Rotating mirror method for measuring the visible and NIR spectrum of plasmas

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Abstract. We report the construction and operation of an apparatus for measuring optical Doppler shift based on a rotating mirror, and its preliminary application to the measurement of the spectrum of some light sources. We describe preliminary results, and discuss the detection limits and the possibility of using the apparatus for plasma diagnostic.

1. Introduction

In a previous paper [1], we described an apparatus for measuring the Doppler shift using a rotating mirror. Optical Doppler shift experiments are not a simple task since the light source cannot usually be moved in a sufficiently smooth and uniform manner to keep the level of noise well below of that of the signal.

Using a rotating mirror it is possible to overcome many of the noise generating effects. The beam from a light source passes a beam splitter that separates the beam, part is reflected from the advancing side of a rotating mirror; part is reflected from the receding part of a rotating mirror. After reflection the beams are recombined using a beam splitter and measured by a fast photo-detector. Beat between the two beams produces fluctuations in the light intensity at the photo-detector.

Since the spectrum of the measured interference signal is proportional to the spectrum of the original source, then it is possible to use this experiment as an online scanner of the light spectrum of the source.

2. Apparatus

Using a rotating mirror in which one beam is reflected from the advancing side and the other beam is reflected from the receding part of a rotating mirror two effective sources with different velocities can be created. The Doppler beat frequency, f_b, between the two sources is given by [1]

$$f_b = \frac{4\pi dF}{\lambda} \tag{1}$$

where F is the frequency of the rotating mirror, d the beam separation and λ the wavelength of the light. In figure 1 a sample beat pattern of a laser source is shown. The FFT (also shown in figure 1) exhibits a peak at the frequency f_b given by (1).

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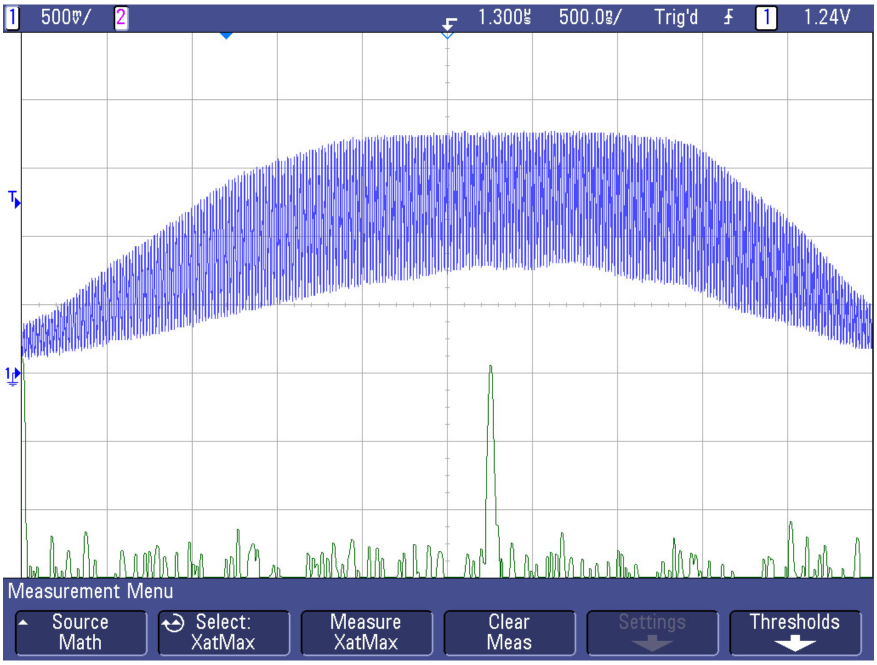

Figure 1. Sample beat pattern of a laser (upper trace, vertical scale 500 mV/div, horizontal scale 500 ns/div) and its FFT transform (lower trace, vertical scale 10 dB/div, horizontal scale 10 MHz/div). From the FFT, the wavelength of the source is obtained using (1).

