Patent RU2548388C1

Fibre laser with nonlinear radiation frequency conversion in high-q resonator (versions)

Inventors: S.M.Kobtsev, S.A.Khripunov, D.A.Radnatarov.

Priority: 2013-12-30 | Filing: 2013-12-30 | Grant: 2015-04-20 | Publication: 2015-04-20

Abstract: *FIELD: physics. SUBSTANCE: fibre laser with nonlinear radiation frequency conversion comprises a pumping source, a fibre linear resonator, a module for guiding pumping radiation into amplification fibre, a spectrally selective reflecting element on one side of the linear resonator and having a nonlinear optical crystal of a high-Q resonator on the other side, as well as a focusing element located between the end of the fibre and the high-Q resonator. One of the two flat working surfaces of the nonlinear crystal, or the optical element located in the high-Q resonator, is perpendicular to the incident radiation and serves as exit mirror of the linear resonator. Between the fibre and the focusing element there is a collimating optical element, between which there is a polariser, the surfaces of which are inclined towards the axis of the resonator by an angle of not less than one degree. EFFECT: efficient generation of nonlinearly converted radiation with improved temporal stability of radiation power.*
24 cl, 11 dwg

Description

The present invention relates to lasers - gears for generation of coherent of electromagnetic waves and is industrially applicable in devices and systems using laser radiation.

From the prior art known fiber laser with nonlinear frequency conversion in the external high-Q resonator (JW Kim et al. Efficient second-harmonic generation of continuous-wave Yb fiber lasers coupled with an external resonant cavity. Appl Phys B, 108, 539-543 (2012)). The high-Q resonator is external to the fiber laser and has with him any common elements. The disadvantage of this technical solution is the relatively large temporary instability of the intensity of the second harmonic, which can reach a few percent (<4% rms), and this instability is caused by unstable optical coupling two resonators - and a high-cavity laser resonator - because of the independence of their designs. A further disadvantage of this solution is not optimal output power of the laser radiation, which is caused by sub-optimal transmittance of the output mirror of the laser resonator is 96%, the output mirror is formed perpendicular to the beam of the laser output fiber quartz end, not having any coverage.

The closest to the claimed technical solution is a fiber laser with nonlinear frequency conversion in the domestic high-Q resonator (WO 2012/101391 A1, Optical fiber lasers, publ. 02.08.2012). In this solution, high-Q resonator contained within a linear laser cavity ("cavity resonator", in this case, the laser generates at those frequencies which are common to both resonators - laser generates at the longitudinal modes of the linear resonator, which fall within the bandwidth of a high-Q resonator. Disadvantage this solution is that the quality factor of the internal cavity is constrained by the need to enter into the inner cavity radiation and output therefrom to provide feedback. That is, two mirror inner cavity to be partially transmitting laser radiation, the radiation loss is increased in the inner cavity that lowers the Q of the inner cavity and, consequently, reduces the efficiency of nonlinear frequency conversion in the internal cavity.

The task to be solved by the claimed invention is to provide a fiber laser with increased power output radiation and increased efficiency of nonlinear frequency conversion of the radiation in a high-cavity, as well as reduced time instability of the intensity of the converted light.

This problem is solved by the fact that in a fiber laser with nonlinear frequency conversion in a high-cavity containing optically coupled pumping radiation source, a fiber line resonator that includes supporting the polarization of the radiation enhances the fiber optic module of spectral information for the institution of the pump radiation in the amplifying fiber spectrally-selective reflective element on one side of a linear resonator having a nonlinear optical crystal high-Q cavity on the other side of the linear resonator disposed between a high-Q cavity and the reinforcing fiber end of the fiber and does not reflect laser light back into the fiber disposed between the fiber end and high-Q resonator focusing element focusing emanating from the fiber end radiation in the high-Q resonator and agreed to fashion a linear resonator with fashion high-Q resonator according to the invention one of the two flat working surfaces of the nonlinear crystal with anti-reflective coatings, perpendicular to the incident beam of radiation and serves as the output mirror linear resonator fiber laser, between the end of the fiber and the focusing optical element located collimating element and the focusing element, and between the collimating element is a polarizer, reflecting surfaces which are inclined to the axis of the laser resonator at an angle of not less than one degree.

