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Study of mode locking in a microwave-pumped diode laser close to the generation threshold

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***Abstract*. Active mode locking is studied in a diode laser with a three-mirror resonator upon the microwave modulation of the pump current. The mode-locking region with the minimal width of the spectrum of intermode beats is found, when the microwave frequency is close to the intermode frequency of an external resonator. This region is shown to be located close to the threshold pump current.**

Keywords: *diode laser, active mode locking, pump current, beat spectrum.*

One of the most important modern problems is the development of optical systems for synthesis of frequencies covering a broad spectral region from the radio to UV range. The elaboration of methods and elements for synthesis of any frequencies in this region [1 – 3] opens up possibilities for the development of new spectral instruments with unique parameters. The creation of frequency and time standards in the microwave and optical ranges based on the recent advances in the field of diode lasers is also related to this problem [4 – 11].

However, the successful application of diode lasers having a number of attractive features such as frequency tuning, compactness, etc. is complicated by some their disadvantages related to the generation of narrow lines, tuning in a broad spectral range, mode locking with a comparatively broad spectrum, etc. In Ref. [5], the generation of equidistant modes was reported in a diode laser with an external resonator with a diffraction grating. The influence of microwave modulation at the intermode frequency on the number of generated modes was considered. The average width of the laser line was $\sim$8 MHz. The maximum width of the spectrum in the passive Q-switching regime [7] was 15 – 16 nm (at $\sim$860 nm), and the pulse duration achieved in the active Q-switching regime was $\sim$5 ps [8 – 10] (the width of the spectrum was $\sim$6 nm). It was found that the reflection coefficient of the exit face of a diode laser affects the output pulse parameters. These results provide reasons to hope that diode lasers can be used to generate radiation in a broad spectral range.

In this paper, we obtained active mode locking in a three-mirror diode laser using the microwave modulation of the near-threshold pump current at a frequency close to the intermode frequency of the external resonator. Mode locking was observed by the spectrum of intermode beats recorded with a spectrum analyser. The mode spectrum drastically narrowed down upon mode locking.

Figure 1 shows the block diagram of the experimental setup for studying the operation regimes of a microwave-pumped diode laser. The setup consists of the laser itself with an external mirror, a power supply, a microwave generator, a photodetector, and a spectrum analyser. Unlike [6], where a diffraction grating was used, the external resonator is formed by a broadband (metal) mirror. The resonator contains also a collimating lens. The diode laser was modulated by cw microwave generator (*2*) placed in parallel with direct current supply (*3*) via capacitor (*9*). The frequency range of the microwave generator was 290 – 120 MHz, and the microwave radiation power could be continuously varied from 0 to 0.3 W. The relative stability of current supply (*3*) was 10^{-4}, and temperature controller (*4*) provided the temperature setting error within $\pm 10^{-2}$ °C. The external resonator was formed by a mirror with the reflectivity $\rho \simeq 0.4$ and the exit face of the diode with $\rho_{\rm d} \simeq 0.03$. In this case, the feedback ratio T was $\sim$0.67. According to Ref. [12], these conditions correspond to the feedback ratio at which both the external and internal resonators are involved in the mode composition formation.

Figure 2 shows the typical spectrogram demonstrating intermode beats obtained at the $\sim$27-mA current close to the threshold value (the threshold current of the diode laser

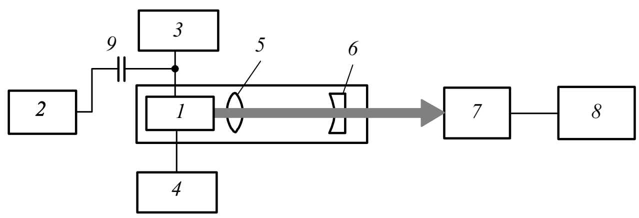

Figure 1. Block diagram of the experimental setup for studying the operation regimes of a diode laser: (*1*) diode laser; (*2*) microwave generator; (*3*) power supply; (*4*) temperature controller; (*5*) lens; (*6*) external mirror; (*7*) photodetector; (*8*) spectrum analyser; (*9*) capacitor.

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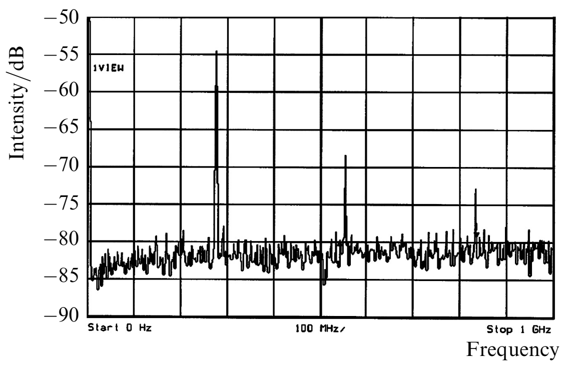

Figure 2. Spectrum of intermode beats.

