Stability of distributed feedback fiber laser sensor array with unequal wavelength spacing

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ABSTRACT

A 16 channel distributed feedback fiber laser sensor array is reported. The spacing of neighbor lasers is 100 GHz and 200 GHz in turn. Compared with grating sideband reflection, Rayleigh backscattering from ~24 m long passive fiber is more responsible for the instability, and it's found that increasing the reflection of grating could reduce the sensitivity of DFB FL to Rayleigh backscattering.

Keywords: Fiber laser sensor array, DFB fiber lasers, mode hopping

1. INTRODUCTION

Distributed feedback fiber lasers (DFB FLs) have been developed for more than 30 years[1], due to their high strain sensitivity, small size, low frequency noise and ease of multiplexing, they are suitable for highly sensitive and distributed sensors[2-6], such as fiber laser hydrophone.

For a sensor array, DFB lasers with different wavelengths are serially multiplexed along a single fiber, and pumped by only one laser diode. The maximum number of sensors in the array is a widely mentioned parameter, which is limited by loss, available pump power, lasing threshold power and minimum sensor spacing[7], and the maximum length of array is an another important parameter, which is related to Rayleigh backscattering (RB) from passive fiber[8-10]. Due to RB, each DFB FL experiences external reflection which causes excess frequency and intensity noise, and even mode hopping. The longer the fiber is, the stronger the RB is, and the more instable the fiber laser sensor array is, so RB should be taken care of.

In this paper, the stability of DFB FL sensor array and the influence of RB are investigated. First, an introduction to the FL sensor array is presented, which consists of 16 DFB fiber lasers with 100 GHz (~0.8 nm) and 200 GHz (~1.6 nm) spacing, referring to the International Telecommunications Union (ITU) WDM grid suggest. Then the experimental research of stability related to the external reflections from the grating sidebands of neighbor lasers and RB is followed. Results show that compared with sideband reflection, RB is more responsible for stability and frequency noise, it is the limited factor for long distance DFB FL sensor array. And we also found that the increase of the coupling coefficient (i.e. reflectivity) could improve the tolerable level of RB in DFB FL sensor array.

2. DFB FL SENSOR ARRAY

The fiber laser sensor array system includes 16 DFB FLs and phase generated carrier (PGC) demodulator, as shown in Fig. 1. The DFB FLs are serially pumped by a grating stabilized pump diode at 976 nm through wavelength division multiplexers (WDM). The outputs of FLs travel across an optical isolator (ISO) and dense WDM (DWDM) into the PGC demodulator. The noise level of PGC demodulator is 5e-7 pm/√Hz from 150 Hz to 2 kHz[1]. More details of the demodulator can be found in Ref. 8. The number of FLs from FL1 to FL 16 is defined by the progressive wavelength increase.

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[1] The unit is given by pm/√Hz, and it could be transferred to Hz/√Hz by: $FN_{Hz/\sqrt{Hz}} = c/\lambda^2 \cdot FN_{pm/\sqrt{Hz}}$, where c the velocity of light, λ the operating wavelength.

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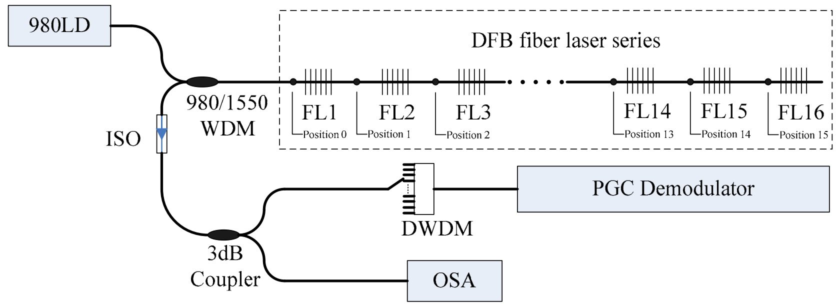
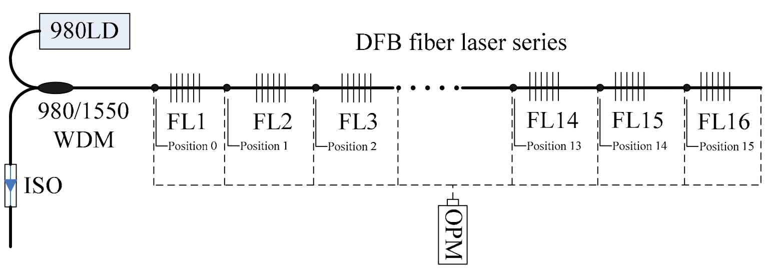


