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An experimental study of low-frequency amplitude noise in a fibre Bragg grating laser diode

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Abstract. **We have studied the amplitude noise in a fibre Bragg grating laser diode. It has been shown that discontinuities in noise characteristics correlate with those in the power – current and spectral characteristics of the laser diode, whereas the noise characteristics of the pump source have no such discontinuities. The highest noise level has been observed at pump currents corresponding to concurrent generation of two longitudinal modes.**

Keywords: *single-frequency laser diode, fibre Bragg grating, emission noise.*

1. Introduction

Low-frequency amplitude noise has been the subject of extensive studies (see e.g. Refs [1, 2] and references therein), which highlights the importance of such studies for the ability to improve the performance of electronic devices under development. High-frequency (0.1 to 10 GHz) noise in laser diodes (LDs) has been investigated in detail, and there are no serious discrepancies between theory and experiment [3]. In the low-frequency (LF) range (below $f = 10^5 – 10^6$ Hz), the spectral density of emission intensity fluctuations exhibits $1/f$ behaviour (flicker noise). Existing theory provides no description of the noise characteristics of LDs in this frequency range, and results of experimental studies are sometimes contradictory. Bessonov and Kornilova [4] reported low-frequency noise to correlate with the pump current amplitude and fluctuations. At the same time, no such correlation was found in experiments described by Dandridge and Taylor [5].

Gelikonov et al. [6] reported an interrelation between LF emission intensity fluctuations and voltage fluctuations in LDs. Varying the resistance in the power supply circuit of a laser, they showed that there was no conversion of pump current fluctuations to intensity fluctuations. Marugin and Kharchev [7] studied the effect of pump current technical noise on the low-frequency (10 to 10^5 Hz) emission fluctuation spectrum of an LD and concluded that the noise characteristics of lasers in this frequency range were determined not by technical instability sources but by quantum effects associated with the dynamics of the laser.

The amplitude noise resulting from mode beating in a single-frequency injection laser was investigated by Bogatov et al. [8]. They concluded [9] that the power fluctuation level depended on mode switching in the LD. The $1/f$ noise component was shown to be due to transitions from 'quiet' lasing to fast mode switching. This was accompanied by an increase in white noise, and the amplitude fluctuation distribution deviated from the normal law.

This paper examines the low-frequency amplitude noise in a fibre Bragg grating (FBG) single-frequency laser diode intended for pumping and detection of the reference quantum transition of caesium atoms in quantum frequency standards [10 – 13].

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2. Experimental

For laser fabrication, we grew an AlGaAs/GaAs heterostructure with a single, 9-nm-thick quantum well and 120-nm-thick waveguide layers. The heterostructure was used to produce a gain element with a stripe contact width of 2.5 – 3 μm and a cavity length of 600 μm. A protective optical coating was grown on one of the cavity faces, and an antireflection coating with a reflectivity no higher than 0.5% was grown on the other. The laser diode was soldered, with its active region up, onto a contact plate. Next, a single-mode fibre with a Bragg grating was positioned and fixed. The diode and grating were mounted on two separate thermoelectric coolers (TECs), one of which was used to stabilise the temperature of the contact plate and laser diode, and the other stabilised the temperature of the grating. A two-lens, antireflection-coated ($R < 0.5\%$) micro-objective produced a quasi-parallel light beam.

Figure 1 shows a schematic of the experimental setup. Noise characteristics were measured using a selective microvoltmeter and photodetector (FD-24K photodiode). The load resistance of the photodiode was $R_2 = 1$ kΩ. To reduce the noise level, a capacitor with $C = 3400$ μF was connected to the output terminals of the laser power supply through a switch (S). The emission noise intensity was measured by the selective microvoltmeter, and the constant voltage V_0 (across the resistor with $R_2 = 1$ kΩ), proportional to the output power of the FBG LD, was measured by a voltmeter. The power supply noise was measured by the selective microvoltmeter across a resistor with $R_1 = 15$ Ω. The emission wavelength was determined using an optical spectrum analyser (not shown in Fig. 1).

