Wave Kinetics of Random Fibre Lasers

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Traditional wave kinetics describes slow evolution of wave spectrum of the system with many degree of freedoms to statistical equilibrium via numerous weakly nonlinear interactions [1]. In classical wave kinetics, initial wave spectrum evolves gradually to a statistically stationary wave spectrum when energy pumping/dumping is homogeneous over the evolution time. The evolution is governed by wave kinetic equation. However, many practically important optical systems, like lasers, are dissipative (active) in their nature. Moreover, in lasers the energy pumping/dumping act in a periodic way resulting in cycling dynamics and double-scale evolution of the wave (i.e. optical) spectrum. When the energy pumping/dumping changes within the cycle, the wave spectrum is locally non-stationary exhibiting strong changes within each cycle. At the same time, the spectrum evolves in a gradual incremental way from cycle to cycle similar to classical wave kinetics. If overall pumping within the cycle is equal to energy dumping, the system approaches the global stationary solution. Traditional wave kinetics cannot be applied for such systems.

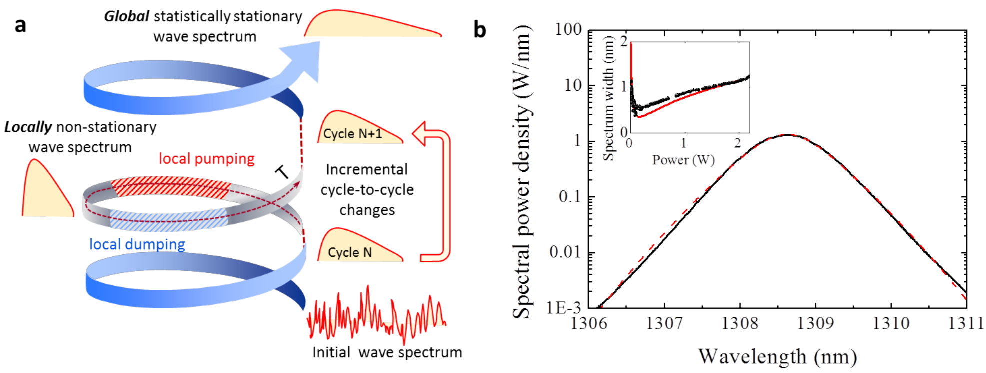

Fig. 1. (a) The concept of wave kinetics in active media. (b) Optical spectra and (inset) optical width vs output generation power for random distributed feedback laser. Black is experiment, red is theoretical prediction.

In the present work we propose and develop the concept of the wave kinetics of active cyclic systems, Fig. 1a, and derive a local wave kinetic equation governing strong changes in wave spectrum over each cycle. We apply the concept to describe spectral properties of a random distributed feedback fiber laser operating via Raman gain and random Rayleigh backscattering-based feedback [2]. Using the concept of wave kinetics of active cyclic systems, we formulate first ever nonlinear kinetic theory of the laser's spectrum [3]. To experimentally verify the theoretical predictions, we designed a random fiber laser and observe output spectrum. Both the spectrum shape and width dependence on pump power are well-predicted, Fig. 1b.

The general formalism of wave kinetics of active cyclic systems could be applied for various optical systems where stochasticity is important: random lasers of other types, lasers with open or unstable resonators, multi-mode lasers with large number of modes, long-haul fiber transmission links, and other systems. However, it could be applied beyond photonics for description of other non-Hamiltonian systems, which evolve to the statistical equilibrium in cycles: day and year cycles in meteorology, Rayleigh-Taylor instabilities in various media (water, atmosphere, coatings in surfaces).

References

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