DEVELOPMENT OF A NEW INJECTION LOCKING RING LASER AMPLIFIER USING A COUNTER INJECTION: MULTIWAVELENGTH AMPLIFICATION

Rosen Vanyuhov Peev[1], Margarita Anguelova Deneva [1], Marin Nenchev Nenchev [1,2]

[1] Dept. Optoelectronics and Lasers, Technical University – Sofia, Branch Plovdiv, 61 blvd. St.Peterburg, 4000 Plovdiv, e-mail: mdeneva@yahoo.com
[2] Institute of Electronics – Bulgarian Academy of Sciences, 72 blvd. Tzarigradsko Chausse, 1784 Sofia, Bulgaria

Earlier we have proposed a new approach for high gain (~ 10^4 - 10^7), all-optical linear amplification of a periodically modulated, low power (~µW), laser radiation that is based on a bi-directional injection locking control in a ring laser. As a new development of this system we have shown that it is able to amplify simultaneously and linearly a number (three and more) of injected amplitude modulated radiations with different wavelengths (at spectral distance high than 1 nm or ~ 800 GHz each from other) and applied an original arrangement for multiplexing. This confirms the potential of the amplifier proposed for effective applications in optical communication system. The investigation is based of theoretical modeling of the amplifier action by adapting the rate differential equation system and its numerical solutions. Nonlinear distortions are estimated using a harmonics analysis with Fast Fourier Transformation

Keywords: light amplification, injection locking, periodically modulated laser light

1. INTRODUCTION

The amplification of low power (~µW) periodically modulated laser light is important for optical communications, for atmospheric studies with Doppler lidar systems and in scientific works. The known techniques are related with the use of semiconductor light amplifiers or Er-doped fiber amplifiers. The low gain saturation effects are typical for the first type that limits the gain to be ~ 10^3 and less; the analogical situation is realized in the fiber amplifiers – the amplifying is accompanied by the strong nonlinear effects for high power amplified light. Earlier we have proposed a new approach for high gain (~ 10^4 - 10^7), all-optical linear amplification of a periodically modulated, low power (~µW), laser radiation that is based on a bi-directional injection locking control in a ring laser with homogeneously broadened active medium.[1, 2]. We have modified this system to be based on linear laser configuration [3, 4] which permits lowest length of the laser resonator and amplification of increased modulation frequency beams, respectively. From systematic investigation, the potential of such linear resonator system for application – low nonlinear distortion, low noise, amplification of Gigahertz range frequency beams, is carried out. Nevertheless the noted advantages of the linear-resonator amplifier, the proposed by us ring cavity amplifier is very simple in construction for injecting and extracting of the amplified laser radiation as well as a system with natural decoupling of the injected subsystem from the oscillator-amplifier without necessity of optical isolation. The study of the properties of the ring-configuration injection – counterinjection amplifier is important for revealing of its relevant peculiarities and possibilities.

2. BASIC PRINCIPLE AND MULTIWAVELENGTH INJECTION-COUNTERINJECTION RING AMPLIFIER

As it is well known, the injection-locking control leads to very high amplification of the injected laser light, providing spectral and spatial locking of near all laser emission at the injected low-power laser beam. However, the essential limits of such devices as amplifiers of information laser signals are related with the drastically temporal distortion of the input signal after the amplification. This is due to the amplification, which is realized by the locking of all laser generation practically with no dependences from the power of injected light (after some minimal its values). Our approach, convenient for homogeneously broadened active medium, introduces the idea to use in the ring amplifier an intensity controlled second, CW injection beam, oppositely directed to the modulated injected beam in the ring cavity. This opposite beam (the counter injection), with an appropriately chosen intensity, assures fast and linear response of the output power in the amplified beam due to the strong wave competition effect. The principle is illustrated schematically in Fig.1a.

