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Accuracy Evaluation of Wavelength Modulation Spectroscopy with Time Resolution at 50Hz on Laser Plasma Diagnostics
レーザープラズマ診断に関する時間分解能50Hzの波長変調分光法の精度評価

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Wavelength modulation spectroscopy (WMS) was developed to diagnose CO_2 flow generated by laser driven plasma wind tunnel (LDPW). Since flow characteristics were found to fluctuate at power frequency, WMS is required to application of plasma oscillation. In this study, we examined improvement of WMS to measure oscillation of plasma 50Hz and evaluated the acquired signal. As a result, signal of 50Hz oscillation plasma was acquired about 92% by improving process for acquisition of signal and improvement of filter.

1. Introduction

Thermal protection system (TPS) is developed for development of planet atmospheric entry vehicle, and atmospheric entry environment simulation is needed. Arc-heaters and induced coupled plasma generators (IPG) ever had developed for atmospheric entry environment simulation of the Earth and Mars. However, wind tunnel for atmospheric entry environment simulation of the Venus has not established yet. This is because atmospheric main composition is carbon dioxide and stagnation pressure is high.

To solve this problem, laser driven plasma wind tunnel (LDPW) is developed, and generation of carbon dioxide plasma flow has been verified at atmospheric pressure. However, airflow characteristic such as the specific enthalpy has not been obtained. Then, carbon dioxide plasma was measured using laser absorption spectroscopy (LAS), the diagnostic data could not be obtained. This is because the number density of excited level of oxygen OI 777nm which is measurement target is small. In the past study, the temperature of carbon dioxide plasma is measured by using optical emission spectroscopy, and it has turned out the temperature of flow is about 3000K-6000K [1]. Additionally, the fractional absorption of OI 777nm is about 0.1-0.01%. In contrast, the fractional absorption of measurement limit of LAS is about 1%. In another problem, plasma oscillation is also present. In previous study, sensitivity was increased one to two orders of magnitude by WMS. Moreover, By increasing sweep frequency of important variables in the WMS, sampling of plasma absorption signal involved oscillation is examined. However, sweep frequency increases, absorption signal decreases. This is because signal also attenuated by the filter of the noise cut. Oscillation signal is acquired by performing WMS without sweep, but acquisition signal is not able to get enough because of filter characteristics.

In this study, to reduce the attenuation of the signal, we implement the improvement of filter to WMS without sweep. In additionally, we tried to obtain the absorption signal using improved filter, and evaluated the adequacy of signal obtained.

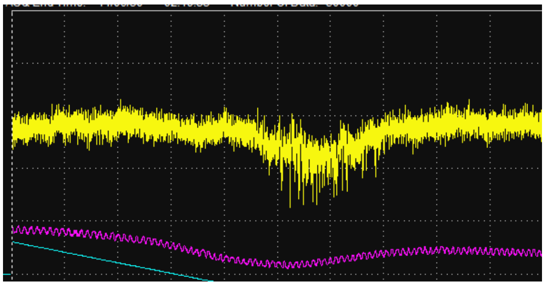
Fig.1. Absorption signal of plasma oscillation

2. Measurement Principle

2.1 *Wavelength modulation spectroscopy (WMS)*

Laser beam is emitted from laser diode, and passes through the plasma. The plasma absorbs part of the laser beam, transmitted light is measured by a photodetector. Wavelength sweep is performed by changing input current of laser diode using function generator 1. Laser beam is modulated sinusoidally using function generator 2. The glow discharge tube plasma is vibrated sinusoidally using function generator 3. Detected signal is input into a lock-in amplifier. Harmonics in the particular frequency component can be obtained using lock-in amplifier by the frequency of the reference wave directly input from the function generator 2. Harmonic extracted by the lock-in amplifier is sent to oscilloscope, where waveform can acquired.

