

COMPACT LASER APPARATUS AND METHOD**BACKGROUND OF THE INVENTION**

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3 The present invention relates to a laser system
4 and more particularly to a miniature pulsed laser
5 system using coupled resonator cavities and to a
6 method of producing a beam of coherent light which is
7 eyesafe.

8 Increase in the use of lasers in recent years has
9 produced a requirement for lasers of higher power that
10 are safe for the human eye. The greater the power of
11 the laser, the more risk there is to people who may
12 come into contact with the laser beam when a coherent
13 beam of light enters the eye cornea and either passes
14 through or is absorbed by the vitreous humor. The
15 portion of the beam that is not absorbed by the
16 vitreous humor is focused by the eye onto the retina.
17 Under normal conditions, the light energy is converted
18 by the retina into chemical energy to stimulate
19 optical sensation. Injury can result to the eye when
20 the focused energy laser beam cannot be absorbed and
21 causes damage to the retina. This damage does not
22 occur when conventional sources of illumination are
23 exposed to the eye because the light is emitted in all
24 directions and produces a sizeable but not a focused
25 image on the retina that can be safely absorbed.
26 Laser beams having wavelengths in the range of 1.5 μm
27 - 2.2 μm are absorbed by the vitreous humor, thereby
28 alleviating damage to the retina. Laser systems used
29 as optical radar and communication transmitters in
30 populated locations need to be operated so as to avoid
31 eye damage.

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1 Lasers operating in the 1.5 μm - 2.2 μm
2 wavelength have generally been of low efficiency and
3 of larger size. Two available eyesafe lasers are
4 based on laser emissions in erbium-doped solid state
5 host materials pumped by pulsed gas discharge lamps or
6 frequency conversion of a neodymium laser using
7 stimulated raman scatter in a molecular gas, such as
8 methane. These devices, however, have shortcomings.
9 The erbium lasers typically have an efficiency of less
10 than .1% owing to the low stimulated emission
11 coefficient of the laser transition in erbium 3+ ion
12 at a 1.54 μm output and to the low efficiency for
13 optical pumping with a visible flashlamp. The erbium
14 laser can only be operated in a pulsed mode.
15 Stimulated Raman conversion requires a cell containing
16 a high pressure flammable gas. This gas is excited by
17 the neodymium pumped laser to emit stimulated
18 radiation in the eyesafe region. Raman conversion
19 therefore is not amenable to continuous wave operation
20 and the Raman process deposits energy in the
21 conversion medium causing thermal distortion so that
22 the eyesafe Raman laser cannot be conveniently
23 operated at high average power or repetition rate.

24 An article in Optics Communications, Volume 75,
25 No. 3,4 of March 1, 1990, entitled Generation of
26 Tunable Mid-IR (1.8-2.4 μm) Laser From Optical
27 Parametric Oscillation in KTP by J.T. Lin and J.T.
28 Montgomery, describes an optical laser system in which
29 an Nd:YAG laser is used in an optical parametric
30 oscillator setup where the pumping beam of YAG laser
31 pumps an optical parametric oscillator to produce an
32 output in an eyesafe wavelength. Similarly, in the
33 Burnham et al. patent, No. 5,181,211, for an Eye-Safe
34 Laser System, an Nd:YAG or Nd:YLF solid state laser is

1 used to produce a polarized output beam which is
2 passed through a non-linear crystal in an optical
3 parametric oscillator to convert the wavelength of the
4 pump laser to a wavelength that is absorbed by the
5 human eye.

