DEVELOPMENT OF A TWO-WAVELENGTH CW RED SEMICONDUCTOR LASERS IN ORIGINAL RESONATOR ARCHITECTURES

Suat Topcu[1], Yasser Alaily[1], Nadejda Yordanova Kaimakanova[2], Margarita Angelova Deneva[3], Marin Nenchev. Nenchev[3,4]

[1] LIRIS - University of Versailles, 78035 Versailles, France
[2] PlovdivUniversity, 24 "Tzar Assen", 4000 Plovdiv, Bulgaria
[3] Technical University – Sofia, Branch Plovdiv, 61 bvd St. Peterburg, 4000 Plovdiv, Bulgaria
[4] IE-Bulgarian Academy of Science, 72 Tsarigradsko Chausse, 1784 Sofia, Bulgaria

Using two original two-cannel resonator architectures we have developed a CW red semiconductor lasers that produce simultaneously in a single beam or/and in separate beams emissions at two independently tunable wavelengths (in the experiments in the range 0.628 - 0.632 μm). We give the detailed description of the two our interference-wedge based laser scheme that is very effective and simple for realization. As addition, one of them permits simultaneous selection of the two outputs of the semiconductor active medium by a single selective structure thus reducing strongly the amplified spontaneous emission. The peculiarities of the obtained emissions are investigated. The advantages in comparisons with two separate lasers - use of a single expensive laser diode (with AR coated surfaces), low pumping, high efficiency, and natural output in a single beam and the problem - tuning limitation due to the wavelength competition are discussed. The cases of competitive applications of the proposal are carried out.

Keywords: tunable lasers, two-wavelength emission, CW operation, red semiconductor lasers

1. INTRODUCTION

The natural possibility of the wide gain lasers is to be operated simultaneously and in controlled manner at two or more independently tunable wavelengths in different spectral intervals. This mode of operation (two-wavelength lasers) is earlier realized and studied in details for dye, F-color centers and Ti:Saphhire lasers [e.g. 1]. Many practical applications relate of the use of laser light at two independently tunable wavelengths [e.g. 2]. The important case is a Differential Absorption Spectroscopy (DAS) that permits to monitor different corposants of the complex substances, including the atmosphere pollutants such as NO_2, SO_2 (the known LIDAR variant); the modern and efficient method of laser isotopes separations; nonlinear frequency mixing experiments to produce a sum and difference of wavelengths, in holography, in metrology. The best situation for such applications is when the two emissions are produced in a single beam and simultaneously. Here we describe how by applying our original and effective schemes of two-channel laser resonators, we have realized (and studied) such mode of operation in the CW red diode lasers. The red semiconductor lasers are promising simplest sources for the many of noted applications, competing the He-Ne lasers. In comparison with two separate lasers the advantageous of the two-wavelength lasers are:

In technical aspects, what is evident, the two-wavelength laser is simplest and chipper – use of a single laser diode with AR coated surfaces and respectively with a high price, use of a single stabilized supply and temperature controlled subsystem. ***In basic aspects*****:** i) Being the threshold phenomenon, the two-wavelength laser operation needs of low pump power than this one after division to pump two separate lasers. ii) The CW laser output power is proportional to the difference (P_{pump}/P_{th} -1), where P_{pump} and P_{th} are the pump and the threshold power, respectively. This simple relation shows directly that the output power in the each emission for the two-wavelength laser is a few times higher than this one obtained in two separate lasers.

The disadvantage for the most interesting case of generation in one beams of the two emissions is relate with so called mode-competition effects [1,2], essential for homogeneously widened media. The two generations compete nonlinearly and the small unbalance of the losses produces suppression of one of the generations by the other. This limits the tuning of the generations However, in many practical cases one time tuning of both wavelength is sufficient.

2. New Solutions of the Two-Wavelength Red Diode Lasers

In our consideration we have used a red AR coated front surface laser diode of AMS Technology (model SAL-635), optimized for wavelength of 635 nm. The threshold current of ~ 60 mA, nominal laser operation at 80 – 90 mA and maximum pumping to 100-110 mA.