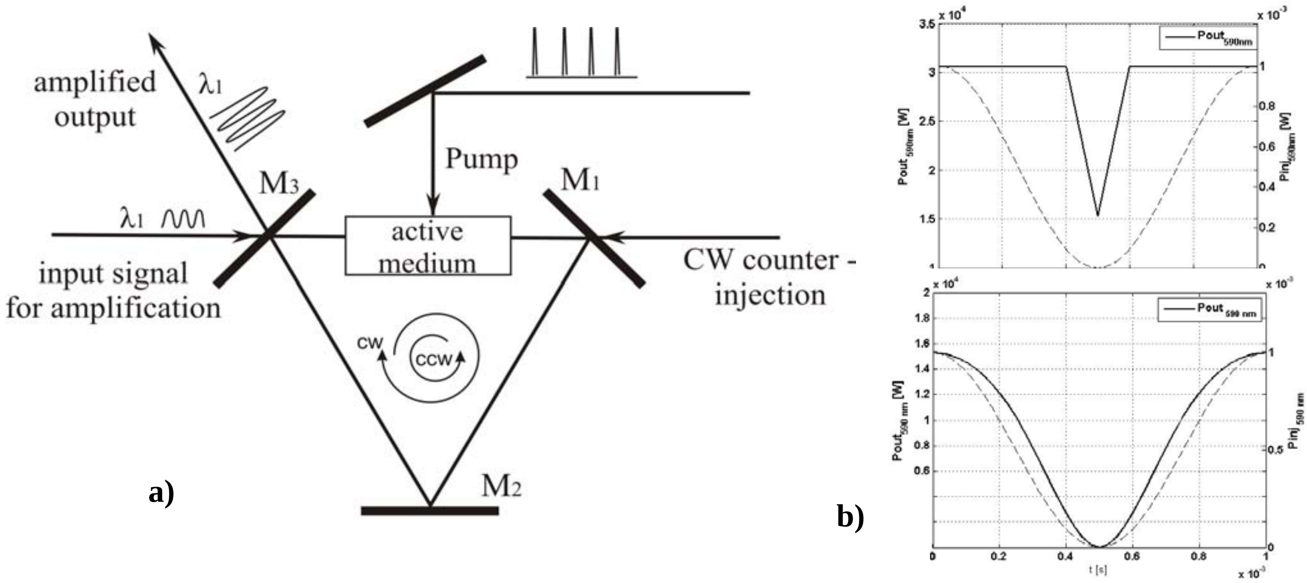


Fig. 1 (a) Principle of the injection - conterinjection ring amplifier for linear amplification
(b) Computed response of the input low signal without counterinjection and with counternjection

In Fig.1b are given the response of the system of sine-low modulated input signal without (up graph) and with counterinjection (down).

The further development of our ring system, given here is its use for amplification of few modulated beams at different wavelength, injected simultaneously – i.e. the use as a multiwavelength amplifier. Such mode of operation needs of systematic study, the first step of which is the theoretical modeling and numerical analysis. Below we present such model and investigate the simultaneous amplification at 4 different wavelengths each from other at distance of 1 nm (~ 800 GHz). We apply an original multiplexing device in the amplifier output, based on our patented method with Interferences Wedges IW [5, 6].

This multiplexer permits wavelength tuning of its inputs. Schematically, our amplifier is presented in Fig.2. Our investigations here are based on the optical scheme of the bi-directional injection locked ring laser amplifier that is presented in Fig.1. The study of the proposed basic principle is performed on the base of simulation of a ring Rh6G-dye laser, pumped by Cu-vapor laser. The pump laser produces pulses with energy of

