Novel method for fiber chromatic dispersion measurement based on microwave photonic technique

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In this letter, we propose and demonstrate a simple and novel method for fiber chromatic dispersion (CD) measurement based on microwave photonic technique. The radio frequency (RF) signal is modulated simultaneously on two light-waves with different wavelengths, and the light-wave carrying RF signals transmit through the dispersive medium under test. CD can be obtained by monitoring the power changing of the interference RF signals after photo detector. The CD values of the single-mode and dispersion compensation fibers are both measured within the wavelength range from 1 525 to 1 605 nm, which verifies the feasibility of this method.

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Chromatic dispersion (CD) of optical fibers is critical to the design of long-haul optical transport system with high data rate and radio over fiber (ROF) transmission systems with high radio frequency (RF)[1,2]. A variety of techniques have been proposed for measuring CD of optical fiber, including the pulse-delay, phase-shift, and interferometric methods[3−5]. Recently, several novel approaches for CD measurement utilizing microwave-photonic techniques have been proposed[6−12]. CD can be determined by measuring relative group delay through the frequency spectrum range of microwave notch filter[6]; however the accuracy of this method is susceptible to the environmental conditions that add different phase noises to the reference path and the test path. CD can also be obtained with precise measurement using the phase to intensity modulation conversion[7]; however, the wavelength of the light source and the frequency of the modulation microwave have to be scanned if CD in a large light-wave range is needed. The coherent heterodyne detection method, which down converts the spectrum of digitally modulated signals from the optical to the RF domain has been used for CD monitoring[8]. Improvements have been made to the method by measuring the power of clock tones that are down converted to very low frequencies to avoid extra costs from expensive electronic devices[9]. The RF power spectrum[10] and RF clock power ratio with optical notch filter[11,12] have been proposed and demonstrated for CD monitoring with high speed optical transmission systems.

In this letter, we propose and demonstrate a novel and simple microwave photonic technique to measure optical fiber CD. CD can be measured by monitoring the power values of the interference microwave signals, which vary with the scanning wavelength of the tunable laser source (TLS). The CD curves of both single-mode fiber (SMF) and dispersion compensation fiber (DCF) can be measured easily, thereby demonstrating that this approach is a simple and feasible method for use in CD measurement.

The schematic diagram of our proposed system is shown in Fig. 1. Light-waves from the two lasers, one with a fixed wavelength λ_1 and the other with a tunable wavelength λ_2, were coupled into an electro-optic Mach-Zehnder modulator (MZM) through an optical coupler. The amplitudes of the two lasers were simultaneously modulated by the same RF signal with frequency f_{RF} and initial phase φ_0. The modulated light-waves were transmitted through a dispersion medium being tested (SMF or DCF), after which the phase shifts of the two light-wave carrying RF signals accumulated owing to the CD of the medium. The two RF signals detected by the photo detector (PD) can be expressed as[13]

$$A_1(t) \propto A_{10}\cos\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_1^2}{c}\right)\cos(2\pi f_{\mathrm{RF}} t + \varphi_0 + \varphi_1), \tag{1}$$

$$A_2(t) \propto A_{20}\cos\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_2^2}{c}\right)\cos(2\pi f_{\mathrm{RF}} t + \varphi_0 + \varphi_2), \tag{2}$$

where A_{10} and A_{20} are the amplitudes of the two RF signals, DL is the total CD value (ps/nm), c is the speed of light in vacuum, and φ_1 and φ_2 are the phase shifts of the RF signals through the dispersion medium.

