THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 62, No. 2, February 1983
Printed in U.S.A.

Chromatic Dispersion Measurements in Single-Mode Fibers Using Picosecond InGaAsP Injection Lasers in the 1.2- to 1.5-μm Spectral Region

By C. LIN, A. R. TYNES, A. TOMITA, P. L. LIU and D. L. PHILEN

(Manuscript received September 23, 1982)

We describe the use of picosecond InGaAsP injection lasers for measuring chromatic dispersion in single-mode fibers in the 1.2- to 1.5-μm spectral region. Injection lasers at various wavelengths and a single-mode fiber-to-fiber switch are used in the pulse delay and pulse-broadening measurements. The simplicity and the compactness make the setup useful for field measurements and quality control.

I. INTRODUCTION

Modal and chromatic dispersion measurements in multimode and single-mode fibers provide important information about the bandwidth limitations in optical fiber transmission. A near-infrared, fiber Raman laser with subnanosecond pulses in the 1- to 1.7-μm region can be used for dispersion measurement in both multimode and single-mode fibers.[1-3] While this infrared-fiber, Raman-laser-based measurement system has been very useful and widely adopted, it has its limitations in terms of time resolution (by the mode-locked laser pulsewidth, ~140 ps) and is not suitable for field measurements because of its large size.

In this paper we describe a simpler dispersion measurement system based on picosecond InGaAsP injection lasers and ultrafast InGaAs p-i-n detectors. This is similar to the measurement system we used for measuring high-bandwidth multimode fibers,[4] except now in order to study the chromatic dispersion in single-mode fibers by pulse delay measurements, we need to use injection lasers at different wavelengths in the 1.3-μm spectral region. Besides being more compact, this system also has a better time resolution than the fiber Raman laser setup.

II. EXPERIMENTAL APPROACH

The experimental approach is straightforward. Figure 1 shows the setup in which several InGaAsP injection lasers with wavelengths in the 1.2- to 1.5-μm spectral region are used for pulse delay and pulse-broadening measurements in single-mode fibers. A picosecond electrical pulser is used to drive one or two injection lasers at a time to obtain optical pulses of 30 to 80 ps in duration. The laser pulses coming out of single-mode fiber pigtails are selected by a low-loss, single-mode, fiber-to-fiber switch[5] and sent through the test fiber, the output of which is detected with a pigtailed InGaAs fast-pin photodiode.[6] The optical pulsewidth and wavelength-dependent pulse delay information can be stored in the digital oscilloscope for further processing.

The InGaAsP injection lasers used are supplied by Lasertron Co. and have their center wavelengths near 1.21, 1.26, 1.315, 1.335, and 1.525 μm when pulsed to give short optical pulses. The technique of generating short optical pulses is that of gain-switching,[7,8] which manifests itself as controlled relaxation oscillation[9] and requires proper adjustment of the pumping level to give a single, short, optical pulse. Either the short electrical pulses from a comb generator[7] and step-recovery-diode circuit[10] or a high radio frequency (RF) sinusoidal drive[11] can be used as the pump, except it has been shown that for low repetition frequencies (a few hundred MHz or less), short electrical pulse pumping results in shorter optical pulses.[9] The laser spectral width is typically ~7 nm owing to multi-longitudinal-mode oscillation in the short-pulse generation.[7,8]

Figures 2a and b illustrate a typical measurement result obtained with a 6-km-long single-mode test fiber. The laser pulses at 1.335 and 1.315 μm are selected with the single-mode fiber switch and are sent

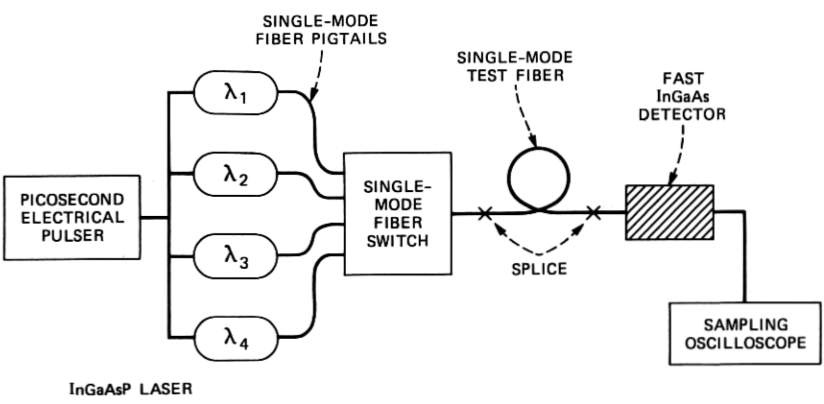

Fig. 1—The schematic of the experimental setup. A 4 × 1 switch is shown. Five injection lasers are actually used in our preliminary measurements. The fifth laser has a connectorized fiber pigtail for direct connection to the test fiber.

