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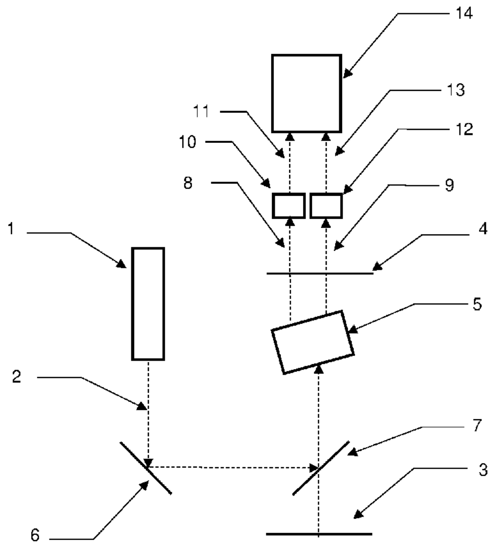
FIG 3



(57) **Abstract:** A light emitting apparatus for the dermatological treatment of a patient comprising: pulsed laser generator; an optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal; a first harmonic generator to produce from the idler its nth harmonic; a second harmonic generator to produce from the signal its nth harmonic; an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.

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PULSED LASER FOR DERMATOLOGY TREATMENTS

BACKGROUND OF THE INVENTION

Dermatological treatments have drastically evolved with the discovery of ruby lasers by Theodore Maiman in 1960, and the first use of a laser on human skin in 1968. Lasers are now commonly used for the treatment of a large range of benign pigmented and vascular skin pathologies, as well as in cosmetic procedures such as skin whitening and tattoo and hair removal. Most laser-based treatments involve an intense laser light source directed at the affected skin tissue, enabling, in most cases, a photothermal reaction and occasionally a photochemical reaction targeting specific chromophores, resulting in their elimination and/or downregulation as shown by R. Anderson *et al.* (*"Selective photothermolysis: precise microsurgery by selective absorption of pulsed radiation"* Science 20, 524-527 (1983)).

The wide variety of skin pathologies and cosmetic procedures, intertwined with the broad range of light-based processes involved in their respective treatments, implies that many different laser wavelengths, operating modes (*i.e.* continuous wave or pulsed with different pulse duration and repetition rate) and light intensity levels are required. For example, pulsed infra-red radiation such as one produced by CO_2 lasers (λ=10.6μm) or mid infra-red lasers (λ=1.45 μm and λ=1.064 μm) are used for resurfacing facial rhytides and acne scars as well as skin rejuvenation. Tattoo-removal lasers are typically operated at wavelengths between 670 nm and 1200 nm with picosecond to sub-nanosecond pulse durations, while hair-removal lasers use wavelengths between 700 nm and 1.064 μm. Shorter wavelengths, typically ranging from 400 nm to 700 nm, have also been extensively used for treating pigmented and vascular lesions such as melasma, lentigines, seborrhoeic keratoses, café-au-lait macules, port-wine stain birthmarks, telangiectasiae, rosacea, spider angiomas, cherry angiomas, venous lakes and others and for treating variations of skin pigmentation (*i.e.* skin whitening).

It is widely accepted that melanin is mainly responsible for abnormal skin pigmentation and its local alteration through a laser-induced photothermal reaction is an efficient treatment. The same approach has also been successful for skin whitening procedures. Vascular lesions in the dermis are effectively treated by locally closing the targeted blood vessels 250 to 425 micrometres below the skin surface as demonstrated by Jacques *et al.* (*"Average depth of blood vessels in skin lesions deduced by optical fiber spectroscopy"* Proc. SPIE 2128 (1994)), through the coagulation of haemoglobin via a photothermal process. The locally-induced slow heating of the blood vessel results in intravascular coagulation and collagen contraction, thereby blocking the affected blood vessel, as shown by T.L. Wall (*"Current concepts: laser treatment of adult vascular lesions"* Semin. Plast. Surg. 21, 147-158 (2007)).

FIG. 1 shows the absorption spectra of both melanin and haemoglobin, exploited for the treatment of abnormal skin pigmentation and vascular lesions respectively. Examination of both spectra reveals that while melanin exhibits a monotonous decay of its absorption with increasing wavelengths, haemoglobin is characterized by three distinct absorption peaks - at 412 nm and 542 nm - and again at 577 nm, where the haemoglobin absorption is greater than melanin. Otherwise, melanin absorption is always higher than haemoglobin. This unique behaviour allows for specifically targeting either melanin or haemoglobin as a function of wavelength for photothermal or photochemical treatment, enabling selective treatment of either pigmented or vascular tissue.

While in theory three different wavelength regions (*i.e.* 412, 542 and 577 nm) could be exploited for the treatment of skin related vascular lesions, their respective penetration depth into the skin tissues greatly varies as shown in the FIG. 2. Yellow wavelengths, centred around 577 nm, offer superior penetration into the dermis allowing the treatment of blood vessels, while exhibiting a reduced absorption by melanin. Consequently, 577 nm is the preferred wavelength when haemoglobin is targeted.

Shorter wavelengths, especially in the UV (below 300 nm) and in the visible (around 490nm) are well suited for the treatment of melanin, as the melanin absorption at these wavelengths is high and haemoglobin absorption low. UV wavelengths are, however, best avoided for skin treatments as they could induce ionising damage as shown by R. Kaufmann *et al.* (*"Pulsed Er:YAG and 308 nm UV-excimer laser: an in vitro and in vivo study of skin-ablative effects"* Laser Surg. Med. 9, 132-140 (1989)), leaving the wavelength in the visible region, centred around 490 nm, as the most viable option.

Pulsed laser regimes have the advantage that the shorter the pulse duration - typically tens of nanosecond to hundreds of picoseconds - the higher the energy peak delivered per pulse when compared with the same average power in CW or long pulse duration laser sources. The combination of wavelength and pulse energy duration results in much greater penetration depth in tissue which is advantageous for evoking photochemical processes throughout the thickness of the epidermis without collateral thermal damage to surrounding tissue.

The aforementioned wavelengths, centred around 490 nm and 577 nm, are notoriously difficult to produce, especially when both high repetition rate and pulse energies are required for photothermal damage. The most efficient laser sources for yellow wavelengths are gas plasma copper vapour and copper bromide lasers, which coincidently emit two wavelengths simultaneously at 511 nm and 578 nm, making them the perfect tool for treating both pigmented and vascular skin lesions with a single laser system as shown in multiple reports from by H.I. Lee *et al.* (*"Clinicopathologic efficacy of copper bromide plus/yellow laser (578nm with 511nm) for treatment of melasma in Asian patients"* Dermatol. Surg. 36, 885-893 (2010)), K.Y. Park *et al. ("Combined treatment with 578-/511-nm copper bromide laser and light-emitting diodes for post-laser pigmentation: a report of two cases"* Dermatol. Ther. 27, 121-125 (2014)), S.E. McCoy (*"Copper bromide laser treatment of facial telangiectasia: Results of patients treated over five years"* Laser Surg. Med. 21, 329-340 (1997)). Unfortunately, gas plasma lasers are bulky and inherently inefficient (~2% efficiency) meaning the vast majority of the input energy required to power such gas plasma lasers is dissipated in heat. Furthermore, the gas tubes containing the gaseous gain medium must be changed regularly to maintain optimum laser performance. Dye lasers, while capable of delivering the appropriate wavelength range, suffer from the same disadvantages as gas plasma, requiring frequent maintenance as the organic dyes used as gain medium are susceptible to photobleaching and consequently need to be changed regularly. Furthermore, while most dye lasers are tuneable owning to the large gain bandwidth for the gain medium, their ability to emit within the two wavelength ranges of interest is still limited. In this context, a solid-state alternative is highly desirable, as it would mitigate the need for demanding maintenance and would also be much more energy efficient. Such solid-state alternatives have been developed in the form of optically pumped semiconductor lasers, using a uniquely formulated quantum well heterostructure, especially for yellow wavelengths. However, this approach has failed to deliver the high pulsed energy, typically around 100 µJ per pulse required for triggering the photochemical/photothermal reaction essential for dermatological treatments. Apart from the semiconductor approach, there is no solid state gain medium, such as rare earth elements (Er^{3+}, Nd^{3+}, Tm^{3+}, Ho^{3+}, Pr^{3+} etc..) or transition metal ions (Ti^{3+}, Cr^{2+}, Cr^{3+}, Cr^{4+} etc...) which either shows significant optical gain in the yellow portion of the optical spectrum or that could be frequency doubled, tripled or quadrupled using standard non-linear crystals to achieve the wavelength and power requirements. Furthermore, none of these approaches would enable the generation of multiple wavelengths simultaneously such as 511 nm and 578 nm produced by a copper bromide gas plasma laser which remains the gold standard, allowing for the treatment of both abnormal skin pigmentation and vascular lesions with a single laser system.