Noise characteristics of the FBG LD at a varied pump current were obtained at constant frequencies of 0.167, 1 and 60 kHz. The frequency 0.167 kHz was chosen in order to min-

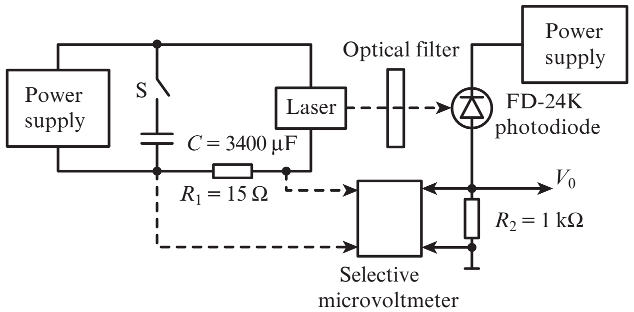

Figure 1. Schematic of the experimental setup for noise and wavelength measurements. In wavelength measurements, a spectrum analyser (not shown) was placed instead of the photodetector.

imise the influence of mains frequency (50 Hz) and its harmonics. The selective microvoltmeter was calibrated using a sine-wave oscillator and its bandwidth at the 0.7 level, Δf, was determined at the above frequencies.

An optical filter was used for the photodetector to operate in its linear range. The filter and photodiode were inclined at a certain angle to the LD beam to avoid back reflection of the beam into the LD.

The relative LD emission noise intensity was determined as

$$\mathrm{RIN} = 20\lg\left(\frac{U_{\mathrm{noise}}/\sqrt{\Delta f}}{U_0}\right), \qquad (1)$$

where U_{noise} is the noise voltage measured across the R_2 = 1 kΩ resistor of the photodiode by the selective microvoltmeter and U_0 is the constant voltage measured across that resistor by the voltmeter. The relative pump source noise intensity was also determined using Eqn (1), but U_{noise} and U_0 were then the voltages measured across resistor R_1 by the selective microvoltmeter and voltmeter, respectively.

We used a Pilot-4DC power supply unit [14], designed for pumping light-emitting and laser diodes. In this unit, special measures are taken to protect LDs from mains voltage surges and the voltage is applied to LDs only after the TECs have reached a steady state. The temperature was maintained with a stability of ±0.1 °C or better.

3. Measurement results

Figure 2a shows the RIN values of the LD and pump source [curves (*1*), (*2*)] obtained at a frequency f = 60 kHz with capacitor C switched off. Also shown is the voltage U_0 (across the R_2 = 1 kΩ resistor) as a function of pump current [curve (*3*)]. Figure 2b shows the spectral density of voltage fluctuations, measured across resistor R_2 [curve (*4*)], which is proportional to the spectral density of output power fluctuations, and the spectral density of pump source noise, measured across the R_1 = 15 Ω resistor [curve (*5*)]. It is seen that the LD noise exceeds the pump source noise by more than ten times [Fig. 2, curves (*4*), (*5*)]. In Fig. 2, U_{noise} and U_0 (measured across resistor R_2) are multiplied by a correction coefficient that takes into account the attenuation caused by the optical filter.

Connecting capacitor C in parallel to the output terminals of the pump source (Fig. 1) considerably improved the noise characteristics of the LD (Fig. 3). Comparison of curves (*1*) in Figs 2 and 3 indicates that capacitor connection considerably reduces the relative noise intensity.

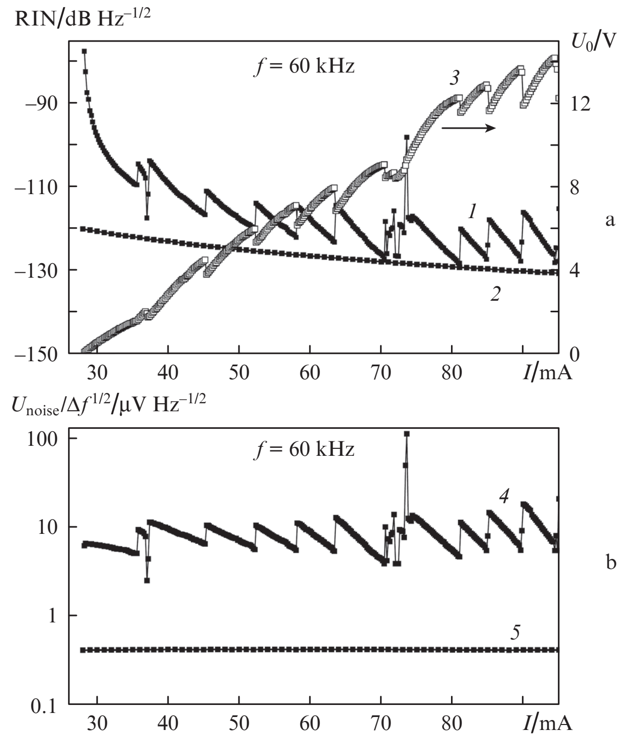

Figure 2. (a) (*1*) Relative LD voltage fluctuation intensity, (*2*) relative pump source noise intensity, (*3*) voltage U_0 across the 1 kΩ resistor of the photodetector, (b) (*4*) spectral density of LD voltage fluctuations and (*5*) spectral density of pump source noise as functions of laser pump current at f = 60 kHz with capacitor C switched off.

