplet was formed at the end of an optical fiber with a diameter of 125 μm . The droplet consisted of an optically transparent coating mixed with the required type of phosphor.

During the initial phase of the experiment, in order to obtain a comparative indication of the efficiency of the proposed technical solution, the phosphor was simply placed adjacent to the end of the optical fiber.

The experimental results showed that the re-emitted optical power reached 1 mW at a laser pump optical power of 2 mW. This represents an exceptionally high result, particularly considering that the phosphor had not been specifically or selectively optimized for this application.

Figure 7. *The figure shows the external appearance of the same module – an optical fiber with a phosphor droplet mixed with an optically transparent coating – with the laser operating in the lasing state*



Other configurations of the proposed system are also possible.

The diameter of the optical fiber is 125 μm .

The emitter may have various geometrical configurations. The emitter material may consist of a phosphor or a mixture of phosphors combined with an optically transparent adhesive that becomes optically stable after polymerization or curing.

A particularly preferred configuration involves mixing a phosphor, or a combination of phosphors, with a monomer of an optically transparent and chemically resistant polymeric material, such as polymethyl methacrylate (PMMA), polycarbonate, or other suitable polymers, followed by polymerization using non-contact heating under vacuum or microwave-assisted processing. The outer diameter of the emitter must not exceed 0.45 mm.

As demonstrated by the results of a comprehensive analysis, the same technical system, in various design configurations, can be effectively applied in numerous other technological fields, including applications at the intersection of different technologies.

For example:

5. Online Inspection System for Nuclear Reactor Containment Structures and Systems Located in the Vicinity of Nuclear Reactors

The proposed configuration of the invention could potentially be used for the online inspection and monitoring of nuclear reactor containment structures and systems located in the vicinity of nuclear reactors. The estimated cost of the proposed configuration of the invention may amount to several hundred thousand U.S. dollars.

Several hundred such devices may potentially be required worldwide. In addition, several hundred similar devices may be required for the inspection of nuclear reactors installed on submarines and other facilities equipped with nuclear propulsion or nuclear power systems. The operational lifetime of the proposed configuration of the apparatus is primarily determined by the operational lifetime of the laser diode. Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use

of specialized materials and coatings, including synthetic diamond films – the expected opera-

tional lifetime of the laser diode can be estimated at approximately 10,000 hours or more.

Figure 8. *The figure shows how the light emitted by the phosphor is projected onto a screen*



6. Underwater Illumination Systems, Particularly for Bathyscaphes and Divers

The proposed technology can also be applied to underwater illumination systems, particularly illumination equipment designed for bathyscaphes, submersibles, and divers.

The estimated cost of such a system may reach approximately USD100,000.

There are also several possibilities for developing standalone products based on the same technological principle.

One such standalone product is a light source.

For a single-use configuration, the estimated demand may exceed 5,000 units per month. A disposable version of the product may be commercially feasible provided that its price remains relatively low and below the cost of comparable products currently manufactured and used.

For a reusable configuration, the projected demand is approximately 3,000 modules per month. There is also significant potential for the development of numerous specialized applications based on the proposed product and technology.

Another standalone product based on the same technological principle may have a current estimated demand of at least 5,000 units per month. The potential market demand

may exceed 1,000,000 units per month for a single-use version of the product. One of the principal limitations of comparable products currently manufactured and available on the market is insufficient light intensity.

Figure 9. *The figure shows how the light emitted by the phosphor is projected into the corner of the box*



The operational lifetime of the proposed apparatus depends on a number of individual components; however, the operational lifetime of the illumination system itself is

primarily determined by the operational lifetime of the laser diode. Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime of the laser diode can be estimated at approximately 10,000 hours or more.

If there is specific interest in this application, the system can be developed and analyzed in greater detail.

7. Underwater Communication Between Divers, Surface Vessels, and Submarines

Another potential application of the proposed technology is an underwater optical communication system between divers, surface vessels, and submarines.

Green light may be used in coastal waters, while blue light may be used in the open ocean. The communication range between underwater users may reach approximately 100 m, while communication between a surface vessel and a bathyscaphe or other submersible may reach approximately 10,000 m.

The estimated cost of an integrated system of this type may be approximately USD1 million, particularly when the system is intended for operation under military conditions, emergency situations, or technological and industrial disasters.