Multiple approaches have been developed for producing simultaneous discrete wavelengths from a single laser system for a wide range of applications. Notably, Moulton et al. *("Three-color Coherent Light System"* US005740190A) developed a laser system capable of generating 3 different wavelengths in the blue (455 nm), green (532 nm) and red (618 nm), produced by a combination of non-linear effects including second harmonic generation and optical parametric oscillation, which can be subsequently recombined to generate any visible colour for illumination and display applications. However, this complex system requires 2 different pump laser sources and does not generate light at the wavelengths of interest (490 nm and 576 nm) for the specific excitation of both melanin and haemoglobin required for the treatment of pigmented and vascular lesions, respectively.

Hunziker et al. ("Dermatological picosecond laser treatment systems and method using optical parametric oscillator", US2019/0151019A1) also used a combination of second harmonic generation and optical parametric oscillation to create a laser system capable of generating multiple wavelengths suitable for dermatological treatment including tattoo removal and pigmented lesions. However, the different wavelengths can not be produced simultaneously but are instead collected after each non-linear process stage to produce either the fundamental of pump laser (1000nm to 1200nm, preferably between 1050 and 1070 nm), after the first second harmonic generation (500nm to 600nm, preferably between 525 and 535nm) and after the optical parametric oscillation spectra (*i.e.* between 630nm and 755nm, preferably 670nm). Depleting the energy carried by the laser beam at a given stage of the laser system inevitably impacts the ability to generate the other wavelengths in the subsequent non-linear stages. This drawback is due to the very nature of the non-linear processes whose wavelength conversion efficiency is depending on the power 2 of the input light intensity. Consequently, the different wavelengths can not be produced simultaneously.

US 2016/0143692A1 (Laser System for skin treatment) describes a laser system skin treatment using a second harmonic generation stage to produce the 2nd harmonic from a YLF crystal (1048nm) at 524nm. The YLF crystal is pumped by a Alexandrite laser and passively Qswitch (Cr:YAG), and so there is no control over the repetition rate. The temporal output is a train of short pulses (1 to 200ns) produced by the passive Qswitch. This train of pulses is further modulated by the operation of the Alexandrite laser which typically has a 1 to 10 Hz repetition rate. The output wavelengths are 524nm (2nd harmonic) for the treatment of vascular lesions and 1064nm for collagen stimulation.

US2019/0336213A1 (High power tuneable optical parametric oscillator for selective photothermolysis laser surgery) discloses operation of multiple identical Optical Parametric Oscillator in parallel (One pump laser with multiple beam output pump multiple Optical Parametric Oscillator which produce identical wavelengths subsequently recombined). The output is continuously tuneable but requires each Optical Parametric Oscillator crystal to be rotated simultaneously which requires precise control of movement.

Marceau et al. "*Second-harmonic frequency-resolved optical gating covering two and a half optical octaves using a single spectrometer*" Appl. Phys. B 119,339-345 (2015) describes a method for resolving the pulse shape of a femtosecond laser. None of the wavelengths are emitted simultaneously, but require constant alteration of the Optical Parametric Oscillator (crystal rotation) and subsequent second harmonic generation stage to cover the optical range. The arrangement must be modified based on the wavelength range of both the signal and idler and the patent is focused on ts ability to perform the measurement over a 2.5 optical octave.

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgement or any form of suggestion that the prior art forms part of the common general knowledge.

SUMMARY OF THE INVENTION

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising a pulsed laser generator; an optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal; a first harmonic generator to produce from the idler its nth harmonic; a second harmonic generator to produce from the signal its nth harmonic; an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed laser generator; an optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a plurality of light redirectors and a non-linear crystal; a first harmonic generator comprising a crystal to produce from the idler its nth harmonic; a second harmonic generator comprising a crystal to produce from the signal its nth harmonic; wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA; an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a laser emitting at 500nm to 850 nm with a pulse duration of between 700 picoseconds to 30 nanoseconds and a repetition rate of between 100 Hz to 100 kHz; an optical parametric generator comprising a plurality of light redirectors selected from reflectors and refractors and a non-linear crystal positioned between a first and a second light redirector, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility; a first harmonic generator comprising a crystal to produce from the idler its nth harmonic; a second harmonic generator comprising a crystal to produce from the signal its nth harmonic; wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA; an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient; the apparatus comprising a resonator.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a laser emitting at 500nm to 550 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz; an optical parametric generator comprising a plurality of reflectors: a non-linear crystal positioned between a first and a second reflector, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility; a first harmonic generator comprising a crystal to produce from the idler its 2nd harmonic; a second harmonic generator comprising a crystal to produce from the signal its 2nd harmonic; wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising a resonator selected from a linear resonator, a singly resonant optical parameter oscillator, a doubly resonant parametric generator, and a ring resonator.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a laser emitting at 500nm to 532 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz; wherein the laser is selected from frequency doubled Nd:YAG laser, Nd:YVO4, Nd:LuVO4 or Nd:GdVO4, Yb:YAG, Yb:YVO4, Yb:GdVO4 or Yb:LuVO4; a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator; an optical parametric generator comprising a plurality of reflectors: a non-linear crystal positioned between a first and a second reflector, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility; wherein the non-linear crystal comprises KTA crystal type II; a first harmonic generator comprising a BBO crystal to produce from the idler its 2nd harmonic; a second harmonic generator comprising a BBO crystal to produce from the signal its 2nd harmonic; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising a linear resonator.

A light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a laser emitting at 500nm to 532 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz; wherein the laser is selected from frequency doubled Nd:YAG laser, Nd:YVO4, Nd:LuVO4 or Nd:GdVO4, Yb:YAG, Yb:YVO4, Yb:GdVO4 or Yb:LuVO4; a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator; an optical parametric generator comprising a plurality of reflectors: a non-linear crystal positioned between a first and a second reflector, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility; wherein the non-linear crystal comprises BBO crystal type II; a first harmonic generator comprising a BBO crystal to produce from the idler its 2nd harmonic; a second harmonic generator comprising a BBO crystal to produce from the signal its 2nd harmonic; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising a linear resonator.

A light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz; a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator; an optical parametric generator comprising: a back reflector, an output reflector, a non-linear crystal positioned between the back and output reflectors, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where P(t) is the dielectric polarization density, E(t) is the electric field and ε0 the vacuum permittivity (8.854x10-12 F/m); wherein the non-linear crystal comprises KTA crystal type II and exhibits a tuning curve according to Fig. 5; wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm; a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz; a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator; an optical parametric generator comprising:

a back reflector, an output reflector, a non-linear crystal positioned between the back and output reflectors, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where P(t) is the dielectric polarization density, E(t) is the electric field and ε0 the vacuum permittivity (8.854x10-12 F/m); wherein the non-linear crystal comprises BBO crystal type II and exhibits a tuning curve according to Figure 4; wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm; a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

In some embodiments, the invention provides a light emitting apparatus for the dermatological treatment of a patient comprising: a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz; a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator; an optical parametric generator comprising:

a back reflector, an output reflector, a non-linear crystal positioned between the back and output reflectors, the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where P(t) is the dielectric polarization density, E(t) is the electric field and ε0 the vacuum permittivity (8.854x10-12 F/m); wherein the non-linear crystal comprises KTA crystal type II and exhibits a tuning curve according to Fig. 5; wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm; a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm; an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient; the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

According to some aspects the present invention provides a system for producing both high pulse energy and repetition rate yellow and green laser light simultaneously from a single laser system for dermatological treatment. The invention relies on a combination of optical parametric generation and harmonic generation to produce two laser outputs in the visible portion of the optical spectrum.

According to one aspect of the invention, there is provided a light emitting system for the dermatological treatment of a patient comprising: a pulsed laser generator to generate a pulsed light; an optical parametric generator; a first harmonic generator; a second harmonic generator; an applicator, arranged to receive and apply either the n^{th} harmonic of the idler, the n^{th} harmonic of the signal or both to the skin of the patient.

In some preferred embodiments, the invention provides a light emitting system for the treatment of abnormal skin pigmentation, skin pigmentation variations and vascular lesion comprising: a pulsed laser generator to generate a first pulsed light train with a 700 picoseconds to 30 nanoseconds pulse duration, a repetition rate of 100 Hz to 100 kHz and a wavelength ranging from 500nm to 850nm; an optical parametric generator, comprising a non-linear crystal inside an optical cavity formed by at least two reflectors, arranged to receive the first pulsed light train and generate two other pulse light trains, the idler and the signal, with their respective wavelengths higher than the first pulsed light train; a first harmonic generator comprising at least one non-linear crystal to generate the n^{th} harmonic of the idler with an output fluence ranging from $5x10^4$ W/cm^2 to $5x10^7$ W/cm^2; a second harmonic generator comprising at least one non-linear crystal to generate the n^{th} harmonic of the signal with an output fluence ranging from $5x10^4$ W/cm^2 to $5x10^7$ W/cm^2; an applicator, arranged to receive and apply either the n^{th} harmonic of the idler, the n^{th} harmonic of the signal or both to the skin of the patient.

