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Hollow-core antiresonant optical fiber activated with $YAG{:}Yb^{3+}$

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Abstract. This article presents methods for modifying the structures of an antiresonant optical fiber with a hollow cardiovascular system, with the help of which it is possible to detect a large number of active substances without resorting to the ways and technological processes of cardiovascular diseases. To obtain luminescence centers, a hollow antiresonant fiber is bound to capillaries with a solution of a $YAG{:}Yb^{3}+$ composite and an organic solvent of dimethylformamide. After the procedure, several processing options are identified that cause the stocks of blanks to dry under normal conditions at a temperature of 150 °C and heat treatment at a temperature of 1000 °C. As a result, film tissues based on $YAG{:}Yb^{3+}$ were formed inside the capillaries. The obtained luminescence peaks in the main and one of the additional peaks for $YAG{:}Yb^{3+}$.

Keywords: hollow core antiresonant optical fiber, activated optical fiber, luminescence

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Полое антирезонансное оптическое волокно, активированное $YAG{:}Yb^{3+}$

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Аннотация. В статье представлен способ модификации структуры антирезонансного оптического волокна с полой сердцевиной, с помощью которого можно сформировать слои активного вещества, не прибегая к дорогим и технологически сложным процессам CVD. Чтобы получить центры люминесценции, полое антирезонансное волокно с четырьмя капиллярами заполняли раствором композита $YAG{:}Yb^{3+}$ и органического растворителя диметилформамида. После процедуры заполнения происходило несколько этапов последующей обработки, которые включали в себя сушку заполненной заготовки в печи в нормальных условиях при температуре 150 °С и ее термообработку при температуре 1000 °С. В результате внутри капилляров формировались тонкие пленки на основе $YAG{:}Yb^{3+}$. Полученные пики люминесценции соответствуют основному и одному из дополнительных пиков для $YAG{:}Yb^{3+}$.

Ключевые слова: полое антирезонансное оптическое волокно, активированное оптическое волокно, люминесценция

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Introduction

In the modern world, it is hardly possible to do without the use of optical fiber. [1–8]. Optical fiber is actively used to solve the problems of information transmission, object detection, etc. [5, 6, 9–16]. Optical fibers are also used in various systems to control physical processes and the operation of differnt devices [17–26]. In addition, the development of optical fibers allows them to be used in areas that were previously occupied by other materials [27–29]. One of these areas is associated with luminescence.

Nanosized lanthanide-activated phosphors are widely used as base materials for the manufacture of fluorescent labels, contrast agents, upconverting media, lighting elements, and displays [30–32]. The practical value of oxide phosphors is determined by their strong emission in the visible and infrared (IR) regions of the spectrum, long lifetime, increased Stokes shift, resistance to photobleaching, low toxicity, as well as their ease of preparation and commercial availability of raw materials [32].

The creation of activated nanosized phosphors based on YAG:Yb^{3+} usually occurs using a variety of methods such as hydrothermal synthesis, sol-gel process, polyol process, codeposition method, aerosol pyrolysis and solution-fuel synthesis. The crystal structure and emissive properties of phosphors are very dependent on the way in which they were obtained.

The polymer-salt method is a liquid-phase process in which mixtures of inorganic compounds and soluble organic polymers are used as film-forming compositions. This approach makes it possible to form one-component or multicomponent coatings from oxide nanoparticles on the substrate surface. The polymer-salt method, in contrast to the sol-gel processes, does not contain the stage of colloid formation. As a result, film-forming compositions do not contain a mixture of colloidal particles, which facilitates the application of highly uniform coatings. The polymer-salt method is simple and economical, and makes it possible to reduce the temperature of nanocrystal synthesis.

Recently, the polymer-salt method has been used to deposit YAG:Nd^{3+} nanocrystals inside a microstructured fiber[33]. The results of the analysis of the resulting fiber showed the presence of nanocrystals with YAG:Nd^{3+} luminescence spectra. However, due to the too small transverse dimensions of the channels, the modifying solution filled the preform inhomogeneously, which led to an uneven distribution of nanocrystals inside the resulting fiber.