Note that the beat frequency is a function of the rotational frequency. Therefore, in order to provide a reliable measurement the old motor (used in the previous version) was replaced by an outrunner brushless motor located at the bottom of the mirror. Also an electronic controller was built so the rotational frequency can be varied in a 1 Hz step up to 100 Hz. In figure 2 the new mounting is shown at rest (left) and operating at 50 Hz (right) were the reflected laser beams (separated by 2.4 cm) are also visible. The experimental setup is shown in figure 3, were two sources may simultaneously be used.

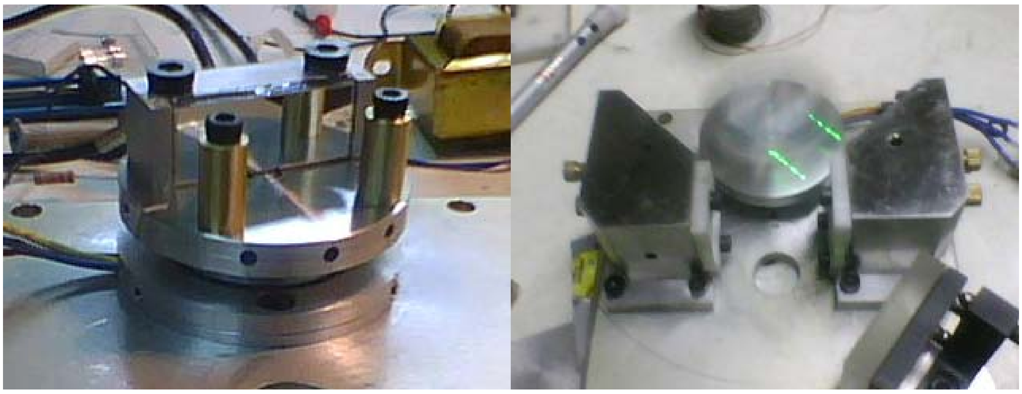

Figure 2. Improved mounting and driver of the rotating mirror (left). The mirror working at 50 Hz (center-right) in between the optical positioners. The green laser beams are also visible.

3. Calibration and preliminary tests

The first idea was to use the apparatus for resolving spectral lines of a given source. Working at 50 Hz and a beam separation of 0.024 m the Doppler beat of the visible spectrum lies between 20 and 40 MHz.

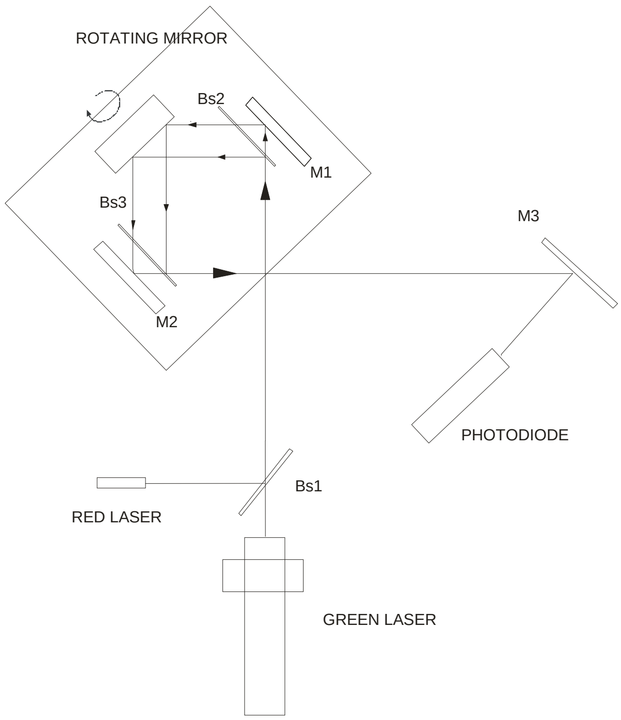

Figure 3. Experimental setup used for calibration. Any of the laser may be replaced by another source.

Using a 500,000 record length, 2 GSa/s digitizer the error of the beat frequency due to the FFT resolution is lower than the error due to the rotational stability that is about 0.1%. Using these values the theoretical resolution will be of about 0.5 nm.