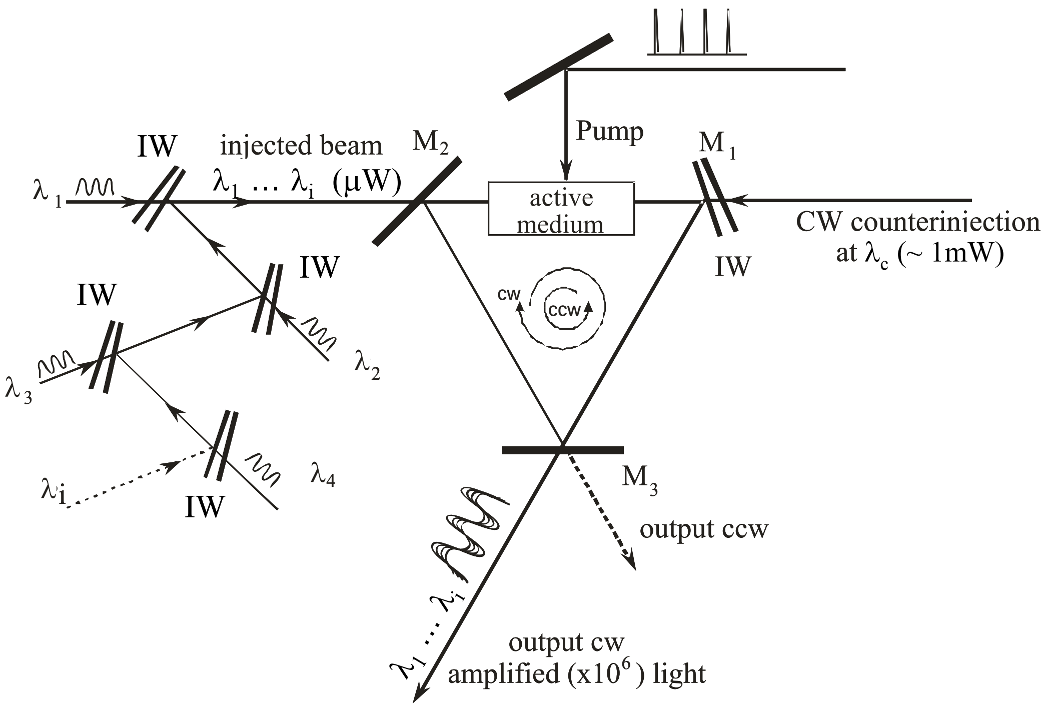


Fig.2 Schematic diagrams of the developed injection – counterinjection amplifier

1 mJ each and pulse length of ~ 20 ns and repetition rate 10 kHz. The frequency modulated beam with a power P_{inj2} (into the resonator) is injected through the mirror M_2 (dichroic, reflectivity R_2 = 0.8 for 570 - 610 nm and transmission of 0.95 for 520 - 560 in the clockwise direction in the ring resonator (cw directed wave, cw laser output, respectively). The second counterinjected beam is injected in the opposite direction (ccw direction, ccw output; power P_{inj1} = 1 mW - into the resonator). We assume that the complete number of the injected photons is introduced in the generated mode volume. We performed computer simulations by adapting a conventional set of rate equations for laser generation [e.g. 7, 2, 6]. The case of multimode injection and operation in the ring laser is considered, neglecting hole burning effects. Under condition of a large number of generated modes, we should expect laser locking at the every wavelength of the injected beam. The time dependence of the powers in the pulses from the cw output (Output cw, output powers $P_{\lambda i}$) and from the counter injected beam ccw wave (Output ccw, $P_{\lambda c}$) is proportional to the generated photon numbers $q_{\lambda i}$ and $q_{\lambda c}$ in the cw and ccw directions, respectively. Thus we can write:

$$\begin{cases} \dfrac{dN_2}{dt} = R_p - N_2 \cdot \sum_1^i B_i \cdot q_{\lambda i} + N_2 B_c \cdot q_{\lambda c}) - \dfrac{N_2}{\tau} \\ \dfrac{dq_{\lambda i}}{dt} = B_i \cdot q_{\lambda i} \cdot N_2 \cdot Va - \dfrac{q_{\lambda i}}{\tau_c} + \dfrac{Pinj_2}{h \cdot \nu_i}(1 - R_2) \\ \dfrac{dq_{\lambda c}}{dt} = B_c \cdot q_{\lambda c} \cdot N_2 \cdot Va - \dfrac{q_{\lambda c}}{\tau_c} + \dfrac{Pinj_1}{h \cdot \nu_c}(1 - R_1) \end{cases}$$

