Anomalously wide continuous tuning range of the emission frequency of an injection laser with an external selective resonator


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A study was made of an anomalously wide continuous tuning range of the emission frequency of an injection laser with an external resonator operating under conditions of self-stabilized single-frequency lasing. The self-stabilization was observed for a large number of lasers with different structures, both at room and liquid nitrogen temperatures. A study was made of the influence of the power, degree of coupling with the external part of the laser, resonator length, and pass band of a selective component on the continuous tuning range. In the self-stabilization regime this range was 10–30 times greater than the corresponding range for a laser operating under conventional conditions. A nontrivial feature of hopping between longitudinal laser modes at the limit of the tuning range was observed. This feature was explained on the basis of a theory proposed by Bogatov, Eliseev, Okhotnikov, Rakhval'skii, and Khairetdinov [Sov. J. Quantum Electron. 13, 1221 (1983)].

INTRODUCTION

An injection laser with an external resonator has a number of advantages over a laser with a conventional resonator formed by the cleaved faces of a semiconductor. The most important advantages are: 1) feasibility of single-frequency lasing and suppression of discontinuities in the tuning characteristic of a single-frequency injection laser; 2) a considerable reduction in the width of the emission line because of an increase in the photon lifetime in the resonator; 3) a wider tuning range at a given temperature of the active region of an injection laser. On the other hand, the simplest methods for continuous tuning of the emission frequency, usually employed in lasers with a conventional resonator (tuning by variation of the current or temperature), are not very effective in the case of an injection laser with an external resonator (because the continuous tuning range is narrow). Continuous tuning of the emission frequency over a sufficiently wide range is essential for the applications of an injection laser with an external resonator in high-resolution spectroscopy, metrology, and heterodyne fiber-optic communication.

The present paper is a study of the methods for continuous frequency tuning of an injection laser with an external resonator in the case when the efficiency of the external feedback loop is sufficiently high and the length of the external part of the resonator \( L \approx 0.3–3 \) m is much greater than the optical length \( nL \) of a laser diode. In an analysis of the methods for tuning injection lasers with an external highly selective resonator (for example a holographic total-internal-reflection selector or a grating with an etalon) we have to allow for the existence of two modifications of single-frequency lasing. One of them will be called, following Ref. 4, the regime of self-stabilization of single-frequency lasing, whereas the other will be called the conventional single-frequency regime (for brevity, we shall refer to these as self-stabilization and conventional operation). We shall concentrate our attention on the tuning characteristics of a laser operating in the self-stabilization regime, because tuning in the conventional regime has been investigated sufficiently thoroughly.\(^{1,5,6}\)

Figure 1 shows the tuning characteristics obtainable in the conventional (a–d) and self-stabilization (A–D) regimes. The envelope of the dependence of the power on the current \((a,A)\) is determined in both cases by a shift of a normal mode of an injection laser relative to the selector resonance. The asymmetry is due to the dependence of the refractive index on the output radiation power.\(^5\) Periodic variation of the output power in the conventional regime \((a)\) associated with hopping of longitudinal modes of the composite resonator, disappears in the self-stabilization regime \((A)\) because lasing involves emission of one mode throughout the range of currents from the appearance and suppression of stimulated emission. There is a corresponding disappearance of the discontinuities also in the dependence of the

\[ \frac{\Delta v}{\lambda} = \frac{\Delta n L}{\lambda} \]

FIG. 1. Tuning characteristics in the conventional single-frequency regime (a,b,c,d) and in the self-stabilization regime (A,B,C,D), representing the dependence of the power \((a,A)\) and of the emission frequency \((b,B)\) on the injection current, and the dependences of the power \((c,C)\) and of the emission frequency \((d,D)\) on the length of the external part of the resonator.
frequency on the current (b,B).

A change in the length of the external part of the resonator operating in the conventional regime results in successive switching of lasing to the nearest longitudinal mode of the composite resonator. Displacement of the external mirror needed to produce such switching is \( \frac{\lambda}{2} \) and the tuning interval of each mode is localized in the same region of minimal losses determined by selective components (Fig. 1d). In the self-stabilization regime it is possible to tune continuously the emission frequency under the same conditions (change in the length of the external part and fixed positions of selective components) by an amount considerably greater than the intermode interval. This is a unique property of an injection laser with an external resonator operating in the self-stabilization regime and it distinguishes it from all other types of tunable laser.

