論 文 の 内 容 の 要 旨

Study on ultralow-intensity-noise mode-locked fiber lasers
(モード同期ファイバレーザの超低強度雑音化に関する研究)

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This dissertation focuses on constructing an ultralow-intensity-noise mode-locked fiber laser, which is suitable for high-sensitivity measurements like SRS microscopy. We first introduced the principle of SRS microscopy in Chapter 2, which is a powerful method of biomedical imaging. In Chapter 3, we make it clear the requirement of laser sources for SRS microscopy and the challenges faced by fiber lasers now. For expanding the application of SRS microscopy, it is highly recommended to use an ultralow-intensity-noise mode-locked fiber laser with moderate optical power. For realizing this target, we proposed a mode-locked fiber laser with several excellent characteristics like an ultralow RIN of -161.4 dB/Hz, a wide wavelength-tuning range of >18 nm, and a moderate power of 190 mW. Such performance is realized by the following steps:

In Chapter 4, we carefully designed the laser oscillator by reducing the intracavity loss to only about 2.6 dB, the laser oscillator can mode-lock smoothly without using any active devices like phase modulator to facilitate mode-locking. We point out the defects of the current method of intensity noise evaluation, which can only measure the intensity noise at a <10-mW power region. By analyzing the power dependence of noise components, we reveal that the excess noise is proportional to the square of optical power while the shot noise is proportional to the optical power. Thus, it is necessary to analyze the noise at a >10-mW power regime to make sure the excess noise is sufficiently suppressed or not. By using such a noise evaluation method, we discussed how the RIN is changed by intracavity dispersion and pump power. By doing so, we proposed two important strategies to reduce the RIN. This first is to reduce the intensity noise by reducing the pump power to the mode-lock threshold. The second is to increase the intracavity dispersion for higher average power, thus lower RIN. We finally realized an ultralow RIN of -161.4 dB/Hz at the optical power of 24.4 mW.

In Chapter 5, we mounted the CFBG of the oscillator onto a hybrid-material substrate for wavelength tuning. By putting such a substrate between two U-shaped grooves, we realized a wavelength tuning range of > 18 nm. Such a method of wavelength-tuning can expand the tuning range while making the substrate material easy to go back to the original position at the same time. Compared with the previously proposed wavelength-tuning scheme like fiber OPO or spectral filtering of broad spectrum. Our scheme can realize wavelength-tuning conveniently without introducing noise. We measured the RIN of the wavelength-tunable fiber laser and proved it is as low as -159.2 to -161.2 dB/Hz.

In Chapter 6, we proposed an all-PM-fiber noise suppressor based on NOLM. Such a noise suppressor can avoid the extra ASE noise from the gain fiber in NALM like the situation in previous works. The noise suppressor is connected after the output of the ultralow-intensity-noise oscillator is amplified by a fiber amplifier to about 270 mW. We finally get an output of 190 mW and the RIN at 30 mW is suppressed by 1.1 dB to about -161.4 dB/Hz, which is an ultralow-intensity-noise mode-locked fiber laser with moderate output power. By using liquid nitrogen, we also reveal that GAWBS is one of the limiting factors for the performance of the noise suppressor. Such an experiment can be a good reference for a noise suppressor operating when the intensity noise of the input laser source is low.

In summary, we proposed an ultralow-intensity-noise mode-locked fiber laser with a RIN of only -161.4 dB/Hz at the power of 30 mW, the output power is over 190 mW which ensures a

good SNR when the laser is applied to SRS microscopy considering the optical loss. Besides, the wavelength-tuning range is over 18 nm, which can cover important vibrational modes such as CH2-stretching(2850 cm^{-1}), CH3-stretching (2930 cm^{-1}), and CH stretching associated with C=C (3010 cm^{-1}). We anticipate that this compact laser will be useful for high-sensitivity measurements like SRS microscopy or for pumping a FOPO.