This study is aimed at developing a prototype of an active quartz optical fiber with nanosized YAG:Yb^{3+} phosphors uniformly distributed (in the transverse and longitudinal directions) inside the fiber. The main criteria for the development of preforms were the limited number and large internal diameter of the capillaries in order to eliminate the inhomogeneity of filling with the modifying solution.

Optical system and research methodology

The design of the hollow antiresonance fiber had to be simple to fill with a modifying solution, and the fiber should also have a bandwidth in the spectral regions close to the photoluminescence excitation wavelength of 940 and 975 nm and the reflection wave characteristic of 1030 nm. For these purposes, a fiber with formed capillaries with a diameter of 310 μm, an internal diameter of 200 μm and internal capillaries with a diameter of 48 μm and a wall of 8 μm perfectly suited. The design of the capacitor is shown in Fig. 1.

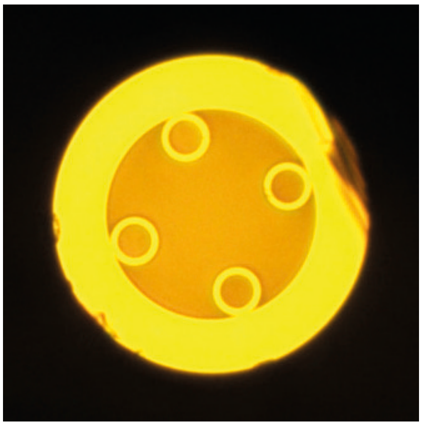

Fig. 1. Construction of a hollow antiresonant light guide

The raw material for the synthesis of the modifying solution was a composite based on YAG:Yb^{3+} dissolved in dimethylformamide in a ratio of 1 part solid to 3 parts solvent.

The formation of thin-film uniform luminescent coatings on the inner surfaces of the capillaries took place in several stages, which included a sequence of operations, the first stage was the impregnation of the workpiece. To simplify the process of blank impregnation with a modifying solution, the air pressure in the channels was reduced, which in turn made it possible to evenly fill the air channels.

After filling the preform proceeded to the second stage, which consisted of convective drying of the filled preform at a temperature of 150°C for 4 hours. To prevent uneven distribution of the substance, the excess of the modifying solution was removed before drying, which made it possible to form composite layers on the inner surfaces of the fiber capillaries.

In order to form a sufficient layer of composite inside, the first and second steps were repeated 3 times before proceeding to the last step.

At the last stage, the dried workpiece was heat treated at a temperature of 1000 °C for 2 hours. As a result of heat treatment, chemical decomposition of solvent residues and metal salts occurred, followed by the formation of thin films based on YAG:Yb^{3+} inside the capillaries.

The result of the fiber after heat treatment at a temperature of 1000 °C is shown in Fig. 2.

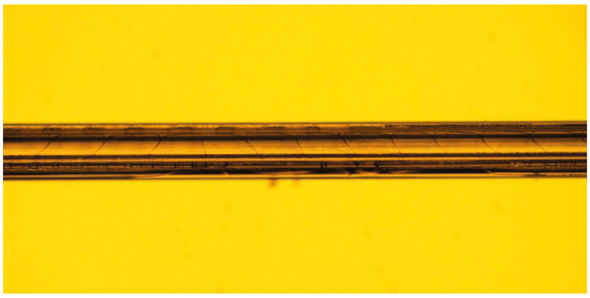

Fig. 2. Capillary with formed thin films inside

Results and Discussion

After the filling and heat treatment procedures, it was decided to test the light transmission of the resulting fiber to make sure that the resulting fiber transmits light at the wavelengths we need in the range of 940-1050 nm. To check the light transmission of the fiber, light from a 64642 HLX halogen lamp (Osram) was applied to its input, and the dependence of the signal level on the wavelength was taken using an AQ-1212B spectrophotometer (Ando Electric Corporation). The resulting dependence is shown in Fig. 3, the dot on the graph marks the absorption wavelength (975 nm) for YAG:Yb^{3+}.

