A SIMPLE NEW TECHNIQUE FOR LASER SPECTRUM LOCKING AT ATOMIC ABSORPTION LINE

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ABSTRACT.

We have shown that the control by external injection of two cross-axes resonator in a common homogeneously broadened active medium can be successfully applied to produce a laser emission at the wavelength of an absorption atomic line. From the theoretical study and computer simulation the feasibility of such system is proved and have been shown a few essential its advantages. Except the simplicity of realization, our system permits an essential narrowing of the locked spectrum (by an order of magnitude or more) compared to the absorption linewidth. In contrast to the conventional systems with active laser frequency locking, our technique does not use any complicated comparative electronic circuitry and thus its action cannot be influenced by the external electrical, magnetic or radiation fields. The volume with the absorbing atoms can be located at a long distance (meters or more) from the controlled laser. Such system is of essential interest for application in metrology and optical communications as a frequency standard, for LIDAR applications in ecological monitoring and in the scientific work.

1. INTRODUCTION

Lasers with emission spectrally locked at reference atomic lines are of essential interest for metrology as wavelength standards, for optical system testing and possibly for DIAL atmospheric survey systems as well as for isotope separation experiments.

Injection locking is a well known and useful approach for laser emission spectral and spatial control. Its main advantages, such as high energetic efficiency of the controlled laser, protection of the selective element from high intensity light illumination and facility to obtain high power single, mode emission, have been widely discussed in the literature [1-2].

In the present work we consider the case of a control by external injection of two cross-axes resonators in a common homogeneously broadened active medium. The aim of the study is to show that such type of injection control can be successfully applied to produce a laser emission at the wavelength of an absorption atomic line. A natural property of this emission is the essentially narrower spectrum (by an order of magnitude or more) compared with the atomic linewidth, due to the strong competition of the waves in a common part of the two resonators in the active medium. In contrast to the conventional systems for laser generation at an absorption line frequency [3] with active laser frequency locking, our technique does not use any complicated comparative electronic circuitry and thus its action cannot be influenced by the external electrical, magnetic or radiation fields. The volume with the absorbing atoms can be located at a long distance (meters or more) from the controlled laser. The desired laser output is only at the wavelength of the selected atomic line. No undesirable detuning is possible. To provide such emission the injecting laser spectrum must be scanned around the absorption line. Earlier we have described and realized experimentally a technique for ring dye laser frequency locking at reference atomic absorption line [4]. The proposed here technique is further development of this question with the advantage of more simple arrangement of the laser that this one of the ring laser.

The developed technique can be considered as a new and useful application of the injection locking approach for laser control. Some other possibilities for passive self-frequency locking, using dispersive properties of the absorbing atoms in the cavity are also under consideration in the literature [5,6]. However, in this case the loss control elements and absorption species must be incorporated in the locked laser cavity.

2. PROPOSED PRINCIPLE AND THE LASER ARRANGEMENT.

The experimental set-up for bi-resonator injection locking is presented in Fig. 1. The study was performed on the example of an injection controlled dye lasers with 10^{-3} mol/1 solution of Rhodamine 6G in ethanol filled the cell with length of 0.3 cm. The solution is pumped with 15 ns duration 1 mJ energy pulses at repetition rate of 10 Hz. The pumping was provided by a frequency-doubled (0.53 μm) Q-switched Nd:YAG laser. The principle of the action of the bi-injection locking system can be understood from the Fig.l.