where N_2 is the inversion population per unit volume; $B = (\sigma_{21} \cdot l \cdot c_0)/(Va \cdot L')$, where σ_{21} depends on λ and is the emission cross-section with maximum value of $\sigma_{21}^{\max} = 1.23 \cdot 10^{-16} cm^2$ [2]. Here $l=1cm$ and $Va = 2 \cdot 10^{-3} cm^{-3}$ are the length and the working volume of the active medium respectively (here and below we give the values used in our experiment); $c_0 = 3 \cdot 10^{10} cm/s$ is the light velocity and $L' = L + (n-1) \cdot l = 5.33\ cm$ is the optical length of the cavity, $h \cdot \nu_i \approx 3.4 \cdot 10^{-19}\ J$ is the energy of the injected photons (i corresponds to the injected wavelength). The time interval's τ= 3 ns and $\tau_c = L'/(\gamma \cdot c_0)$ are the lifetimes of the upper laser level and of a photon in the ring cavity, respectively, where γ describes losses in the cavity [7]. The pump pulse is approximated by a trapezium shape with a start front rise time of 5 ns, a plateau of 4 ns and a fall front of 7 ns. This gives a good description of a typical pump emission of our Cu-vapor laser. The reflections of the mirrors are: R_1=R_2=0.95 and R_3=0.8. The mirror M_1 can be realized as a tunable Interference Wedge (IW) for non resonant position for λ_i and transmission resonance for the CW injection at the wavelength λ_c of the counterinjection. The system is solved numerically by Dormand-Prince method. From the solution we obtain $q_{\lambda i}$ and their time integration give the output. In some cases, the results of the numerical solution arc compared with the analytical solution of the system.

Results : The analysis is for the injected beam with a time-varied power as $Pinj2_{\lambda i} = Pinj^{(0)} + k \cdot Pinj^{(0)} \cdot \cos(\omega \cdot t)$, where $\omega = 2 \cdot \pi \cdot \nu$, ν is the frequency modulation of the injected for amplification laser light, k is depth of modulation. In the investigation, given here, we considered the case with $\nu = 10^3$ Hz.

Firstly, from the detailed investigation, varying laser and counterinjection parameters, we have shown that the given above laser and injection light parameters corresponds to the conditions for effective amplification. The temporal shape of the input modulated beam (dashed line) for one period of oscillation, and this one of the amplified output radiation are plotted in Fig.3 (left). The modulated beam at a single wavelength is injected. From the figure it can be seen that for the chosen values of the scheme and light parameters there are very good correlation of the two temporal shapes, given in different convenient scales. Below we will consider numerically this coincidence using the Fast Fourier Transformation analysis. In the Fig.3 (right) are given the spectrum of the amplified signal. The powers of the harmonics in comparison with this one in the fundamental is negligible, about 1 % and less, that confirms the low nonlinear distortion during the amplification (the highest line correspond of the constant component of the signal–ν=0Hz.). The parameters here are: λ_1=590nm, $Pinj_{\lambda i}$= 0.1 mW, k=1, $Pinj_{\lambda C}$=1 mW.

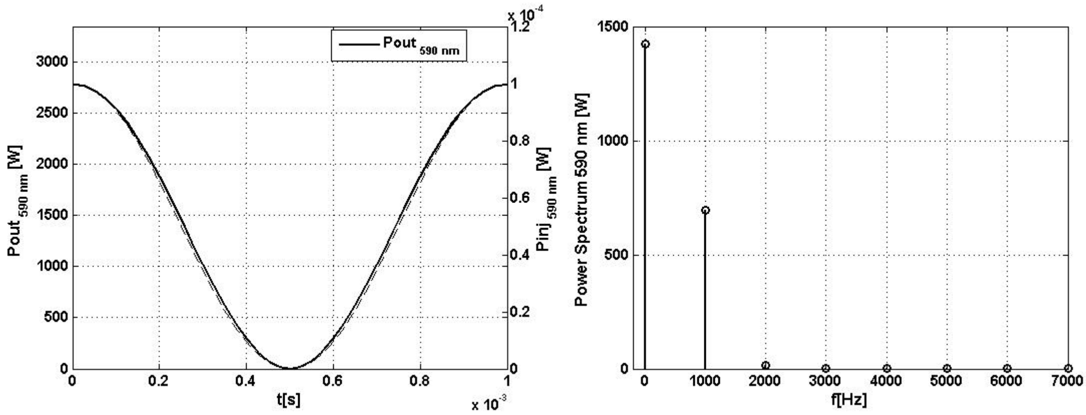


Fig. 3

As a second step we have considered a simultaneous injection of four beams with different wavelengths (λ_1=590nm, λ_2=591nm, λ_3=592nm, λ_4=593nm, λ_C=590.2 nm). The used parameters here are $Pinj_{\lambda i}$= 0.1 mW, k=1, $Pinj_{\lambda C}$=1 mW. The computed curves, similar to these ones in Fig. 3 with their Fourier spectrums are shown in Fig. 4. From the obtained curves we can conclude that the proposed amplifier is able to assure a high (~10^5-10^6) amplification with acceptable low level nonlinear distortion (~ 1% and less) of the amplified signal.