The actual resolution will depend also on the optical components. During these preliminary feasibility tests we have used teaching-grade positioners and optics (ie, from standard teaching kits).

The calibration of the apparatus is performed using two monochromatic sources of known wavelength. The beat spectrum is obtained by means of a FFT transform (a built-in function in most oscilloscopes), and using (1) the corresponding wavelength are obtained. In figure 4 the spectrum of a simultaneous Doppler beat of a red (658.1 nm) and a green lasers (543.5 nm) is shown. The two peaks are clearly resolved in the spectrum and can be used to define the scale for the wavelength. Calibration can also be performed using only a green diode laser since the FFT shows the peaks of the green wavelength (532 nm), the IR pumping wavelength (807.5 nm), and the IR lasing wavelength (1064 nm), see figure 5.

As a preliminary test, a Mercury lamp was used as a source. In figure 6 the Doppler beat and the wavelength spectrum are shown. Acquiring at 100 MSa/s the peaks 576.9+579.0 nm and 546.1 nm are resolved with a resolution of about 2 nm.

4. Conclusions

Using a simple Doppler technique based on the beat between the two beams that reflects off a rotating mirror, it is possible to obtain the line spectrum (or at list a part of it) of a light source with an inexpensive apparatus.

By varying the rotational speed and the beam separation it is possible to scan a wide part of the electromagnetic spectrum. The method is not limited to visible light. The method can be used in any range of the electromagnetic spectrum as long as beam-splitters and mirrors are available.

Work is still in progress. According to these preliminary results a resolution of 0.1 nm will be possible to achieve by an appropriated choice of parameters.

Plasmas are an interesting source of electromagnetic radiation. The present method can be applied to stationary or quasi-stationary plasmas (the maximum time resolution is given by the rotational frequency) to obtain an online scanner of the light spectrum as a complement to more sophisticated and expensive spectrometers.

5. Acknowledgements
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References
[1] L. Bernal and L. Bilbao 2007 *Am. J. Phys.* **75** 216.

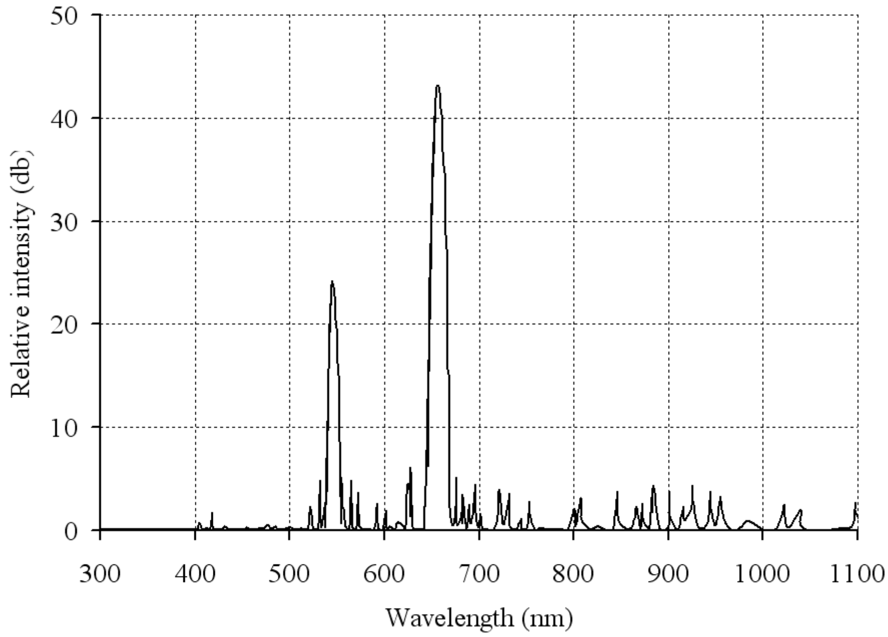


Figure 4. Spectrum of a combined green (543.5 nm, left peak) and a red (658.1 nm) lasers, used for calibration purpose.