In particular, high-Q resonator can be formed of a four, a three-mirror and two-mirror configuration. The three-mirror configuration instead of one of the mirrors used a prism.

In particular, the nonlinear optical crystal has a rectangular parallelepiped shape with two working surfaces, which are perpendicular to the incident radiation beam and have antireflective coatings for the laser radiation.

In particular, the nonlinear optical crystal has a second surface oriented at Brewster's angle with respect to the laser beam.

In particular, spectrally-selective reflective element of may be a fiber Bragg grating or volumetric a diffraction grating.

In particular, spectrally selective reflecting element may be a prism in combination with a reflecting mirror or a Littrow prism with a reflective coating on a surface on which normally incident laser beam after refraction on the entrance surface of the prism.

In particular, the reflection of an enlightened working surface of the nonlinear optical crystal of laser radiation for less than 1%.

In particular, the transmittance of a high-Q resonator input mirror for the laser radiation has a value in the range of 1-5%.

In particular, the nonlinear optical crystal can be frequency-doubling crystal for generating parametric or stimulated Raman (Raman) conversion frequency generation.

In particular, as a reinforcing fiber can be used as a glass optical fiber and glass optical fiber doped with rare earth elements or doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include a compound of the chemical elements Si, N, Ga, Al, Fe, F, Ti, B, Sn, Ba, Ta, Zr, Bi.

In particular, the source of pump radiation of a fiber laser can serve as a Raman laser using as reinforcing fibers glass fibers doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include a compound of the chemical elements Si, N, Ga, Al, Fe , F, Ti, In, Sn, Ba, Ta, Zr, Bi, while the Raman laser resonator formed by two fiber Bragg gratings having perpendikuryarnye beam or slanted strokes and reflect radiation of the first Stokes component of the Raman laser.

In particular, in addition to the spectral-selective reflective element may be used spectrally selective transmission element, such as a Fabry-Perot interferometer mounted in a collimated beam of radiation in a laser resonator.

In particular, of a four-high-Q resonator can be arranged in two nonlinear optical crystal, carrying various types of non-linear transformation of the emission spectrum of the fiber laser.

In particular, as a spectrally selective reflective element using fiber Bragg grating with an oblique stroke.

This problem is solved by the fact that in a fiber laser with nonlinear frequency conversion in a high-cavity containing optically coupled pumping radiation source, a fiber line resonator that includes supporting the polarization of the radiation enhances the fiber optic module of spectral information for the institution of the pump radiation in the amplifying fiber spectrally-selective reflective element on one side of a linear resonator having a nonlinear optical crystal high-Q cavity on the other side of the linear resonator disposed between a high-Q cavity and the reinforcing fiber end of the fiber and does not reflect laser light back into the fiber disposed between the fiber end and high-Q resonator a focusing element focusing emanating from the fiber end emission in the high-Q resonator and matching fashion line resonator mode high-Q resonator in accordance with the invention in a high-Q resonator is an optical element, one of the two flat working surfaces which having antireflection coating perpendicular to the incident beam of radiation and provides an output a mirror linear resonator fiber laser, between the end of the fiber and the focusing optical element located collimating element and the focusing element, and between the collimating element is a polarizer, reflecting surfaces which are inclined to the axis of the laser resonator at an angle of not less than one degree.

In particular, the spectrally selective element can be a fiber Bragg grating or volume grating.

In particular, spectrally selective reflecting element may be a prism in combination with a reflecting mirror or a Littrow prism with a reflective coating on a surface on which normally incident laser beam after refraction on the entrance surface of the prism.

In particular, reflection enlightened working surface of the optical element for the laser radiation is not greater than 1%.

In particular, the transmittance of a high-Q resonator input mirror for the laser radiation has a value in the range of 1-5%.

In particular, the nonlinear optical crystal can be frequency-doubling crystal for generating parametric or stimulated Raman (Raman) conversion frequency generation.

