Spatial-Resolution Improvement in Optical Frequency Domain Reflectometry System Based on Tunable Linear Fiber Laser

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Abstract. In optical frequency domain reflectometry (OFDR) system, the spatial resolution is obtained by using the total frequency-sweep span of the tunable laser. However, in practice, the spatial resolution is severely limited by nonlinearity in the lightwave-frequency sweep of the tunable laser. A closed-loop PZT modulated DBR linear fiber laser is proposed to improve the spatial resolution of the OFDR system. Experimental results show that the spatial resolution of OFDR system has improved greatly. When the frequency sweep excursion is 66GHz and the fiber under test (FUT) is 7 m, the OFDR system has a spatial resolution of 1.5 m with open-loop PZT modulated laser. But the spatial resolution increases to 35 cm with closed-loop PZT modulated laser.

1. Introduction
Optical reflectometry is a powerful technique for the characterization of optical fibers and components. Different techniques have been developed, depending on the desired spatial range, resolution, dynamic range and sensitivity [1]. Now, Time domain techniques based on Optical time-domain reflectometry (OTDR) have maximum measurable fiber spans of a few tens kilometers, with resolutions of a few meters. However, the OTDR technique generally has to suffer from a tradeoff between dynamic range and spatial resolution. OFDR based on frequency-modulated continuous-wave (FMCW) reflectometry promises many advantages over the OTDR. It offers the possibilities of much higher sensitivity and larger dynamic range combined with higher spatial resolution than that of the OTDR [2].

In optical frequency domain reflectometry (OFDR) system, the spatial resolution is obtained by using the total frequency-sweep span of the tunable laser. That is, a wide frequency-sweep span provides a high spatial resolution. However, in practice, the spatial resolution is severely limited by nonlinearity in the lightwave-frequency sweep of the tunable laser [3].

In this paper, A way is proposed to improve the spatial resolution of the OFDR system by introducing a closed-loop PZT modulated DBR fiber laser. The PZT directly stretches the cavity length of the DBR fiber laser, so the frequency-modulation excursion is as much as 100GHz.
2. Experimental setup

Figure 1 is a schematic diagram of our experimental setup for OFDR measurement. The active fiber used in the DBR laser was Er/Yb co-doped fiber, the fiber has a B-Ge-Si annulus with a diameter of 16µm around the 4-µm diameter Er-Yb phosphosilicate core. The DBR laser was fabricated by directly inscribing grating pair in active fiber with 193nm excimer laser and phase mask method. The laser cavity was fixed by the supports, and the PZT could control the laser cavity to stretch. The output optical power of the DBR fiber laser was kept 4 mW during the frequency tuning process.

![Figure 1. Experiment setup for OFDR measurement.](image)

The ISO avoids the reflected light back to the DBR fiber laser. Two optical waves, which are derived from the DBR fiber laser whose frequency is modulated with a function generator but have traveled along different paths, are recombined at a point in the fiber [4,5]. The main interferometer is built with a 3dB coupler that is used for launching the light wave into the FUT and receiving the reflected light. The frequency-swept light from DBR laser is split using a 3dB coupler, 50% of the optical power goes into the FUT, and the remaining optical power goes into reference arm. Finally the reflected lights generate interference signal at a photodetector (PD), and the beat signals are acquired using the data acquisition card with a triggering signal generated each time when the frequency sweep begins.

3. Experimental results and discussion

3.1. tunable DBR fiber laser based on PZT modulation

In order to improve the spatial resolution of OFDR measurement system, the nonlinearity of the tunable fiber laser must be improved. But the PZT has the hysteresis characteristic, which leads to nonlinearity of the tunable fiber laser. A way is proposed to improve the linearity of the tunable DBR fiber laser based on closed-loop PZT modulation. That is, the fiber laser is modulated by a closed-loop PZT instead of open-loop PZT. The theory of closed-loop PZT modulation is as follow: the PZT stretches with the driving voltage increases, but the stretch of PZT has displacement difference because of hysteresis character. The displacement sensor attached to the PZT will monitor the displacement difference of the stretch, and the displacement difference is converted into the voltage signal, then the voltage signal modifies the driving voltage of the PZT, which assures the linearity of the PZT stretch. Fig.2 shows the nonlinear curve of the tunable DBR fiber laser based on open-loop PZT modulation.
Figure 2. The tunable curve of DBR fiber laser based on open-loop PZT modulation.

The solid rectangles represent the tunable laser peak wavelength with driving voltage increases, and the hollow circles represent the tunable laser peak wavelength with driving voltage decreases. The solid line and the dashed line show the fit curves of rising and falling peak wavelength data, and they don’t coincide with each other. From the figure 2, the open-loop PZT has serious hysteresis character, so the tunable curve of the DBR fiber laser based on open-loop PZT modulation is nonlinear apparently.

Figure 3. The tunable curve of DBR fiber laser based on closed-loop PZT modulation.

The solid rectangles represent the tunable laser peak wavelength with displacement increases, and the hollow circles represent the tunable laser peak wavelength with displacement decreases. The solid line and the dashed line show the fit curves of rising and falling peak wavelength data, and they coincide with each other. From the figure 3, the tunable curve of the DBR fiber laser based on closed-loop PZT modulation is linear apparently.

3.2. Spatial resolution improvement in OFDR system

In OFDR system measurement, the frequency sweep excursion is 66GHz, the FUT is 7m, and the DBR fiber laser is modulated by open-loop PZT, the spatial resolution is 1.5m, as shown in figure 4. The sweep nonlinearity of the tunable fiber laser based on open-loop PZT modulation causes its frequency to fluctuate, and this frequency fluctuation is converted to an amplitude change in an
electric signal. So the OFDR waveform in figure 4 is indistinct with many sidebands, and the signal noise ratio (SNR) is low.

![Graph of OFDR measurement based on open-loop PZT modulation.](image1)

**Figure 4.** OFDR measurement based on open-loop PZT modulation.

In the figure 5, the frequency sweep excursion and the FUT are same as that in figure 4, but the tunable DBR fiber laser is modulated by closed-loop PZT, experimental results show that the spatial resolution of OFDR system increases to 35cm. The sweep linearity of the tunable fiber laser based on closed-loop PZT modulation decreases its frequency fluctuation, so the OFDR waveform in figure 5 is distinct with few sidebands, and the SNR is higher than SNR in figure 4.

![Graph of OFDR measurement based on closed-loop PZT modulation.](image2)

**Figure 5.** OFDR measurement based on closed-loop PZT modulation.

4. **Conclusion**
The spatial resolution improvement in OFDR system based on tunable linear fiber laser is studied. Experimental results show that the spatial resolution of OFDR system has improved greatly. When the frequency sweep excursion is 66GHz and the FUT is 7 m, the OFDR system has a spatial resolution of 1.5 m with open-loop PZT modulated nonlinear laser. But the spatial resolution increases to 35 cm with closed-loop PZT modulated linear laser.

5. **References**
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