Spectral Vector Beams for High-Speed Spectroscopic Measurements

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Spectroscopic measurements are amongst the most important optical experimental methods with applications ranging from physics to chemistry, material science, and biology [1]. Conventionally, spectroscopy is performed by measuring wavelength-dependent changes in the transmitted light. In one recent study, it was shown that a strong correlation between a transverse position and the polarization in spatial vector beams can be beneficially applied in high-speed kinematic sensing [2]. We extend this idea to the spectral domain and generate states of light, in which beams have a varying polarization vector across their frequency spectrum. We term such states of light spectral vector beams and use them for spectroscopic measurements.

We generate a spectral vector beam by superposing a left and right circularly polarized femtosecond pulse with a time delay. The pulse generated by a Ti:Sapphire laser with an 80 MHz repetition rate has a duration of 220 fs and is centered around 808 nm. It is diagonally polarized and subsequently sent through a 2 mm thick birefringent BBO crystal, which has different group indices for the horizontal and vertical polarization components of the pulse and which thus generates the time delay between the two orthogonal polarizations (see Fig. 1 a for a sketch of the setup). A quarter-wave plate then turns the linear into circular polarization. Since a time delay translates into a linear phase shift in the frequency domain, coherently superposing the circularly polarized pulses causes the polarization to vary through all linear polarization states across the bandwidth of the spectrum [3,4]. Fig. 1 b) shows a recorded spectrum with its corresponding polarization ellipses. We use this correlation between frequency and polarization to link a polarization measurement outcome to a change in the spectrum, e.g. through absorption.

To demonstrate the capabilities of spectral vector beams as a spectroscopic method, we analyze the effect of a tunable bandpass filter on the spectrum. Therefore, the measured polarization state is compared to a calibration measurement, which is obtained with a spectrometer of the unperturbed spectrum, e.g. as displayed in Fig. 1 b). As shown in Fig. 1 c), the center wavelength of the filter can be inferred with a standard deviation of 0.30 nm averaged over all reconstructed wavelengths. An averaged discrepancy of 0.20 nm with the expected wavelength is obtained from the reference measurement. Similarly, a tunable absorption line is tracked across the spectrum with an averaged standard deviation of 1.84 nm and an averaged mean discrepancy of 0.34 nm. In a final set of experiments, we show the high-speed capabilities of this technique by tracking a time-varying long-pass filter. Changes in the spectrum down to 166.5 ns are resolved within the bounds of the errors. The read-out speed can be further increased with a faster varying spectrum. The errors in our measurements are mainly resulting from instabilities from the light source.

In summary, we demonstrate a simple method to generate spectral vector beams, i.e. light with strong correlation between polarization and its frequency components. Benefitting from this direct correlation, we show that high-speed spectroscopic experiments such as narrow line absorption or transmission measurements are possible using only polarization measurements. As such measurements can be done with fast photodetectors, the method is capable of tracking changes of the frequency spectrum with read-out rates that are only limited by the repetition rate of the laser and the response time of the detectors, i.e. in the GHz regime.

References

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