Suppression of neighboring modes ensuring self-stabilization is due to the following physical features of an injection laser with an external highly selective resonator: 1) a narrow-band feedback ensures single-frequency emission of stimulated radiation of sufficiently high power (typically 1–10 mW); 2) in the presence of a strong field when one of the neighboring modes of an injection laser with an external resonator is excited, the expression for the radiation intensity acquires an interference term proportional to the amplitude of the strong field; 3) the frequency of beats between the fields of the strong modes and the nearest neighboring modes within the selection band is comparable with the reciprocal of the lifetime of nonequilibrium electrons \((\tau \approx 2–4 \text{ nsec})\), so that beats of this kind cause a strong modulation of the electron density because of the influence of stimulated transitions on the effective lifetime; 4) such modulation is in the form of oscillations which are synchronous throughout the length of the active region because the shift of the nodes and antinodes of the neighboring modes of the composite resonator in the length of the semiconductor crystal is negligible. Oscillations of the population inversion, which do not vanish when we integrate over the volume of the active region, modulate the effective gain and interaction between a pair of modes with one another and with the strong field (we are speaking here of a pair of modes located symmetrically on the frequency scale relative to the frequency of the dominant mode; it is incorrect to consider just one additional weak mode\(^4\)). This interaction gives rise to weak neighboring modes for certain conditions relating to the intensity of the field in the active region, parameters of the medium, and ratio of the losses in the modes.\(^3\,8\)

The possibility of this effect was pointed out in a theoretical treatment given in Ref. 7. This mechanism was investigated in Ref. 8 for an injection laser with a conventional resonator where it appeared relatively weakly (the third and fourth of the physical factors mentioned above do not apply to short resonators). It was shown theoretically and experimentally in Ref. 4 that in an injection laser with an external resonator this interaction alters radically the characteristics of a laser, resulting in an improved stability of single-frequency lasing compared with modulation of the current at the intermode beat frequency and in an increase of the width of the tuning range when the length of the external part of the resonator is varied. We shall report of a detailed investigation of the latter of these self-stabilization effects.

**APPARATUS**

A resonator consisted of two parts (Fig. 2). The active region 1 was an injection laser waveguide and the external passive part included a matching microscope 2, rotatable mirrors 3 and 4, and a holographic total-internal-reflection selector 5. For convenience of tuning and measurement in the case of anomalously wide continuous tuning intervals, it was necessary to make a number of modifications in the resonator construction described earlier.\(^9\) The amplitude of modulation of the length of the external part of the resonator had to be increased in order to determine the limits of the continuous tuning range. Therefore, the mirror 3 was placed on a piezoelectric ceramic base which could displace the mirror by 10 \(\mu\) on application of a voltage of 300 V. Guides were used for fine adjustments of the objective along the resonator axis and once again a ceramic plate was employed: it shifted the microobjective by ± 30 \(\mu\) when a voltage variable within the range ± 1000 V was applied. Instead of transverse translational displacements of the objective, use was made of angular tilting of the mirror 4 which was attached to a bimorph piezoelectric ceramic membrane with a square electrode geometry, which made it possible to rotate the mirror about two mutually perpendicular axes. Remote control of the resonator component by piezoelectric ceramic units accelerated and optimized its alignment. Such an external resonator of length from 0.3 to 1 m was used in the majority of our

![FIG. 2. Schematic diagram of the apparatus: 1) injection laser; 2) matching microscope with a piezoelectric ceramic support; 3) mirror on a piezoelectric support; 4) mirror on a square piezoelectric ceramic support; 5) holographic selector; 6) power meter; 7) diffraction grating; 8) television monitor; 9) exit objective; 10) Fabry-Perot interferometer; 11) confocal interferometer; 12) confocal scanning interferometer; 13) power supply unit; 14) generator of sinusoidal oscillations; 15) generator of sawtooth voltage.](image)
experiments (Table I). Moreover, some experiments were carried out using external resonator variants with two selective components: a holographic selector with a quartz etalon (d = 1 cm, finesse 5, transmission 0.65) when the length of the external part of the resonator was L ~ 3 m and a diffraction grating (600 lines/mm, first order) and the same etalon (λ ~ 886 nm). *Lasers with antireflection coating. **Measurements at liquid nitrogen temperature.

All the measurements were carried out on a laser operating continuously. The relative amplitude of the fluctuations of the pump current did not exceed 10^-4.

During the stage of preliminary selection of the lasers the number of modes in the active part of the injection laser and the efficiency of the external coupling as well as the effects of the selective component were monitored by a diffraction grating (600 lines/mm, first order) and the same etalon when the external part of the resonator was 0.6 m long. A single diffraction grating was insufficient to ensure self-stabilization.