In some embodiments, the wavelength of n^{th} harmonic of the idler is ranging from 565nm to 595nm and the wavelength of n^{th} harmonic of the signal is ranging from 480nm to 535nm. In some embodiments, the wavelength of n^{th} harmonic of the idler is ranging from 480nm to 535nm and the wavelength of n^{th} harmonic of the signal is ranging from 565nm to 595nm.

In another aspect of the invention, there is provided a light emitting system for the treatment of abnormal skin pigmentation, skin pigmentation variations and vascular lesion comprising: a pulsed laser generator to generate a first pulsed light train with a 700 picoseconds to 30 nanoseconds pulse duration, a repetition rate of 100 Hz to 100 kHz and a wavelength of 532 nm; an optical parametric generator, comprising a β-Barium Borate (BBO) non-linear crystal inside an optical cavity formed by at least two reflectors, arranged to receive the first pulsed light train and generate two other pulse light trains, the idler and the signal, with their respective wavelengths higher than the first pulsed light train; a 1^{st} harmonic generator being a Second Harmonic Generator (SHG) comprising a BBO non-linear crystal to double the frequency of the idler with an output fluence ranging from $5x10^4$ W/cm^2 to $5x10^7$ W/cm^2; a 2^{nd} harmonic generator being a SHG comprising a BBO non-linear crystal to double the frequency of the signal with an output fluence ranging from $5x10^4$ W/cm^2 to $5x10^7$ W/cm^2; an applicator, arranged to receive and apply either the second harmonic of the idler, the second harmonic of the signal or both to the skin of the patient.

In some preferred embodiments, the wavelength of second harmonic of the idler is 578nm and the wavelength of second harmonic of the signal is 492.5nm. In some preferred embodiments the wavelength of second harmonic of the idler is 492.5nm and the wavelength of second harmonic of the signal is 578nm.

In some embodiments, the pulse laser generator may be actively or passively Q-switched.

The optical parametric generator may be located in a number of positions, and in some preferred embodiments it is located within the optical cavity of the pulse laser generator.

An optical parametric generator can take a variety of forms. In one simple form otherwise known as an Optical Parametric Oscillator (OPO), it is an optical cavity formed by at least two mirrors surrounding a non-linear crystal. Like any other optical cavity, it requires a pump source to be operated, which can only be a coherent light source such as a laser source. The pump laser, once launched into the cavity, interacts with the non-linear crystal to generate two other wavelengths - the signal and idler. The pump wavelength, signal and idler wavelengths are related to each other by the equation 1.

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

Phase matching between the pump, idler and signal wavelength is simply tuned by rotating the non-linear crystal, resulting into the generation of different pairs of signal and idler wavelengths satisfying equation 1. More complex optical parametric generator architectures, for example Optical Parametric Amplifier (OPA), require a second laser input, the seed laser, matching one of the two output wavelengths, typically the signal. This allows for amplifying the energy output of the wavelength matching the seed laser wavelength. A person skilled in the art would appreciate that the optical parametric generator used in this invention could be either an Optical Parametric Oscillator or an Optical Parametric Amplifier, both fulfilling the required function.

A harmonic generator is a device also exploiting the optical properties of a non-linear crystal to generate the n^{th} harmonic of the wavelength passing through. The different harmonics (*i.e.* 2^{nd} harmonic, 3^{rd} harmonic, 4^{th} harmonic and so on) are produced through a combination of different non-linear effects with increasing complexity and decreasing efficiency as the harmonic order increases:

- Second Harmonic Generation (SHG) is the simplest harmonic generation, requiring a single non-linear crystal, whereby two photons of the same frequency, ω_1, are combined to produce a photon with frequency $\omega_2=2\times\omega_1$.
- Third Harmonic Generation (THG) refers to the combination of two photons with different frequencies where the first photon has a frequency ω_1 and the second photon has a frequency $\omega_2=2\times\omega_1$ to produce a third photon with a frequency $\omega_3= \omega_1+\omega_2$. This is typically achieved by using two non-linear crystals, the first one for generating ω_2 through SHG and the second one for Sum Frequency Generation, combining the photons with the different frequencies.
- The Fourth Harmonic Generation (FHG) refers to interaction between 4 photons with the same frequency ω_1 to generation a single photon with a frequency $\omega_4=4\times\omega_1$. This is typically achieved through two consecutive SHG stages.

Higher harmonics, with n>4, are possible although being very inefficient.

In one example embodiment of this invention, the pulsed laser generator is a frequency doubled near infra-red laser emitting a first pulsed light train - typically between 515 nm and 532 nm. This first pulsed light train is directed into the optical parametric generator, where it may for example pass through a first non-linear crystal, set at a fixed incidence angle, to generate the idler and signal. The incidence angle is set in such a way that the idler wavelength is 1156nm and the signal wavelength is 985nm. Both the idler and signal wavelengths are then directed toward two harmonic generators, being SHG in this example, thereby doubling their respective frequencies. This results in the simultaneous generation of both 576nm and 492.5nm which can be used independently through an applicator for treatment of the patient's skin.

Throughout this specification (including any claims which follow), unless the context requires otherwise, the word 'comprise', and variations such as 'comprises' and 'comprising', will be understood to imply the inclusion of a stated integer or step or group of integers or steps but not the exclusion of any other integer or step or group of integers or steps.

DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the relative absorption of two naturally occurring chromophores, haemoglobin and melanin.

FIG. 2 shows the depth of which a variety of wavelengths penetrate human skin.

FIG. 3 shows the system for generating two wavelengths using a combination of second harmonic generation and optical parametric generator.

FIG. 4 shows the tuning curve of a β-barium borate (BBO) type II crystal at room temperature with a 532nm pump laser input. The resulting Idler and Signal wavelength as well as parametric gain are provided as functions of the incidence angle of the pump laser onto the BBO crystal.

FIG. 5 shows the tuning curve of a potassium titanyle arsenate (KTA) type II crystal at room temperature with a 532nm pump laser input. The resulting Idler and Signal wavelength as well as parametric gain are provided as functions of the incidence angle of the pump laser onto the KTA crystal.

FIG. 6 shows the details of the optical parametric generator arranged with a ring cavity.

DETAILED DESCRIPTION OF THE INVENTION

Referencing FIG. 3, a basic example embodiment of the present invention is illustrated. Generally, a pump laser 1, emitting a coherent laser beam 2 at the wavelength λ_P is directed by a diverter (comprising reflectors 6 and 7) into the optical parametric generator, which comprises a back reflector 3 and output reflector 4 and a first non-linear crystal 5 positioned between the reflectors 3 and 4. The optical parametric generator in turn produces two coherent laser beams 8 and 9, named the idler and signal respectively. The wavelength of the idler, signal and the pump laser are related by equation 1. The idler 8 is then passed through a first harmonic generator 10 to produce its n^{th} harmonic 11, while the signal 9 is passed through a second harmonic generator 12 to generate its n^{th} harmonic 13. The resulting signal 11 and 13 are then directed into an applicator 14, allowing their delivery to the patient's skin.

In one particular example, the pump laser 1 is a diode pumped, frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce 1 to 100 mJ per pulse with a pulse duration of 700 picoseconds to 30 nanoseconds and a repetition rate of 100 Hz to 100 kHz. In some preferred embodiments, the pulse duration is in the range 5-30ns and the repetition rate is in the range 15kHz to 22kHz. In one preferred embodiment, the pulse duration is 30ns, in another it is 25ns and in another it is in the range 5-10ns. In one preferred embodiment, the repetition rate is 22 kHz, in another it is 18kHz and in another it is 15 kHz. In one embodiment, has 2W of output at 578nm and 90mJ pulses delivering about 3kW peaks of energy.

A person skilled in the art can appreciate that other solid state laser pump sources can be used instead of a frequency doubled Nd:YAG laser, such as but not limited to a frequency doubled Nd:YVO4, Nd:LuVO4 or Nd:GdVO4. Similarly, a frequency doubled Yb:YAG, Yb:YVO4, Yb:GdVO4 or Yb:LuVO4 emitting at 515nm or any other harmonic of a crystal rod doped with a gain medium emitting in the infra-red could be used. Another alternative is to use the second harmonic of a fiber laser such as a Nd^{3+} doped fiber laser or Yb^{3+} doped fiber laser or any other pump source emitting between 500 nm and 550 nm. The pump laser could be either actively Q-switched, requiring an acousto-optic or electro-optic actuator, or passively Q-switched with a saturable absorber, for generating the appropriate pulse duration and repetition rate.

A wide variety of non-linear materials, defined here as having a high second order susceptibility (χ^2), as defined in equation 2, can be used as non-linear crystal 5 in the optical parametric generator or in the harmonic generators in this invention.

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

Where *P(t)* is the dielectric polarization density, *E(t)* is the electric field and ε_0 the vacuum permittivity (8.854×10^{-12} F/m).