6 An optical parametric oscillator or OPO places a
7 non-linear crystal within a resonant optical cavity in
8 which mirrors transmit the pump wavelength from a
9 laser beam through a non-linear crystal, such as
10 potassium titanyl phosphate or KTP. The non-linear
11 crystal can be rotated to change the output
12 wavelength. The existence of a resonant optical
13 cavity makes the parametric oscillator superficially
14 similar to lasers since they also generate a coherent
15 beam. However, since there is no stimulated emission
16 within the parametric oscillator cavity, it does not
17 act as a laser simply because the parametric
18 oscillator is in a resonant optical cavity. The
19 oscillator can be brought within the laser cavity.
20 The use of a short pulse (<10 ns) Nd:YAG laser to pump
21 a non-critically phased matched KTP optical parametric
22 oscillator in the eyesafe region results in
23 unacceptably low conversion efficiencies, such as less
24 than ten percent. This low efficiency apparently was
25 due to the short pump pulses. When the OPO was placed
26 intracavity to the pump laser, the conversion
27 efficiency increased but the output consisted of
28 multiple pulses rather than a clean single pulse
29 required for many applications.

30 The present laser system in contrast to the prior
31 art uses coupled laser cavities to maintain the high
32 efficiency of an intracavity system while at the same
33 time achieving a single pulsed output to thereby
34 overcome the problems of an extra cavity optical

1 parametric oscillator used in combination with an
2 Nd:YAG laser and also overcomes the shortcomings of
3 placing the OPO intracavity to the pump laser. The
4 present laser system is very compact for placement in
5 very small packages which compactness has been
6 accomplished using a single common substrate mirror
7 with four separately coated regions and a single
8 corner cube to form two primary laser resonators. A
9 second smaller corner cube is used to couple the
10 resonators.

11 A typical optical parametric oscillator apparatus
12 in which the OPO is external of the laser may be seen
13 in U.S. Patent No. 4,180,751 to Ammann which has a
14 laser having a laser cavity mounted adjacent a second
15 resonant cavity of an optical parametric oscillator
16 with the laser being directed into the optical
17 parametric oscillator. In the Geiger et al. patent,
18 No. 5,195,104, an internally stimulated optical
19 parametric oscillator and laser places the optical
20 parametric oscillator within the laser cavity to form
21 a dual optical resonator containing a single optical
22 parametric oscillator and laser crystal intracavity.
23 A frequency modified laser which places a non-linear
24 crystal within the laser cavity can also be seen in
25 the Anthon et al. U.S. patent, No. 4,884,277.

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27 SUMMARY OF THE INVENTION

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29 A laser system includes an apparatus and method
30 having a primary laser resonator having a laser medium
31 therein for producing a laser beam of a first
32 wavelength and a second laser resonator optically
33 connected to the primary resonator to allow a portion
34 of the laser energy from the primary laser resonator

1 to pass into the secondary laser resonator. An
2 optical parametric oscillator is located intracavity
3 of the secondary laser resonator and includes a non-
4 linear crystal for producing a laser beam of a second
5 wavelength therefrom. A coherent beam output is
6 coupled to the optical parametric oscillator for
7 producing an output beam of predetermined wavelength
8 of the second wavelength while blocking the output of
9 the laser beam of the first wavelength so that a dual
10 resonator combines a secondary laser cavity and an
11 optical parametric oscillator to produce a
12 predetermined output wavelength. The compact multiple
13 resonator laser system has a substrate mirror system
14 having four mirror surfaces thereon positioned to form
15 two laser resonators. A multi-pass corner cube is
16 mounted to fold the light beams between a pair of
17 substrate mirrored surfaces while a transfer corner
18 cube is positioned to transfer a laser beam from one
19 resonator to the second resonator to form a very
20 compact pair of laser resonators. One of the laser
21 resonators is a dual resonator forming both the laser
22 resonator and an optical parametric oscillator
23 resonator. A method of producing a coherent light
24 beam of a predetermined output wavelength uses the
25 compact laser system apparatus.

