Characterization of dispersion in components for ultrafast lasers

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Abstract

Using a broadband supercontinuum fibre laser we measured (using an interferometric set-up) the dispersion curve of a Cr: YAG laser rod used for femtosecond pulse generation. © 2000 Published by Elsevier Science B.V. All rights reserved.

Recent improvements in ultrafast Ti:sapphire lasers allowing the generation of pulses of less than 5 fs [1], which corresponds to less than two optical cycles, have only been made possible by carefully controlling the dispersion, dispersion slope and higher order terms of the cavity design [2]. Each of the cavity and extra-cavity components has to be tailored, manufactured and certified to reach the net design goal of dispersion. Several methods to measure the dispersion of individual optical components or the complete cavity exist. But in order to examine the accuracy of manufacturing of the components it is important to characterize each individual component [3]. This characterization is also important for modeling the cavity design using the real values of the dispersion of each component. Only with the data of each component is it possible to determine the limitations given by these devices and not by the design of the system. The optical bandwidth of these ultrashort laser materials exceeds all conventional light sources and therefore a broadband light source is essential to determine the dispersion curve.

Cr:YAG has considerable potential for sub 10 fs pulse generation in the near infrared but to date pulse durations of ~ 40 fs have been reported [4]. The broad tuning range from 1.35 µm to 1.6 µm indicates that even shorter pulses should be possible. In order to achieve the shortest femtosecond pulses a low negative group velocity dispersion of the cavity is desired. It is therefore important to fully characterize the dispersion characteristics of the intracavity elements. In this letter we report on the application of our novel broadband fiber based source for the measurement of the dispersion of a Cr:YAG laser rod.

We used an interferometric method to determine the delay time and dispersion of the 5 cm long Cr:YAG laser rod. A similar set-up with a Mach–Zehnder fiber based interferometer was used previously to measure the dispersion in optical fibers with a high spectral coverage [5,6]. The light source was again a supercontinuum fiber laser with a spectral range from 1 µm – 2.2 µm and a spectral brightness of > 0.2 mW/µm up to 1.7 µm [7]. The laser is laser diode pumped and delivers up to 500 mW of

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average power. It generates pulses at a repetition rate of \( \sim 10 \) kHz with a rise time shorter than 1 ns and pulse duration of less than 5 ns. The spectral range and brightness enables continuous measurement of the delay time without any signal enhancement. Instead of the fiber-coupler based Mach–Zehnder interferometer we utilized a bulk element Michelson interferometer with beam splitter to reliably enable the measurement of very small delay time differences.

The experimental set-up consists of the fiber laser source, collimating and focusing lens, a broad band silver coated beam splitter BS, a mirror mounted on a \( \mu \)m-stepper as a variable delay line in the reference path and the 5 cm laser rod in the test path (Fig. 1). The interference pattern was coupled into a fiber and detected with a standard spectrum analyzer (OSA) (Anritsu spectrum-analyzer MS9701B with display unit MS9030A). The interference pattern with a dispersive element shows a minimum in the rate of interference for matched path lengths and an increase of the interference pattern with wavelengths towards longer and shorter wavelengths. In the limit of no delay difference (no dispersion) the interference pattern rate would stay constant and with increasing delay difference the increase in the interference rate increases. Because the total amount of delay difference for the laser rod is quite small it means that the separation of maxima and minima is large (in the order of up to 50 nm).

The wavelength for matched pathlengths can easily be determined from the interference pattern and to obtain a detailed delay curve the variable delay of the reference path was scanned and the corresponding matching wavelength recorded [5,6,8]. Fig. 2 shows the experimental data of the obtained delay curve (circles) and a fifth order Sellmeier equation fit (upper line). The delay curve consists of more than 100 data points and the accuracy was limited by the product of the \( \mu \)m-stepper resolution and the resolution of the spectrum analyzer. Therefore the fitting improved the accuracy of the measurement. Fifth term order Sellmeier equation (Eq. 1) are commonly used to describe delay time and dispersion properties of materials [8]. The group velocity dispersion (Fig. 2, lower line) can be calculated from the obtained delay curve (Fig. 2, upper line) by differentiation. We measured a value of 400 fs at 1.5 \( \mu \)m and the coefficients for the Sellmeier-equation of the GVD for 5 cm in fs\(^2\) are given in Table 1

\[
\text{GVD} = P_1 \cdot \lambda^{-4} + P_2 \cdot \lambda^{-2} + P_3 + P(4) \cdot \lambda^2 + P_5 \cdot \lambda^4.
\] (1)

The results were confirmed by a second method determining the dispersion for a single wavelength from one spectrum. The experimental set-up was the same as above but the calculation was done from the

![Fig. 1. Experimental set-up (see text for description).](image)

![Fig. 2. Delay and dispersion for 5 cm of Cr:YAG.](image)

![Table 1](image)
separation of the maxima and minima relative to the wavelength of matched pathlengths [8]. The pathlengths can be matched for any wavelength and therefore single values for any wavelength can be obtained. The squares in Fig. 2 indicate the values determined by this method which are in good agreement to the derivative of the fit (line) to the Sellmeier equation. The agreement was also good compared to values measured elsewhere [9].

It should be noted that the latter measurement of dispersion was undertaken with the Cr:YAG laser rod inverted, this would indicate that there is little effect to the dispersion in the pumped and unpumped regimes. It can be assumed that the major contribution of the dispersion is due to the host material and that the variations due to the dopant are minor [10]. When used in a steady state inversion the absorption properties do not change and from the Kramers–Kronig relation the effect on dispersion is negligible.

In conclusion the dispersion properties of a femtosecond device was determined over the wavelength range of emission. A supercontinuum fiber laser was used as a light source for white light source interferometry and enabled continuous measurement of the delay time of the device with a standard spectrum analyser. Measurements with this method and a single shot measurement were in good agreement with other methods.

References