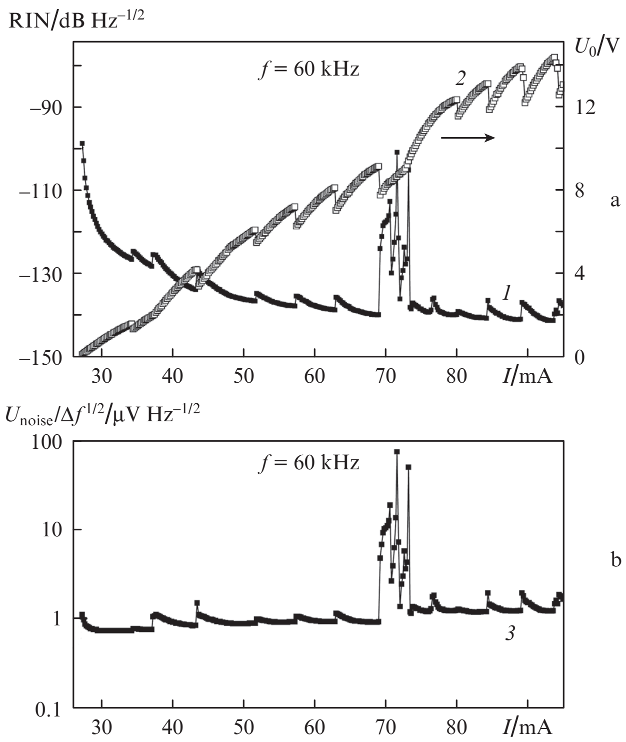

Figure 3. (a) (*1*) Relative LD voltage fluctuation intensity, (*2*) voltage U_0 across the 1 kΩ resistor of the photodetector and (b) (*3*) spectral density of LD voltage fluctuations as functions of laser pump current at f = 60 kHz with capacitor C switched on.

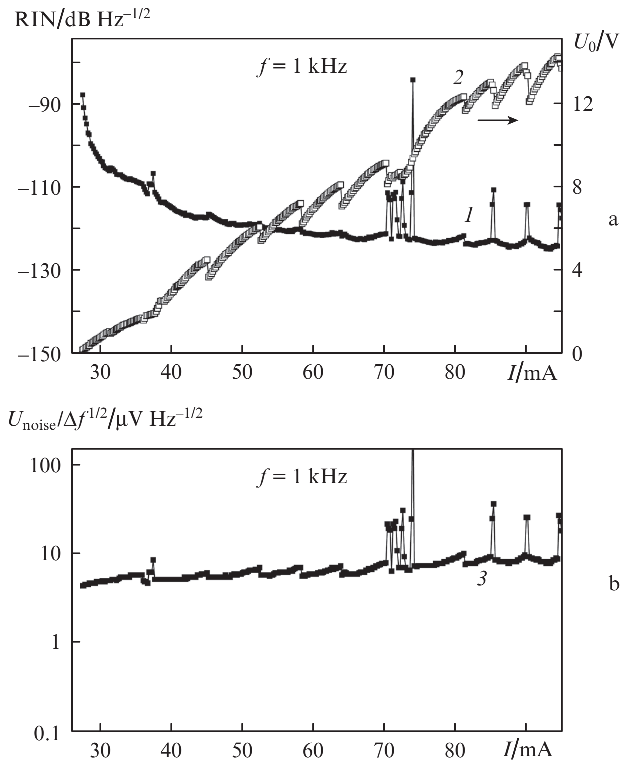

Figure 4. Same as in Fig. 3 at a frequency of 1 kHz.

In particular, at a pump current of 60 mA and f = 60 kHz, the relative noise intensity is –118 dB Hz$^{-1/2}$ with no capacitor (Fig. 2) and –138 dB Hz$^{-1/2}$ with the capacitor connected (Fig. 3).