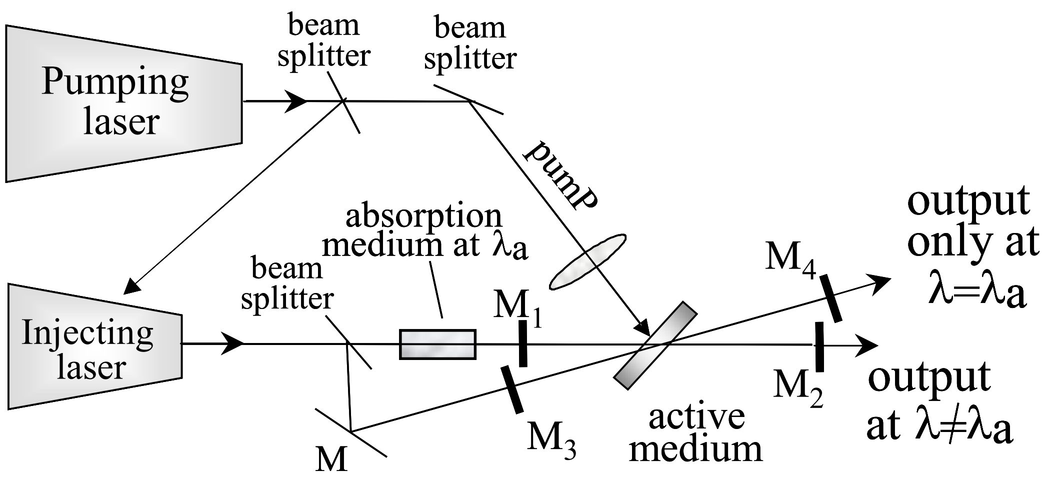

Fig. 1. Set-up of injection controlled be-resonator laser schema for producing emission spectrally locked at atomic absorption line.

The frequency scanned injection controls the emission in the two crossed resonators due to the use of a common active volume in the active medium (AM).

Four flat mirrors form the two resonators: M_1, M_2 form the first resonator and M_3, M_4 - the second one. The lengths of the resonators are 5 cm. The output beam of the injected laser is split at two beams with a beam splitter and both beams are injected each in corresponding resonator as it is shown in the Fig.1. M is the flat full reflecting mirror. In one of the beams, between the beam-splitter (BS) and M_1 is placed the absorption medium with atoms that have the desired atomic absorption transition at λ_a. The injection power ratio, the delay between the moments of the injections, given by the difference between the two ways BS-M_1 and BS-M-M_3 and the resonator parameters are chosen to assure an operation only in the resonator M_1-M_2 (output 1, output power P_{out1}) when the injection frequency no matches the absorption line. Such choice of the parameters leads that the lasing in the resonator M_1-M_2 suppresses operation in the second resonator M_3-M_4. In the other hand the noted parameters are chosen so that when the frequency of the injected light matches the absorption line, due to the change of the injected powers ratio, the injection provides most favorable conditions for generation in the second resonator M_3-M_4 with suppressed generation in the first resonator. In this moment, the described system produces a single output from M_4 (output 2, output power P_{out2}) exactly at the frequency λ_a of the absorption laser line. Thus, during the scanning of the injected frequency, every time when the last matches the absorption line, the system will produces an emission only at output 2, locked at the absorption line.

Below we will shown that it is very realistic to obtain such conditions and to realize the described very simple for realization system.

3. THEORETICL DESCRIPTION OF THE SYSTEM ACTION AND NUMERICAL INVESTIGATIONS

We performed computer simulations by adapting a conventional set of rate equations for laser generation [7]. We consider the case of multimode injection and operation, neglecting hole-burning effects. Under the condition of a large number of injecting modes, we expect as a rule the coincidences at minimum of one injected frequency with some resonators longitudinal mode. The time dependence of the powers in the pulses from output 1and output 2 are proportional to the generated photon numbers $q_1(t)$ and $q_2(t)$ in the firs and in the second resonator, respectively. We have:

$$\frac{dN}{dt} = W_P(t)\cdot N_t - (B_1 \cdot q_1 + B_2 \cdot q_2)\cdot N - \left[W_P(t) + \frac{1}{\tau}\right]\cdot N$$

$$\frac{dq_1}{dt} = \left[B_1 \cdot V_a \cdot N - \frac{1}{\tau_{c_1}}\right]\cdot q_1 + \frac{k_1 N}{\tau} + \frac{P_{inj_1}}{h\nu_1}$$

$$\frac{dq_2}{dt} = \left[B_2 \cdot V_{a_2} \cdot N - \frac{1}{\tau_{c_2}}\right]\cdot q_2 + \frac{k_2 N}{\tau} + \frac{P_{inj_2}}{h\nu_2}$$