In particular, as a reinforcing fiber can be used as a glass optical fiber and glass optical fiber doped with rare earth elements or doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include a compound of the chemical elements Si, N, Ga, Al, Fe, F, Ti, B, Sn, Ba, Ta, Zr, Bi.

In particular, the source of pump radiation of a fiber laser can serve as a Raman laser using as reinforcing fibers glass fibers doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include a compound of the chemical elements Si, N, Ga, Al, Fe , F, Ti, In, Sn, Ba, Ta, Zr, Bi, while the Raman laser resonator formed by two fiber Bragg gratings having perpendikuryarnye beam or slanted strokes and reflect radiation of the first Stokes component of the Raman laser.

In particular, in addition to the spectral-selective reflective element may be used spectrally selective transmission element, such as a Fabry-Perot interferometer mounted in a collimated beam of radiation in a laser resonator.

The technical result provided by the above set of characteristics is to achieve increased power output radiation and increased efficiency of nonlinear frequency conversion of the radiation in a high-cavity, as well as to achieve a reduced time of instability converted radiation intensity. Increased output power is achieved through an optimal transmission of the output mirror of the resonator is 99% or more. Use as fiber laser output mirror enlightened working surface of the nonlinear optical crystal with a reflection light of not more than 1% is the optimum for maximum power output of the fiber laser. According to Dr. annym work Liao et al. Optimization of Yb3 + - doped double-clad fiber lasers using a new approximate analytical solution. Optics & Laser Technology, 43 (1), 55-61 (2011), the optimal transmission of the output mirror of the laser fiber is 99% or more. Increased efficiency of nonlinear frequency conversion of the radiation in a high-cavity is achieved by the fact that the proposed technical solution, high-Q resonator has only one partially transparent mirror - something through which the laser light is put in high-Q resonator. In addition, a further increase in the efficiency of nonlinear frequency conversion in a high-cavity is achieved through the use of fiber laser radiation polarization supporting reinforcing fiber and a polarizer, providing linear polarization of the laser radiation. Reducing the time of instability of the radiation intensity of the converted is achieved by a partial connection configurations of two resonators - part of a high-Q resonator is part of a linear laser cavity.

Should be noted that audio one separately details commitment made device does not gives such effect what gives totality stated features. Before filing this application it was not obvious that the combination of the claimed signs would solve the problem of increasing the power of the laser radiation and increase the efficiency of nonlinear frequency conversion in a high-cavity, as well as the task of reducing the intensity of temporary instability converted radiation.

Essence invention is explained following schemes.

FIG. 1 is a schematic diagram of a fiber laser with nonlinear frequency conversion in a high four-mirror cavity: 1 - pumping radiation source, 2 - spectrally selective reflecting unit 3 - fiber module of spectral information, 4 - supports the polarization of radiation reinforcing fiber, 5 - end fiber linear resonator 6 - collimating optical element 7 - polarizer 8 - focusing optical element 9 - input mirror high-Q resonator 10 - dichroic mirror a high-cavity through which the converted radiation 14 exits the high-Q resonator, 11 - non-linear optical crystal 12 - Coated the working surface of the nonlinear optical crystal 13 - high-Q resonator, 15, 16 - a high-cavity mirror, fully reflecting the laser light.

FIG. 2 is a schematic diagram of a fiber laser with nonlinear frequency conversion in a high-cavity consists of two mirrors 9, 10 and 17 of the prism.

FIG. 3 is a diagram of a fiber laser with nonlinear frequency conversion in a high-cavity consists of two mirrors 9 and 10.

FIG. 4 is a diagram of a fiber laser with nonlinear frequency conversion in a high-four-mirror cavity with nonlinear optical element having a second surface, orientation at the Brewster angle with respect to the laser beam.

FIG. 5 is a diagram of a fiber laser with nonlinear frequency conversion in a high resonator 13 using as spectrally selective reflecting element fiber Bragg grating.

FIG. 6 is a diagram of a fiber laser with nonlinear frequency conversion in a high resonator 13 using as spectrally selective reflecting unit volume grating. Institution radiation on bulk diffraction grating is made through the fiber end face 18 of the linear resonator does not reflect the laser light back into the fiber and collimating element 6.