To study the luminescence spectrum of the resulting fiber, a setup was used that included a 64642 HLX halogen lamp (Osram) as a light source, an MDR-23 monochromator (LOMO) for applying a signal with a wavelength of 975 nm to the fiber input, an AQ-1212B spectrophotometer (Ando Electric Corporation), a germanium photodiode for the 900-1700 nm spectral range, an eLockIn 204 optical amplifier (Anfatec Instruments), and an AQ-1135E optical power meter (Ando Electric Corporation). Using a multimode fiber with a length of ~150 cm, radiation from a monochromator with a wavelength of 975 nm was transmitted to the resulting fiber. The output signal was monitored from 1000 to 1200 nm to eliminate the influence of the input radiation. The resulting dependence is shown in Fig. 4.

The resulting luminescence peaks correspond to the main 1030 nm and one of the additional peaks 1066 nm for YAG:Yb^{3+}.

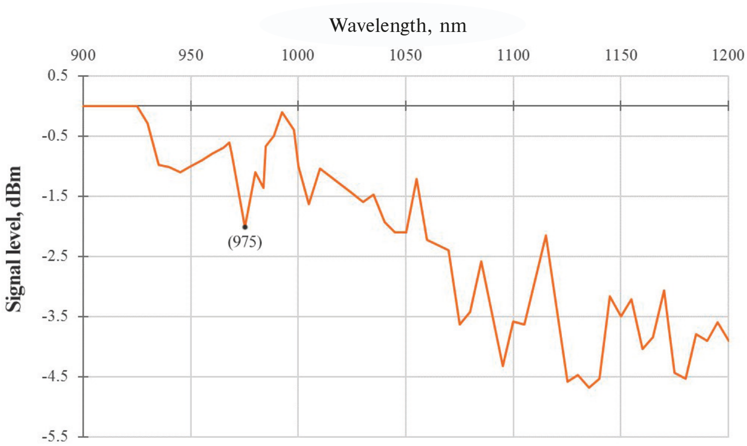

Fig. 3. Transmission spectrum of the resulting fiber

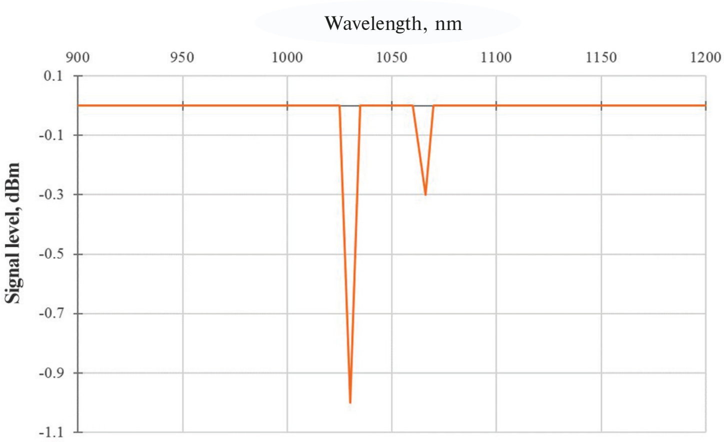

Fig. 4. Dependence of the signal level on the wavelength when applying to the input wavelength of 975 nm

Conclusion

To obtain luminescence centers, a hollow antiresonance fiber with four capillaries was filled with a solution of a YAG:Yb^{3+} composite and an organic solvent of dimethylformamide. After the filling procedure, several stages of subsequent processing took place, which included drying the filled billet in an oven under normal conditions at a temperature of 150 °C and its heat treatment at a temperature of 1000 °C. As a result, thin films based on YAG:Yb^{3+} were formed inside the capillaries. The resulting luminescence peaks correspond to the main and one of the additional peaks for YAG:Yb^{3+}. The presented method for modifying the structure of an antiresonant optical fiber with a hollow core makes it possible to form active layers of YAG:Yb^{3+} crystals with a thickness of several hundred nanometers without using conventional CVD processes, which are usually technologically complex and expensive.

Data on the spectral and luminescent properties of the fabricated fiber confirmed the presence of YAG:Yb^{3+} nanophosphors with the main emission peak at a wavelength of 1030 nm.

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