The choice of non-linear material is dictated by a number of considerations such as its optical transparency at the considered wavelengths (*i.e.* visible and near infra-red wavelengths for this invention), its chromatic dispersion and birefringence which determines the necessary phase matching conditions and phase matching bandwidth and its optical damage threshold (*i.e.* ability to sustain high optical power). Many different materials are suitable as non-linear crystals for this invention, such as borate based materials (LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB), lithium based materials ($LiNbO_3$, $LiTaO_3$) or potassium niobate ($KNbO_3$) and potassium titanyl phosphate (KTP, Potassium Titanyle Arsenate (KTA), RTP, RTA). A person skilled in the art will appreciate that this is a non-exhaustive list and different crystal materials and many optical cut and/or periodic poling combinations are possible for the design of a set of non-linear crystals suitable for this invention.

In one particular example the second harmonic of a Nd:YAG pump laser is directed into the optical parametric generator with a BBO crystal type II as non-linear crystal 5. The tuning curve of the optical parametric generator using such crystal is shown in the FIG. 4, which exhibits the idler and signal wavelengths, as well as the optical parametric gain, as a function of the incidence angle of the pump laser at 532 nm. FIG. 4 shows that two incidence angles would yield the combination where the resulting wavelength outputs are 1156nm and 985nm. However, the shorter incidence angle (*i.e.* 31.43 deg), where the idler and signal are equal to 1156nm and 985nm respectively is more advantageous as it exhibits the highest optical parametric gain (*i.e.* 1.18×10^{-4} $W^{1/2}$). The first harmonic generator 10 produces the second harmonic of the idler 8 through its interaction with a BBO crystal cut at 21.7 deg to generate 578 nm. The second harmonic generator 12 produces the second harmonic of the signal 9 through its interaction with a BBO crystal cut at 24.2 deg to generate 492.5 nm. In another example, the optical parametric oscillator uses a Potassium titanyle arsenate (KTA) crystal as non-linear crystal 5. The tuning curve of the optical parametric generator using such KTA crystal is shown in the FIG. 5, which exhibits the idler and signal wavelengths, as well as the optical parametric gain, as a function of the incidence angle of the pump laser at 532 nm. FIG. 5 shows that only one incidence angle (*i.e.* 39.66 deg) would yield the combination where the resulting wavelength outputs are 1156nm and 985nm, with an optical parametric gain of 2.02×10^{-4} $W^{1/2}$, almost twice the optical parametric gain achieved with a BBO crystal. A person skilled in the art will appreciate that a multitude of combinations of non-linear crystals in place of the non-linear crystals 5 or the harmonic generators 10 and 12 are possible to achieve the same outcome.

In some simple implementations of the invention, in order to exploit the optical parametric generation, the construction of an optical cavity is required. In its simplest form, the cavity is created by two reflectors, which can be flat or curved, surrounding the non-linear crystal, and arranged to have their reflective surfaces parallel to each other. This architecture is often referred as a linear resonator. More complex cavity geometries can be designed with more than 2 reflectors to achieve the same purpose and can be referred to for example as a ring resonator. An example ring resonator is shown in the FIG. 6 where the pump laser beam 2 enters the cavity formed by 4 reflectors 15,16, 17 and 18.

The reflectivity of the reflectors is chosen so that they reflect the signal laser beam 9 emerging from the non-linear crystal 5 and transmit both the idler 8 and pump laser 2. This arrangement is often referred to as a singly resonant optical parametric generator. One particularly preferred embodiment is a singly resonant Optical Parametric Oscillator cavity with 2 reflectors. It is relative simple to manufacture and far less sensitive to alignment issues than other configurations as discussed below.

A double resonant parametric generator whereby both the signal 9 and idler 8 are reflected into and resonate within the cavity is also possible and is more efficient. However, it is more complex to implement than a singly resonant Optical Parametric Oscillator cavity as discussed above since the phase for the idler and signal must be matched. This imposes stringent requirements for the design of the cavity which increase the complexity and therefore manufacturing difficulty.

A person skilled in the art will appreciate that the ring resonator architecture presented here is merely one example and that this concept can be extended to either a singly or doubly resonant cavity with n reflectors, with n being an integer equal to or greater than 2.

The modular design of this invention as shown in the FIG. 3 separates the different cavities involved such as the pump laser 1 and the optical parametric generator cavity and the different harmonic generation stages. However, the optical parametric generator can be arranged in such a way that it occurs inside the first pump laser cavity. This particular arrangement is referred to as intra-cavity optical parametric generation. Whilst an intra-cavity arrangement may increase the performance of the current invention it is much more complex to implement and maintain and will not fundamentally change its purpose (*i.e.* generating simultaneously two laser outputs at 492.5nm and 578nm).

The repetition rate and pulse duration of both the signal and idler wavelength depend only on the pump laser. The optical parametric generator has only a marginal effect on the pulse duration, generally compressing the pulse temporal width by 10%. The different second harmonic generation stages involved have no effect on both the pulse duration and repetition rate.

While the approach developed in this invention might be counterintuitive, especially with an optical parametric generator being used which would allow for tuning the output wavelengths within the same desired spectral range in other circumstances, it offers several key advantages:

- Firstly, it allows the simultaneous generation of the two required wavelengths without necessitating any rotation of the non-linear crystal 9 inside the optical parametric generator, as shown in the FIG. 3, to generate either the 492.5 nm or 576 nm. This not only simplifies the device from an engineering perspective, requiring less control systems. More importantly this approach ensures that the output wavelengths do not need constant calibration to guarantee their accuracy since no moving part is involved in the optical parametric generator.
- Secondly, a single stage optical parametric generator capable of a tuneable output within the required wavelength range necessitates a shorter pump wavelength, usually in the UV range (*i.e.* below 400nm), such as the third harmonic of a Nd:YAG at 355 nm which are typically used in these circumstances. However, it is well known that frequency tripling (*i.e.* producing the third harmonic) induces more optical losses than frequency doubling (*i.e.* producing the second harmonic) as shown by Kato *("Frequency conversion of Nd:YAG laser radiation in RDA"* Opt. Comm. 13, 93-95 (1975)), with an overall conservative power conversion efficiencies of 12% and 34% respectively. An optical parametric generator typically has a threshold below which the optical parametric generation does not work, unlike the other non-linear effects involved in this invention (*i.e.* harmonic generation). This threshold is strongly dependant on the architecture of the optical parametric generator (*i.e.* cavity size, reflector spectral response, non-crystal size etc...) and can be difficult to predict. Reports in the literature have shown optical parametric generation threshold in the order of few mJ to tens of mJ per pulse. Therefore, using either second harmonic or the fundamental harmonic in the pump laser, instead of the third harmonic commonly used, allows for a reduction of the pump laser energy output requirement, thereby reducing the complexity and cost associated with the first pump laser.
- Thirdly, more convoluted approaches to achieve the same dual wavelengths output are possible following the same principle of generating the required harmonics for the desired wavelength with an optical parametric generator simultaneously followed by some harmonic generation stage. One example uses an 800 nm pump laser, launched into an optical parametric generator to produce simultaneously a signal and an idler

output at 1734 nm and 1470 nm. Both the idler and signal would have to be frequency tripled (*i.e.* third harmonic generation) to produce the wavelengths of interest for this invention around 578 nm and 490 nm. However, this approach is not as efficient as the approach previously described as the 800 nm pump laser would typically be a femtosecond Ti:sapphire pulsed laser or an millisecond alexandrite pulsed laser, both not quite suitable for generating hundreds of picoseconds to tens of nanoseconds light pulses required for the aforementioned applications. Furthermore, both Ti:sapphire and alexandrite lasers require a pump laser themselves to be operated thereby increasing the energy consumption of such system. More importantly, third harmonic generation is a very inefficient process compared to second harmonic generation as previously stated.

It is convenient to describe the invention herein in relation to particularly preferred embodiments. However, the invention is applicable to a wide range of embodiments and it is to be appreciated that other constructions and arrangements are also considered as falling within the scope of the invention. Various modifications, alterations, variations and or additions to the construction and arrangements described herein are also considered as falling within the ambit and scope of the present invention.

Claims

1. A light emitting apparatus for the dermatological treatment of a patient comprising:
   a pulsed laser generator;
   an optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal;
   a first harmonic generator to produce from the idler its nth harmonic;
   a second harmonic generator to produce from the signal its nth harmonic;
   an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.
2. A light emitting apparatus for the dermatological treatment of a patient comprising:
   a pulsed laser generator;
   an optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a plurality of light redirectors and a non-linear crystal;
   a first harmonic generator comprising a crystal to produce from the idler its nth harmonic;
   a second harmonic generator comprising a crystal to produce from the signal its nth harmonic;
   wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA;
   an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.
3. A light emitting apparatus for the dermatological treatment of a patient comprising:
   a pulsed pump laser generator comprising a laser emitting at 500nm to 850 nm with a pulse duration of between 700 picoseconds to 30 nanoseconds and a repetition rate of between 100 Hz to 100 kHz;
   an optical parametric generator comprising a plurality of light redirectors selected from reflectors and refractors and a non-linear crystal positioned between a first and a second light redirector,
   the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility;
   a first harmonic generator comprising a crystal to produce from the idler its nth harmonic;
   a second harmonic generator comprising a crystal to produce from the signal its nth harmonic;

wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO,SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA;
an applicator arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient;
the apparatus comprising a resonator.