FIG. 7 is a diagram of a fiber laser with nonlinear frequency conversion in a high resonator 13 using as spectrally selective reflecting element prism in combination with a reflecting mirror. The prism is optically coupled with a linear resonator through a fiber end face 18 does not reflect the laser light back into the fiber and collimating element 6.

FIG. 8 is a diagram of a fiber laser with nonlinear frequency conversion in a high-cavity 13 using as a spectrally selective reflecting element prism Littrow. Littrow prism is optically coupled with a linear resonator laser through the fiber end face 18 does not reflect the laser light back into the fiber and collimating element 6.

FIG. 9 is a diagram of a fiber laser with nonlinear frequency conversion in a high resonator 13 by utilizing the pump as the Raman laser formed by four Raman amplifying fiber and two fiber Bragg gratings 19 that form the cavity of the Raman laser.

FIG. 10 is a diagram of a fiber laser with nonlinear frequency conversion in a high-cavity 13, comprising two non-linear crystal 11 and 20 located at the neck of the radiation between the mirrors 9-15 and 16-10. With this scheme uses two dichroic mirrors 15 and 10 to allow output of a high-cavity two beams converted radiation 14 and 21. One chip can convert the laser radiation into the second harmonic, the second - to perform parametric conversion of the emission spectrum of the laser. In this circuit, the output mirror linear resonator fiber laser is closest to the reinforcing fibers Coated worktop nonlinear optical crystal disposed between the mirrors 9 and 15.

FIG. 11 is a diagram of a fiber laser with nonlinear frequency conversion in a high four-mirror cavity containing a nonlinear crystal 11 with two working Brewster surfaces and the optical element 24 with a flat working surface 12 enlightened.

The device operates as follows.

The pump radiation generated by the source 1, the optical pumping radiation, through the fiber module spectral information 3 enters the reinforcing fibers 4, turning the laser gain medium to an active state; generation of laser is carried out in a linear resonator mirrors which are spectrally selective reflecting element 2 and enlightened working surface 12 of the nonlinear optical crystal 11, located in a high four-mirror cavity 13; radiation from the reinforcing fiber 4 enters the high-Q resonator 13 through the fiber end of the linear resonator 5, the collimating optical element 6, the polarizer 7 and the focusing optical element 8 that serves for matching the linear mode and a high-Q resonators. As collimating and focusing elements could be used as a lens, and lenses. Reflective surfaces of the polarizer 7 are inclined to the axis of the laser resonator at an angle of not less than one degree to radiation reflected from the surfaces of the polarizer, do not fall back into the laser cavity. The output laser light passing enlightened working surface 12 of the nonlinear optical crystal 11, is "locked" in a high-cavity 13, which mirrors 15, 16 and 10 fully reflect the laser light. The loss of the laser resonator 13 are determined mainly by passing the input mirror 9 having a value in the range of 1-5%. The high Q resonator 13 can significantly increase it in the laser intensity and significantly increase the efficiency of nonlinear frequency conversion in a nonlinear crystal 11. Spectral-converted radiation 14 exits the high-Q resonator through a dichroic mirror 10, fully reflecting the laser light and passes the converted radiation. To ensure linear polarization fiber laser uses light polarization supporting reinforcing fibers 4 and a polarizer 7. The end of the fiber linear resonator 5 does not reflect the laser light back into the fiber due to the fact that there has been or cleave angle of not less than 8 degrees, or butt ends fiber without a core (coreless fiber). Using spectrally selective element 2 in the resonator fiber laser allows to narrow the spectrum of the laser radiation to the spectral width of the laser radiation does not exceed the spectral width of the synchronism of the nonlinear crystal 11, it allows a nonlinear transform the entire spectrum of the laser radiation.

When used as a spectral-selective reflective element volume (no fiber) elements, the radiation of the reinforcing fibers is output through the end face 18, and does not reflect laser light back into the fiber due to the fact that it has or cleave angle of not less than 8 degrees, or butt ends of fiber without a core (coreless fiber). When using the Littrow prism, a diffraction grating and a pair of "prism and the reflecting mirror" wavelength tuning of the laser by turning the prism or a grating.

