# Nonlinear Spectral Transformation of Partially Coherent Pulses of Mode-locked Fiber Laser

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All-normal dispersion fiber lasers mode-locked due to the effect of nonlinear polarization evolution (NPE) are simple and efficient tools for generation of pulses with different duration. These lasers feature reliable design and resistance to power damage, they can produce relatively high pulse energies without wave breaking and are able to operate in a variety of lasing regimes [1]. Besides generation of commonly used stable trains of bell-shaped pulses, these lasers support partially mode-locked operation in which wave packets filled with quasi-stochastic ultra-short pulses are generated [2, 3]. Partially coherent pulses with relatively high energy levels have been discovered recently in fiber lasers comprising ultra-long oscillators [2–5] and to the best of our knowledge, applications of such pulses have not as yet been studied. However, because these high-energy wave packets contain tightly-spaced femtosecond pulses with high peak power, their pulse structure may be useful in many applications including material processing, super-continuum generation, as well as other non-linear optical transformations.

In this work, we investigate for the first time the applicability of novel partially-coherent lasing regimes using second harmonic generation (SHG) as the most basic test of non-linear optical transformation of partially coherent pulses. Here we make use of the same numerical model based on a set of non-linear Schrödinger equations as earlier [2–4] to simulate lasing in NPE-mode-locked oscillator. This model provides us with laser field distributions that we then use as input data for simulation of SHG by multimode waves according to the method [6]. Starting from a stable lasing regime we then gradually tune the laser toward noise-like generation by changing the phase shift introduced by intra-cavity polarization controller PC2 (see Fig. 1 a). At the same time, we observe the evolution of SHG efficiency as a function of PC2 phase shift (see Fig. 1 b). We have found that SHG efficiency deteriorates slightly when the laser leaves fully-mode-locked regime. This is obviously due to emergence of phase fluctuations in laser pulses. As we continue to tune the laser further, the fluctuations tend to grow so that SHG efficiency decreases. However, this decrease is quite moderate, with SHG efficiency dropping by only ~20% relative to the values reached in the stable lasing regime. Since pulse energy attainable in stochastic regimes can be almost twice as high as that for the stable generation regime, we are led to conclusion that partially-mode-locked regimes are very promising for SHG and other non-linear spectral transformations and applications where the internal pulse structure does not play a major role. Among examples of such applications one could mention Raman amplifiers, biomedicine, microscopy methods, etc.

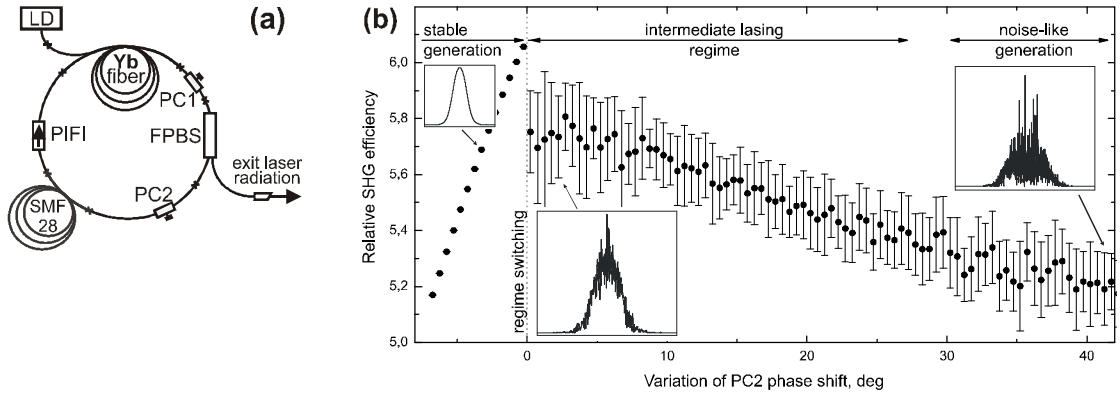


**Fig. 1** (a) Laser layout (PC – polarization controller, PIFI – polarization-independent fiber isolator, FPBS – fiber polarization beam splitter, LD – pump laser diode) and (b) simulated relative second harmonic generation efficiency for different generation regimes as a function of PC2 phase shift. Insets show temporal intensity distributions for stable, intermediate and noise-like generation regimes.

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