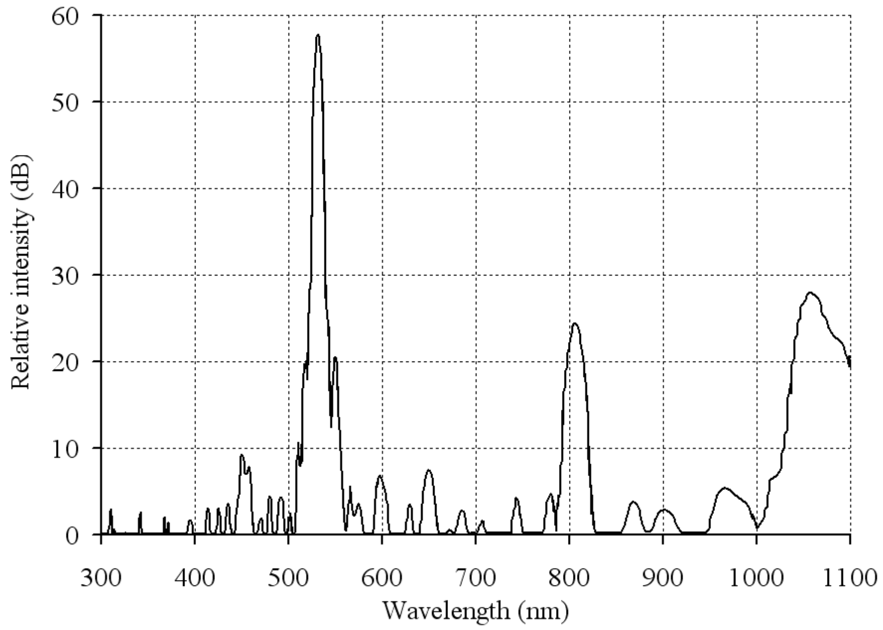
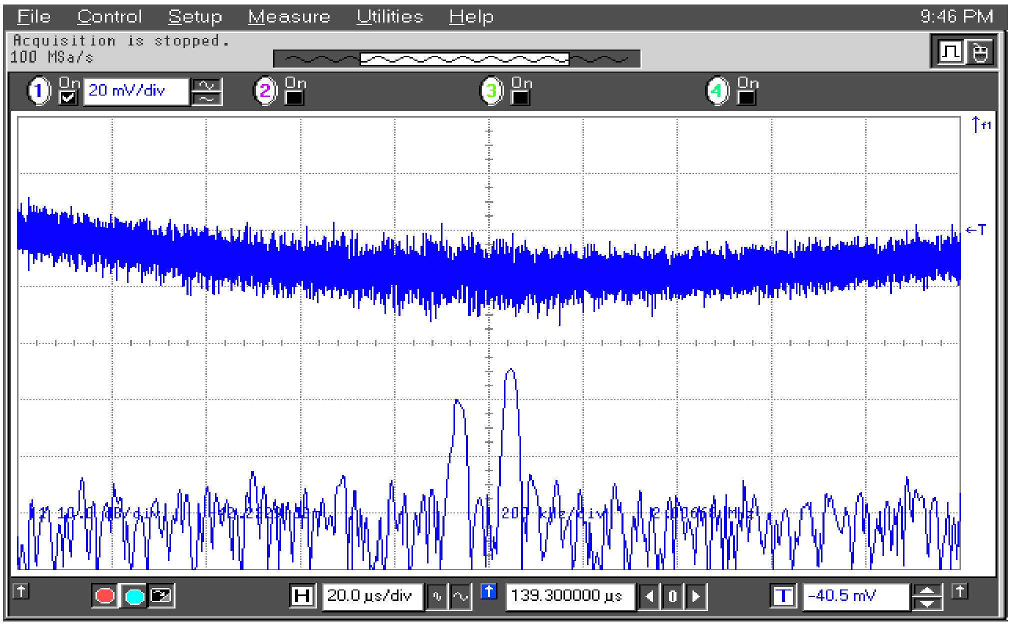
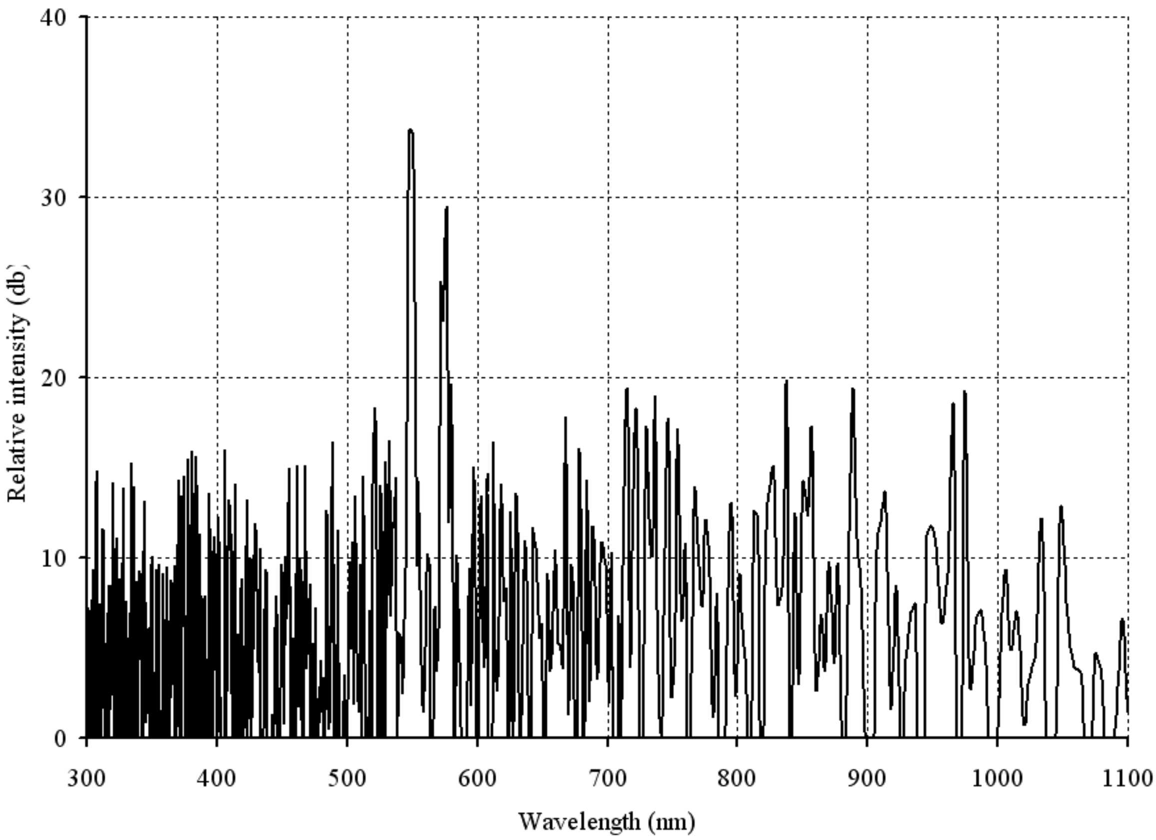


Figure 5. Spectrum of a green diode laser. The peaks (from the left) of the green laser 532 nm, the IR pumping wavelength 807.5 nm, and the IR lasing wavelength 1064 nm are shown.



(a)



(b)

Figure 6. Spectrum of a Hg lamp. (a) Beat pattern at 100 MSa/s (upper trace, vertical scale 20 mV/div, horizontal scale 20 μs/div) and its correspondent FFT (lower trace, vertical scale 10 dB/div, horizontal scale 200 kHz/div). (b) Spectrum obtained using (1) from the FFT, showing the peaks for 576.9+579.0 nm lines (right peak) and for 546.1 nm line (left peak).