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SELF-MIXING INTERFEROMETRY FOR PLASMA DIAGNOSTICS

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Abstract. The feature of the diode laser that it, besides producing coherent light, has an integrated photodiode, was exploited as the reference branch of interferometers in several applications. A set of continuous laser diodes, emitting at various wavelengths, was initially calibrated by measuring the mechanical motion of an external mirror mounted on a speaker, controlled by a signal generator. Afterwards, the possibility of applying this so-called self-mixing interferometer for the study of low-pressure pulsed discharge and laser-produced plasmas was investigated and assessed.

1. INTRODUCTION

Since they could be stable and coherent light sources, lasers are unavoidable in optical interferometric investigations and sensors. In contrast to most of the other laser systems, a laser diode has very large gain of active medium (Ma et al., 2013), allowing its optical resonator cavity to have an exit mirror of lesser reflection. This unique construction detail reflects both on their multi-mode regime of operation, as well as on the possibility of strongly coupling them with an external optical system. In more complex optical systems, effort is made to avoid this coupling as much as possible, usually using optical isolators, because of its influence on the inverse population in active media and hence on the laser behavior. Here, on the contrary, the coupling effect is used as a method of producing interference, an approach which was studied with gas discharge lasers for plasma electron density measurement (Rasiah, 1994). Experimental, as well as theoretical studies of the effect of strong coupling with the external resonator could be found in a variety of papers for earlier references, see (Salathé, 1979), (Kobayashi et al., 1981). Various applications of this, so called self-mixing effect, could be seen in the PhD thesis (Alexandrova, 2017), for instance.

The optical path of the self-mixing interferometer is shown on Figure 1. It is important to emphasize the fact that the only external component of the system that needed to be adjusted was the external mirror 3. The low reflectivity of the laser diode exit mirror (numbered 2. on Figure 1), which is on the order of 20% up to 50% (in contrast to, for example, a He-Ne laser exit mirror with a reflectivity close to 99%), enables simple coupling of the external mirror, which in turn becomes part of the resonator of the more complex system.

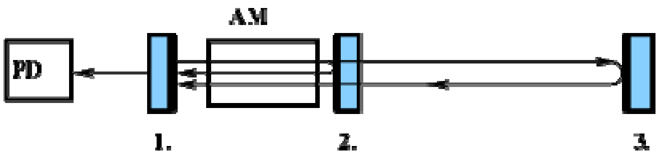

Figure 1: The simplified optical scheme of the self-mixing interferometer: AM – active medium, PD – monitoring photodiode, 1. – back mirror and 2. – front mirror are constructive parts of the laser diode, mirror 3. – external part.

2. EXPERIMENTAL RESULTS

The experiment presented here was a two-phase investigation. First, a study of the applicability and capabilities of the available diodes for the self-mixing effect detection was carried out. An external mirror (denoted by 3. on Figure 1) was mounted on the membrane of a speaker for its position to be mechanically modulated, leading to the detection of an interferometric figure on the monitoring photodiode of the laser diode module. Not all laser diodes showed equal potential for producing the self-mixing effect; the desired effect could only be observed in the case of pure continuous emitting laser diodes that are produced with integrated monitoring photodiodes. In addition, only a limited number of laser diodes was capable of producing coherence high enough to induce a measurable interference effect on the monitoring diode signal. In order to characterize a laser diode, work has been carried out to determine the conditions and limits where it can produce detectable interference (see for instance Figure 2 for the measured signals). In addition, the displacement of the speaker membrane versus time was measured from the interferograms, and the frequency of the movement of the membrane was compared to the one applied from the generator.

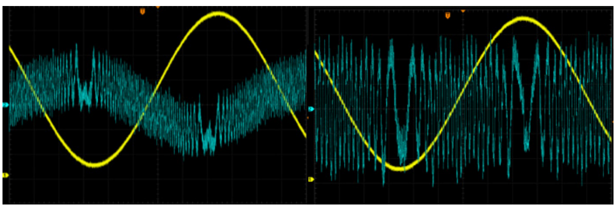

Figure 2: Self-mixing interferograms (thin blue line) for different sound frequencies applied to the speaker (thick yellow line).

The possibility of applying the laser diodes for plasma interferometry was investigated on two experimental setups, the pulsed discharge source described in detail in (Stankov et al., 2018), as well as in laser-induced breakdown spectroscopy (LIBS).

