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BROADBAND METHOD FOR GROUP VELOCITY DISPERSION MEASUREMENTS IN THE MID-INFRARED

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A setup for broadband measurements of dispersion parameter in optical fibers based on the Mach–Zehnder interferometer is developed. Tm-doped fiber pumped at 1.61 μm was used as a source of broadband emission, that allowed to achieve the measurement spectral range of 1700 to 2000 nm. The method is applicable for comparatively short pieces of optical fiber with lengths of less than 1 meter. The method was successfully tested for the standard telecommunication SMF-28 fiber. (E-mail : nikolai.tolstik@ntnu.no)

Key Words: optical fiber, dispersion measurements, mid infrared.

Introduction

Solid-state and fiber lasers working at 2-μm wavelength are of great interest because of several favorable characteristics. Owing to the strong absorption by liquid water, the 2-μm laser is an ideal light source for bio-medical applications. The 2-μm laser can also be used for range finding, coherent laser LIDAR and atmospheric sensing since it is in the eye-safe spectral range. In addition, high-power 2-μm lasers are preferable as pump sources for optical parametric oscillators (OPOs) and optical parametric amplifiers (OPAs) in the mid-infrared region than 1-μm lasers since they provide higher quantum efficiency. Based on these considerations, solid-state and fiber lasers operating around the 2-μm waveband have been intensively investigated recently [1–4].

However, only few demonstrations of mode-locked subpicosecond fiber lasers operating at 2 μm have been reported to date, mainly due to lack of proper pulse initiative components and large anomalous dispersion of conventional optical fibers at 2 μm [5–8]. Precise cavity design or dispersion management of active as well as passive optical fibers became essential for generation and delivery of ultrashort pulses in this spectral range. Measuring of dispersion in fibers is also important since it became possible to produce special microstructured optical fibers (photonic crystal fibers - PCF) with controllable group-velocity dispersion [9, 10]. Such fibers with precisely positioned zero-dispersion wavelength are used as sources of superbroadband emission (supercontinuum) [11, 12], which are important for spectroscopic applications, detection of gases etc.

Several methods were developed for measuring of dispersion parameter of optical fibers since 1980's [13–17]. Most of the techniques are interferometric and require the source of low-coherent emission to be used in the setup. The most challenging task on the way of adopting these methods for mid-IR spectral range is the lack of the broadband sources of low-coherent light in this spectral region. In this work we present a setup for measurements of dispersion parameter in optical fibers in the wavelength range from 1.7 to 2.0 microns. The setup is distinguished from the existing similar measurement systems by using the broadband high-power superluminescent fiber source, allowing to achieve broad spectral coverage with a high signal-to-noise ratio. For the demonstration of capabilities of the setup we present dispersion parameter measurement of standard telecommunication fiber.

Description of the method

The experimental setup is presented in figure 1. The setup is based on Mach-Zender interferometer. As a source of superluminiscent emission a high numerical aperture 5-m long Tm-doped fiber was used. The luminescence in the fiber was excited by CW Er-fiber laser emitting at 1610 nm. To prevent lasing in Tm-fiber its output end was cleaved to 7 degrees and excitation power was limited to 600 mW. The spectrum of the superluminescence is presented in figure 2. The optical power of the amplified spontaneous emission with about 50 nm FWHM reached 5 mW. This power level exceeds, to our knowledge, the optical power of the best commercially available superluminescent semiconductor lasers at this wavelength.