The continuity of the frequency tuning was monitored by passing the laser radiation through a Fabry–Perot interferometer 10 with a base 2 mm long and a transmission resonance 15 GHz wide. Rotation of this interferometer ensured that the transmission resonance (at the 0.5 level) coincided with the frequency tuning range of the injection laser. At the exit of such a frequency discriminator the continuous variation of the emission frequency was accompanied by a continuous change in the intensity of the transmitted light (Fig. 3) and switching between modes was accompanied by intensity discontinuities, which could be used to determine the number of intermode intervals by which the emission frequency changed as a result of such switching. The continuous tuning range was determined more accurately employing a confocal interferometer 11 with a free spectral range 1.5 GHz.

When the length of the active part of the resonator was varied (or when the current was modulated), the continuous tuning range did not exceed 60 MHz, so that we used a confocal scanning interferometer 12 with a free spectral range of 120 MHz and a finesse of 60. Its length was modulated, in accordance with a sawtooth law at a frequency of 50 Hz, synchronously with the oscilloscope sweep and the laser current was subjected to sinusoidal modulation (~10 Hz).

### Table I

<table>
<thead>
<tr>
<th>Sample</th>
<th>(I_{in}, mA)</th>
<th>(I_{in}, mA)</th>
<th>(P, mW)</th>
<th>(L, cm)</th>
<th>(\Delta v, GHz)</th>
<th>(\Delta v/\beta v)</th>
<th>(\Delta v_1, MHz)</th>
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<tr>
<td>1M1</td>
<td>70</td>
<td>85</td>
<td>2.5</td>
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<td>2</td>
<td>7.6</td>
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<tr>
<td>1M2</td>
<td>75</td>
<td>74</td>
<td>3.4</td>
<td>49</td>
<td>3.2</td>
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<td>25</td>
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<tr>
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<td>63</td>
<td>2.4</td>
<td>90</td>
<td>5.5</td>
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<td>47</td>
<td>4</td>
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<tr>
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<td>109</td>
<td>1</td>
<td>50</td>
<td>2</td>
<td>6</td>
<td></td>
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<td>185</td>
<td>6</td>
<td>50</td>
<td>6</td>
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<tr>
<td>1T2**</td>
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<td>40</td>
<td></td>
<td>40</td>
<td>&gt;2</td>
<td>&gt;5</td>
<td></td>
</tr>
<tr>
<td>3M1**</td>
<td>10</td>
<td>40</td>
<td></td>
<td>40</td>
<td>&gt;2</td>
<td>&gt;5</td>
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<tr>
<td>3S1</td>
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<td>5.0</td>
<td>17</td>
<td>36</td>
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Note. The first number identifies the batch, the letter identifies the structure, and the last number identifies the sample. The letter has the following meaning: M is a double heterostructure with a shallow mesa, H is a strip double heterostructure, T is a terrace structure, D is a diffused strip geometry, and S is a step geometry with separate confinement. The laser 1D1 exhibits the shortest-wavelength emission at \(\lambda \approx 690\) nm and 3S1 exhibits the longest-wavelength emission at \(\lambda \approx 886\) nm.

![FIG. 3. Dependence of the emission frequency (transmission by a Fabry–Perot interferometer with a base of 2 mm) on the length of the external part of the resonator. A wide tuning range results in emergence beyond the linearity of the discriminator and alters the scale at the edges of the range. The reduced scale (c/2L = 280 MHz) corresponds to the middle linear part of the range.](image)
Consequently, the transmission resonance of the confocal scanning interferometer changed its position at the same frequency on the oscilloscope screen. The amplitude of such oscillations and the separation between neighboring resonances of the confocal scanning interferometer (spectral range) were used to determine the laser frequency deviation.

**LASER SELECTION METHOD AND CONSTRUCTION OF LASERS**

In selecting lasers for investigation, we set the following requirements: 1) a sufficiently effective matching to the external selective component ensuring generation of a single mode of the interval (crystal) resonator of the laser diode and tuning between these modes (at this stage the procedure was applied using the spectrum displayed on the television monitor); 2) a high homogeneity of the active region ensuring generation of a single mode of the composite resonator (at this stage the spectral analysis was made by the confocal interferometer); 3) existence of the self-stabilization regime. The simplest method for monitoring at this stage was provided by recording of the watt-ampere characteristic of a laser with an external selective feedback. A characteristic manifestation of the self-stabilization regime was the absence of discontinuities associated with switching between modes (Fig. 1A).