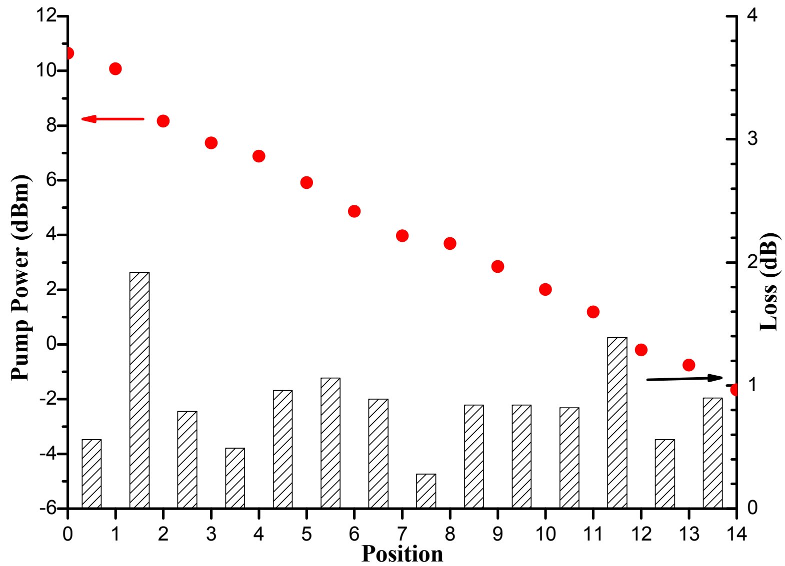
Fig. 1. Configuration of 16 DFB FL sensor array system

The DFB FLs were fabricated on the photosensitive erbium doped fiber by 248 nm KrF excimer laser. The saturated absorption was ~1 dB/m at 980 nm. The π phase shift was in the center of the grating, and the total grating length was L ~ 40 mm. Low gain and short length was to reduce the pump adsorption. Eight pieces of phase masks with 300 GHz spacing were used to fabricate the 16 channel DFB FLs, because of the limited wavelength tuning range, the spacing of neighbor lasers was 100 GHz and 200 GHz in turn. In the writing process, though the exposure condition was kept the same, coupling coefficient κ (i.e., the visibility of the index change) was different, it could vary from 126 m^{-1} to 161 m^{-1}, moreover the threshold power, pump efficiency and frequency noise were also different. The reason might come from the non-uniformity of germanium and erbium dopant, or the phase error of the grating. With κ=131 m^{-1}, L=40 mm and π phase shift in the center, the calculated sideband reflection around 0.8 nm (100 GHz) away from center wavelength oscillated severely, the maximum reflection was -20 ~ -25 dB and the measured value was about -23 dB.

To be serially multiplexed along a single fiber, two ends of phase-shifted grating were spliced to passive fiber, and the fiber length between two adjacent gratings was 1.5 m. Compared with absorption loss, splice loss was dominant, so the splice parameters between active and passive fibers should be optimized. With the adjustments of splicer, the average loss per splice reduced from 1.5 dB to 0.3~0.4 dB. Further, we investigated the loss per FL in the sensor array by a low power light (seen in Fig. 2(a)), and the pump power distribution and loss along the fiber were given in Fig. 2(b).



(a)



(b)

Fig. 2. Loss in DFB FL sensor array. (a) experimental setup
(b) pump power distribution and loss along the sensor array.[2]

Because of the different threshold power and pump efficiency, the 16 channel DFB FLs were not serially arranged from short to long wavelength along the fiber, their sequence was optimized to ensure all the FLs lase. The spectrum of 16 DFB FLs under 360 mW pump power was shown in Fig. 3. There were about 26 dB variation in the output power, more works should be done to improve the flatness. The transmission spectrum of DWDM in Fig. 3 was measured by ASE in a separate experiment.

