Four-wave mixing induced turbulent spectral broadening in CW fiber lasers

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The output radiation of conventional partially coherent (PC) continuous-wave (CW) fiber lasers consists of numerous longitudinal modes. Typically, ytterbium-doped fiber laser having a ~10 m long cavity supports simultaneous generation of ~10^3 longitudinal modes, while in Raman fiber lasers (RFLs) modes number can be up to 10^8 in ultra-long (up to 300 km) cavities. Moreover, CW fiber lasers usually delivers high light power (>1W) in a tiny fiber core of ~5-10 um diameter. As a result, in a CW fiber lasers nonlinear interaction of numerous longitudinal modes is well pronounced despite the small values of nonlinearity in pure glasses.

Nonlinear modes interactions in a dispersive media define the practical performances of the fiber lasers – output power, spectral shape, and spectral broadening law. Commonly used simple laser models based on balance equations do not take into account wave-mixing (FWM) interactions and, thus, can not predict generation properties. Numerical modeling based on non-linear Schrödinger equation (NLSE) can provide both power and generation spectrum, but complex and time consuming.

Contrary to dynamic description usually applied in fiber optics, we have used a statistical approach to describe CW fiber laser generation performances on the example of high-Q cavity RFL. The wave kinetic equation for spectral density evolution was derived, using a technique of averaging and splitting of correlation functions in the context of the weak turbulence theory. For a longitudinally homogeneous Stokes wave intensity and the typical Gaussian shaped reflections spectrum of cavity mirrors, the analytical solution for the Stokes spectrum inside the cavity takes a hyperbolic secant shape with exponential tails. Moreover, the spectral width grows with increasing power according to a square-root law. The experimental observations are in excellent agreement with model predictions.

A big challenge is to implement the similar methods to describe the generation properties and mechanisms of spectral formation in recently developed random distributed feedback (DFB) fiber lasers having no any point-based reflectors. In such laser the lasing is possible owing to the random distributed feedback provided by Rayleigh scattering on fiber refractive index micro-inhomogenities. As the RDFB laser has an ultra-long (up to several hundred kilometers) cavity, a total cavity nonlinearity is extremely large and nonlinear interaction of huge number of random spectral components should be a key factor which allows stable CW generation and determines the generation properties and spectrum localization in RDFB fibre laser.