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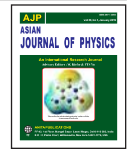

Experimental study of the relationship between phase noise and linewidth of distributed feedback fiber laser

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We characterized the phase noise and linewidth of asymmetrical Distributed Feed Back Fiber Lasers (DFB FLs) using unbalanced Michelson interferometer and delayed self-homodyne method, respectively. Experimental results verified the close relation between the phase noise and linewidth of the DFB FLs tested, the phase noise increased from –109dB to –94dB as the linewidth increased from 1.6 kHz to 4.8 kHz. This relationship can be utilized for the assessment of the DFB FL phase noise based on the linewidth characteristics.

Keywords: Distributed feedback fiber laser, Phase noise, Linewidth, Unbalanced interferometry.

1 Introduction

Short cavity single frequency Distributed Feed Back Fiber Lasers (DFB FLs) have been a topic of continued interest due to their small size, narrow linewidth and compatibility to transmission fiber [1]. Their extremely low phase noise characteristic is of great importance to unbalanced interferometer applications such as laser hydrophone [2], laser accelerometer [3] and fiber- optic ultrasonic sensing [4]. Therefore, accurate measurement and control of the DFB FL phase noise is in urgent need.

Phase noise of DFB FL originates from the random laser phase fluctuations induced by spontaneous emission, surrounding temperature change and acoustic noise. In the frequency domain, increased phase noise will lead to the generation of random side lobes around the central frequency, which will broaden the spectral linewidth in return. Currently the associated research is focused on the suppression of phase noise with different pump setups [5], active acousto-optic modulation [6] and external interferometer [7]. However, there are few studies reported on the relationship between the narrow linewidth fiber laser phase noise and linewidth.

In this paper, we will present experimental data which strongly suggest that the phase noise of DFB FL is directly related to its linewidth. We measured the phase noise and linewidth of 6 different DFB FLs, and then analyzed the results to show the linear relationship between their phase noise and linewidth. Finally, we briefly discuss the theoretical explanation of this relationship and its possible application.

2 Experiment setup

The DFB FLs used in this experiment are manufactured with scanning phase mask method using 244 nm ultraviolet argon laser as the grating writing device on the erbium doped fiber [8], an off center single π phase-shift is introduced to the grating during the beam scanning process through a micro phase mask displacement to achieve asymmetrical laser output. The details of the DFB FLs are listed in Table 1.

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Table 1. Tested DFB FL specifications

	DFB FL No.1	DFB FL No.2	DFB FL No.3	DFB FL No.4	DFB FL No.5	DFB FL No.6
Cavity length(mm)	44	44	44	44	44	44
Wavelength (nm)	1539.18	1541.46	1532.05	1534.50	1536.79	1532.02
Slope Efficiency (‰)	1.10	0.99	1.23	1.17	1.13	1.20
Linewidth(kHz)	1.6	2.0	2.6	3.2	3.9	4.8

The linewidth measurement setup is shown in Fig 1. The DFB-FL was pumped with 100mw/ 980 nm laser diode, a 980nm/1550nm Wavelength-Division Multiplexer (WDM) connected to the pump with the DFB-FL employing its 980nm and 1550nm arm, respectively.The laser output then went through the signal arm of the WDM into a 1550nm optical isolator and was then sent to the sound insulated Delayed Self-Homodyne Interferometer (DSHI) [9].

The DSHI interferometer is a modified Mach--Zehnder interferometer setup which consists of 3dB coupler 1 (90/10), 50km fiber delay line and 3dB coupler 2 (50/50). The input laser beam is split into two paths by coupler 1, 10% of the laser goes directly to coupler 2, while the rest 90% of the laser goes through a 50km single-mode fiber delay line to coupler 2. We then use a photodiode to detect the recombined incoherent beat spectra; this signal is analyzed using a Personal Computer (PC) with Labview software demodulation. Both the DFB FL and the interferometer are put in sound insulated boxes to shield out environmental perturbations.