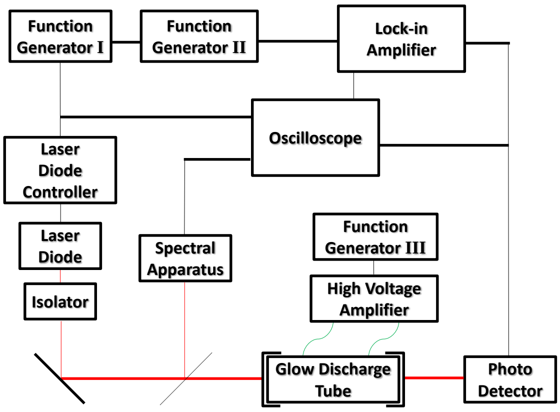

Fig.2. Experimental system of WMS

2.2 *Fixed wavelength sweep WMS*

To suppress the spread of frequency components generated by wavelength sweep, we attempt WMS without wavelength sweep for absorption profile. By fixing the measurement wavelength in the WMS, the value of second harmonic wave corresponding to a wavelength can be obtained. In addition, by plotting the signal obtained discretely over a certain wavelength range, same operation as the wavelength sweep is available. Measurement of plasma number density can be calculated from the peak value of the second harmonic. By matching the center wavelength to the peak value , time-varying number density is measured.

3. Improvement of Filter

Butterworth filters are built into the lock-in amplifier. This filter is characterized by a flat passband and attenuation slope that indicates the degree of the cut-off is gradual. Therefore, we consider the application of the Chebyshev filter. This filter has a large attenuation slope. This filter is to produce a ripple in the passband, reduction of the pass band signal other than the vibration components and acquisition of vibration components at a rate close to 100% is available. In this research, cut-off frequency of 50Hz is set. Passband ratio of each filter is shown in Fig.3. Butterworth filter is used in WMS. This filter can only get about 30% of oscillation signal at 50Hz. However, Chebyshev filter can be acquired almost all of the 50Hz signal value.

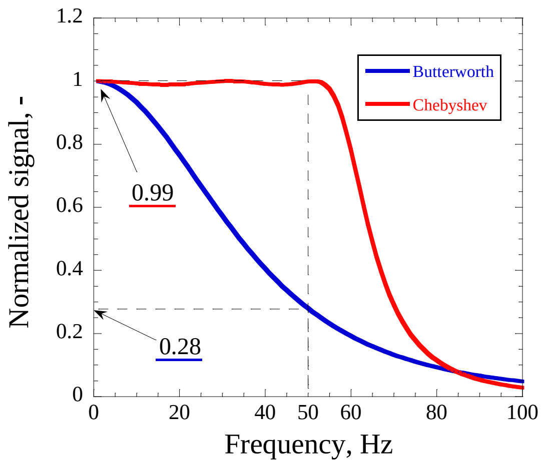

Fig.3. Characteristics of each filter

4. Result and Discussion

Plot of second harmonic wave obtained at near center wavelength is shown in Fig.4. Peak value of second harmonic wave is shifted from the center frequency. This is because temperature and current for operating the output of laser diode is varied slightly. As a result of converting the number density from the peak value measured, number density of about 92% for true absorption signal value is obtained.

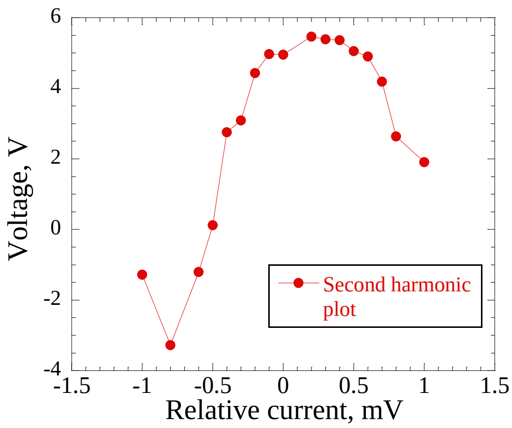

Fig.4. Second harmonic value at near center wavelength

References

[1] Matsui, M., Tanaka, K., Yamagishi, S., Matsumoto, S., Yamagiwa, Y., Komurasaki, K,. and Arakawa, Y., "Temperature Measurement of Atmospheric Pressure CO2 Plasma Flows Generated by a Laser Driven Plasma Wind Tunnel", Frontier of Applied Plasma Technology 4 (2011), pp.1-5.

[2] Hejie Li, Gregory B. Rieker, Xiang Liu, Jay B. Jeffries, and Ronald K. Hanson : Extension of wavelength-modulation spectroscopy to large modulation depth for diode laser absorption measurements in high-pressure gases", Applied optics 45 (2006), pp.1052-1061.