To generalize the conditions for such linear response we have calculated the amplify-cation curves for four wavelengths as functions of their input powers, varied from 0.01 mW to 1 mW for a constant counterinjection power of 1 mW. From the Fig. 5 it can be seen the linear response for injected power variation between 0.01 mW and ~ 0.3 mW. All the reported results are for the given above

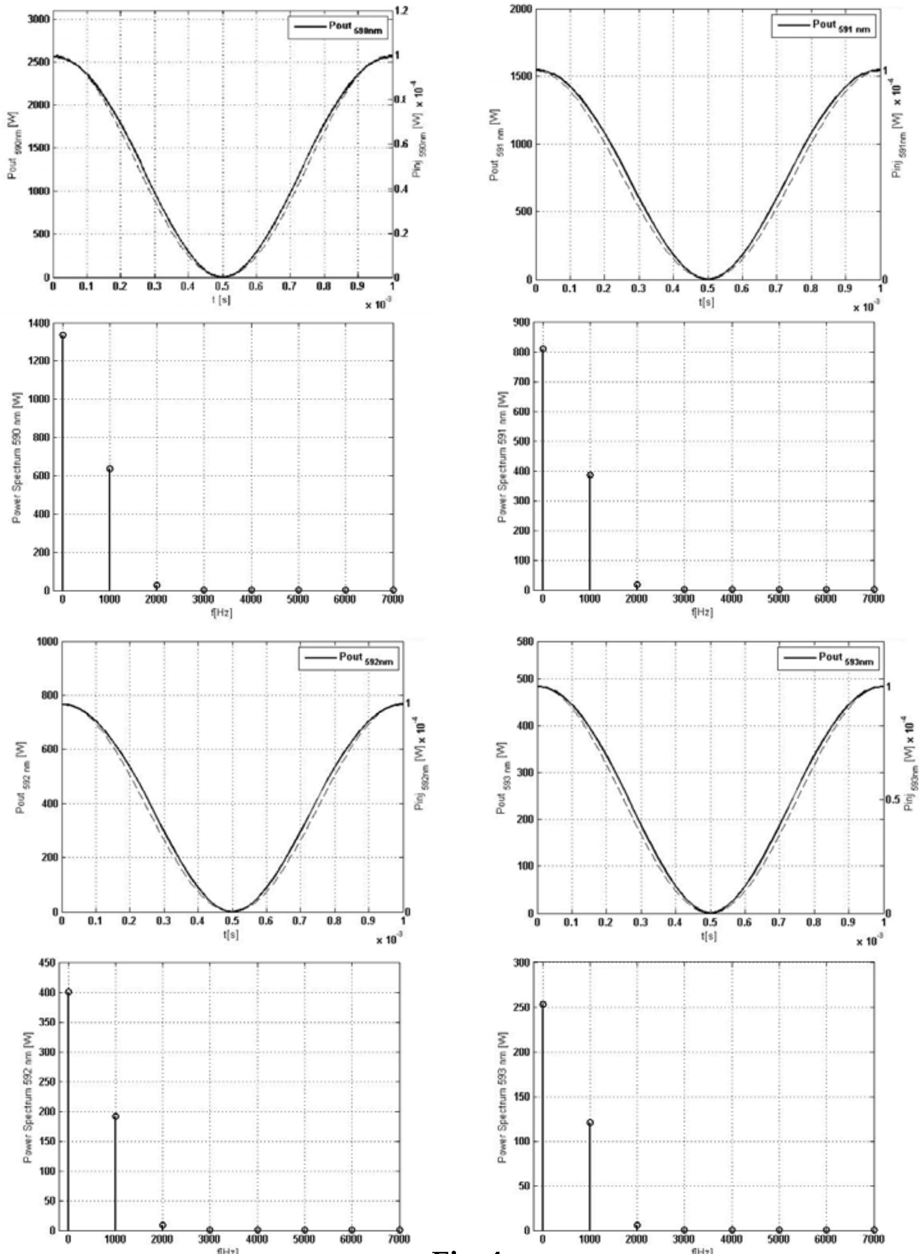
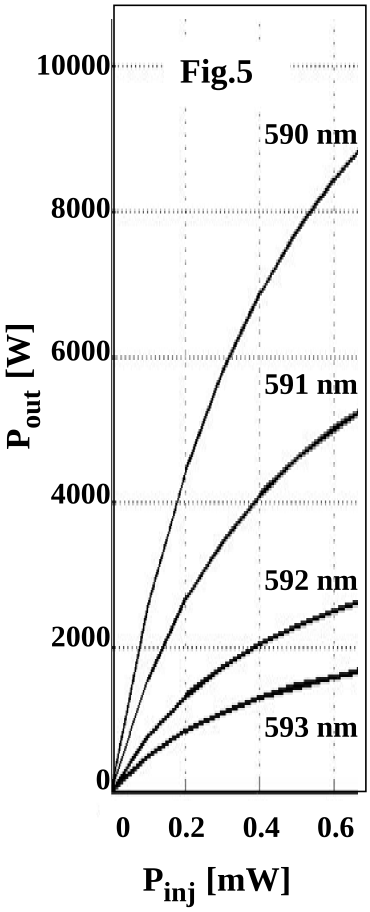