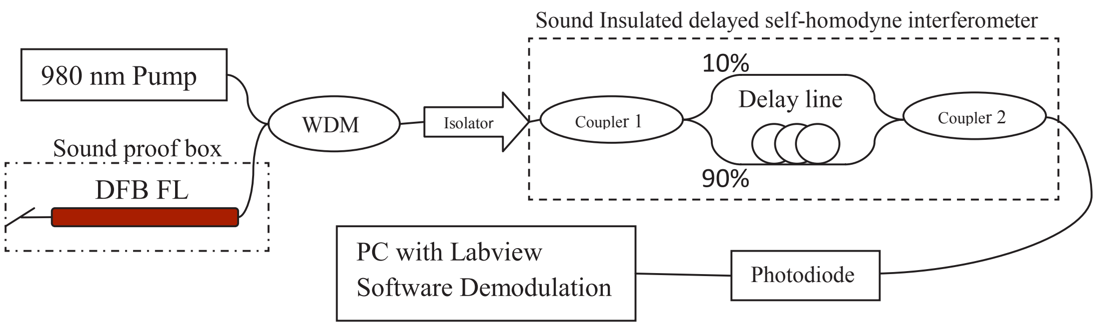


Fig 1. Delayed self-homodyne interferometry linewidth measurement setup

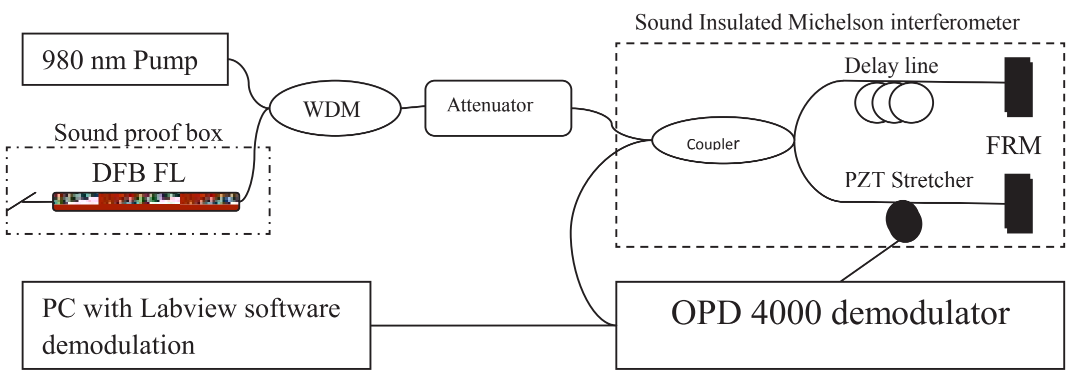


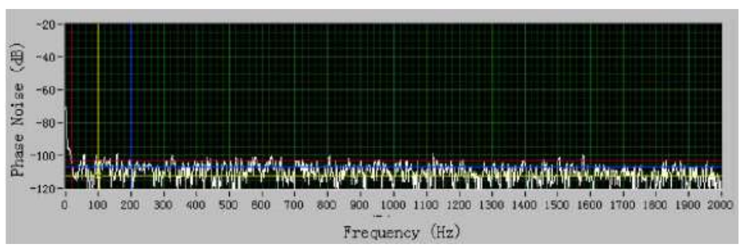
Fig 2. Michelson interferometry phase noise measurement setup

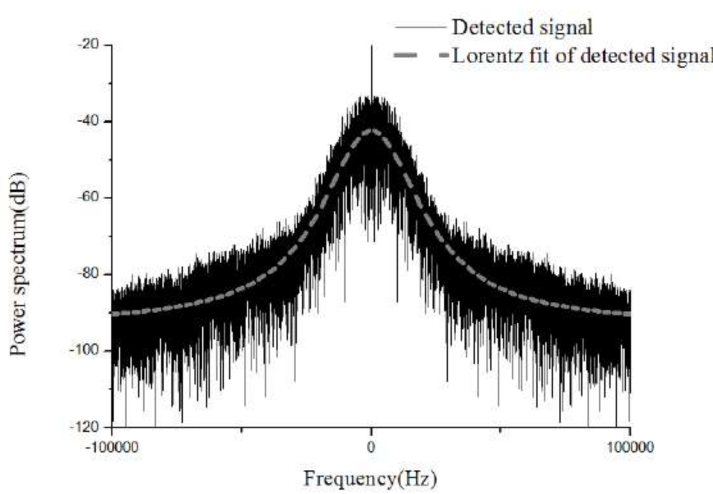
Figure 2 shows the phase noise measurement setup. Employing the same pumping scheme as shown in Fig 1, the DFB FL output goes through an intensity attenuator into the sound insulated Michelson interferometer which is an unbalanced structure with 30m single-mode fiber delay line added on one arm to create the optical path length difference. Two Faraday Rotation Mirrors (FRMs) are put at the end of each arm to reduce polarization induced visibility degeneration. One piezoelectric (PZT) fiber stretcher is incorporated into one arm to ensure the phase quadrature bias. The recombined signal is received by optical phase demodulator (OptiPhase OPD 4000) which also controls the PZT stretcher. Finally the demodulated signal is analyzed with PC using the Labview software.