The values of A_{10} and A_{20} can be set to the same amplitude $A_{10} = A_{20} = A_0$ in the measurement process, which is the condition for optimal interference effect. Then the RF power after PD can be expressed as

$$\begin{aligned} P \propto \overline{|A_1(t) + A_2(t)|^2} &\propto A_0^2\cos^2\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_1^2}{c}\right) \\ &+ A_0^2\cos^2\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_2^2}{c}\right) + 2A_0^2\cos\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_1^2}{c}\right) \\ &\cdot \cos\left(\frac{\pi \mathrm{DL} f_{\mathrm{RF}}^2 \lambda_2^2}{c}\right)\cos(\Delta\varphi), \end{aligned} \tag{3}$$

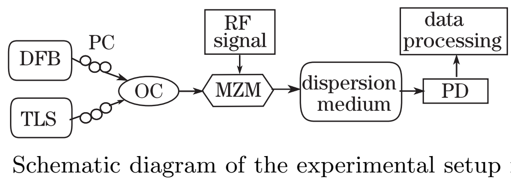

Fig. 1. Schematic diagram of the experimental setup for CD measurement. PC: polarization controller; TLS: tunable laser source; OC: optical coupler.

where $\Delta\varphi = \varphi_2 - \varphi_1$ is the phase difference between the two light-waves carrying RF signals induced by the dispersion medium. This can be written as

$$\Delta\varphi = \omega_{\mathrm{RF}}\Delta\tau = 2\pi f_{\mathrm{RF}}\Delta\tau, \quad (4)$$

where $\Delta\tau$ is the group time delay difference between the two RF signals, and is generated by the two light-waves in the dispersion medium. It can be expressed as[14]

$$\Delta\tau = \mathrm{DL}\Delta\lambda, \quad (5)$$

where $\Delta\lambda = \lambda_2 - \lambda_1$ is the wavelength difference of the two light-waves. According to Eqs. (4) and (5), the phase difference between the two light-waves carrying RF signals in the proposed measurement system can be expressed as

$$\Delta\varphi = 2\pi f_{\mathrm{RF}}\mathrm{DL}(\lambda_2 - \lambda_1) = \Delta\varphi_0 + \delta\varphi, \quad (6)$$

where $\Delta\varphi_0 = 2\pi f_{\mathrm{RF}}\mathrm{DL}(\lambda_{20} - \lambda_1)$, $\delta\varphi = 2\pi f_{\mathrm{RF}}\mathrm{DL}\delta\lambda_2$, $\lambda_2 = \lambda_{20} + \delta\lambda_2$, and λ_{20} and $\delta\lambda_2$ are the initial wavelength and the scanning wavelength range of the TLS, respectively. From Eq. (3), we can see that the received RF power changes periodically with $\delta\lambda_2$ (also shown as the measurement result in Fig. (2), and the total CD value can be achieved by

$$\mathrm{DL} = \frac{\delta\varphi}{2\pi f_{\mathrm{RF}}\delta\lambda_2}. \quad (7)$$

When the received RF power varies in one period, the phase separation $\delta\varphi$ becomes equal to 2π. Thus, the phase separation is π for the received RF power varying from maximum to minimum. The total CD can be calculated by Eq. (7) with the wavelength scanning range $\delta\lambda_2$.

In CD measurement, the experiment setup consisted of a TLS (Agilent 81600B) with tuning range from 1 525 to 1 605 nm, a distributed feedback laser (DFB) (Emcore-1772) with center wavelength of 1 550 nm, an MZM (Covega Mach-LN$^{\mathrm{TM}}$ 058) with bandwidth of 20 GHz, and a PD with bandwidth of 40 GHz (u^{2}t 2120R). The RF signals at different frequencies were generated by a signal generator (Agilent 8267D). The RF signal power was monitored by a microwave power meter. The LABVIEW platform was used to collect data from the scanned wavelength of TLS and the obtained RF signal power. In the experiment, the optical power of the DFB-LD and TLS were both set to 6 dBm. The wavelength λ_2 of the TLS was scanned from 1 525 to 1 605 nm. The CD values of the 25-km SMF and 200-m DCF available in our laboratory were also measured.

Figure 2 shows the typical measured RF signal power and fitted curve for the dispersion medium of the 25-km SMF (with RF frequency of 1 GHz). The measured RF signal power varies periodically with the wavelength of the TLS, which is consistent with Eq. (3). The red solid line represents the fitted curve following the sine function. The total CD DL can be calculated with Eq. (7).