where N is the inversion population per unit volume in the active medium. N_t is the total number of the dye molecules per unit volume, which in our computation is equal to $6\text{x}10^{17}$ cm^{-3}, $B_{l,2}=\sigma_{1,2}(l_{1,2}).l_{1,2}.c_0/V_a.L'_{1,2}$, $\sigma_{21}(\lambda_{1,2})$ - the emission cross-sections, corresponding to λ_1 and λ_2, respectively ($1.85\text{x}10^{-16}$ and $1.71\text{x}10^{-16}$); $V_a = 2.7\text{x}10^{-4}\,\text{cm}^3$ is the working volume of the active medium (here and below we give the typical experimental values); c_0 is the speed of light in vacuum, $\tau = 3$ ns and $\tau_{c1,c2} = L'_{1,2}/c_0.\gamma_{1,2}$ are respectively the lifetimes of the upper laser level and of photon in the ring cavity, where $\gamma_{1,2}$ describes losses in the cavity channels. The reflectivity of mirrors M_2 and M_4 is 0.8 and this one of M_1 and M_3 – 0.9. The terms k_iN_i/τ give for i=1,2 the rates of photons produced in the laser mode volume by the spontaneous emission with $k_i = 6\text{x}10^{-16}$ in our case. In the system $W_P(t)$ is the pumping rate in the pulse that pumps AM. We assume for simplicity a complete superposition of both resonator axes in the active medium. The system is solved numerically by the Runge-Kuta-4 method. From the solution we obtain $q_1(t)$ and $q_2(t)$ and respectively the laser output powers P_{out1} and P_{out2} [7].

In Fig.2 (left) with the solid lines are plotted the computed curves of power P_{out2} of the emission from output 2 (top) and P_{out1} from output 1 (bottom) as a function of the wavelength – i.e. obtained when the injected wavelength is scanned.

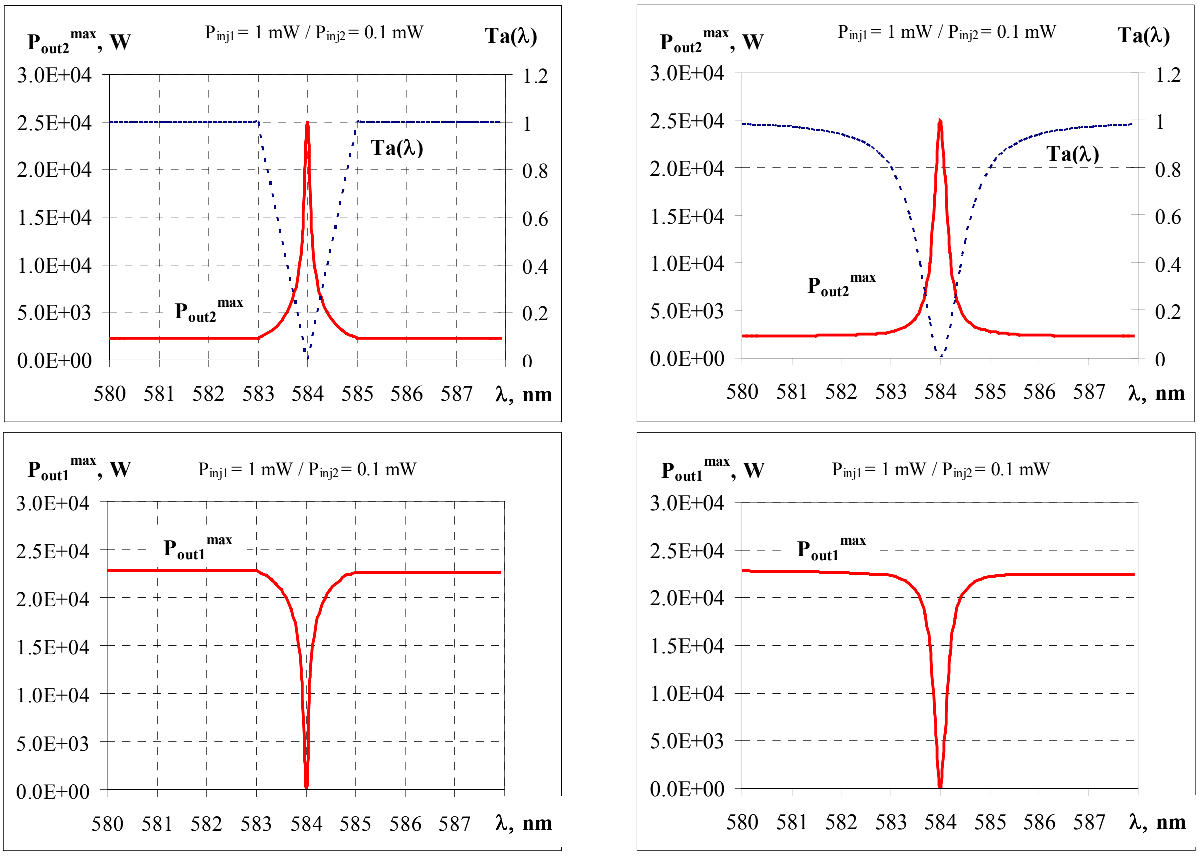

Fig. 2. Output powers from both resonators (P_{out1} and P_{out2}) obtained during the scanning of the injected wavelength – computed curves. The locking for P_{out2} can be seen.