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27 BRIEF DESCRIPTION OF THE DRAWINGS

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29 Other objects, features, and advantages of the
30 present invention will be apparent from the written
31 description and the drawings in which:

32 Figure 1 is a optical schematic of a laser system
33 in accordance with the present invention.

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1 DESCRIPTION OF THE PREFERRED EMBODIMENT

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3 The present invention is for a miniature pulsed
4 laser capable of producing 5-10 mJ at about 1.58 μm
5 and utilizes an intracavity optical parametric
6 oscillator in a unique coupled cavity design to
7 achieve high efficiency without multiple pulsing in a
8 compact mechanically and optically stable package.
9 The compact package is less than 75 cubic centimeters
10 and may have an eyesafe wavelength of 1.5 μm - 1.6 μm
11 capable of generating 5-10 ns pulses for use in
12 handheld rangefinders and the like. The output of a
13 miniature 1.064 μm Nd:YAG laser is shifted into the
14 eyesafe region with a non-critical phased matched
15 potassium titanyl phosphate (KTP) optical parametric
16 oscillator (OPO). The coupled cavity design of Figure
17 1 maintains the high efficiency of an intracavity
18 device while at the same time achieving a single
19 pulsed output. This coupled cavity laser system meets
20 the efficiency and output requirements and allows the
21 laser transmitter to be very compact.

22 Referring to the schematic of Figure 1, the
23 overall laser transmitter 10 includes a primary 1.06
24 μm resonator 11 containing a Nd:YAG rod 12 pumped by
25 a flashlamp 19 along with a pair of steering wedges 13
26 and a Q-switch 14, which is illustrated as a chromium
27 doped YAG saturable absorber. A polarizing element 15
28 may be a brewster plate. These elements are mounted
29 inside a resonator formed by the 1.06 μm decoupling
30 region of a common substrate mirror 16 having the
31 substrate 17 having a 30% reflectance of 1.06 μm
32 mirror 18 mounted on the substrate 16 and a 100% 1.06
33 μm reflecting mirror 20 mounted on the substrate to
34 form a resonance cavity between the mirrored surfaces

1 20 and 18. The laser rod 12 is in the beam path,
2 illustrated as 21, which is folded by the multi-pass
3 corner cube 22 providing folding surfaces to fold the
4 beam 21. Thus, the laser rod 12 is pumped by an
5 optical flashlamp (not shown) to produce the lasing
6 action within the resonant cavity between the mirrored
7 surfaces 18 and 20. The beam passes through the 30%
8 reflecting surface 18 where the beam is folded by the
9 transfer corner cube 25 and passes back through the
10 substrate 16 and through a mirrored surface portion 26
11 which has a zero reflectance for the 1.06 μm .

12 The 1.06 μm laser beam passes into a secondary
13 1.06 μm resonator 27 where it is folded by the multi-
14 pass corner cube 22 back to a fourth mirrored surface
15 area 31 on the common substrate 16. Mirror 31 has an
16 80% reflectance of 1.06 μm wavelength and allows 20%
17 to pass therethrough into the 1.06 μm dump 32. Since
18 the mirror 31 is reflecting 80% of the 1.06 μm , a
19 portion of the energy is passed back through the
20 secondary resonant cavity 27 and back through the
21 mirrored surface 26 through the corner cube 25 where
22 a portion of the energy passes through the mirrored
23 surface 18 while a portion of it is reflected back
24 into the secondary cavity.

25 The secondary cavity 27 forms a dual optical
26 resonator which is both a secondary laser resonator
27 and an optical parametric oscillator resonator. The
28 optical parametric oscillator is formed by having the
29 potassium titanyl phosphate (or KTP) crystal 33 within
30 the beam path within the cavity 27. This OPO
31 resonator is a 1.58 μm resonator containing the down
32 scope 34 along with a pair of steering wedges 35 and
33 a KTP crystal 33. The resonator is formed by the 1.58
34 μm outcoupling region of the common substrate mirror

1 26 which is 50% reflective of the 1.58 μm beam but
2 transparent to the 1.06 μm beam. The 1.58 μm mirror
3 31 reflects 100% of the energy while reflecting only
4 80% of the 1.06 μm beam. Similarly, the 1.58 μm
5 resonator also uses the multi-pass corner cube 22.