4. A light emitting apparatus for the dermatological treatment of a patient comprising:
a pulsed pump laser generator comprising a laser emitting at 500nm to 550 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz;
an optical parametric generator comprising a plurality of reflectors:
a non-linear crystal positioned between a first and a second reflector,
the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility;
a first harmonic generator comprising a crystal to produce from the idler its 2nd harmonic;
a second harmonic generator comprising a crystal to produce from the signal its 2nd harmonic;
wherein the non-linear crystal, the first harmonic generator crystal and the second harmonic generator crystal each comprise a crystal selected from one or more of LBO, CLBO, BBO, BIBO, BBO, SBBO, KAB, LiNbO3, LiTaO3, KNbO3, KTP, KTA, RTP, RTA;
an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;
the apparatus comprising a resonator selected from a linear resonator, a singly resonant optical parameter oscillator, a doubly resonant parametric generator, and a ring resonator.

5. A light emitting apparatus for the dermatological treatment of a patient comprising:
a pulsed pump laser generator comprising a laser emitting at 500nm to 532 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz;
wherein the laser is selected from frequency doubled Nd:YAG laser, Nd:YVO4, Nd:LuVO4 or Nd:GdVO4, Yb:YAG, Yb:YVO4, Yb:GdVO4 or Yb:LuVO4;
a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator;
an optical parametric generator comprising a plurality of reflectors:
a non-linear crystal positioned between a first and a second reflector,

the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility;
wherein the non-linear crystal comprises KTA crystal type II;
a first harmonic generator comprising a BBO crystal to produce from the idler its 2nd harmonic;
a second harmonic generator comprising a BBO crystal to produce from the signal its 2nd harmonic;
an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;
the apparatus comprising a linear resonator.

6. A light emitting apparatus for the dermatological treatment of a patient comprising:
a pulsed pump laser generator comprising a laser emitting at 500nm to 532 nm, Q-switched to produce about 10-100 mJ per pulse with a pulse duration of between 5-30 nanoseconds and a repetition rate of between 100 Hz to 22 kHz;
wherein the laser is selected from frequency doubled Nd:YAG laser, Nd:YVO4, Nd:LuVO4 or Nd:GdVO4, Yb:YAG, Yb:YVO4, Yb:GdVO4 or Yb:LuVO4;
a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator;
an optical parametric generator comprising a plurality of reflectors:
a non-linear crystal positioned between a first and a second reflector,
the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility;
wherein the non-linear crystal comprises BBO crystal type II;
a first harmonic generator comprising a BBO crystal to produce from the idler its 2nd harmonic;
a second harmonic generator comprising a BBO crystal to produce from the signal its 2nd harmonic;
an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;
the apparatus comprising a linear resonator.

7. A light emitting apparatus for the dermatological treatment of a patient comprising:
a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz;

a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator;

an optical parametric generator comprising:

a back reflector,

an output reflector,

a non-linear crystal positioned between the back and output reflectors,

the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ^2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where *P(t)* is the dielectric polarization density, *E(t)* is the electric field and ε_0 the vacuum permittivity ($8.854\text{x}10^{-12}$ F/m);

wherein the non-linear crystal comprises KTA crystal type II and exhibits a tuning curve according to Fig. 5;

wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm;

a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm;

an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;

the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

8. A light emitting apparatus for the dermatological treatment of a patient comprising:

a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz;

a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator;

an optical parametric generator comprising:

a back reflector,

an output reflector,

a non-linear crystal positioned between the back and output reflectors,

the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ^2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where *P(t)* is the dielectric polarization density, *E(t)* is the electric field and ε_0 the vacuum permittivity (8.854×10^{-12} F/m);

wherein the non-linear crystal comprises BBO crystal type II and exhibits a tuning curve according to Figure 4;

wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm;

a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm;

an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;

the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

9. A light emitting apparatus for the dermatological treatment of a patient comprising:

a pulsed pump laser generator comprising a frequency doubled Nd:YAG laser emitting at 532 nm, actively Q-switched to produce about 10 mJ per pulse with a pulse duration of between 5-10 nanoseconds and a repetition rate of between 10 kHz to 20 kHz;

a diverter comprising a reflector to direct the output of the pulsed pump laser generator into the optical parametric generator;

an optical parametric generator comprising:

a back reflector,

an output reflector,

a non-linear crystal positioned between the back and output reflectors,

the optical parametric generator to produce an idler laser beam and a signal laser beam, and comprising a non-linear crystal having a high second order susceptibility (χ^2), as defined in equation 2:

$$P(t) = \varepsilon_0\left(\chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots + \chi^n E^n(t)\right) \qquad (2)$$

where *P(t)* is the dielectric polarization density, *E(t)* is the electric field and ε_0 the vacuum permittivity (8.854x10^{-12} F/m);

wherein the non-linear crystal comprises KTA crystal type II and exhibits a tuning curve according to Fig. 5;

wherein the wavelength of the idler, signal and the pump laser are related to each other by equation (1):

$$\frac{1}{\lambda_{Pump}} = \frac{1}{\lambda_{Idler}} + \frac{1}{\lambda_{Signal}} \qquad (1)$$

a first harmonic generator comprising a BBO crystal cut at 21.7 degrees to produce from the idler its 2nd harmonic at 578nm;

a second harmonic generator comprising a BBO crystal cut at 24.2 degrees to produce from the signal its 2nd harmonic at 492.5nm;

an applicator arranged to receive and apply either the 2nd harmonic of the idler, the 2nd harmonic of the signal or both to the skin of the patient;

the apparatus comprising two reflective surfaces arranged as a singly resonant Optical Parametric Oscillator cavity.

10. A light emitting system for the dermatological treatment of a patient comprising:

a pulsed laser generator to generate a pulsed light;

an optical parametric generator;

a first harmonic generator to generate the nth harmonic;

a second harmonic generator to generate the nth harmonic

an applicator, arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.

11. A light emitting system for the treatment of abnormal skin pigmentation, skin pigmentation variations and vascular lesion comprising:

a pulsed laser generator to generate a first pulsed light train with a 700 picoseconds to 30 nanoseconds pulse duration, a repetition rate of 100 Hz to 100 kHz and a wavelength ranging from 500 nm to 850 nm;

an optical parametric generator, comprising a non-linear crystal inside an optical cavity formed by at least two reflectors, arranged to receive the first pulsed light train and generate two other pulse light trains, the idler and the signal, with their respective wavelengths higher than the second pulsed light train;

a first harmonic generator comprising of at least one non-linear crystal to generate the nth harmonic of the idler with an output fluence ranging from 5x104 W/cm2 to 5x107 W/cm2;

a second harmonic generator comprising of at least one non-linear crystal to generate the nth harmonic of the signal with an output fluence ranging from 5x104 W/cm2 to 5x107 W/cm2;

an applicator, arranged to receive and apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient.

12. The laser system of claim 11, wherein the wavelength of nth harmonic of the idler is ranging from 565 nm to 595 nm and the wavelength of nth harmonic of the signal is ranging from 480 nm to 535 nm.
13. The laser system of claim 11, wherein the wavelength of nth harmonic of the idler is ranging from 480 nm to 535 nm and the wavelength of nth harmonic of the signal is ranging from 565 nm to 595 nm.
14. The laser system of claim 11, wherein the pulse laser generator is actively Q-switched.
15. The laser system of claim 11, wherein the pulse laser generator is passively Q-switched.
16. The laser system of claim 11, wherein the optical parametric generator is located within the optical cavity of the pulse laser generator.
17. A light emitting system for the treatment of abnormal skin pigmentation, skin pigmentation variations and vascular lesion comprising:

a pulsed laser generator to generate a pulsed light train with a 700 picoseconds to 30 nanoseconds pulse duration, a repetition rate of 100 Hz to 100 kHz; a pulse and a wavelength of 532 nm;

an optical parametric generator, comprising a BBO non-linear crystal inside an optical cavity formed by at least two reflectors, arranged to receive the second pulsed light train and generate two other pulse light trains, the idler and the signal, with their respective wavelengths higher than the second pulsed light train;

a first harmonic generator being a SHG comprising a BBO non-linear crystal to double the frequency of the idler with an output fluence ranging from 5x104 W/cm2 to 5x107 W/cm2;

a second harmonic generator being a SHG comprising a BBO non-linear crystal to double the frequency of the signal with an output fluence ranging from 5x104 W/cm2 to 5x107 W/cm2;

an applicator, arranged to receive and apply either the second harmonic of the idler, the second harmonic of the signal or both to the skin of the patient.

