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Influence of Optical Feedback Strength on the Intensity Noise and Photon Number Probability Distributions of InGaAsP/InP Laser

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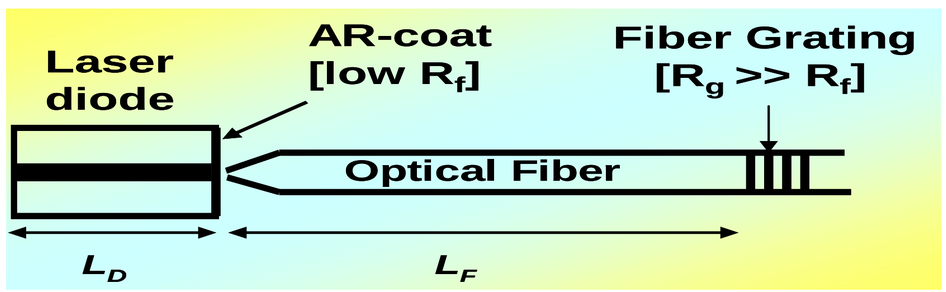
INTRODUCTION & AIM

In recent fiber communication systems



Fiber amplifiers → increase trans. distance
Laser diodes → pumping sources
Fiber gratings → tune the pumping frequency

AIMS OF THE WORK

Investigating influence of optical feedback strength on the instability of semiconductor lasers in terms of noise and photon number probability distributions.

Determine the optimum conditions to stabilize feedback induced instabilities in InGaAsP SLs subject to a wide range of optical feedback

THEORETICAL FRAME

Modified Rate Equations Including Noise Sources

$$\frac{dS}{dt}=\left\{A-BS-G_{th0}+\frac{c}{n_D L_D}\ln|T|\right\}S+\frac{a\xi}{V}N+F_S(t)$$

photon number equation

$$\frac{d\theta}{dt}=\frac{\alpha a\xi}{2V}(N-\bar{N})-\frac{c}{2n_D L_D}(\phi-\bar{\phi})+F_\theta(t)$$

optical phase equation

$$\frac{dN}{dt}=-\frac{a\xi}{V}(N-N_g)S-\frac{N}{\tau_s}+\frac{I}{e}+F_N(t)$$

carrier number Equation

Langevin noise sources [Poisson random processes]

Modified oscillation conditions

Threshold gain condition

$$G_{thc}=G_{th0}-\frac{c}{n_r L}\ln|T|$$

Phase condition

$$2\beta_1 L+\phi_b+\phi_1+\phi=2n\pi$$

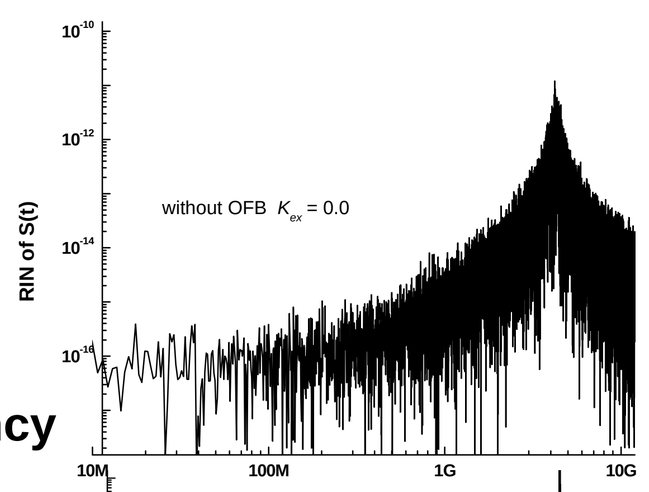
Amount of delayed feedback:

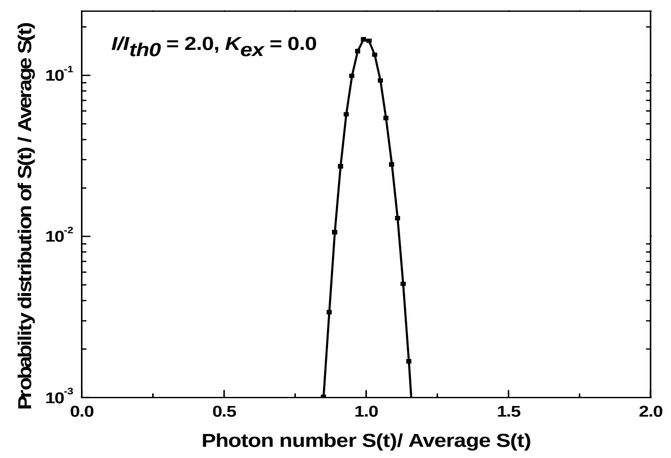
$$T=1-\frac{1-R_f}{R_f}\sum_{m=1}^{\infty}(R_f R_g)^{m/2}e^{-jm\psi}\sqrt{\frac{S(t-m\tau)}{S(t)}}e^{j[\theta(t-m\tau)-\theta(t)]}=|T|\,e^{-j\varphi}$$