6 The 1.58 μm output from the dual resonant cavity
7 27 passes through the mirrored portion 26 and is
8 coupled out of the system as the energy passes through
9 the transfer corner cube 25 and impinges on the
10 dichroic beam splitter 36. The dichroic beam splitter
11 reflects the entire 1.58 μm energy along the path 37
12 where it impinges against a second dichroic beam
13 splitter 38 to produce a 1.58 μm output 40. Thus, the
14 output from the 1.58 μm resonator is produced from the
15 output of the laser while the 1.06 μm energy passes
16 back through the dichroic beam splitter 36 and a
17 portion of which passes through the mirrored surface
18 18 while a portion is reflected back through the
19 beam splitter 36, transfer corner cube and back into
20 the secondary laser cavity 27.

21 The operation of the laser resonator is as
22 follows: Firing of the flashlamp causes the gain to
23 begin to buildup in the Nd:YAG rod 12. Initially, the
24 single pass loss of the saturable absorber 14 is high
25 and this loss combined with the out coupling mirror 18
26 losses prevents the buildup of laser oscillation.
27 Eventually, the round trip gain exceeds the round trip
28 losses and the 1.06 μm field begins to grow in both
29 primary 1.06 μm cavity 11 and the secondary 1.06 μm
30 cavity 27. The feedback from the mirror in the
31 secondary 1.06 μm resonator 27 lowers the threshold at
32 which the 1.06 μm oscillation will begin. As the 1.06
33 μm field grows, the absorption loss due to the
34 saturable absorber 14 begins to saturate allowing yet

1 more growth of the 1.06 μm field. This cycle
2 continues until the saturable absorber transmission
3 has increased significantly and a Q-switch 1.06 μm
4 pulse has begun to develop. As the 1.06 μm field in
5 the secondary resonator 27 grows, it eventually
6 reaches a level at which it begins to be converted by
7 the KTP crystal 33 into two longer wavelengths. The
8 crystal 33 angle determines what two wavelengths are
9 generated by the crystal 33 and the angle has been
10 chosen in the present crystal, such as to produce
11 wavelengths of 1.58 μm and 3.26 μm . In a pure
12 intracavity optical parametric oscillator, the non-
13 linear conversion of the 1.06 μm field to the longer
14 wavelengths causes the 1.06 μm field to be depleted
15 and to cease oscillation before the stored energy in
16 the Nd:YAG rod has been fully extracted. This
17 residual stored energy can result in one or more
18 secondary 1.06 μm and 1.58 μm pulses. By placing the
19 OPO in a secondary 1.06 μm cavity that does not
20 contain the 1.06 μm gain medium, the non-linear
21 conversion process does not directly interact with the
22 1.06 μm field that extracts the stored energy in the
23 Nd:YAG rod 12. This allows the 1.06 μm oscillation to
24 continue in the primary cavity 11 even as the 1.06 μm
25 field in the secondary cavity 27 begins to be
26 depleted. The net result is a suppression of
27 premature termination of the 1.06 μm oscillation.
28 That leads to a significantly reduced tendency for
29 secondary pulsing and increased conversion of 1.06 μm
30 pump to eyesafe 1.58 μm output.

31 The key to the compactness of the laser 10 is the
32 use of a dual path corner cube 22 along with a
33 transfer corner cube 25 and a single common substrate
34 mirror 16 having the four mirrored surfaces thereon to

1 form all of the optical resonators, as shown in Figure
2 1. In actual practices, it has found that the present
3 laser transmitter can be placed in a total volume of
4 less than 75 cubic centimeters to produce an output in
5 excess of 6 mJ of output at 1.58 μm . Thus, the output
6 energy of greater than 5 mJ per pulse at 1.58 μm is
7 achieved with the efficiency of intracavity OPO
8 without the multiple pulsing problem experienced with
9 an intracavity laser OPO. In addition, the use of a
10 common substrate mirror 16 and the multi-pass corner
11 cube 22 along with the transfer corner cube 25 to form
12 the coupled resonator system results in an overall
13 miniaturization of a laser transmitter to a very small
14 volume of space and also allows for a high degree of
15 alignment stability over extreme temperature and
16 vibration environments. The illustrated laser
17 transmitter of Figure 1, however, should not be
18 considered as limited to the schematic shown but
19 should be considered illustrative rather than
20 restrictive.

