CMD's dispersion slope is static and deterministic, and hence, it can be compensated using digital post-processing [35–37]. Thus, knowledge of the CMD dispersion combined with the appropriate laser source and detector will enable high spectral resolution, real-time spectroscopy at any wavelength for which the fiber is transparent or a hollow waveguide can be constructed.

4. Conclusion

In summary, we have demonstrated and characterized a compact device that produces large and tunable group velocity dispersion. This has been achieved by transforming the large modal dispersion of a multimode fiber into chromatic dispersion. The amount of dispersion as well as the zero dispersion wavelength is tunable and produces normal or anomalous dispersion, with maximum dispersion limited only by the coupling length and NA of the multimode fiber used. As a proof of concept demonstration, we stretch a sub-picosecond optical pulse to nearly 2 ns in 20 m of multimode optical fiber. By adjusting the grating groove density and separation, The CMD can be configured to accommodate larger or smaller bandwidth pulses, while maintaining the same output pulse width. To demonstrate one of its utilities, we demonstrated single-shot atomic absorption spectroscopy of rubidium vapor. The large dispersion and small footprint of the device make the CMD potentially useful for on-chip dispersion compensation using optical components such as integrated gratings and planar multimode waveguides. The CMD's physical compactness, combined with the magnitude and tunability of its dispersion suggest its use as a versatile tool for pulse stretching or compression in a variety of applications in which the capabilities of singlemode fiber or diffraction grating-based dispersive elements will not suffice.

5. Methods

The CMD used in all experiments except for absorption spectroscopy is constructed from a pair of 900-grooves/mm ruled diffraction gratings spaced 14 cm apart, a f = 35 mm, 25.4-mm diameter, antireflection-coated achromatic doublet lens, and a 20-m long, 200-μm diameter core, 0.37-NA step-index pure silica core, polymer cladding multimode optical fiber. The lens and fiber are mounted on the same linear translation stage, such that as the transverse alignment of the lens is altered, the fiber tip remains at the focus of the lens. Modulation phase shift measurements were performed using a custom-built continuous wave Ti:sapphire laser. The laser linewidth full width at half maximum for each measurement point was less than 0.20 nm. The RF lock-in amplifier time constant was set to 1 second for all measurements. Time-domain measurements were performed by connecting an unamplified InGaAs photodiode with a 25-ps impulse response time to the output of the CMD. Electrical signals from the photodiode are recorded using a 50-gigasample/s, 16-GHz analog bandwidth oscilloscope. Real-time atomic absorption spectroscopy was performed on a heated 75-mm length rubidium vapor cell (natural isotope mixture) in a triple-pass geometry. A narrow bandpass filter ($\Delta\lambda$ = 3 nm) centered at 780-nm was placed after the rubidium cell to limit the optical bandwidth entering the CMD. The CMD configuration used in this experiment consisted of two 30-mm length, 2000 grooves/mm ruled diffraction gratings spaced by 28 cm. The lens and fiber were the same as used in all other experiments.

Acknowledgments

E. D. D. and B. J. conceived the design of the CMD. J. C. and T. S. performed initial simulations of the device. E. D. D., N. K. H., Z. T., and C. W. performed the experiments and data analysis. E. D. D. wrote the first draft of the manuscript.