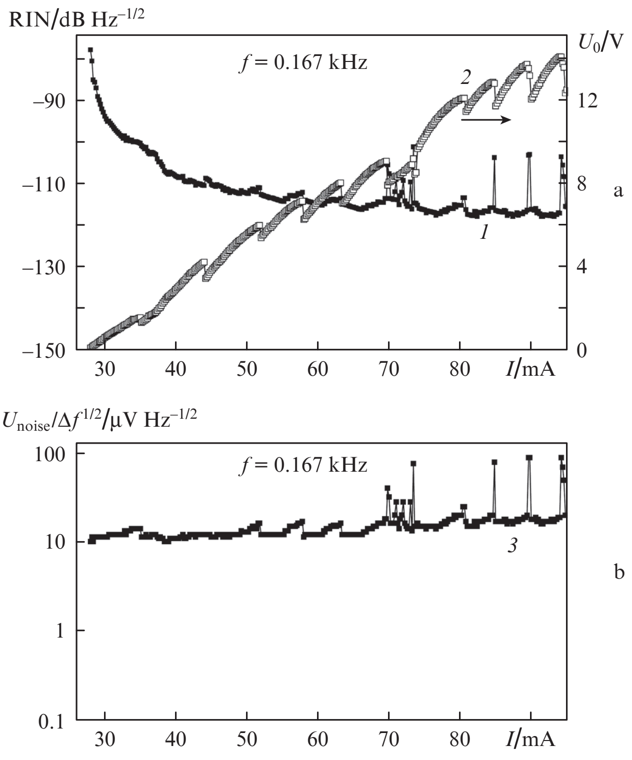

Figure 5. Same as in Fig. 3 at a frequency of 0.167 kHz.

Noise measurement results at frequencies f = 1 and 0.167 kHz with the capacitor connected are presented in Figs 4 and 5. Comparison of curves (*1*) and (*3*) in Figs 3–5 indicates that the noise level increases with decreasing frequency. At pump currents in the range 80–95 mA, the noise rises steeply (compared to the range 30–70 mA) at mode switching points of the external cavity.

Figure 6 shows the emission wavelength [curve (*1*)] and output power [curve (*2*)] as functions of pump current for the FBG LD. Using an optical spectrum analyser, we identified mode switching at pump currents in the range 70–73 mA. Also possible is concurrent generation of two modes with approximately equal amplitudes when the pump current is varied.

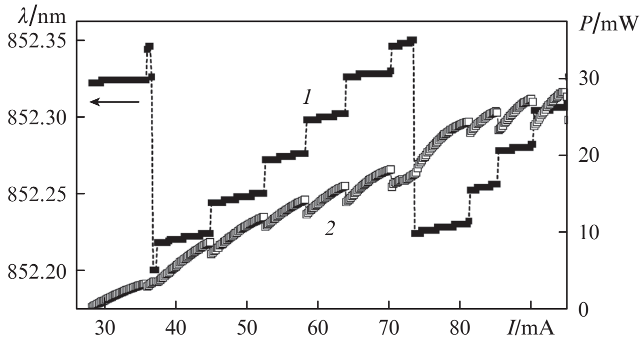

Figure 6. (*1*) Emission wavelength and (*2*) output power as functions of pump current for the LD.

Figure 7 shows the frequency dependences of RIN at pump currents of 40, 60 and 80 mA [derived from the data represented by curves (*3*) in Figs 3–5]. The data points are seen to fall close to a straight line.

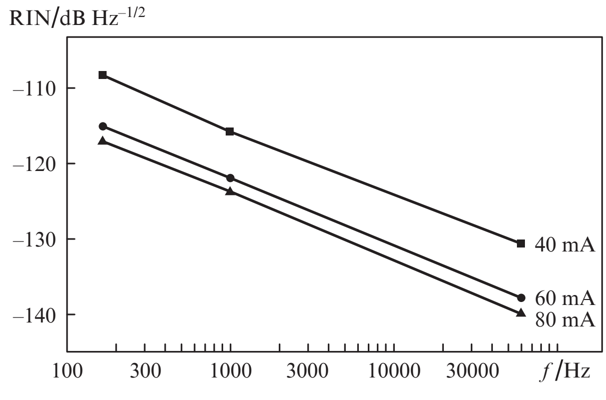

Figure 7. Relative emission intensity fluctuations as a function of frequency at pump currents of 40, 60 and 80 mA.