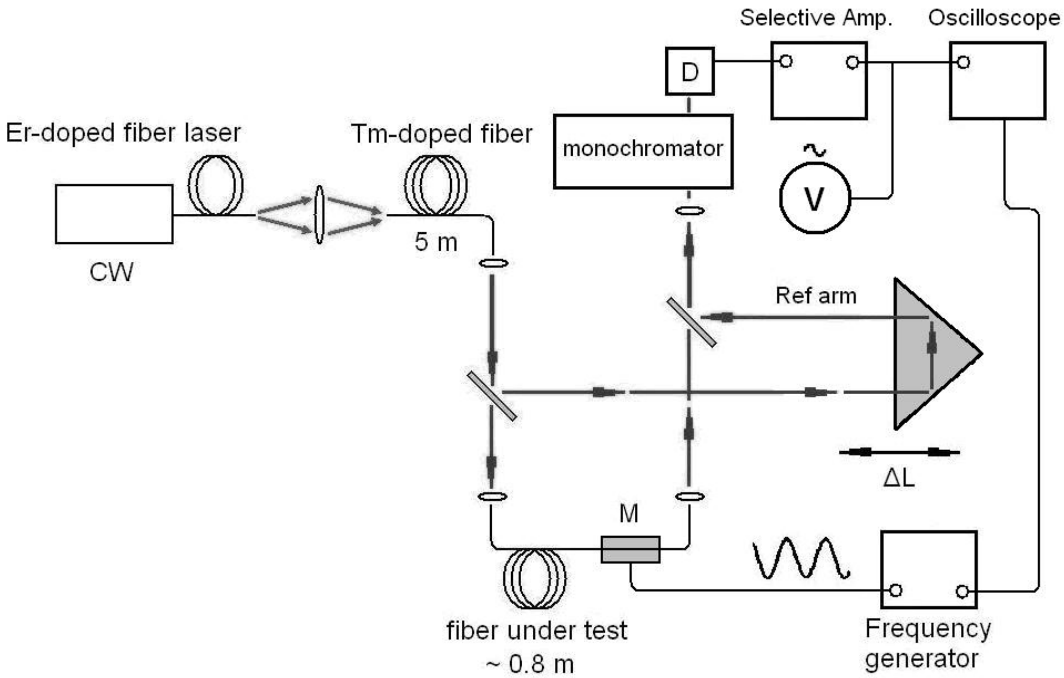

Figure 1 – Experimental setup for measurements of dispersion parameter in optical fibers in mid-IR spectral region

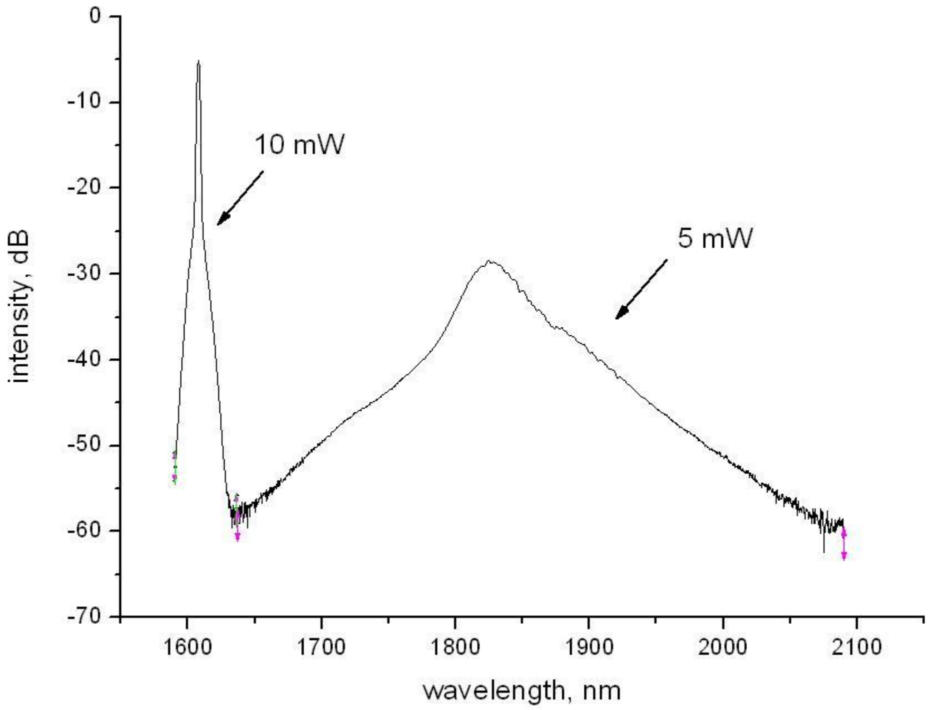

Figure 2 – Spectrum of superluminescence of 5-m long Tm-doped fiber. The narrow band at 1610 nm is the emission of erbium fiber laser used as excitation source

The luminescence emission produced in the fiber was collimated and divided to two equal parts by 50/50 dielectric beamsplitter (at 2000 nm, 45°). The fiber under test was placed into the sample arm and the air arm is used as the reference arm with variable length. The fiber in the sample arm was modulated. As a modulator «M» we used electromagnetic system that induced periodical longitudinal tension of the fiber and thus provided sinusoidal change in optical path length of the sample arm. The modulation amplitude was equal to several micrometers. The electromagnetic modulator was connected to the frequency generator and operated at about 190 Hz. The optical length of the reference arm was tuned to be equal to the optical length of the sample arm. After the propagation through reference and sample arms, the beams were recombined by another dielectric beamsplitter. If the difference between optical lengths of the arms is lower than coherence length of the light source, than periodically changing interference pattern arises. After recombination the resulting beam was passed through the double-prism Carl Zeiss monochromator with sensitive extended-InGaAs photodetector installed on the output slit. The monochromator allowed to filter out the certain narrow band and to scan over the spectrum.