Use as a spectrally selective reflecting element fiber Bragg grating with an oblique stroke increases the coefficient of polarization of the radiation, as a fiber Bragg grating with an oblique stroke is a polarizer with a high degree of polarization of radiation (XP Cheng et al. Tunable single polarization Yb3 + - doped fiber ring laser by using intracavity tilted fiber Bragg grating. Proc. SPIE, v. 7134, 71342V (2008)).

The four-mirror high-Q resonator with an optical element 23 of the linear output mirror of the laser resonator is a flat surface Coated optical element perpendicular to the laser beam. This nonlinear crystal has a working surface oriented at Brewster's angle to minimize radiation losses during the passage of the working surfaces of the nonlinear crystal.

Experimental testing of the proposed scheme fiber laser frequency-doubled radiation in a high four-mirror cavity shown in FIG. 7, showed the following results: using ytterbium-doped fiber reinforcement the maximum output power of the laser at a wavelength of 536 nm was 800 mW at a pump power of 6 W at a wavelength of 976 nm tuning range of the emission wavelength: 521-545 nm, with a power output radiation at the edges of the working spectral range of 420 and 220 mW, respectively, the instability of the emission intensity of the second harmonic was not more than 1% (rms). The spectral width of the fundamental radiation (0.5 nm) is not greater than the spectral width of the synchronism (1.8 nm) of the nonlinear optical crystal LBO, is used in noncritical phase matching mode.

Claims (25)
1: A fiber laser with nonlinear frequency conversion in a high-cavity containing the radiation source is optically coupled pump fiber line resonator including the polarization of radiation supports reinforcing fiber optic module of spectral information for the institution of the pump radiation in the reinforcing fibers, spectrally selective reflecting element with a side line resonator having a nonlinear optical crystal high-Q cavity on the other side of the linear resonator disposed between a high-Q cavity and the reinforcing fiber end of the fiber and does not reflect laser light back into the fiber disposed between the fiber end and high-Q resonator focusing element focusing emanating from the fiber end radiation in the high-Q resonator and matching fashion line resonator mode high-Q resonator, characterized in that one of the two planar working surfaces of a nonlinear crystal with antireflective coating, perpendicular to the incident beam of radiation and provides an output mirror linear resonator fiber laser, between the end of the fiber and the focusing element collimating optical element is located, and between a collimating element and the focusing element is a polarizer with passage for the laser radiation surfaces having a tilt angle to the axis of the laser resonator is not less than one degree.

2: Laser according to Claim. 1, characterized in that the high-Q resonator is made in four-mirror configuration.

3: Laser according to Claim. 1, characterized in that the high-Q resonator is formed in a three-mirror configuration with two mirrors and a prism.

4: Laser according to Claim. 1, characterized in that the high-Q resonator is made in a two-mirror configuration.

5: Laser according to Claim. 1, characterized in that the spectral-selective reflective element is a prism in combination with a reflecting mirror or a Littrow prism with a reflective coating on a surface on which normally incident laser beam after refraction on the entrance surface of the prism.

6: Laser according to Claim. 1, characterized in that the flat working surface of the second nonlinear crystal is not an exit mirror of the cavity is oriented at Brewster's angle with respect to the laser beam.

7: The laser of claim. 1, characterized in that the spectral-selective reflective element is a fiber Bragg grating or volume diffraction grating.

8: The laser of claim. 1, characterized in that the reflection of the working surfaces of the nonlinear crystal for laser emission is not more than 1%.

9: The laser of claim. 1, characterized in that the transmission of a high-Q resonator input mirror for the laser radiation has a value in the range of 1-5%.

10: The laser of claim. 1, wherein the nonlinear optical crystal is a crystal for frequency doubling, or parametric generation or stimulated Raman (Raman) conversion frequency generation.