Firstly, the total CD DL of the 25-km SMF was measured. Figures 3(a)–(c) show the results of the RF signals at frequencies of 1, 2, and 6 GHz, respectively. The proposed method works well for the CD measurement of SMF. The total CD DL of the 25-km SMF is about from 375 to 490 ps/nm linearly varying from 1 525 to 1 605 nm; in addition, the CD slope can be calculated as 0.058 ps/nm^2·km with the slope of the fitted line.

In the fixed wavelength range, there are fewer measured data points for a lower RF frequency (f_{RF}=1 GHz, Fig. 3(a)) and more for a higher RF frequency (f_{RF}=6 GHz, Fig. 3(c)). This can be understood with Eq. (7), which shows that with higher RF frequency, the scanning range $\delta\lambda_2$ of TLS for one interference period is shorter than the one with lower RF frequency. Thus, there are more periods in the fixed wavelength range that produce more calculated data points, and

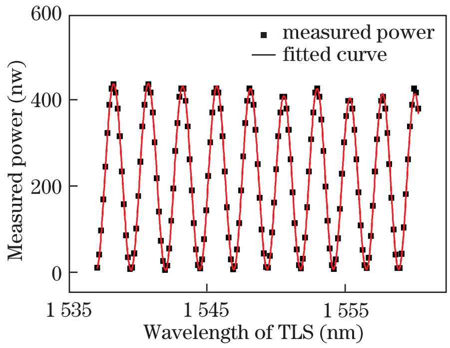

Fig. 2. Measured RF power versus the wavelength of TLS.

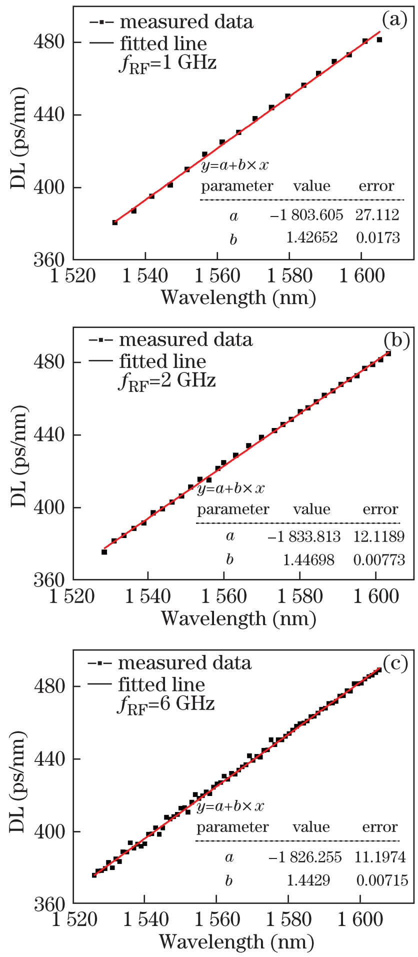

Fig. 3. Measured total CD of the 25-km SMF with RF frequencies of (a) 1, (b) 2, and (c) 6 GHz.

the measurement accuracy can be improved. However, data processing becomes more complex when the RF frequency is extremely high.

The total CD DL of 200-m DCF was measured with RF frequencies of 20, 10, and 4 GHz. The results for all frequencies are shown in Figs. 4(a)–(c), respectively. The total CD DL of the 200-m DCF ranges from −27 to −35 ps/nm and varies from 1 525 to 1 605 nm; it also has absolute total dispersion value that is smaller than that of the 25-km SMF. For the small DL, there are fewer measured data points with lower RF frequency as shown in Fig. 4(c); this induces measurement error and cannot provide the correct CD slope.

With the slope of the fitted line in Fig. 4(a), the CD slope of the DCF can be calculated as −0.53 ps/(nm^2·km), which agrees well with the calibration value −0.50 ps/(nm^2·km) given by the fiber manufacturers (DCF-G.652C/250, Changfei Corp).

The CD values of the 25-km SMF and 200-m DCF were obtained with the proposed method. To gain accurate results with simple data processing, the frequency of RF signal should be chosen properly. For example, when the dispersion medium has a large total CD value |DL|, the RF frequency should be set to a relatively smaller value in order to simplify the data processing. On the contrary, when the dispersion medium has small |DL|, the microwave frequency should be set relatively higher in order to obtain accurate results.