3 Results and Discussion

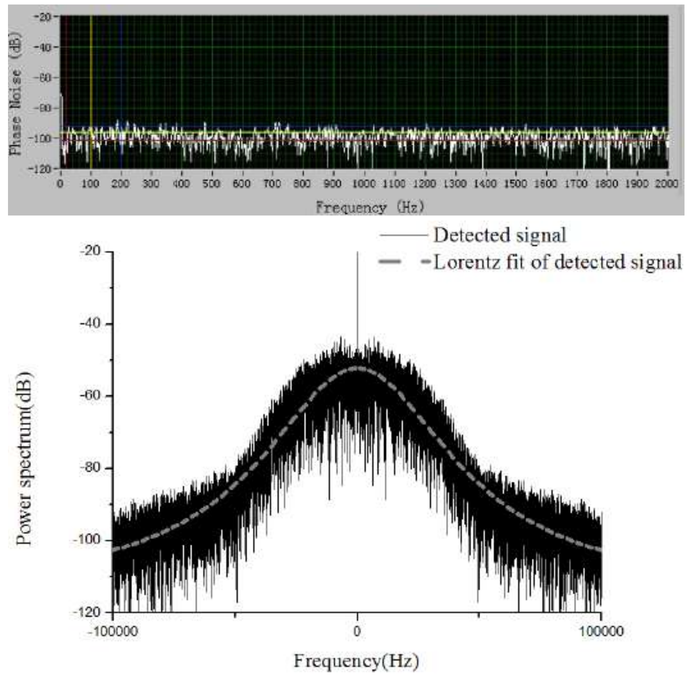
As shown in Fig 3, all 6 DFB FLs are tested using previously mentioned setup. For phase noise measurement, we record the frequency spectrum ranging from 0 Hz to 2000 Hz which is the most crucial part for low frequency sensitive sensing applications, and then take 50 times average of the signal to neglect the potential random noise perturbation; the final phase noise level is approximately read from the stabilized spectrum pattern. For linewidth measurement, the recombined beat spectra was recorded and then analyzed using a Lorentz fit curve to characterize the obviously Lorentzian linewidth line shape, then we take 20dB down from the top of the curve to estimate the DFB FL linewidth.

The phase noise of each DFB FL is plotted against corresponding linewidth in Fig 4. It is very obvious that the phase noise/linewidth increased from the lowest DFB FL No.1 (–109 dB/1.6kHz) to the highest DFB FL No.6 (–94 dB/4.8kHz) with a definite linear relationship.