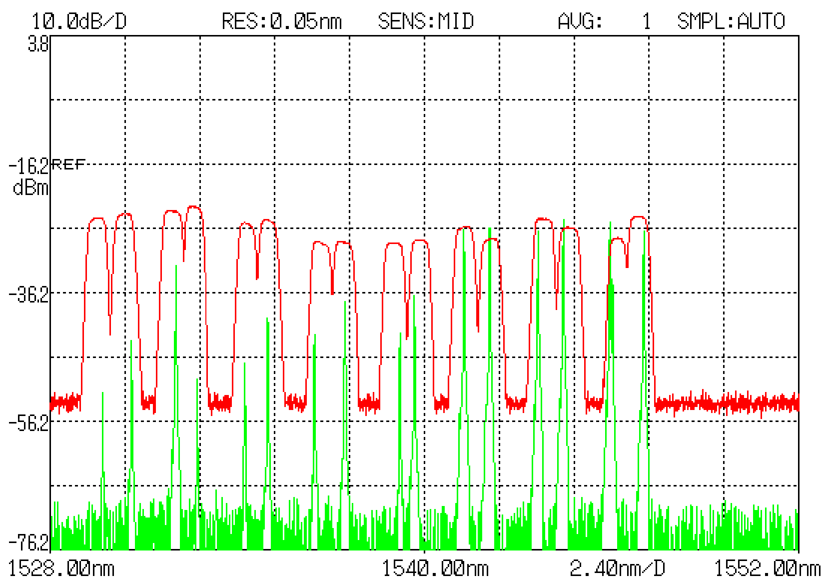


Fig. 3. 16 DFB FL sensor array output spectrum and DWDM transmission spectrum

3. EXPERIMENTAL RESULTS

In the sensor array, each FL experiences unintentional reflection such as return loss from WDM and ISO, grating

[2] The final FL was missed in the experiment.

sidebands of neighbor lasers, and RB. The return loss of WDM and ISO is typical less than -45 dB, grating sideband reflection is related to κ, L and $\Delta\lambda$ (the wavelength deviation away from center wavelength), the measured maximum reflection was about -23 dB around 0.8nm, the average level of RB in 24 m long passive fiber calculated with the typical value -73 dB/m is -59 dB[3]. Through such feedback is small, it can have dramatic effects on the laser's stability. The measurement results are shown in Fig. 4.