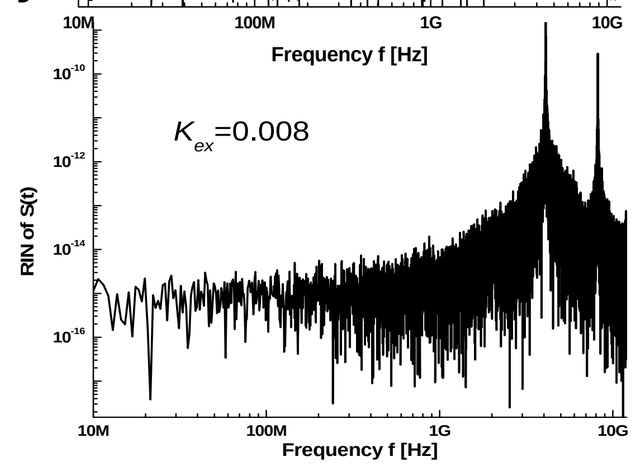
Ψ: Phase difference between delayed and reflected field at R_f

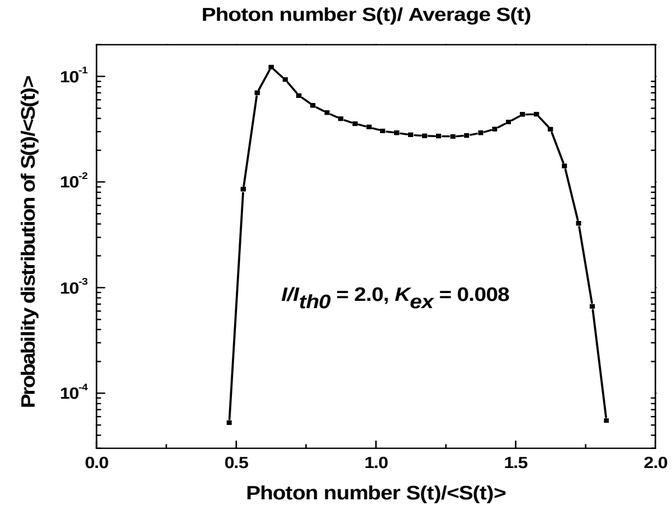
RESULTS & DISCUSSION

RIN and Probability Distributions

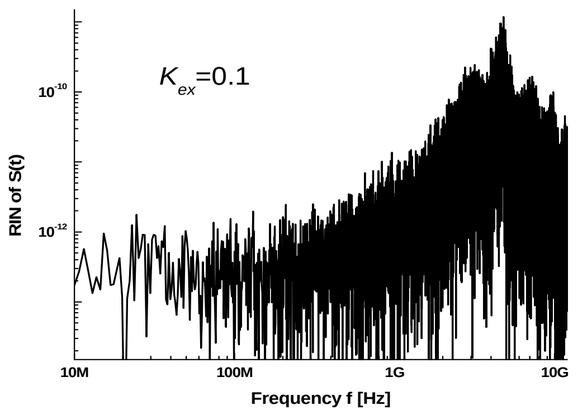


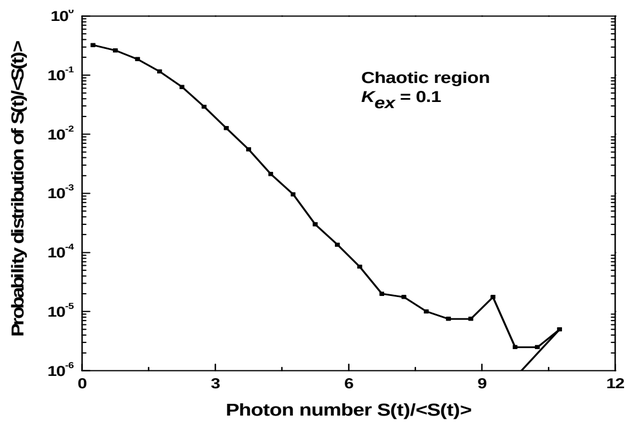






Shape of the distribution changes with including weak OFB strength (K_{ex}=0.008). There is two maximum in the distribution shape.





The probability shows a peak at low intensity and rolls off at several times the average.
A probability of this type is expected for pulsating laser with irregular, pulses (chaos) of a peak power of several times the average S.
The RIN enhanced to be higher than quantum noise level six orders of magnitude.

CONCLUSION

Optical feedback strength significantly affects the intensity noise and photon number probability distributions. Intensity noise is reduced at relatively weak and strong optical feedback regimes. The shape of the photon number probability distributions is strongly influenced by OFB strength, transitioning from symmetric to asymmetric at weak to strong optical feedback, respectively. In the moderate optical feedback range (chaotic region), the photon number probability distributions exhibit a peak at low intensity and tail off at several times the average photon number.
The authors suggest that operating semiconductor lasers under weak or strong optical feedback regimes may reduce their instability.

REFERENCES

[1] S. Abdulrhmann, et al., IEEE J. Sel. Top. Quantum Electron., 9 , pp. 1265–1274, 2003.
[2] Salah Abdulrhmann, and Jabir Hakami, Appl. Sci., 13(24), pp. 13099, 2023.