CLAIMS:

I claim:

- 1 1. A laser system (10) comprising:
 - 2 a primary laser resonator (11) having a lasing
 - 3 medium (12) therein for producing a laser beam of a
 - 4 first wavelength;
 - 5 a secondary laser resonator (27) optically
 - 6 connected to said primary resonator (11) to allow a
 - 7 portion of the laser energy from said primary laser
 - 8 resonator (11) to pass into said secondary laser
 - 9 resonator (27);
 - 10 an optical parametric oscillator (27,33) located
 - 11 intracavity of said secondary laser resonator (27),
 - 12 said optical parametric oscillator (27,33) having a
 - 13 nonlinear crystal (33) for producing a laser beam of
 - 14 a second wavelength therefrom; and
 - 15 a coherent beam output (40) coupled to said
 - 16 optical parametric oscillator (33,27) for producing
 - 17 an output beam of predetermined wavelength from said
 - 18 optical parametric oscillator resonator (27,33) of
 - 19 said second wavelength, and to block the output of
 - 20 said laser beam of a first wavelength, whereby a dual
 - 21 resonator combines a secondary laser cavity (27) and
 - 22 an optical parametric oscillator cavity (27) to
 - 23 produce a predetermined output wavelength.
- 1 2. A laser system (10) in accordance with claim
- 2 1 in which said laser system includes a common
- 3 substrate mirror (16) having a plurality of mirrored
- 4 surfaces (18,20,26,31) each having a predetermined
- 5 reflectance for predetermined wavelengths.



1 3. A laser system (10) in accordance with claim
2 1 in which said primary laser resonator (11) includes
3 a saturable absorber (14) located intracavity.

1 4. A laser system in accordance with claim 1 in
2 which said laser system includes a single corner cube
3 (25) optically forming said primary laser resonator
4 (11) and said secondary laser resonator (27).

1 5. A laser system (10) in accordance with claim
2 1 in which said transfer corner cube (25) couples the
3 primary and secondary resonators (11,27).

1 6. A laser system (10) in accordance with claim
2 1 in which said optical parametric oscillator (27,33)
3 includes a downscope (34).

1 7. A laser system (10) in accordance with claim
2 1 in which said primary laser resonator (11) includes
3 a polarizing element (15).

1 8. A laser system (10) in accordance with claim
2 1 in which said primary laser resonator (11) includes
3 a steering wedge pair (13) therein for beam alignment.

1 9. A laser system (10) in accordance with claim
2 1 in which said optical parametric oscillator (27,33)
3 includes a steering wedge pair (35) therein for beam
4 alignment.

1 10. A laser system (10) in accordance with claim
2 1 in which said primary laser resonator (11) active
3 medium (12) is Nd:YAG and produces an output
4 wavelength of 1.06 μm .



1 11. A laser system (10) in accordance with claim
2 2 in which said common substrate mirror (16) has 1st,
3 2nd, 3rd and 4th mirror surfaces (18,20,26,31)
4 thereon, each mirror having a predefined reflectance
5 to a predetermined wavelength.

1 12. A laser system (10) in accordance with claim
2 1 in which said optical parametric oscillator (27,33)
3 includes KTP crystal tuned for 1.58 μm wavelength
4 output.

1 13. A laser system (10) in accordance with claim
2 1 in which said secondary laser resonator (27) has an
3 extra-cavity first wavelength dump (32).

1 14. A laser system (10) in accordance with claim
2 1 in which said coherent beam output (36,38) includes
3 a dichroic beam splitter (36) which reflects said
4 second wavelength without reflecting said first
5 wavelength.

1 15. A laser system (10) in accordance with claim
2 1 in which said saturable absorber (14,15) a chromium
3 ion doped YAG.