In the considered case the profile of the absorption line is accepted to be rectangular as it is shown by the dashed line in the top figure. The injected powers in the first resonator is P_{inj1} = 1 mW and in the second – P_{inj2} = 0.1 mW. When the wavelength of the injected light matches the maximum of the absorption line, the absorption for the beam trough the cell is total in the considerate case. These two graphs show very good locking, obtained for the chosen parameters (output 2 is only at the wavelength of the absorption line). In Fig.2 (right) are shown the same computed dependencies as in Fig.2 (left), but for Gaussian profile of the absorption line. The locking is evident.

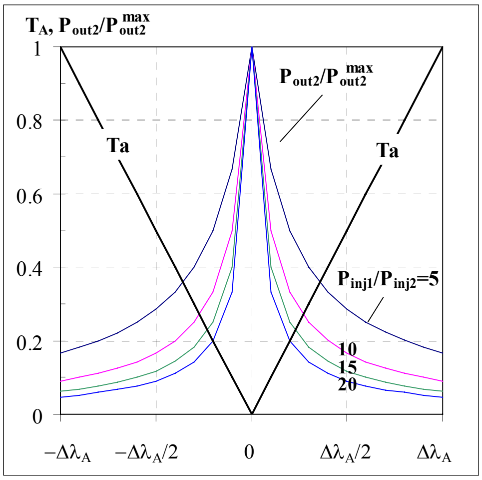

Fig. 3. Narrowing of the locked line (fine graphs) by respect to the absorption line Ta (thick line) - computed curves.

As it can be seen from Fig.2 the locked line is essentially narrowed by respect of the absorption line what is as results of wavelength competition effect. We have studied these important futures of our technique. In Fig.3 are presented the computed curves versus wavelength in unites of linewidth $\Delta\lambda_A$ of the absorption line. The narrowing depends essentially on the ratio between the injected powers as it can be seen from the figure. In Fig.4 is plotted the dependence of the ratio $\Delta\lambda / \Delta\lambda_A$ between the emission linewidths and the absorption linewidths as a function of injected power ratio. The narrowing of the emission can be high of the order of magnitude what is very important advantage of our methods.

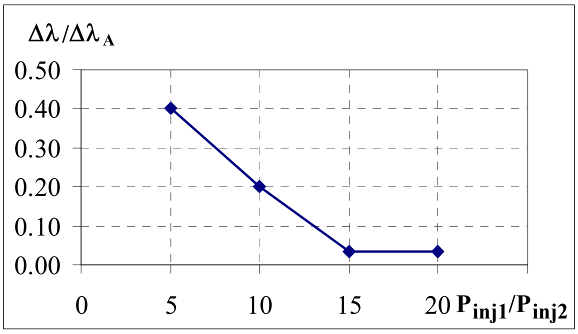

Fig. 4. Dependence of the ration between the emission linewidth $\Delta\lambda$ and the absorption linewidth $\Delta\lambda_A$ versus the ratio of the injected powers.

Thus, the presented investigation shows the feasibility of the proposed system and shows the essential advantage of additional narrowing of the emission by respect of the absorption line – more than of order of magnitude.

4. CONCLUSION.

A novel arrangement for spectral control of laser with homogeneously broadening active medium that assures an emission locking at the wavelength of a desired atomic absorption line by means of injection has been proposed and investigated. The technique exhibits specific advantage. No comparative electronics is needed. The desired emission spectrum can be narrowed more than of order of magnitude in comparison with the absorption linewidth, as it is shown. This effect is due to the strong wave competition. Important for practical applications is the possibility to locate the absorbing element at a long distance from the controlled laser and to connect both apparatus purely optically. This can be very useful for some experiments such as evaluation of the reference absorption of a cloud of cold atoms, which are produced, in a large size experimental arrangement. To achieve the desired mode of laser spectral emission, it is necessary only to scan the wavelength of the injected light around a highly absorbing reference line. The linewidth of the locked emission is essentially narrowed than the one of the absorption line. The desired emission for the practically important high repetition rate lasers can be produced at high average power. Thus, in a variety of applications the proposed technique can be very useful as a simple method to produce high power laser output at a wavelength of an absorption atomic line.

5. ACKNOWLEDGEMENTS

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