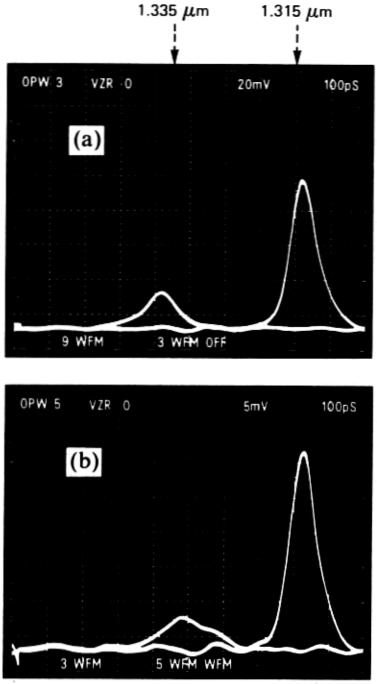

Fig. 2—The pulse pair at 1.335 μm and 1.315 μm (a) before and (b) after the 6-km-long single-mode fiber.

through the test fiber. The pulses before and after the fiber as recorded and stored are shown in Figs. 2a and b, respectively. These are both doubly exposed oscilloscope pictures showing the relative pulse delay change and pulsewidth change owing to dispersion in the test fiber. Note that the pulse at 1.315 μm being near the minimum dispersion wavelength, λ_0, experiences no broadening, while the pulse at 1.335 μm shows considerable broadening owing to chromatic dispersion in the fiber. The display is adjusted to show the relative delay difference between the two optical pulses before and after the test fiber. The change in the delay difference ($\Delta\tau$) is ~60 ps, with the 1.335-μm pulse experiencing more delay because the 1.315-μm pulse lies much closer to the minimum dispersion wavelength, λ_0. Figures 3a and b show similar results for the pulse pair at 1.21 and 1.315 μm. The 1.21-μm pulse has experienced more delay and broadening than does the 1.315-μm pulse. In time, the 1.21-μm pulse falls behind the 1.315-μm pulse after the 6-km fiber, even though it is ahead of the latter by more than 2 ns. The relative delay change $\Delta\tau$ is 3.1 ns.

Similar wavelength-dependent pulse-delay change and pulse-broadening results are obtained for the pulses at 1.26 and 1.525 μm with respect to 1.315 μm. The experimental results $\Delta\tau(\lambda)$ (in ns/km) are

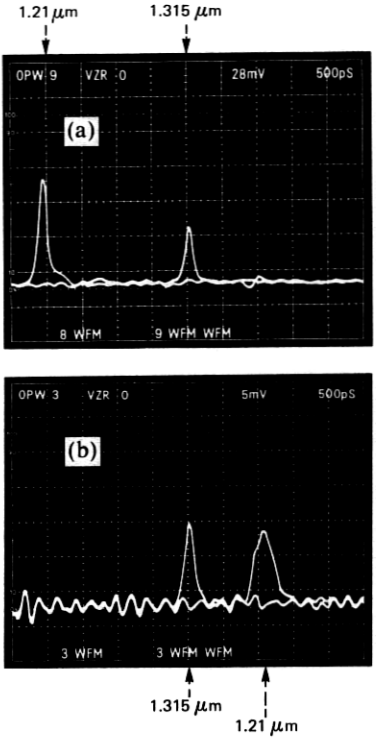

Fig. 3—The pulse pair at 1.21 μm and 1.315 μm (a) before and (b) after the 6-km-long single-mode fiber.

plotted as dots in Fig. 4a. The solid line is a third-order, Chebyshev polynomial fit ($F(\lambda) = a + b\lambda + c\lambda^2 + d\lambda^3$) on an *HP*-85 computer. The derivative of this fitted polynomial is a second-order polynomial whose root (zero-crossing point) gives λ_0, the minimum chromatic dispersion wavelength. Figure 4b plots the obtained chromatic dispersion M(λ) in ps/nm-km. The obtained λ_0 is ~1.314 μm ± 0.004 μm, in reasonable agreement with the 1.309-μm value measured with the fiber Raman laser setup.