18. The laser system of claim 11, wherein the wavelength of second harmonic of the idler is 578nm and the wavelength of second harmonic of the signal is 492.5 nm.
19. The laser system of claim 11, wherein the wavelength of second harmonic of the idler is 492.5nm and the wavelength of second harmonic of the signal is 578 nm.
20. The laser system of claim 11, wherein the pulse laser generator is actively Q-switched.
21. The laser system of claim 11, wherein the pulse laser generator is passively Q-switched.
22. The laser system of claim 11, wherein the optical parametric generator is located within the optical cavity of the pulse laser generator.

FIGURES

FIG. 1

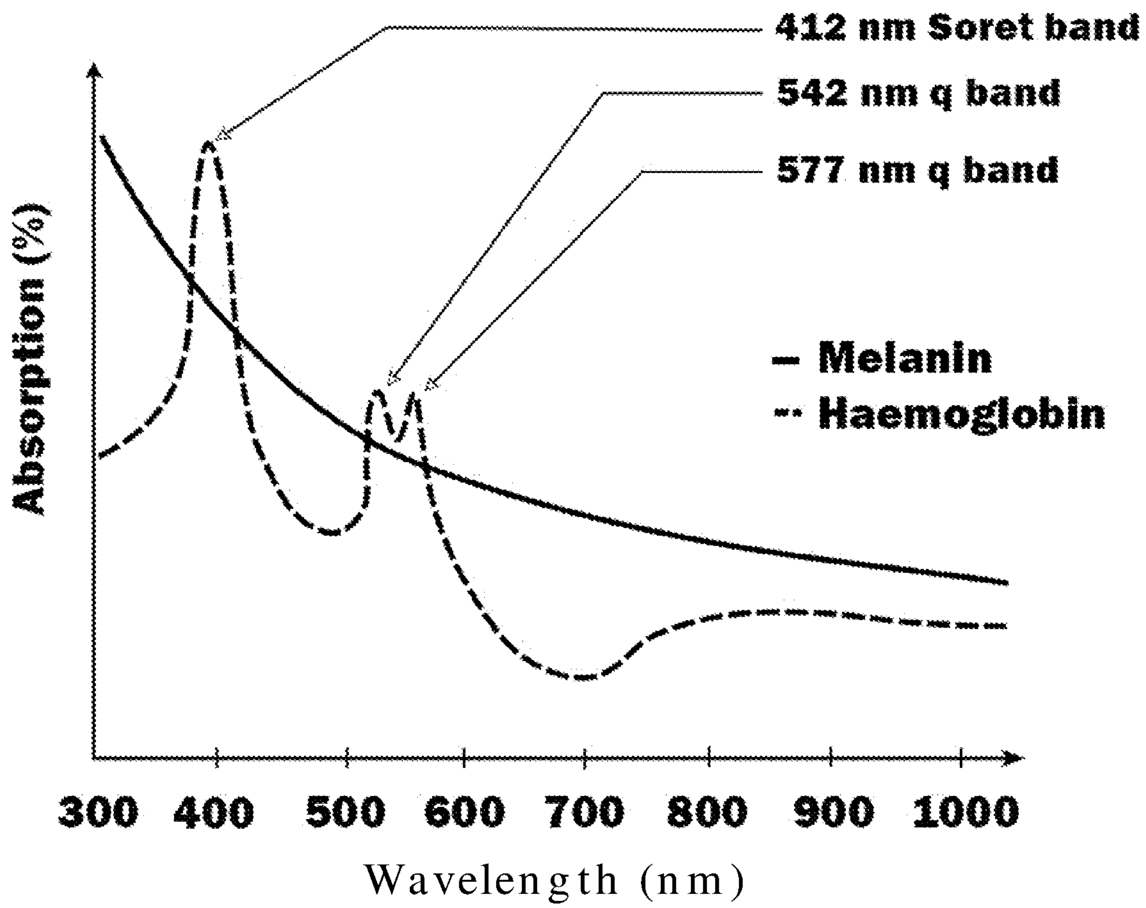


FIG. 2

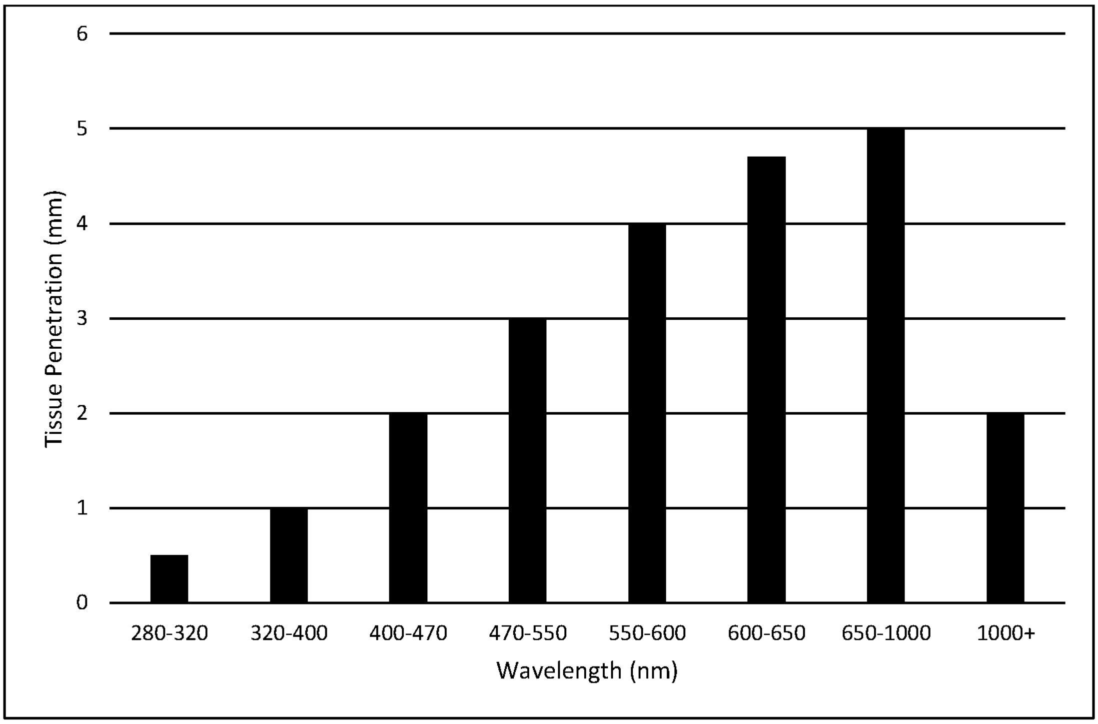

6
5
4
3
2
1
0
Tissue Penetration (mm)
280-320
320-400
400-470
470-550
550-600
600-650
650-1000
1000+
Wavelength (nm)