Fig. 4

wavelength distance of ~800 GHz, thus consists a wide spectral band. We have obtained from the calculation, as expected result, that the gains get closer each to other as the wavelengths difference decreases. Thus the considered amplifier with the given in this Section parameters present high potential to be used in wide frequency range of order of 2400 GHz.



3. CONCLUSION

We have described the further development of our original injction-conterinjection locking ring-configuration laser amplifier for high gain (~10^6) amplification of low-power (~μW) modulated laser radiation. In presented study, we have shown the ability of our amplifier to amplify simultaneously and linearly a number of injected beams with different frequency at a large distance of ~ 800 GHz. The nonlinear distortions, defined by the harmonics relative power are lower than 1 %. Such amplification is possible in very wide range of ~ 2400 GHz.

4. ACKNOWLEDGEMENT

The work is supported partially both by the Contract Ph 1305 and Contract VUPh-12 with NFSI, Bulgaria.

5. REFERENCES

[1] Deneva M., M.Nenchev, R.Barbe, J.C.Keller, *A new injection locking ring laser amplifier of a periodically modulated laser light using an opposite second injection*, Proceedings of The Seventh Int. Conference ELECTRONICS'98, Book2, pp. 11-15, 1998.

[2] Slavov D., M.Deneva, E.Stoykova, M.Nenchev, R.Barbe, J-C.Keller, *Output control of a ring laser using bi-directional injection: a new approach for unidirectional generation at a reference atomic absorption line*, Optics Communications 1998, Vol.157, pp. 343 – 351, full length article

[3] Deneva M., S. Saparev, M. Nenchev, J.-P. Wallerand, M. Himbert, *New linear laser amplifiers of a periodically modulated laser radiation based on an injection-locked method*, Proceedings of SPIE, 2001, Vol. 4397, pp. 79-84

[4] Atanasova A., M.Deneva, M.Nenchev, *Development of original injection-locked linear laser amplifiers: noise characteristics*, Proceedings of SPIE, 2005, Vol. 5830, pp. 496-500, USA

[5] Nenchev M., Bulg. Path. IIR № 53348/1981 – 32703/1982, *Tunable two-wavelength laser*

[6] Neveux M., M.Nenchev, R.Barbe, J-.Keller, *A two-wavelength, passively self-injection locked, CW Ti:Al_2O_3 laser*, IEEE J. Quantum Electron., Vol.31, 7 (1995) 1253-1260, USA

M.Deneva, D.Slavov, E.Stoykova, M.Nenchev, *Improved Passive Self-Injection Locking Method for Spectral Control of Dye and Ti:Al_2O_3 Lasers Using Two-Step Pulse Pumping*, Optics Communications, 1997, Vol. 130, pp. 287-298, full length article

[7] Svelto O., *Principle of lasers*, 4-th edn., Plenum, New York, 1998