11: The laser of claim. 1, characterized in that as reinforcing fibers used as fiber glass and glass optical fiber doped with rare earth elements or doped with germanium oxide, phosphorus, and combinations thereof, wherein in the oxide matrix may include Compound chemical element Si, N, Ga, Al, Fe, F, Ti, B, Sn, Ba, Ta, Zr, Bi.

12: The laser of claim. 1, characterized in that the pump radiation source is a fiber laser Raman laser using as reinforcing fibers glass fibers doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include chemical compound of Si element , N, Ga, Al, Fe, F, Ti, In, Sn, Ba, Ta, Zr, Bi, wherein the cavity of the Raman laser is formed by two fiber Bragg gratings having a perpendicular beam or oblique strokes and being reflective to radiation of the first Stokes component Raman laser.

13: The laser of claim. 1, characterized in that the collimated beam of radiation in a laser resonator is spectrally selective transmission element such as, for example, the Fabry-Perot interferometer.

14: The laser of claim. 1, characterized in that of a four-high-Q resonator has two nonlinear optical crystal for the various types of non-linear transformation of the emission spectrum of the fiber laser.

15: A fiber laser with nonlinear frequency conversion in a high-cavity containing the radiation source is optically coupled pump fiber line resonator including the polarization of radiation supports reinforcing fiber optic module of spectral information for the institution of the pump radiation in the reinforcing fibers, spectrally selective reflecting element with a side line resonator having a nonlinear optical crystal high-Q cavity on the other side of the linear resonator disposed between a high-Q cavity and the reinforcing fiber end of the fiber and does not reflect laser light back into the fiber disposed between the fiber end and high-Q resonator focusing element focusing emanating from the fiber end radiation in the high-Q resonator and matching fashion line resonator mode high-Q resonator, characterized in that the high-Q resonator is an optical element, one of the two flat working surfaces which having antireflection coating perpendicular to the incident beam of radiation and provides an output mirror linear resonator fiber laser, between the end of the fiber and the focusing optical element located collimating element and the focusing element, and between the collimating element is a polarizer with passage for the laser radiation surfaces having a tilt angle to the axis of the laser resonator is not less than one degree.

16: The laser of claim. 15, characterized in that the high-Q resonator is made in four-mirror configuration.

17: The laser of claim. 15, characterized in that the optical element is set in a high-beam waist in the resonator radiation.

18: The laser of claim. 15, characterized in that the spectral-selective reflective element is a fiber Bragg grating or volume diffraction grating.

19: The laser of claim. 15, characterized in that the spectral-selective reflective element is a prism in combination with a reflecting mirror or a Littrow prism with a reflective coating on a surface on which normally incident laser beam after refraction on the entrance surface of the prism.

20: The laser of claim. 15, characterized in that the working surfaces of the optical reflection element for the laser is no more than 1%.

21: The laser of claim. 15, characterized in that the transmission of a high-Q resonator input mirror for the laser radiation has a value in the range of 1-5%.

22: The laser of claim. 15, wherein the nonlinear optical crystal is a crystal for frequency doubling, or parametric generation or stimulated Raman (Raman) conversion frequency generation.

23: The laser of claim. 15, characterized in that as reinforcing fibers can be used such as glass fiber or glass optical fiber doped with rare earth elements or doped with germanium oxide, phosphorus, and combinations thereof, wherein in the oxide matrix may include chemical compound of an element Si, N, Ga, Al, Fe, F, Ti, B, Sn, Ba, Ta, Zr, Bi.

24: The laser of claim. 15, characterized in that the pump radiation source may serve a fiber laser Raman laser using as reinforcing fibers glass fibers doped with oxides of germanium, phosphorous, and combinations thereof, wherein in the oxide matrix may include chemical compound element Si, N, Ga, Al, Fe, F, Ti, In, Sn, Ba, Ta, Zr, Bi, wherein the cavity of the Raman laser is formed by two fiber Bragg gratings having a perpendicular beam or slanted strokes, and are reflective to the radiation of the first Stokes components of the Raman laser.

25: The laser of claim. 15, characterized in that the collimated beam of radiation in a laser resonator is spectrally selective transmission element such as, for example, the Fabry-Perot interferometer.