The realized schemes are related to the our patented earlier basic idea to use in convenient manner an Interference Wedge (IW, or Fizeau Interferometer) as a spectral selector and tuning – coupling element for creation two spectral-selective channels laser resonators. Very important property of the IW is that the wavelength of its transmission can be tuned by a simple translation in its plane. This permits, during the tuning, to conserve the direction of the reflection and the transmission of the incident beams. Thus, using in convenient manner a series of Interference Wedges we can realized a very attractive and compact Wavelength Devising and Multiplexing system (WDM) with spectrally tunable input-output. Except the application for creation of the two-wavelength laser resonator, this WDM system presents essential potential for applications in optical communication systems. Its basic principle is published earlier by us [1].

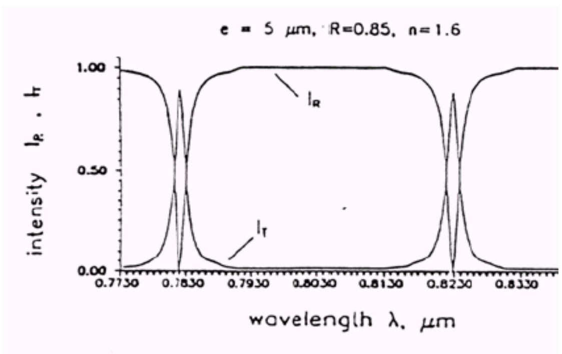

Fig.1. Calculated transmission and reflection of the Interference Wedge versus the wavelength (Ref. 1)

The IW in construction is very similar to the Fabry-Perot Interferometer (FPI). In IW the reflective surfaces consists a small angle of ~ 10^{-5} rad. The properties of this device for laser applications, when is illuminated with a limited diameter beams such the intracavity beams in lasers is studied theoretically and experimentally by us in Ref. 3. In general, they are similar to these ones of the FPI with variable thickness by translation of the IW. The essential practical interest presents the technology, actually under progress, to fabricate very compact IW of "sandwich" type that presents a sequences of disposed on an optical plate a multi-dielectric reflective layer (reflection R ~ 0.8-0.9), a transparent ~ few μm wedged layer-separator and a second reflective layer, similar to the firs one. The example of the calculated transmission and reflection curves vs. wavelength is shown in Fig.1 for the IW with thickness of 5 μm, R=0.8 with angle of 3.10^{-5} rad. The illumination is with 1 mm diameter He-Ne laser beam (at 630 nm).

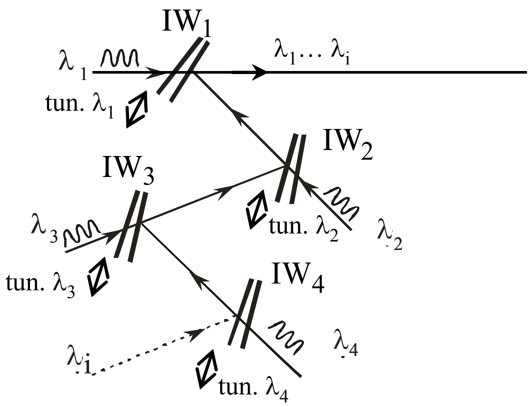

Fig. 2. Principle scheme of the WDM system with Interference Wedges.

In Fig.2 are plotted the principle scheme of the discussed above WDM system that uses the series of Interference Wedges as the described this one. Using our WDM system we have proposed two types of two-channel resonator architectures for two wavelength operation of the diode laser both original and presenting en essential advantages.

Generally, if the high quality IW with resonant transmission of ~ 0.9 and more are available, we can recommend the very simple and attractive scheme for two-wavelength operation shown in Fig.3. In this scheme, we obtain very easily in practice, with non-precise alignment two-wavelength operation with collinear and a different output for each generation. The two generations use a single diode with AR coated front face in single supply and crystal-cooled system.

For 10 cm length nonselective resonator (without IW_1), composed of laser diode, AR coated 0.7 cm lens, that focalized the beam at the end mirror M_1 with reflectivity of 0.84 (~ 0.16 transmission) the threshold current was ~ 60 mA. Note that in parallel intracavity beam the alignment was essentially more difficult with high threshold (75 mA). The laser with focalization operates with the introduced 75% transmission IW_1 and 95 % rerflectivity end mirror M_1 with the threshold of ~ 75 mA.