The operational lifetime of the proposed apparatus depends on a number of individual components; however, the operational lifetime of the illumination system itself is primarily determined by the operational lifetime of the laser diode.

Since the proposed apparatus incorporates a comprehensive range of technical solutions intended to extend the operational lifetime of the laser diode – including intensive cooling, a modified mounting module equipped with control and regulation electronics operating in the radio-frequency range, selective use of specialized materials and coatings, including synthetic diamond films – the expected operational lifetime of

the laser diode can be estimated at approximately 10,000 hours or more.

If there is specific interest in this application, the system can be developed and analyzed in greater detail.

Other Design Configurations

Configuration 1

The diameter of the optical fiber is 125 μm .

The outer diameter of the tube is 0.6 mm. The tube is made of stainless steel, such as 12Kh18N10T stainless steel. The inner diameter of the tube is 0.45 mm. The length of the tube may vary; however, this does not impose a limitation on the product, since variations in tube length can be compensated for by adjusting the length of the optical fiber.

The emitter may have various geometrical configurations. The emitter material may consist of a phosphor or a mixture of phosphors combined with an optically transparent adhesive, which becomes solid after polymerization or curing.

A particularly preferred configuration involves mixing a phosphor, or a mixture of phosphors, with a monomer of an optically transparent and chemically resistant polymeric material, such as polymethyl methacrylate (PMMA), polycarbonate, or other suitable polymers, followed by polymerization using non-contact heating under vacuum or microwave-assisted processing.

The outer diameter of the emitter must not exceed 0.45 mm.

Configuration 2

The diameter of the optical fiber is 125 μm .

The emitter may have various geometrical configurations.

The emitter material may consist of a phosphor or a mixture of phosphors combined with an optically transparent adhesive, which becomes solid after polymerization or curing.

A particularly preferred configuration involves mixing a phosphor, or a mixture of phosphors, with a monomer of an optically transparent and chemically resistant polymeric material, such as polymethyl methacrylate (PMMA), polycarbonate, or other suitable polymers, followed by polymerization using non-contact heating under vacuum or microwave-assisted processing.

To provide complete chemical neutrality and enhanced chemical resistance, it is proposed that the emitter and the adjacent section of the optical fiber be coated with a 5 μm -thick synthetic diamond film.

The outer diameter of the emitter, including the diamond coating, must not exceed 0.45 mm.

Configuration 3

The proposed diameter of the optical fiber is 125 μm .

The outer diameter of the tube is 0.6 mm. The tube is made of stainless steel, such as 12Kh18N10T stainless steel. The inner diameter of the tube is 0.45 mm.

The length of the tube may vary; however, this does not impose a limitation on the product, since variations in tube length can be compensated for by adjusting the length of the optical fiber.

The emitter may have various geometrical configurations. The emitter material may consist of a phosphor or a mixture of phosphors combined with an optically transparent adhesive, which becomes solid after polymerization or curing.

A particularly preferred configuration involves mixing a phosphor, or a mixture of phosphors, with a monomer of an optically transparent and chemically resistant polymeric material, such as polymethyl methacrylate (PMMA), polycarbonate, or other suitable polymers, followed by polymerization

using non-contact heating under vacuum or microwave-assisted processing.

The outer diameter of the emitter must not exceed 0.45 mm.

Configuration 4

The diameter of the optical fiber is 125 μm .

The outer diameter of the tube is 0.6 mm. The tube is made of stainless steel, such as 12Kh18N10T stainless steel. The inner diameter of the tube is 0.45 mm.

The length of the tube may vary; however, this does not impose a limitation on the product, since variations in tube length can be compensated for by adjusting the length of the optical fiber.

The emitter may have various geometrical configurations.

The emitter material may consist of a phosphor or a mixture of phosphors combined with an optically transparent adhesive, which becomes solid after polymerization or curing.

A particularly preferred configuration involves mixing a phosphor, or a mixture of phosphors, with a monomer of an optically transparent and chemically resistant polymeric material, such as polymethyl methacrylate (PMMA), polycarbonate, or other suitable polymers, followed by polymerization using non-contact heating under vacuum or microwave-assisted processing. The outer diameter of the emitter must not exceed 0.45 mm.

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