1 16. A method of producing a coherent beam of
2 light (40) having a predetermined output wavelength
3 comprising the steps of:

4 producing a laser beam of a first wavelength in
5 an active laser resonator (11) having a laser medium
6 (12) therein;

7 directing said laser beam of a first wavelength
8 through a mirror (18) partially reflective to said
9 first wavelength into a passive laser resonator (27);

10 producing a coherent light beam of a second
11 wavelength with an optical parametric oscillator
12 (27,33) located intracavity of said passive laser
13 resonator (27) and pumped by said laser beam of said
14 first wavelength;

15 outputting said coherent light beam of said
16 second wavelength from said optical parametric
17 oscillator (27,33) whereby multiple laser resonators
18 includes an intracavity optical parametric oscillator
19 producing an output beam of a second wavelength.

1 17. A method of producing a coherent beam (40)
2 of light having a predetermined output wavelength in
3 accordance with claim 16 in which the step of
4 directing said laser beam of a first wavelength into
5 a passive laser resonator (27) includes folding said
6 laser beam with a transfer corner cube (25) from said
7 active to said passive resonator (11,27).



1 18. A method of producing a coherent beam (40) of
2 light having a predetermined output wavelength in
3 accordance with claim 16 in which the step of
4 producing a coherent light beam of a second
5 wavelength includes producing a coherent light beam
6 from a dual resonator (11,27) having a passive laser
7 resonator (27) and optical parametric oscillator
8 resonator (27).

1 19. A method of producing a coherent beam (40) of
2 light having a predetermined output wavelength in
3 accordance with claim 16 in which the step of
4 producing a laser beam of a first wavelength produces
5 a beam having a wavelength of 1.06 μm and the step of
6 producing a coherent light beam of a second
7 wavelength produces a light beam having a wavelength
8 of 1.58 μm .



1 20. A compact multiple resonator laser system
2 (10) comprising:

3 a substrate mirror (16) having at least three
4 mirror surfaces (18,20,26,31) thereon positioned to
5 form reflection surfaces for at least two laser
6 resonators (11,27), each of said mirror surfaces
7 having different degrees of reflectance for
8 predetermined wavelengths;

9 a multi-pass corner cube (22) is positioned to
10 fold the laser beams for at least the two laser
11 resonators (11,27) to thereby form at least first and
12 second laser resonators with said mirrored substrate;

13 a laser medium (12) positioned in said first
14 laser resonator (11); and

15 a transfer corner cube (25) positioned to
16 transfer a laser beam from said first laser resonator
17 (11) to said second laser resonator (27) thereby
18 producing a compact multiple resonator laser system
19 (10).

1 21. A compact multiple resonator laser system
2 (10) in accordance with claim 20 having an optical
3 parametric oscillator (27,33) located intracavity of
4 said second laser resonator (27) to produce a beam of
5 predetermined wavelength.

1 22. A compact multiple resonator laser system
2 (10) in accordance with claim 21 having a beam output
3 from said optical parametric oscillator and in which
4 said output includes at least one dichroic beam
5 splitter (36).



1 23. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said first
3 laser resonator (11) includes a saturable absorber Q-
4 switch (14).

1 24. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said optical
3 parametric oscillator (27,33) has a non-linear crystal
4 (33) mounted therein.

1 25. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said optical
3 parametric oscillator (27,33) has a downscope (34)
4 intracavity thereof.

1 26. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which each said
3 substrate mirror (16) reflectance is different for
4 different wavelengths.

1 27. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which first laser
3 resonator (11) has a chromium doped YAG saturable
4 absorber (14).

1 28. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said first
3 laser resonator (11) has a polarizing element (15)
4 therein.

1 29. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said second
3 laser resonator (27) has an optical parametric
4 oscillator (33) mounted intracavity thereof.



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1 30. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said
3 secondary laser resonator (27) has a laser beam dump
4 (32).

1 31. A compact multiple resonator laser system
2 (10) in accordance with claim 20 in which said laser
3 medium (12) in said first resonator (11) is Nd:YAG
4 rod.