The output is taken from the reflection of the IW_1 and is ~ 70 μW for 90 mA pumping. When we reinjected the reflected beam (PSIL technique [1]) in the opposite direction of the output with a second totally reflected mirror the laser output power reaches 270 μW for 90 mA pumping current. The high threshold (~85 μW) of the parallel beams IW selection diode laser, evident is related with high diameter of the intra resonator beams, of order of 3-5 mm and decreasing transmission of the IW in this case [3]. The laser can be tuned in both cases at ~ 5 nm around 630 nm with a linewidth of the emission of ~ 0.4 nm. The improvement of the laser energetic characteristics essentially, using the modification with focalization (Fig.3) is due to the narrowing of the beam diameters, illuminating the IW and respectively a strong increasing its transmission for the selected wavelength (to ~ 85 %) [3]. The two-wavelength scheme can be easily understood from the shown Fig.3. The IW_1 is transmission element for the resonant wavelengths and high reflected element (~ 0.97 and more) for the non-resonant (see Fig.3). Thus, if we reflect back by the second end mirror M_2 the non-resonants wavelength we form the second channel. If in the last is introduced a second interference wedge IW_2, e.g. similar of IW_1, a second spectral selective channel wit selected non-resonant for IW_1 wavelengths is formed for selection of λ_2 .

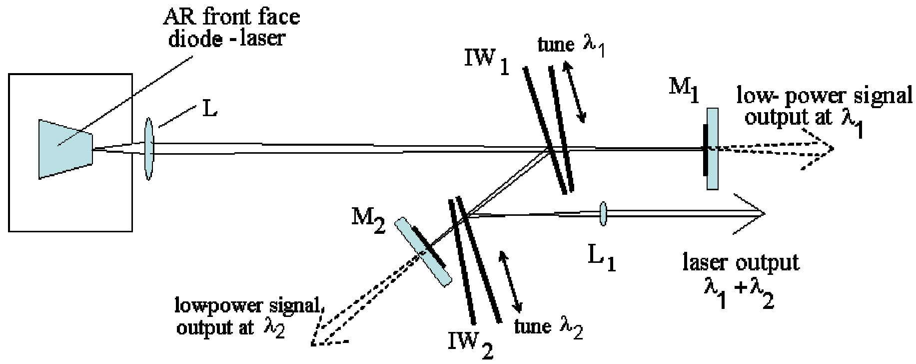

Fig. 3. The two-channel resonator with focalization of the intra-resonator beam. The action of the scheme is with the advantage that the illuminated $IW_{1,2}$ beam is with decreased diameters in the IW-es ,thus assuring additional laser linewith narrowing.

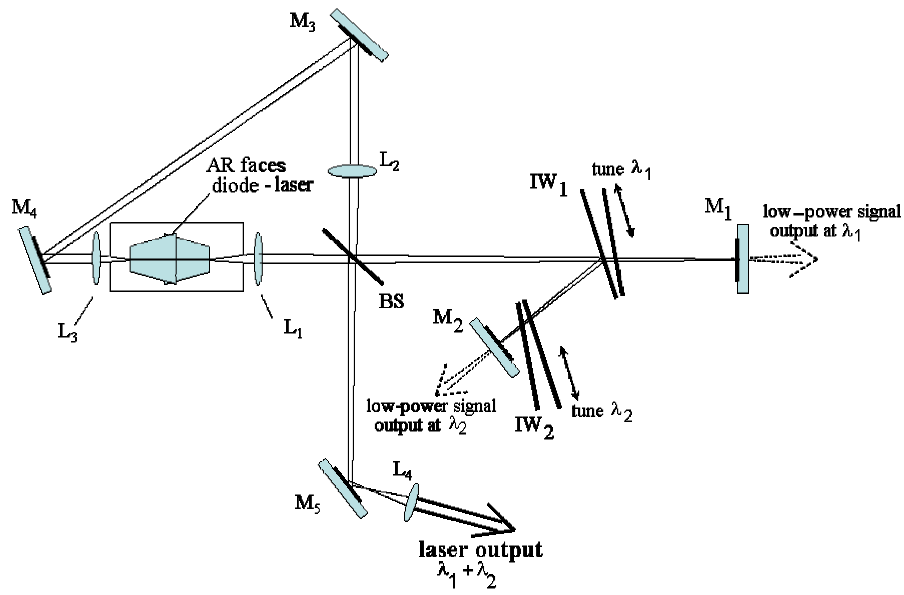

Fig.4 Two-wavelength laser architecture with elimination of reinjection of ASE.