In the first step the interferometer, i.e., the external mirror, is adjusted so that an interference pattern appears in the signal on the photodiode. For easier observation of the effect measured by the interferometer, a large difference in intensity between bright and dark fringes is needed, therefore the alignment of the optical system is adjusted to produce fringes of maximum intensity. A sample interferogram of small mechanical disturbances of a properly adjusted system is shown on Figure 3. Such patterns were obtained for interferometers ranging in length from 15 cm to 50 cm, indicating that the low coherence length of the laser diodes (as compared to gas lasers) does not prevent them from being used in these applications.

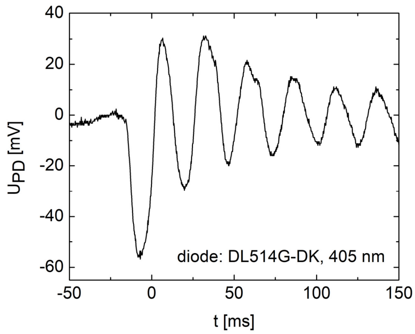

Figure 3: Interferogram of a mechanical disturbance of a properly aligned optical system.

An evaluation of the background plasma glow intensity was performed, to determine whether narrow-band filtering of the combined laser and plasma light is necessary. In the case of the pulsed discharge, the plasma background signal was several orders of magnitude greater that the intensity of the fringes, making the implementation of this diagnostic technique unattainable without additional isolation of the laser signal, which was not attempted as part of this study. However, in the case of LIBS the background glow of the plasma has minimal effect on the output signal, making it possible to test the diagnostic without modifications.

In the case of LIBS, which is suitable for testing the application of the self-mixing interferometer for the diagnostics of a spatially non-homogenous plasma, the axis of the optical setup was positioned 1 mm above a Si target irradiated by a second harmonic (532 nm) Nd:YAG laser beam, with an energy of 150 mJ and a 7 ns pulse duration. The target was positioned inside a T-shaped chamber with a diameter of 38 mm such that the distance from the window to the target was 50 mm, placed on an x-y computer-controlled stage. Due to the small dimensions of the chamber, multiple reflections of the acoustic emission waves off its walls are anticipated, see (Burger et al., 2015). All measurements were performed in air, so the glass windows of the chamber which lie on the optical path were removed. Having in mind that the plasma emission lasts on the order of tens of μs, we can conclude that the signal shown on Figure 4a is integrated, i.e., that the response time of the photodiode is too short for it to be used for plasma electron density diagnostics, even though it exhibits fringing likely arising from the changing N_e.

On the other hand, the fringes seen in the millisecond time range (Figure 4b) encourage further study of potential implementation of this diagnostic method for opto-acoustical or simple acoustical investigation of plasma propagation dynamics (Burger et al., 2015), as well as several potentially accurate methods for measuring various dynamic mechanical processes. As a control, a measurement was made with the axis of the setup positioned 3 cm above the target, outside of the plasma volume, where none of the effects on Figure 4 were observed.

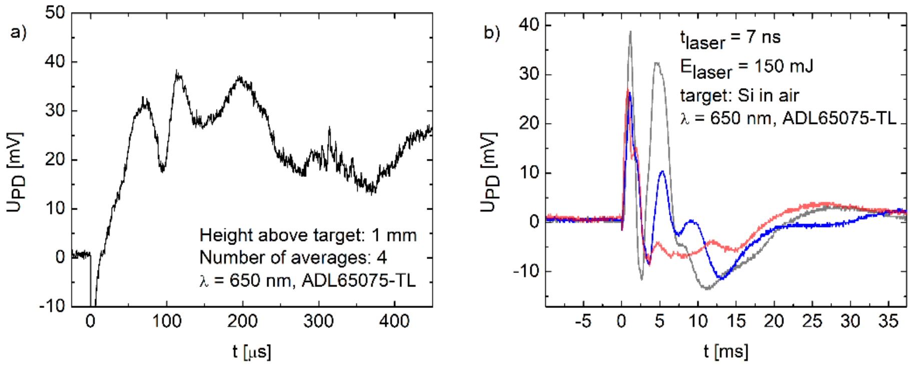

Figure 4: Photodiode signals in the LIBS setup on the a) μs and b) ms timescales.

3. CONCLUSION

The application of the self-mixing method as a means of measuring mechanical movement (disruption of setup and/or controlled movement of external mirror by a frequency generator), and for plasma diagnostics purposes, was proposed and evaluated. The requirements for laser diode characteristics, the necessity of narrow-band optical filtering, as well as the types of pulsed discharges and their characteristics which can be studied by this method (due to the limitations brought about by the response time of the integrated photodiode) were determined.

Acknowledgements

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