An analysis of the statistics of laser selection revealed the following features. The self-stabilization regime was not affected by the construction of the laser (on condition that the external electric feedback ensured single-frequency emission with an output power \( \geq 1 \text{ mW} \)), by the temperature, or by the content of aluminum in the active region (Table I). When some lasers in a given batch (prepared from a given plate) operated in the single-frequency regime, then between 30 and 80% of these lasers exhibited self-stabilization. The higher the reproducibility of the characteristics of lasers in a given batch, the greater the proportion of the lasers which could operate in the regime with an anomalously wide tuning range.

Measurements of the maximum tuning range for modulation of the length of each of the resonator arms were made for the selected lasers. The results of the measurements are summarized in Table I. The first column gives the designation of the sample consisting of the number of the batch, index of the structure (explained in the footnote of Table I), and laser number. The second column gives the threshold current \( I_\text{th} \) of the laser without the external feedback. The next three columns list the values of the current \( I \), power \( P \), and length of the external part of the resonator \( L \) for which measurements were made of the maximum continuous tuning range when the length \( L \) and the current \( I \) were modulated.

**EXPERIMENTAL RESULTS**

The continuous tuning range \( \Delta \nu \) of the majority of the investigated lasers exceeded 3 GHz and in some cases it was 8–9 GHz. The ratio of this range \( \Delta \nu \) to the intermode interval \( \delta \nu \), given in the penultimate column of Table I, exceeded 10 (for five samples it was greater than 20). Therefore, the continuous tuning range obtained in the self-stabilization regime was for most lasers over an order of magnitude greater than the attainable continuous tuning range in the conventional regime, because the latter was practically equal to \( \delta \nu \).

Typical behavior of the power during modulation of the resonator length in the regime of self-stabilization of single-frequency emission is illustrated in Fig. 4. The power variations did not exceed 10–15% for the investigated lasers. For the optimal alignment of the selector the power exhibited a maximum due to the passage of the emission frequency through the loss minimum governed by the superposition of the selector band and the mode of the crystal resonator of the injection laser. A slight rotation of the selector shifted the maximum to the limit of the tuning curve (at the expense of reduction in the tuning range). The asymmetric position of the maximum was due to the power dependences of the refractive index and of the frequency of the normal mode of the internal resonator of the injection laser. This asymmetry was weaker in the case of antireflection-coated lasers.

The tuning range \( \Delta \nu \) depended on the output power, which could be varied by altering the degree of coupling, rate of pumping, and tuning of the selector over the gain profile. In all three cases the dependence was qualitatively the same: the tuning range \( \Delta \nu \) increased on increase in the power. The relevant dependences for the first two cases are given in Fig. 5. The coupling was varied by metal grids. These depen-

![FIG. 4. Frequency tuning in the self-stabilization regime by altering the length of the external part of the resonator (the law representing the change is shown in the lower part of the figure). The oscillogram at the top of the figure shows the change in the power \( \Delta P \) (the maximum value of this change was 10% of the total power). The lower trace in the oscillogram represents the transmission resonances \( \Delta \tau \) of the confocal resonator with a base of 1.5 GHz. The continuous tuning range exceeded 7.5 GHz.](image-url)

![FIG. 5. Dependence of the continuous tuning range on the output power (1,2) and on the degree of coupling (3); \( r_\text{c} \) is the maximum degree of coupling.](image-url)
The anomalously wide continuous tuning range obtained by variation of the external part of the resonator was not the only feature of the tuning characteristics in the self-stabilization regime. The other feature was related to the behavior of the spectrum at an edge of the continuous tuning range. It was found (Fig. 3) that switching of the emission frequency was not to the mode nearest to the loss minimum (this minimum was located approximately in the middle of the tuning range), but to the nearest neighbor of the lasing mode.

This was confirmed by an experiment in which an external perturbation (a negative current pulse or a mechanical interruption of the external feedback) ensured complete suppression of the lasing mode for a time much shorter than the scanning period. We used an interferometer (and the suppression of the lasing mode for a time much shorter than the interruption of the external feedback) ensured complete behavior of the spectrum at an edge of the continuous tuning regime. The other feature was related to the not the only feature of the tuning characteristics in the self-stabilization regime. The continuous closed line 2 represents the conventional single-frequency regime. The continuous closed line 2 is the dependence of the emission frequency on the length of the external part of the resonator for modulation amplitudes in the range \( L > L_{\text{max}} \). The dashed lines represent frequency switching stimulated by brief suppression of lasing. Lasing was renewed always in the regime in which there was no discriminating effect of the strong field, so that the results of the competition between the longitudinal modes were governed by the selective components. Naturally, lasing then reappeared at the loss minimum with a correction for the instantaneous position of the longitudinal mode nearest to the minimum. The subsequent evolution of the emission frequencies observed after switching is represented by the chain lines.