The scheme in Fig.4 presents the essential advantage to eliminate the reinjection of the amplified spontaneous emission (ASE). In this case the diode laser is with two AR coated faces. The proposed shame with the beam-splitter BS of 0.5 transmission assures a selection of both laser outputs by a single selective structure and without retrereflection of the ASE. The action of the laser architecture is clear from Fig.4.

We have obtained simultaneous two-wavelength laser operation in the scheme in Fig.4. The condition is that in a diode laser the net amplification (amplification minus loses) is equalized, that leads to:

$$\gamma'' = \frac{\sigma''.\Gamma''}{\sigma'.\Gamma'}.\gamma'$$

Where [4] $\gamma' = -\ln R_1' + \alpha.L$, $\gamma'' = -\ln R_1'' + \alpha.L$, $\Gamma' = \frac{D'^2}{2 + D'^2}$, $\Gamma'' = \frac{D''^2}{2 + D''^2}$,

$D' = 2\pi.(n_1^2 - n_2^2)^{1/2}.\frac{d}{\lambda'}$, $D'' = 2\pi(n_1^2 - n_2^2)^{1/2}.\frac{d}{\lambda''}$.

Here σ' and σ" are the corresponding of λ_1 and λ_2 gain coefficients [4], n_1 and n_2 - the refractive indices of the active medium and cladding layers for GaAs laser (n_1 =3.6, n_2=3.4), $d \sim 0.1$ μm– the thickness of the active layer, α is the loss coefficient and is of ~10^{-1} cm, the resonator length is of L= 13 cm, R_1' and R_1" are the reflection of the corresponding at λ_1 and λ_2 of the end mirrors.

3. THE TWO-WAVELENGTH RED DIODE-LASER OPERATION

In the investigation, we use the values of the parameters, given for the Fig.3.

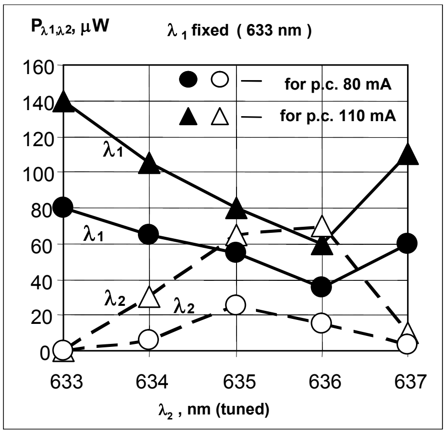

Fig.5. Tuning curves for two-wavelength generation. One of the wavelengths (λ_1) is fixed and the second (λ_2) is tuned. For each wavelength λ_2 the losses in the two channels are appropriately balanced to produce two-wavelength operation.

The diode-laser emission was produced for the constant currant of 80 mA. The laser threshold was ≈ 67 mA. Firstly, we block the operation in the IW_2 channel by inserting a screen in front of the IW_2. The laser output was at single wavelength, selected by the IW_3. The maximum output power was ~ 200 μW at 633 nm. By translation of the IW_1 we perform the tuning of ~ 5 nm around 633 nm. As a second step, we block the mirror M_1 and unblock the operation in the IW_2 channel. We obtain the similar laser characteristics and tuning by translation of IW_2. When the two channels are unblocked simultaneously, as a rule, the generation in one of them suppresses the lasing in the other. By slowly tilting the mirror M_1 we obtain the two wavelength emission. The wavelength competition was exceptionally strong and needed very precise balance of the introduced losses. The two-wavelength operation was possible only near the gain maximum – in a range of ~ 4 nm near 633 nm with linewidth of each emission of 0.1 – 0.3 nm . The maximum sum energy is slowly lower than of the emission at a single wavelength (e.g. 150μW-170 μW). For each tuning of one of the channel, one of the laser emission is suppressed by the other and to reproduce the two wavelength operation it is necessary a new precise balance of the losses. The output beam, after collimation with lens L_1, has diameter of ≈ 2 mm and specific distribution with near rectangular high intensity part along the direction of the diode p-n junction, superimposed on the near homogeneous illumination of the beam spot and a divergence of ≈ 3 mrad. The typical tuning curves, obtained when one of the wavelengths (λ_1) is fixed and the second (λ_2) is tuned are plotted in Fig.5 (for two pump currents: 80 mA and 110 mA).