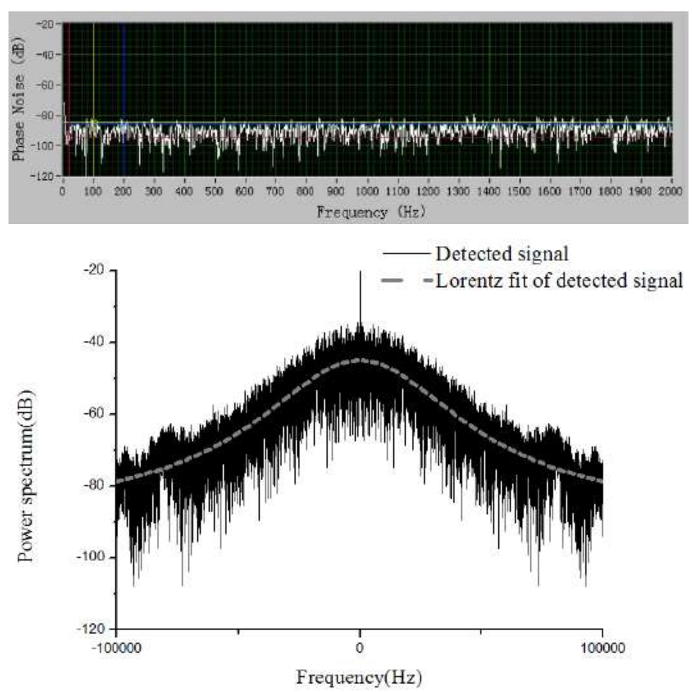




DFB-FL No.1



DFB-FL No.4



DFB-FL No.6

Fig 3. Phase noise (upper graphs) and Linewidth (Lower graphs) of 3 tested DFB FLs

An ideal laser is an optical source that emits single frequency coherent directional beam with zero linewidth. However, in practice, fluctuations such as quantum mechanical uncertainty, cavity length variation and temperature change will greatly deteriorate the laser linewidth performance. For DFB FL, the optical field could be modeled as:

$$E(t) = E_0 \cos [\omega t + \varphi_0 + \delta\varphi(t)]$$

where E_0 denotes the default electric field amplitude, ω is the laser central frequency, φ_0 is the default phase, δφ(t) is the time-varying phase shift. In our experiment, δφ(t) is the origin of both phase noise and linewidth broadening. We use the Michelson and Mach-Zehnder structure interferometer to transfer the optical phase/frequency fluctuations into variations of light intensity, the test results indicate that there exists a direct linear relationship between the transferred power spectral densities, therefore linewidth related parameters will also influence the phase noise of DFB-FL, such factors include pump power, ambient temperature and acoustic noise. This means that for certain DFB FL under different configurations, the exhibition of a wider linewidth is accompanied with a higher phase noise figure, therefore we can use linewidth as an additional assessment standard when it comes to evaluate the phase noise performance of specified DFB FL in varying setups.

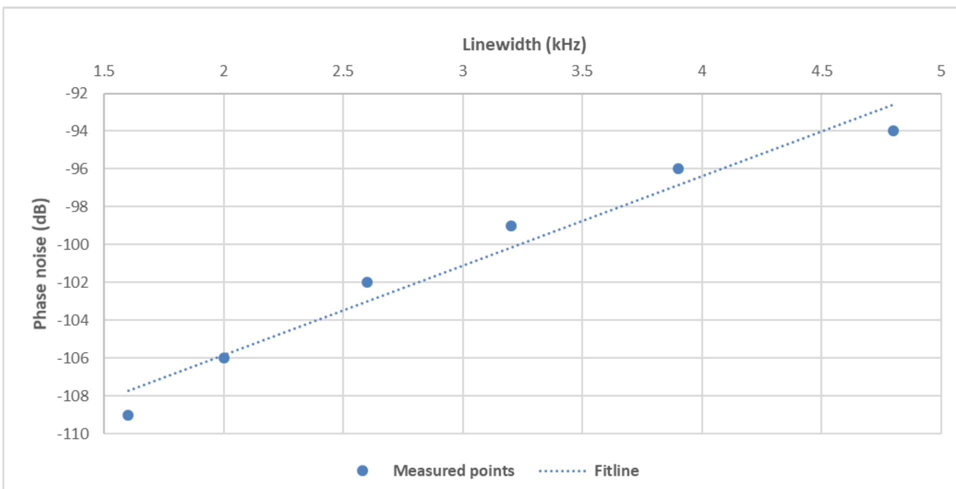


Fig 4. Relationship between Phase noise and Linewidth of tested DFB FLs

4 Conclusion

We experimentally investigated the relationship between phase noise and linewidth of DFB FL. Test results confirmed the approximate linear relationship between DFB FL phase noise and linewidth. Further investigations are expected to study the dependence of phase noise on linewidth-related factors.

Acknowledgement

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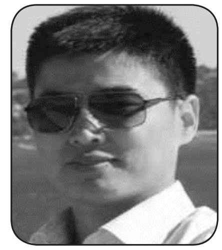

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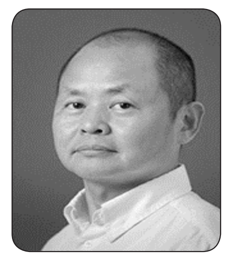

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