**MODULATION OF THE OPTICAL LENGTH OF THE ACTIVE REGION**

The simplest method for altering the optical length \( nl \) of the internal resonator of the injection laser was to use the temperature dependence of the refractive index. The temperature was varied by external heat sources or by varying the pump current. The former method was accompanied by a smaller change in the output power, but it was less convenient because of the inertia of external heaters. We used the method of modulation of the injection current. A typical dependence of the output power on the injection is shown in Fig. 1. Lasing occurred when one of the longitudinal modes of the internal resonator of the injection laser approached the selector band. An abrupt change in the power at low values of the current and the continuous fall at high values were due to the dependence of the refractive index on the power. In the self-stabilization regime the change in the current did not cause switching of the external resonator modes until a specific mode of the internal resonator was excited (this was true of injection lasers without antireflection coating). For a constant degree of coupling between the internal (active) and external parts of the resonator an increase in the power (because of an increase in the pump current and/or rotation of the selector) increased the range of currents in which lasing was observed and the continuous tuning range \( \Delta \nu \) increased. The maximum value of the width of the continuous tuning range by variation of the current was 17–60 MHz, depending on the laser. The limits to the power were set by overheating of the laser or by a...
change in the distribution of the field in the lateral direction and transition to multimode emission. In some cases these forced pumping experiments were not carried out because of considerable degradation of the radiation characteristics. It should be noted that for a constant degree of coupling an increase in $\Delta \nu$, on increase in the power occurred because of an increase in the range of the current in which lasing was observed. The tuning coefficient remained practically constant.

On increase in the degree of coupling the slope of the tuning characteristics $\Delta \nu/\Delta I$ decreased so that widening of the lasing range (on the scale of the pump current) was accompanied by a much slower increase in the tuning range than in the case when the power was increased and the effective coupling was kept constant.

The range of the frequency tuning by the current for the external resonator lengths $L = 0.3 - 1.1 \text{ m}$ was approximately two orders of magnitude less than $\Delta \nu$. Nevertheless, the feasibility of modulation of the frequency by the injection current is very important. This method makes it possible to achieve high-frequency modulation right up to frequencies in the gigahertz range, which is important for stabilization of the frequencies of injection lasers with an external resonator and in the use of such lasers in modulation spectroscopy.

**DISCUSSION OF RESULTS**

The self-stabilization regime is not specific to any particular waveguide structure. It is observed in lasers with different geometries of the active region in a wide range of wavelengths and temperatures. The universality of this effect is in full agreement with the mechanism proposed in Ref. 4 to explain the self-stabilization effect. Nonlinearity of the active medium is a property of all types of injection laser. We can expect the self-stabilization regime to be feasible also in semiconductor lasers made quaternary compounds covering the range 0.66 - 4 $\mu$. There are other features of the self-stabilization effect which confirm the theory of Ref. 4. The effect begins to appear at a relatively low power. It would be more correct to express the threshold of the effect in terms of the radiation flux density. However, lack of detailed information on the confinement factor $\Gamma$ and on the field distribution in the lateral direction makes such estimates inaccurate. The order of magnitude of the flux density in the investigated lasers at which anomalously wide tuning became possible was $10^8 - 10^9 \text{ W/cm}^2$. At these flux densities (intensities) the nonlinear mechanisms associated with intraband relaxation cannot give rise to significant effects, but the nonlinearity due to interband relaxation may appear quite strongly. An increase in the width of the tuning range on increase in the power is also in agreement with the theory of Ref. 4.

This theoretical model can also explain qualitatively the nature of switching of longitudinal modes when the length of the external part of the resonator is varied. The development of an instability preceding switching of the modes begins with a reduction in the intensity of the emitted mode because of an increase of the detuning away from the top of the selector band and an increase in the field of some other mode of the injection laser. However, in the presence of what is still a strong mode a weak field does not appear in just one injection laser mode because of the strong interaction of the oscillation modes. We can expect excitation of a pair of the injection laser modes at frequencies located symmetrically relative to the emission frequency. Clearly, the total losses for a pair separated by a large frequency interval (when one of the components is close to the center of the selector band because of the asymmetry of the losses introduced by the selector in the central part of the selection curve bounded by inflection points) are greater than the corresponding losses for a pair of modes closer to the mode being emitted. An increase in the intensity in the neighboring pair of modes is accompanied by further reduction in the power of the central mode. At some particular moment the weakening of the field of the central mode reduces the coupling inside the pair of modes and all the power is concentrated in that mode which is closer to the center of the selector band. Therefore, even in the process of switching of modes a strong field of the central mode of decreasing intensity reduces lasing in the direct vicinity and prevents lasing at the center of the selector band.