The wavelength competition is a limitation of the application of this attractive technique. Earlier, using a grating or polarizing schemes, experimental realization of the two-wavelength operation in infrared (~ 830 nm) semiconductor laser is reported in Ref.5. The authors are observed similar strong competition and suggest some reasons for the two-wavelength operation – the spatial hole burning effect, filamentation, mode hoping and balanced gain for two emissions. In their point of view, the mode jump process may explain double-mode oscillation. However, they are not presented the temporal investigations. We have investigated the temporal behavior of our two-wavelength red semiconductor laser with resolution to 20 ns. Our conditions permit to observe the temporal behavior of one of the emissions during the two-wavelength operation. This is shown on the oscilloscope traces in Fig.6(a) – for 50 ns/div and in Fig.6(b) – for 20 ns/div. A 300 MHz LeCroy oscilloscope and ns-resolution detector are used, however below 50 ns the oscilloscope trace corresponds to numerical mode of registration with change the real form of the signal. Nevertheless in all cases it can be seen that the wavelength jumping not present. We attribute the possibility for two-wavelength operation with a mechanism of equalized difference gain minus losses for both generations.

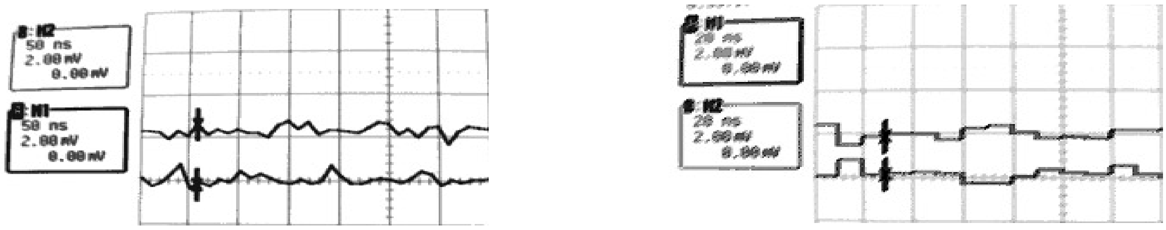

Fig.6. The temporal behavior of the laser emission at the one of the wavelength during the two-wavelength operation.

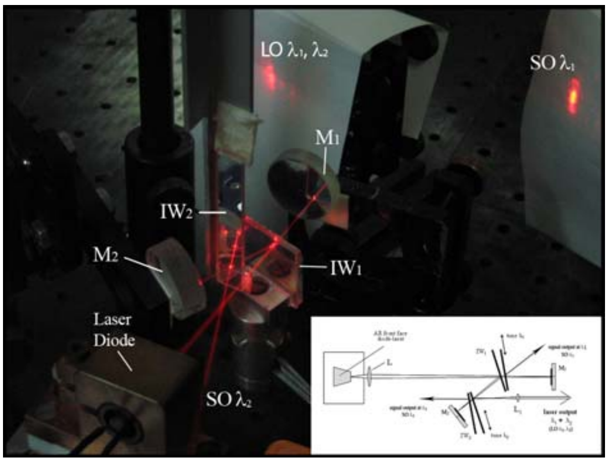

Fig. 7. Actual photograph of a two – wavelength CW red diode laser, realizing the scheme given in Fig.3 with visualization of the two intra – cavity beams. The labels are given in the figure in the inset.

4. CONCLUSION

In the present work, we have presented the effective solution of a red two-wavelength semiconductor laser that produces simultaneously and in single beam emissions at two independently tunable wavelengths. We have shown for the first time that the two emissions from the single diode are really simultaneous The two-wavelength lasers are a simplest and cheaper way to obtain such emission with maximum power for a given pump source used and more energetically efficient.

Despite the tuning range limitation due to the mode competition, the CW two-wavelength laser developed present interest for many practical applications that do not need of wide tenability – in DAS monitoring of the atmospheric corposants, in isotope separation, in non-linear investigations, in holography.

5. ACKNOWLEDGEMENT

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