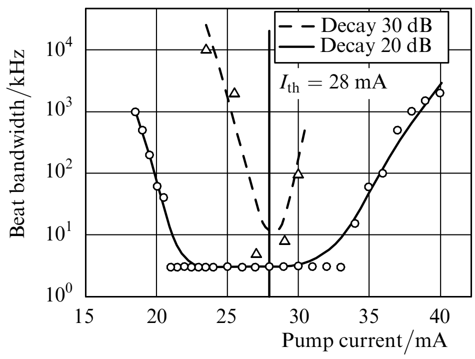

Figure 4. Dependence of the spectral width of beats on the pump current of the diode laser at different microwave pump powers.

was ~28 mA) when the microwave frequency was equal to the intermode frequency of the external resonator. The output power of the microwave generator was 10 mW and the intermode frequency was ~ 260 MHz. The number of observed modes was determined by the speed of response of photodetector (*7*). Later on, we plan to determine the number of locked modes using ultrafast Schottky diodes with the bandwidth up to 3 THz.

Figure 3a shows the spectrum of the intermode beat signal of width $\Delta f_{bt} < 4$ kHz. For comparison, Fig. 3b presents the spectrum of a signal from the microwave generator connected to the diode laser. A careful comparison shows that, despite the presence of technical noises, the spectral width of the microwave line exceeds the width of the beat spectrum by a factor of ~1.2.

We found the pump current of the diode laser and the power of the microwave generator at which the minimum spectral width Δf_{bt} of beats was achieved. The results of these experimental studies are presented in Fig. 4. The vertical straight line corresponds to the threshold current I_{th} and divides the region into two parts: below and above the threshold. Therefore, the dependence of Δf_{bt} on I below and above the lasing threshold is demonstrated. One can see that the spectral width of beats achieves its minimum in the region of I_{th} (in our case, at 28 ± 5 mA) and depends on the microwave power. This also means that there exists the region of currents where mode locking can be easily achieved (mode-locking region), which is located close to the threshold current (Fig. 4). For this diode, this region is virtually maximal because, as the microwave power is further increased, the breakdown of the diode laser is observed. The appearance of mode locking was verified by the generation of pulses with the repetition rate equal to the intermode frequency of the external resonator.

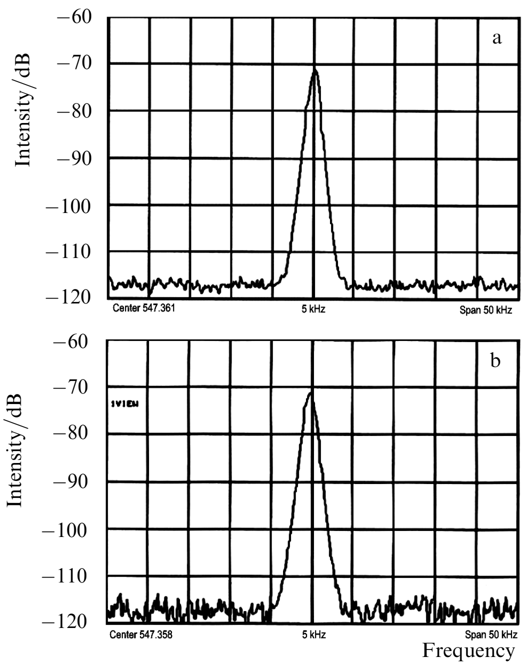

Figure 3. Spectra of one component of intermode beats (a) and the signal of the microwave generator connected to the diode laser (b).

Note in conclusion that it is necessary to study in more detail the narrowing of the beat spectrum (mode locking) observed in the region of currents close to the threshold, as well as the effect of the amplitude compression at weaker feedbacks, but in the multimode regime [12] upon mode locking. This concerns first of all the investigation of factors affecting the beat spectrum, the generation of the mode-locking spectrum as broad as possible, etc.

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References

1. Hall J.L., Ye J. *Optics & Photonics News*, **12** (2), 44 (2001).
2. Bagaev S.N., Chepurov S.V., Klementyev V.M., Kuznetsov S.A., Pivtsov V.S., Zakharyash V.F. *Appl. Phys. B*, **70**, 375 (2000).
3. Zheltikov A.M. *Usp. Fiz. Nauk*, **170**, 1203 (2000).
4. Miller A., Sibbett W. *J. of Modern Optics*, **35** (12), 1871 (1988).
5. Bagayev S.N., Volkov V.G., Ivashko D.Yu., Matyugin Yu.A., Fateev N.V. *Kvantovaya Elektron.*, **26**, 102 (1999) [*Quantum Electron.*, **29**, 102 (1999)].
6. Fofanov Ya.A., Sokolov I.V. *Opt. Spektrosk.*, **91**, 50 (2001).
7. Vasil'ev P.P., Goldobin I.S. *Kvantovaya Elektron.*, **15**, 2421 (1988) [*Sov. J. Quantum Electron.*, **18**, 1519 (1988)].
8. Bessonov Yu.L., Bogatov A.P., Vasil'ev P.P., Morozov V.N., Sergeev A.B. *Kvantovaya Elektron.*, **9**, 2323 (1982) [*Sov. J. Quantum Electron.*, **12**, 1510 (1982)].
9. Van der Ziel J.P. *J. Appl. Phys.*, **52** (7), 4435 (1981).
10. Bowers J.E., Morton P.A., Mar A., Corzine S.W. *IEEE J. Quantum Electron.*, **25** (6), 1426 (1989).
11. Burns D., Finch A., Sleat W., Sibbett W. *IEEE J. Quantum Electron.*, **26** (11), 1860 (1990).
12. Trifonov A.S. *Opt. Spektrosk.*, **86**, 126 (1999).