FIG 3

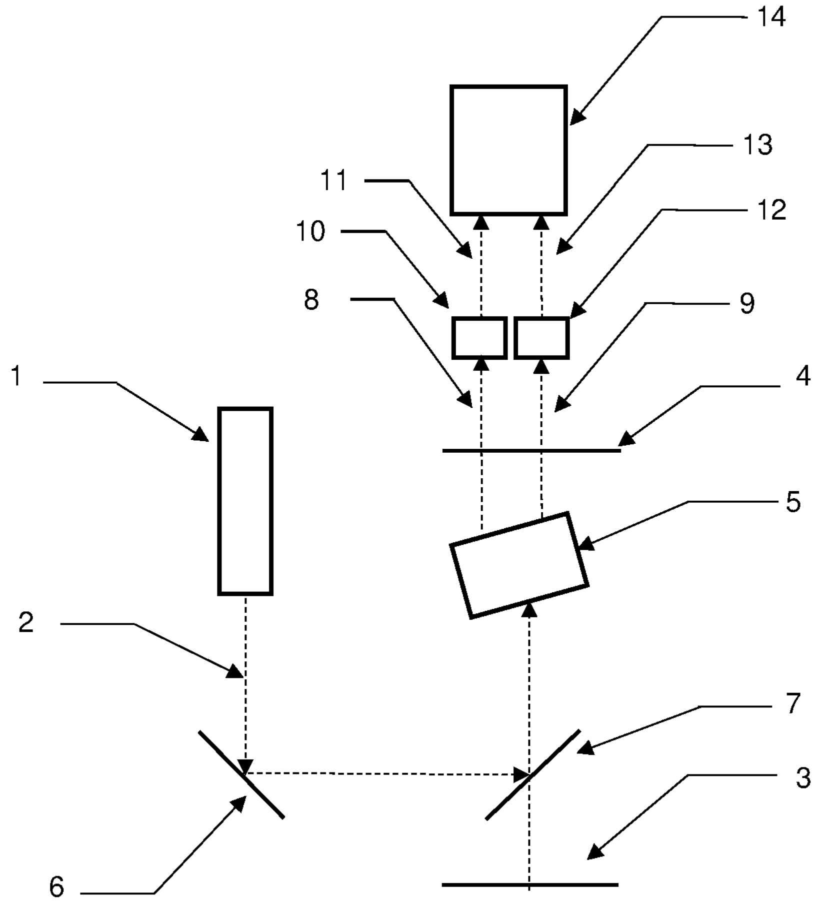


FIG. 4

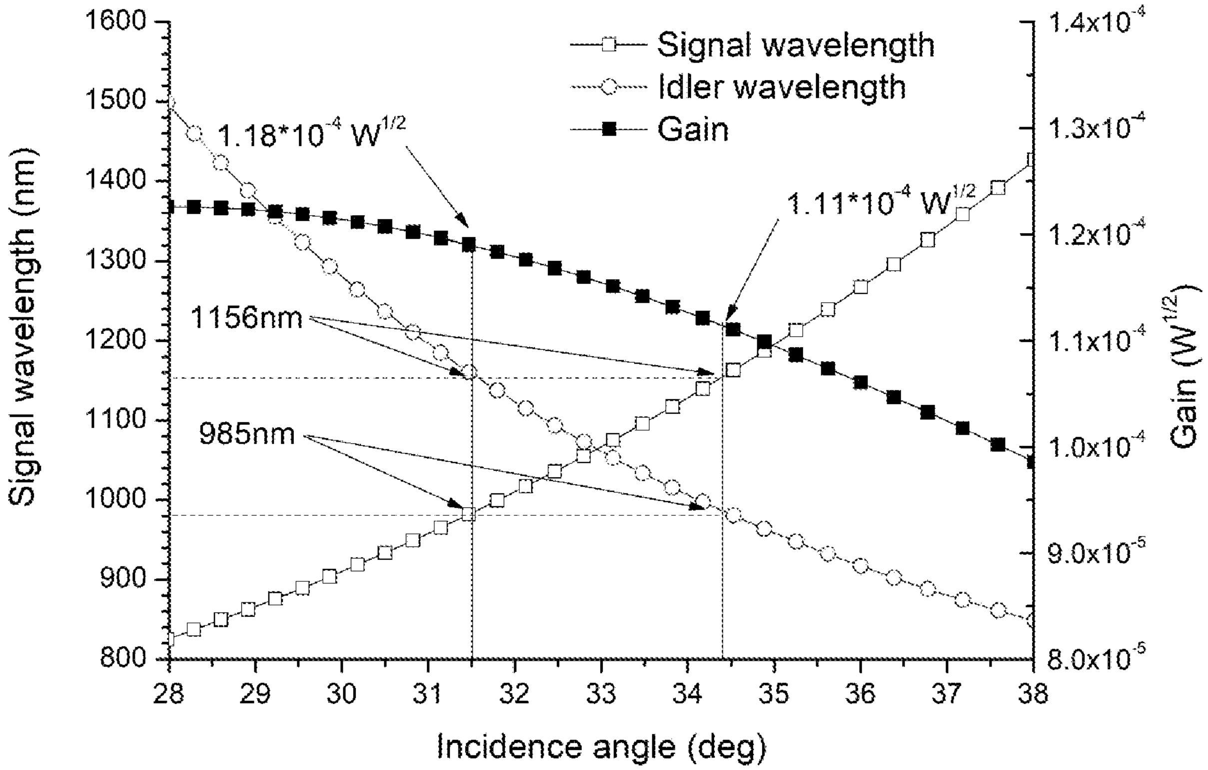

Signal wavelength
Idler wavelength
Gain
1.18*10^-4 W^1/2
1.11*10^-4 W^1/2
1156nm
985nm
Signal wavelength (nm)
Gain (W^1/2)
Incidence angle (deg)
1600
1500
1400
1300
1200
1100
1000
900
800
28
29
30
31
32
33
34
35
36
37
38
1.4x10^-4
1.3x10^-4
1.2x10^-4
1.1x10^-4
1.0x10^-4
9.0x10^-5
8.0x10^-5

FIG. 5

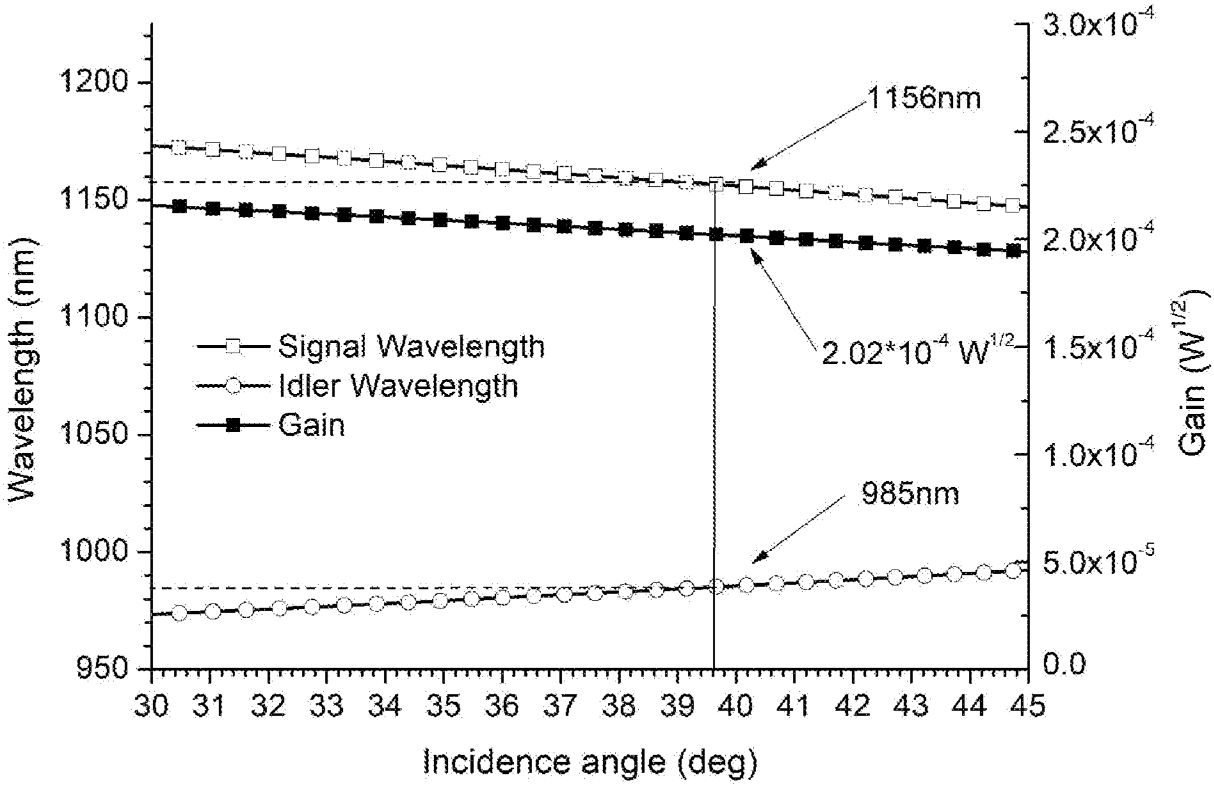
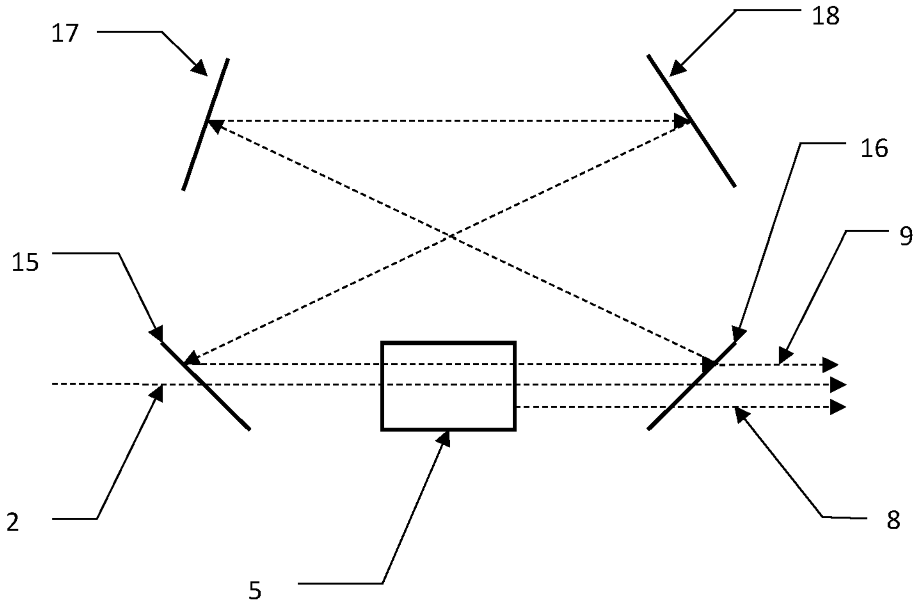

1200
1150
1100
1050
1000
950
Wavelength (nm)
3.0x10^-4
2.5x10^-4
2.0x10^-4
1.5x10^-4
1.0x10^-4
5.0x10^-5
0.0
Gain (W^1/2)
1156nm
2.02*10^-4 W^1/2
985nm
Signal Wavelength
Idler Wavelength
Gain
30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
Incidence angle (deg)

FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2021/050790

A. CLASSIFICATION OF SUBJECT MATTER

A61B 18/20 (2006.01) A61B 18/22 (2006.01) H01S 3/109 (2006.01) H01S 3/11 (2006.01) H01S 3/05 (2006.01) H01S 3/081 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PATENW (EPOQUE search) CPCs, IPCs:H01S3/0057, H01S3/~0092, 11, 113, 109, 108, 1623, 1611, 1666, 05, 081; A61B18/20, A61B2017/00154, A61B2017/00769, A61B2018/00452, A61B2018/0047, A61B, A61N, G02F1/35, G02F1/354, G01F1/353 & the like - lower classification marks in combinations with Boolean operations/operators, proximity operators and the following keywords are used - pulsed laser, generator, Q-switch, optical parametric generator, ring resonator, active passive Q-switching, idler, signal, second harmonic, dermatological, skin, tattoo, cosmetic, SHG, non-linear crystal and the like. Databases Medline & NPL (EPOQUE search) with keywords: , active or passive Q-switching, idler, signal, optical parametric amplifier, non-linearresonator, second harmonic generator and the like. Google patents & Google scholar with keywords and phrases similar to the previous one in addition with keywords BBO, CLBO, BIBO, SBBO, LBO, wavelengths, skin melatonin, frequencies and the like; ESPACENET – advanced search with keywords such as the Applicant/Inventor names, limited by CPCs: H01S3, IPC G02F1 and the like; CPC Classification search: H01S3/11 or H01S3/16 or H01S3/2308 or G02F1/35 – lower classification marks and limited by A61B18/203 and the like. Applicant(s)/Inventor(s) name searched in internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

[X] Further documents are listed in the continuation of Box C [X] See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"D" document cited by the applicant in the international application

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 October 2021	22 October 2021
Name and mailing address of the ISA/AU	**Authorised officer**
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustralia.gov.au	Viara Van Raad AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. +61262832676

INTERNATIONAL SEARCH REPORT	International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT	**PCT/AU2021/050790**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2019/0336213 A1 (RAO) 07 November 2019 Abstract, para[0014-15], [0018-19], elements (1100), (1020), (2340), (4080), OPOs; Figs. 1-6	1, 2, 10-22
X	US 2019/0151019 A1 (CUTERA, INC.) 23 May 2019 Abstract, para[0058-0093]; laser engine (620)/laser pulses (810), a second harmonic generator (630), OPO (640)/(700)/(800); idler & signal pulses - outputs (770)/(850) &(760)/(840), applicator (650), optical multiplexers (665)/(675)/(685)/(695); non-linear crystals C1/C2 (730/(740)/(830); Figs. 1, 6-8	1, 2, 10-22
Y	US 2016/0268764 A1 (BADEN WUERTTEMBERG STIFTUNG GGMBH) 15 September 2016 & EP 3064992 A1 for Fig. 3 Abstract, para[0034-114], esp. para[0026], [0061-91], [0113-114], elements (55), (20),	1-6, 10-22
Y	US 2016/0143692 A1 (CANDELA CORPORATION) 26 May 2016 Abstract; para[0035-45]; elements (504); (536),(512),(508); (516),(524) & (520), Figs. 5 & 7	1-6, 10-22
A	ZHANG, X. et al. "Four-wave mixing based on cascaded second-order nonlinear processes in a femtosecond optical parametric oscillator operating near degeneracy," 2004, Applied Physics B 79, pages 441-447 Entire document	1-6, 10-22
A	US 2019/0221989 A1 (CYNOSURE LLC) 18 July 2019 Entire document	1-6, 10-22

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:

   because they relate to subject matter not required to be searched by this Authority, namely:

   the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including

2. ☒ Claims Nos.: **7-9**

   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

   See Supplemental Box

3. ☐ Claims Nos:

   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☒ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT	International application No. PCT/AU2021/050790

Supplemental Box

Continuation of Box II

Claims 7, 8 and 9 don't comply with Rule 6.2(a) because they rely on references to the drawings. Claims 7 and 9 are characterized by a tuning curve of a crystal (KTA type II) according to Fig. 5, for example. Claim 8 is characterized by a tuning curve of a crystal (BBQ type II) according to Fig. 4.

Continuation of: Box III

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1, 2 and 10 are drawn to a light-emitting system for dermatological treatment of a patient comprising: a Laser Generator (LG) to generate a pulsed light; an optical parametric generator (OPG); a 1st and a 2nd harmonic generators (HGs) each one of them to generate the nth harmonic; and an applicator arranged to receive and apply the so formed harmonics of the signal/idler or both, to the skin of the patient. The feature of that system comprising the LG, the OPG and the 1st and 2nd HGs to generate harmonics of idler/signal/or both and further comprising the applicator is specific to this group of claims.
- Claims 3-6 are drawn to a light-emitting apparatus for dermatological treatment of a patient comprising a pulsed Pump Laser Generator (PLG) emitting in the range of at least 500nm with a pulse duration equal to or less than 30 nanoseconds and repetition rate of at least 100Hz, comprising an OPG and a resonator; a 1st and a 2nd HGs, comprising a plurality of light redirectors/reflectors and a Non-Linear Crystal (NLC) having a high 2nd order susceptibility, positioned between the light redirectors/reflectors and an applicator to the skin of the patient. The feature of the said apparatus comprising the PLG, the OPG and a resonator; the NLC is with a high 2nd order susceptibility and positioned between the reflectors/redirectors, having 1st and 2nd HGs to generate harmonics of idler/signal/or both further comprising the said applicator is specific to this group of claims.
- Claims 11-22 are drawn to a light-emitting system for the treatment of abnormal skin pigmentation and the like comprising a PLG emitting in the range of at least 500nm with a pulse duration equal to or less than 30 nanoseconds and repetition rate of at least 100Hz; an OPG comprising an NLC inside an optical cavity formed by at least two reflectors, a 1st and 2nd HGs/SHGs each one of them comprising of at least one NLC/BBO NLC to generate the nth harmonic of the idler/signal respectively with an output fluence ranging from 5x104 W/cm2 to 5x107 W/cm2; an applicator to apply either the nth harmonic of the idler, the nth harmonic of the signal or both to the skin of the patient. The feature of the said comprising the PLG, the OPG comprising an NLC/BBO NLC inside an optical cavity and the harmonic generators with the particular fluence range is specific to this group of claims.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. The only feature common to all of the claimed inventions and which provides a technical relationship among them is the combination of the PLG, OPG, 1st and 2nd HGs and applicator for the application of the output light to the skin.

However this feature does not make a contribution over the prior art because it is disclosed in:

the following prior art documents US 2019/0336213 A1 - see Abstract and Figs. 1-5 and US 2019/0151019 A1 – see Figs. 6, 1, 7 and 8 and text related to these figures; such features are also well known in the art of light emitting systems in dermatology, cosmetics and skin spots and abnormal skin pigmentation.

Therefore in the light of this document this common feature cannot be a special technical feature. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a posteriori*.

The report addresses claims 1-6 and 10-22.

INTERNATIONAL SEARCH REPORT Information on patent family members	International application No. **PCT/AU2021/050790**

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		**Patent Family Member/s**	
Publication Number	**Publication Date**	**Publication Number**	**Publication Date**
US 2019/0336213 A1	07 November 2019	US 2019336213 A1	07 Nov 2019
		US 10799292 B2	13 Oct 2020
US 2019/0151019 A1	23 May 2019	US 2019151019 A1	23 May 2019
		US 10729496 B2	04 Aug 2020
		US 2020282230 A1	10 Sep 2020
		US 2020315706 A1	08 Oct 2020
US 2016/0268764 A1	15 September 2016	US 2016268764 A1	15 Sep 2016
		US 9735536 B2	15 Aug 2017
		EP 3064992 A1	07 Sep 2016
		EP 3064992 B1	22 Sep 2021
US 2016/0143692 A1	26 May 2016	US 2016143692 A1	26 May 2016
		EP 3023074 A1	25 May 2016
		EP 3023074 B1	04 Mar 2020
US 2019/0221989 A1	18 July 2019	US 2019221989 A1	18 Jul 2019
		US 10581217 B2	03 Mar 2020
		EP 2839552 A1	25 Feb 2015
		KR 20140144304 A	18 Dec 2014
		KR 102136901 B1	22 Jul 2020
		KR 20200094216 A	06 Aug 2020
		KR 102183581 B1	27 Nov 2020
		KR 20200133833 A	30 Nov 2020
		US 2015180193 A1	25 Jun 2015
		US 9780518 B2	03 Oct 2017
		US 2018026417 A1	25 Jan 2018
		US 10305244 B2	28 May 2019
		US 2020176945 A1	04 Jun 2020
		US 11095087 B2	17 Aug 2021
		WO 2013158299 A1	24 Oct 2013

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.