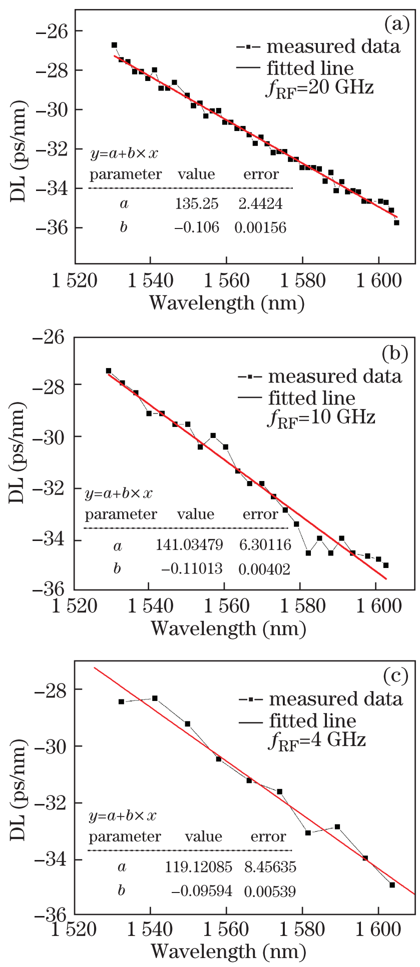

Fig. 4. Measured total CD of the 200-m DCF with RF frequencies of (a) 20, (b) 10, and (c) 4 GHz.

In conclusion, a novel CD measurement method based on microwave photonic technique is proposed and demonstrated. The CD values of the 25-km SMF and 200-m DCF are both obtained using the proposed method. The influence of RF frequency on the measurable data points and data processing are also investigated. This method provides a good choice for future fiber CD measurements.

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References

1. X. Gu, H. Chen, M. Chen, and S. Xie, Chin. Opt. Lett. **10,** 020601 (2012).
2. J. Maeda, K. Kusama, and Y. Fukuchi, Opt. Express **17,** 4518 (2009).
3. L. Cohen, J. Lightwave Technol. **3,** 958 (1985).
4. L. Thevenaz, J.-P. Pellaux, and J.-P. Von der Weid, J. Lightwave Technol. **6,** 1 (1988).
5. J. Lee and D. Kim, Opt. Express **14,** 11608 (2006).
6. X. Yi, C. Lu, W. Fang, Y. Wang, and W. Zhong, in *Proceedings of International Topical Meeting on Microwave Photonics* 293 (2002).
7. T. Yamamoto, K. Kurokawa, K. Tajima, and T. Kurashima, in *Proceedings of Optical Fiber Communication Conference* OThD1 (2009).
8. B. Fu and R. Hui, IEEE Photon. Technol. **17,** 1561 (2005).
9. F. N. Khan, A. P. T. Lau, Chao Lu, and P. K. A Wai, in *Proceedings of IEEE Optoelectronics and Communication Conference* OECC **14,** 1 (2009).
10. J. Zhao, A. P. T. Lau, K. K. Qureshi, Z. Li, C. Lu, and H. Y. Tam, J. Lightwave Technol. **27,** 5704 (2009).
11. J. Yang, C. Yu, Y. Yang, L. Cheng, Z. Li, C. Lu, A. P. T. Lau, H. Y. Tam, and P. K. A. Wai, IEEE Photon. Technol. **23,** 1576 (2011).
12. J. Yang, C. Yu, L. Cheng, Z. Li, C. Lu, A. P. T. Lau, H. Y. Tam, and P. K. A. Wai, Opt. Express **19,** 1354 (2011).
13. G. H. Smith, D. Novak, and Z. Ahmed, IEEE Trans. Microw. Theory Tech. **45,** 1410 (1997).
14. A. J. Barlow, R. S. Jones, and K. W. Forsyth, J. Lightwave Technol. **5,** 1207 (1987).