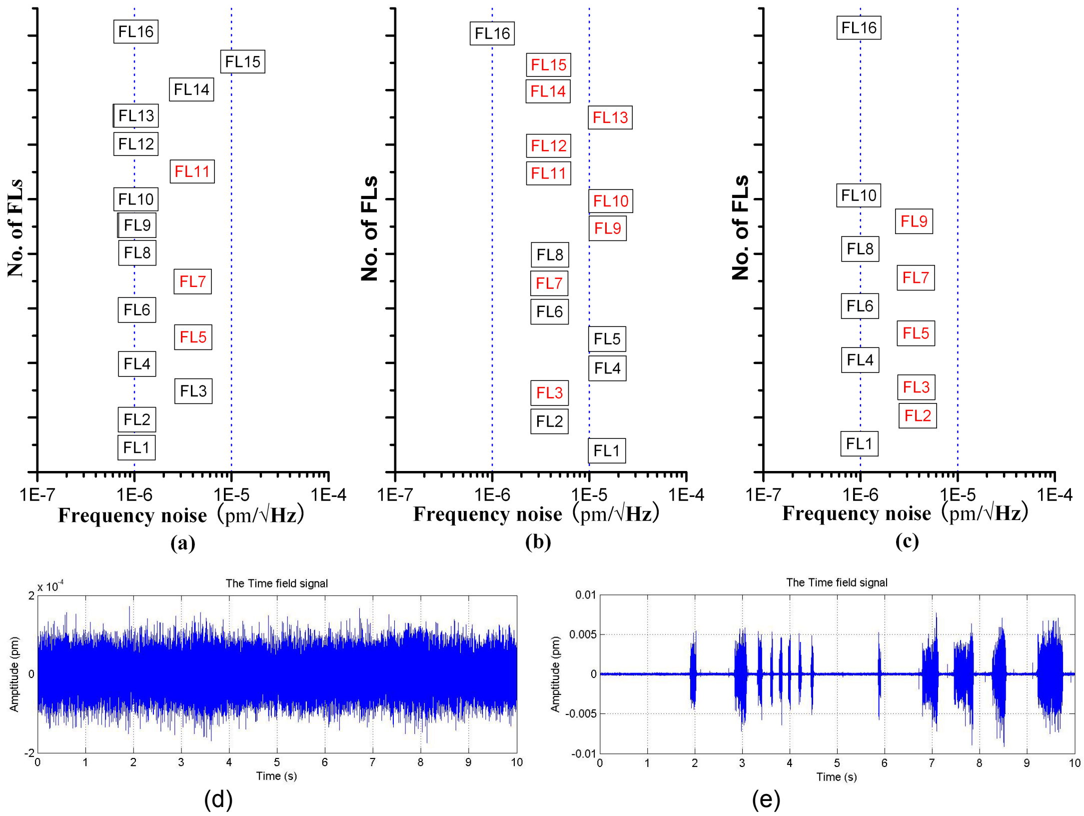


Fig. 4. Frequency noise of DFB FLs. (a) separate measurement for each FL. (b) measurement in 16 channel DFB FL sensor array. (c) measurement in 11 channel DFB FL sensor array. (d) Frequency noise in time field with no mode hopping. (e) Frequency noise in time field with mode hopping. In (a), (b) and (c), "black" means no mode hopping, and "red" means existing mode hopping.

In Fig. 4(a) ~ (c), all the given frequency noises are measured at 1 kHz, "black" means no mode hopping, and "red" means existing mode hopping. (d) and (e) are examples of the time field noise with or without mode hopping after a bandpass filter from 20 Hz to 2 kHz. Fig. 4(a) represents the separate measurements for all the lasers. Fig. 4(b) represents the measurements for the serially multiplexed 16 channel DFB FL array. The wavelength sequence from left to right is FL15, FL11, FL12, FL13, FL14, FL16, FL3, FL10, FL9, FL8, FL7, FL6, FL5, FL4, FL2 and FL1. From Fig. 4(a) to (b), it shows that the stability and frequency noise degrade for almost FLs except FL16. The degradation doubtless comes from the small feedback mentioned above.

Further, the left five FLs from FL11 to FL15 are removed, and the measurements are given in Fig. 4(c). Because the wavelength spacing between the removed FLs and FL1 ~ FL 9 are larger than 2.4 nm, the influence of these five FLs sideband reflections to FL1 ~ FL9 can be omitted[8]. While, through the RB reflectivity only changes about -1.6 dB by reducing the fiber length from 24 m to 16.5m, the intensity and frequency noise level are much improved. This phenomenon shows that RB is more responsible for the instability, and it also shows that besides the reflectivity level, there is another factor inside RB affecting the behaviors of DFB FL, and it should be the length of passive fiber. They work together to determine whether the external mode exists. Because RB is the

[3] The Rayleigh backscattering reflectivity (expressed in dB unit): $R_{dB} = \alpha_{dB/m}+10\cdot\log10(L)$, where $\alpha_{dB/m} \sim -73$ dB/m for single mode transmission fiber, L the fiber length.

intrinsic characteristics in the fiber, it seems impossible to be reduced further, and so it is the limited factor for long distance DFB FL sensor array. However, there are still some countermeasures that could be used to reduce another unwanted reflections, such as choosing high-return loss passive optical components, angled end of fiber pigtail, and Apodized DFB FLs[10].

From Fig. 4(a) to (c), it's interesting to point out that FL16 keeps the excellent performance, and the reason is that κ of FL16 is about 161 m^{-1}, which is the highest in all the FLs. So the increase of phase-shifted grating coupling coefficient (i.e. reflectivity) could be one way to reduce the influence of RB, but the magnitude shouldn't be too high to activize the higher mode[11].

4. CONCLUSIONS

A 16 channel DFB FL sensor array has been investigated. The stability of DFB FL is determined by the unintentional small reflection from return loss from WDM and ISO, adjacent grating sideband feedback, and Rayleigh backscattering. In this FL sensor array with 100 GHz and 200 GHz spacing in turn, Rayleigh backscattering is more important, and we also found that lower sensitivity of DFB FL to RB could benefit from the larger coupling coefficient κ.

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