III. DISCUSSION AND SUMMARY

Compared with the fiber Raman laser setup, the combination of the picosecond injection lasers and the single-mode fiber switch provides a simple, compact, measurement setup for single-mode fiber chromatic dispersion measurements. In addition, the setup has a better time resolution owing to the short pulse duration and the jitter-free characteristics. While it has a lower dynamic range than the fiber Raman laser, with its 10- to 15-dB dynamic range, typical single-mode

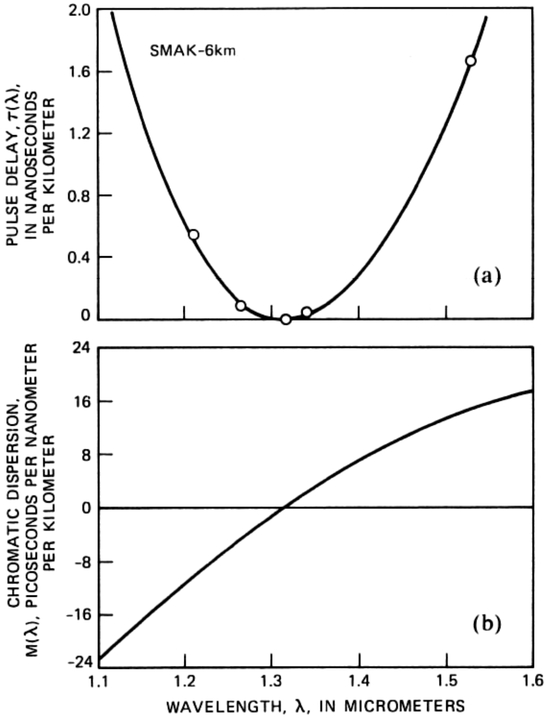

Fig. 4—(a) The time delay vs. wavelength data (dots) with respect to the reference wavelength 1.315 μm. The solid curve is the fitted third-order polynomial. (b) Chromatic dispersion obtained by differentiating the fitted polynomial of (a).

fiber lengths of 5 to 10 km can be measured over the 1.2- to 1.5-μm spectral range, and more than 20 km can be measured over the low-loss region close to 1.3 and 1.55 μm. In practice, the discrete wavelength coverage limits the wavelength resolution. For studying fibers with new or unconventional dispersion characteristics over a wide spectral range, more injection lasers are needed (e.g., 10) for more wavelength coverage. In single-mode fibers for which the design phase has passed and a specific design concerning chromatic dispersion is established, this setup is useful for quality control and field testing by measuring the pulse delay and pulse broadening at a number of selected wavelengths.

IV. ACKNOWLEDGMENTS

We would like to thank R. Knerr and S. Kaufman for supplying the single-mode fiber switch, W. C. Young and L. Curtis for the single-mode fiber connectors, and P. F. Glodis for providing the single-mode fibers.

REFERENCES

1. L. G. Cohen, P. Kaiser, and C. Lin, "Experimental techniques for evaluation of fiber transmission loss and dispersion," Proc. IEEE, *68* (October 1980), pp. 1203–9.
2. W. F. Love, "Bandwidth spectral characterization of G_eO_2-P_2O_5-SiO_2 multimode optical waveguides," Digest of 6th European Conference on Optical Communication, York, U.K., 1980, pp. 113–15.
3. M. Horiguchi, Y. Ohmori, and H. Takata, "Profile dispersion characteristics in high bandwidth optical fibers," Appl. Opt., *19* (September 1980), pp. 3159–69.
4. C. Lin, P. L. Liu, T. P. Lee, C. A. Burrus, F. T. Stone, and A. J. Ritger, "Measuring high bandwidth fibers in the 1.3 μm region with picosecond InGaAsP injection lasers and ultra fast InGaAs detectors," Electron. Lett., *17* (June 1981), pp. 438–40.
5. W. C. Young and L. Curtis, "Cascaded multipole switches for single-mode and multimode optical fibers," Electron. Lett., *17* (August 1981), pp. 571–3.
6. T. P. Lee, C. A. Burrus, K. Ogawa, and A. G. Dentai, "Very-high-speed back-illuminated InGaAs/InP pin punch-through photodiodes," Electron. Lett., *17* (June 1981), pp. 431–2.
7. C. Lin, P. L. Liu, T. C. Damen, D. J. Eilenberger, and R. L. Hartman, "Simple picosecond pulse generation scheme for injection lasers," Electron. Lett., *16* (July 1980), pp. 600–2.
8. P. L. Liu, C. Lin, I. P. Kaminow, and J. J. Hsieh, "Picosecond pulse generation from InGaAsP lasers at 1.25 and 1.3 μm by electrical pulse pumping," IEEE J. Quantum Electron., *QE-17* (May 1981), pp. 671–4.
9. C. Lin, unpublished work.
10. P. T. Torphammer and S. T. Eng, "Picosecond pulse generation in semiconductor lasers using resonance oscillation," Electron. Lett., *16* (July 1980), pp. 587–9.
11. H. Ito, H. Yokoyama, S. Murata, and H. Inaba, "Generation of picosecond optical pulses with highly rf modulated AlGaAs DH laser," IEEE J. Quantum Electron., *QE-17* (May 1981), pp. 663–70.