We shall now consider the practical value of this effect. In the conventional single-frequency emission regime the continuous tuning range is limited to $\delta \nu$. Tuning within a range wider than 1 GHz requires that the length of the external part of the resonator should not exceed 15 cm. It is difficult to place the resonator components within a resonator of this length and it is difficult to align them. Moreover, a reduction in $L$ increases the width of the emission line. The continuous tuning range can be increased by the method of synchronous tuning of the selector band and of the frequency of the emitted mode. An injection laser with an external resonator but without an antireflection coating usually contains two selective components: a diffraction grating and the semiconductor resonator of the laser diode (internal resonator). Continuous tuning over a range of 5 - 10 GHz can be achieved by sufficiently well-matched tuning of the internal resonator and of the length of the external part. Unfortunately, this method suffers from the shortcomings of inertia of the temperature modulation and the relative drift of the length of the external part of the resonator and the optical length of the internal resonator. This drift can be avoided by necessary mutual locking of the resonator arms.

The simplest method of locking is extremal control, but it cannot be used in the case of a single-frequency injection laser with an external resonator because the refractive index of the active medium depends strongly on the electron density and the output radiation power and, therefore, on the mismatch between the internal and external parts of the resonator. This detuning - loss - power - detuning interrelationship is responsible for the absence of an extremum in the tuning characteristic.

It is interesting to note that the same mechanism (representing a strong dependence of the refractive index on the carrier density) which prevents the use of external control, results in an effective interaction of the modes in an injection laser with an external resonator and can under certain conditions be responsible for self-stabilization, i.e., for an increase.
in the stability of the single-frequency lasing regime. In this regime the problem of wide-band continuous tuning of the emission frequency of an injection laser with an external resonator is solved most simply.

Our investigation allows us to draw the following conclusions.

1. The characteristics of the behavior of the injection lasers with an external resonator in the self-stabilization regime when the lengths of the arms of the resonator are modulated and the very existence of this regime in lasers with different waveguide structures are in agreement with the theory of Ref. 4, according to which the mechanism of the interaction between the modes is mainly determined by the optical nonlinearity of the semiconductor, i.e., by the local property of the amplified medium, and not by the geometry and other characteristics of the waveguide in such a laser. However, the geometry determines largely the degree of coupling with the external resonator, the attainable power, and the possibility of ensuring single-frequency emission. Therefore, the waveguide characteristics affect indirectly the possibility of self-stabilization.

2. The anomalously wide continuous tuning range in combination with the simplicity of the method, high monochromaticity of the output radiation, immunity to external perturbations, and self-stabilization in laser structures manufactured by the usual technology opens up new promising applications of such lasers in high-resolution spectroscopy, metrology, and heterodyne coupling techniques.

Translated by A. Tybulewicz

Pulse shortening in a nonlinear amplifier

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An analysis is made of the interaction of radiation with a two-level medium at a high particle density. An explicit allowance is made in the interaction Hamiltonian for the interaction between dipoles induced by a resonance field. A semiclassical description is used to obtain a system of equations describing the propagation of a pulse in the active medium. The equations contain nonlinear terms allowing for the interaction in question. An approximate solution of the equations is obtained for the case of amplification of a weak noncoherent pulse describing pulse compression in the amplifying medium. The theory is compared with experimental results.

INTRODUCTION

Nonlinearity of a resonant interaction of radiation with active media is used widely to shorten (compress) light pulses and it is the most effective method for the generation of ultrashort pulses.\(^1\)\(^2\)\(^3\)\(^4\)\(^5\) Studies have been made of the coherent mechanism of the interaction of radiation with a medium\(^5\) and of the noncoherent interaction.\(^6\) In the latter case the pulse duration decreases because of saturation of an absorbing medium. Distortion of the time profile of a light pulse is a special case of self-interaction of radiation in a nonlinear medium.\(^7\) An analysis of transient processes has to be made for specific material equations.\(^8\)