4. Discussion and conclusions

There is theoretical and experimental evidence [13] that discontinuities in a light power–current (L–I) characteristic correlate with those in a spectral characteristic (due to mode switching in both the external cavity and LD). The present results demonstrate that discontinuities in the $L-I$ curve correlate as well with noise characteristics [Fig. 2, curves (*1*), (*4*); Fig. 3, curves (*1*), (*3*)]. The highest noise was observed at pump currents corresponding to LD mode switching at pump currents from 70 to 73 mA (Fig. 6).

The abnormally high noise level at pump currents in the range 70 to 73 mA is due to multimode lasing (two longitudinal modes). At pump currents in the ranges 30–70 and 73–95 mA, single-mode lasing was observed.

In spite of the discontinuities in the $L-I$ characteristic and noise curves [Fig. 2, curves (*1*), (*3*), (*4*)], the noise characteristics of the pump source have no discontinuities [Fig. 2, curves (*2*), (*5*)].

Comparison of curves (*1*) in Figs 2 and 3 demonstrates that the capacitor sharply reduces the LD noise. For example, at a pump current $I = 60$ mA, capacitor connection led to a drop in RIN by approximately 20 dB. In addition, the capacitor reduced the pump source noise [Fig. 2, curve (*5*)] by more than one order of magnitude, to the level determined by the detection electronics. Thus, the LD noise decreases with decreasing pump source noise. In contrast to what was reported by Marugin and Kharchev [7], the present results demonstrate that the LD noise is determined not only by quantum effects related to the dynamics of the laser but also by technical instability sources.

It follows from analysis of curves (*1*) and (*3*) in Figs 3–5 that the noise level increases with decreasing frequency f and increasing pump current. Moreover, the noise rises steeply at the mode switching points of the external cavity at pump currents in the range 80–95 mA when f decreases from 60 (Fig. 3) to 0.167 kHz (Fig. 5).

In the frequency range 0.167–60 kHz, the relative voltage fluctuation intensity, proportional to the spectral density of output power fluctuations, has the form of flicker noise (Fig. 7).

References

1. Buckingham M.J. *Noise in Electronic Devices and Systems* (New York: Halsted, 1983; Moscow: Mir, 1986).
2. Zhigal'skii G.P. *Fluktuatsii i shumy v elektronnykh tverdotel'nykh priborakh* (Fluctuations and Noise in Solid-State Electronic Devices) (Moscow: Fizmatlit, 2012).
3. Petermann K. *Laser diode modulation and noise* (Dordrecht: Kluwer Academic Publishers, 1988).
4. Bessonov Yu.L., Kornilova N.B. *Kvantovaya Elektron.*, **12**, 2370 (1985) [*Sov. J. Quantum Electron.*, **15**, 1567 (1985)].
5. Dandridge A., Taylor H.F. *IEEE J. Quantum Electron.*, **18**, 1738 (1982).
6. Gelikonov V.M., Mironov Yu.M., Khanin Ya.I. *Kvantovaya Elektron.*, **15**, 1999 (1988) [*Sov. J. Quantum Electron.*, **18**, 1252 (1988)].
7. Marugin A.V., Kharchev A.V. *Zh. Tekh. Fiz.*, **57**, 2380 (1987).
8. Bogatov A.P., Eliseev P.G., Kobildzhanov O.A., Madgazin V.R. *IEEE J. Quantum Electron.*, **23**, 1064 (1987).
9. Bogatov A.P., Drakin A.E., Plisyuk S.A., et al. *Kvantovaya Elektron.*, **32**, 809 (2002) [*Quantum Electron.*, **32**, 809 (2002)].
10. Zhuravleva O.V., Ivanov A.V., Leonovich A.I., et al. *Kvantovaya Elektron.*, **36**, 741 (2006) [*Quantum Electron.*, **36**, 741 (2006)].
11. Zhuravleva O.V., Ivanov A.V., Kurnosov V.D., et al. *Kvantovaya Elektron.*, **38**, 319 (2008) [*Quantum Electron.*, **38**, 319 (2008)].
12. Ivanov A.V., Kurnosov V.D., Kurnosov K.V., et al. *Kvantovaya Elektron.*, **41**, 692 (2011) [*Quantum Electron.*, **41**, 692 (2011)].
13. Zholnerov V.S., Ivanov A.V., Kurnosov V.D., et al. *Zh. Tekh. Fiz.*, **82**, 63 (2012).
14. http://www.superlumdiodes.com.