In the experiment we measured the dependence of beam path difference between the sample and the reference arms of the interferometer on the wavelength. The signal from the detector was preamplified and directed to selective amplifier in order to filter out the interference signal from the noise. The intensity of the signal was measured by the AC voltmeter. The shape and amplitude of interference signal was additionally controlled by the oscilloscope.

Based on these data, the dependence of the path difference Δl on the wavelength λ was plotted. Dispersion parameter $D(\lambda)$ and path difference $\Delta l(\lambda)$ are related through [18]:

$$D(\text{л}) = \frac{1}{Lc}\frac{d[\Delta l(\text{л})]}{d\text{л}}, \qquad (1)$$

where L is the length of the fiber under test; c is the speed of light.

Experimental verification

In order to verify the measurement technique described above the dispersion parameter of standard telecommunication fiber SMF-28 was measured with the setup shown in figure 1. The piece of fiber under test had the length of 80 cm. The spectral resolution of the measurements was defined by the spectral bandwidth of the monochromator slit and was equal to about 35 nm in the current measurements. The data points were taken every 15 nm. The signal to noise ratio was estimated to be about 7 at 1820 nm wavelength and 2 at the limits of our spectral range.

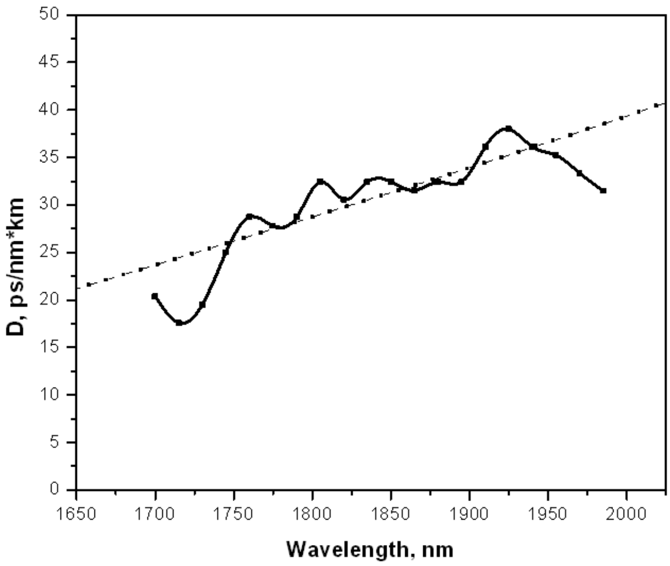

Figure 3 – The results of dispersion measurements in SMF-28 standard telecommunication fiber (solid line) in comparison with investigation results of SMF-28 from Fiber optics research center, Russian academy of sciences (dashed line)

The results of the measurements are presented in figure 3 and compared to the results of the investigation of the same fiber, performed in the Fiber Optics Research Center, Russian Academy of Sciences. It can be seen that the measurement error generally do not exceed 10 % and reaches 30 % at the limits of the available spectral range only, where the signal to noise ratio is quite low. Considerable advantage of the described technique is possibility to perform measurements on short fiber samples – in the current setup the allowable fiber lengths is 0.5 to 2.5 meters. Mentioned feature makes the developed method promising for investigation of novel special optical fibers, where the length of the sample could be critical.

Conclusion

In conclusion, we introduced interferometric setup for measurements of dispersion parameter of optical fibers, particularly prospective for specialty short-length fibers for infrared applications. The characteristic feature of the setup is that it is based on a broadband and rather intensive superluminescent Tm-fiber source, allowing making measurements in a broad wavelength range, at least 300 nm around 1,82 microns. Further optimization of the setup will help us to reduce the currently present measurement errors, thus, allowing obtaining dispersion curves with high accuracy.

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Методика измерений дисперсии групповой скорости в широком спектральном диапазоне в инфракрасной области спектра

Разработана широкополосная методика измерений показателя дисперсии в оптических волокнах, основанная на схеме интерферометра Маха–Цендера. В качестве источника излучения широкого спектрального диапазона использовано оптическое волокно, легированное ионами Tm^{3+}, накачиваемое на длине волны 1,61 мкм, что позволило достичь спектрального диапазона измерений от 1700 до 2000 нм. Метод может применяться для относительно небольших образцов оптических волокон с длиной менее 1 метра. Методика была успешно протестирована для стандартного телекоммуникационного волокна SMF-28. (E-mail : nikolai.tolstik@ntnu.no)

Ключевые слова: оптическое волокно, измерения дисперсии, средний ИК-диапазон.

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