CARAVAGGIO: a new experimental station for characterising materials and optics over a wide range of temperatures

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Abstract

CARAVAGGIO, a new experimental station to characterise optical components and materials and to perform proof-of-concept demonstrations, has been commissioned. CARAVAGGIO is an important tool to enable the scaling of DiPOLE technology, as it allows the optimisation of concepts and optics before they enter the system. The layout of CARAVAGGIO is highly flexible, which allows a variety of measurements to be taken. It consists of two main beamlines: one operating at room temperature, which can be used for measuring reflectivity and transmission of optics over a wide range of angles, while the other allows to measure the optical properties of materials over a temperature range between 77 K and 500 K.

In this report, we describe the experimental setup of both CARAVAGGIO beamlines and explain their merits. We demonstrate this through an example experiment that has been carried out with the setup. We conclude by providing an outlook on the future use of CARAVAGGIO and a potential development to the system.

1 Introduction

Verification of ideas and characterisation of optical components and materials is essential for the development and optimisation of high power lasers. DiPOLE (Diode Pumped Optical Laser for Experiments) laser technology has achieved an average output power of 1 kW at a wavelength of 1030 nm, by delivering 100 J pulses at a 10 Hz repetition rate [1]. Currently, great effort is being devoted to the scaling of DiPOLE power through increasing energy per pulse and pulse repetition rate. This can be obtained by increasing efficiency through the minimisation of unwanted effects and losses. It is therefore important to ensure that full knowledge of the properties of optical materials is acquired and that schemes aimed at improving system performance are tested separately.

DiPOLE relies on advanced cryogenic cooling to manage thermal loads and to increase system efficiency. This means that a number of components are exposed to cryogenic conditions. However, existing literature does not always provide full information on the performance of optical materials at such conditions.

For the reasons stated above, CARAVAGGIO (Cryogenic Advanced Research And Validation Architecture for Ground-breaking Global Investigation of Optics) has been commissioned. Its primary purpose is to measure losses of laser light in materials, be it through transmission, reflection or absorption, and to characterise their properties over a wide range of temperatures.

2 Experimental Setup

CARAVAGGIO consists of two beamlines: one, shown in Figure 1, allows characterisation of optics at room temperature over a wide range of angles of incidence of laser light, while the other, shown in Figure 2, allows measuring optical properties over a temperature range between 77 K and 500 K.

The laser light is supplied to both beamlines through an optical fibre connected to a fibre collimator. Currently, there are two main types of source available on CARAVAGGIO: an Amplified Spontaneous Emission (ASE) source and two diode lasers with motor-controlled adjustable wavelength. The ASE source emits on a 9 nm bandwidth (measured at the full width at half maximum) centred around 1030 nm. The output of the ASE source can be filtered to a desired wave shape and bandwidth by an external programmable optical filter, before being amplified in a fibre amplifier. The diode lasers, on the other hand, provide narrowband emission; one of them is tuneable between 919.5 nm and 980.5 nm, while the other has a range from 1020.5 nm to 1078.8 nm.

A polarising beam-splitter cube can be positioned after the fibre collimator in order to allow the selection of a desired polarisation component. Before reaching the sample, the beam propagates through an uncoated wedge. The wedge directs a faint reflection of the beam towards a photo-detector (PD1), which is calibrated in order to continuously monitor the power incident onto the sample. A second photo-detector (PD2) is either located at the far end of the beamline to measure the energy that has been transmitted through a test sample, or follows a reflection from the sample to measure its reflectivity. Where the effect of a material on the beam's polarisation is the desired measurement, another polariser beam-splitter cube can be placed in front of PD2 to act as an analyser for the polarisation state.

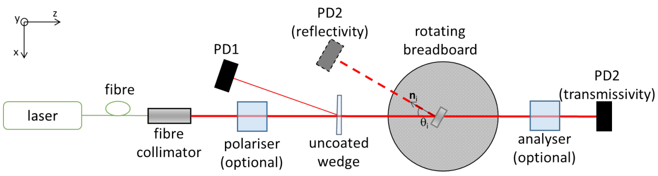

Figure 1: *Experimental setup for the room temperature beamline of CARAVAGGIO.*

The main difference between the two beamlines is the way the sample is mounted. The room temperature beamline (Figure 1) has a rotating breadboard upon which the sample is mounted. This allows precise control of the angle of incidence of the light onto the sample to within 0.5°.

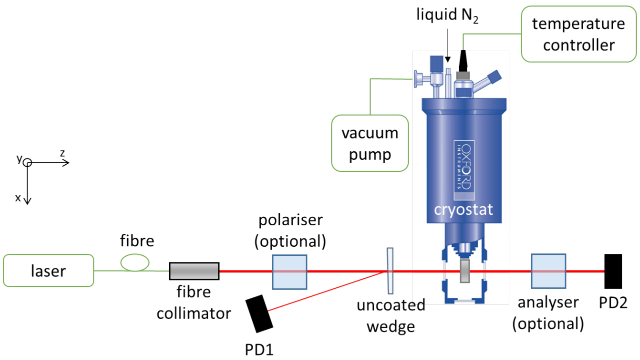

Figure 2: *Experimental setup for the optical cryostat beamline of CARAVAGGIO.*

As seen in Figure 2, the layout of the cryogenic beamline is very similar to the room temperature beamline, with the rotating breadboard replaced by an optical cryostat. The sample is mounted inside a vacuum chamber, in thermal contact with a heat exchanger directly above it. Liquid nitrogen is delivered to the heat exchanger through a capillary tube from the optical cryostat's liquid nitrogen reservoir, which is thermally isolated from the sample. A heater is controlled by a programmable temperature controller, which, together with an exhaust valve to regulate the flow of liquid nitrogen, allows varying the sample temperature between 77 K and 500 K to within 0.1 K.

3 Applications

Figure 3 demonstrates an example set of experimental data that has been obtained using the CARAVAGGIO room temperature beamline using the tuneable diode laser as the light source. It shows the transmission in parts per million (ppm) of light through a mirror, and how it changes for several different angles. The mirror has been coated with a high reflectivity coating designed to reflect no less than 99.8% of 1030 nm wavelength light in any polarisation state, for 45 ± 5°. The mirror is to be sent to our partners in the HiLASE facility in the Czech Republic, where a high power continuous wave fibre laser will be used to test the effects on mirrors in their mounts. This laser operates at 1070 nm, so it was also important to characterise the mirror's properties at that wavelength. For these reasons, the transmissivity of the mirror was measured for p- and s- polarised light at 1030 nm and 1070 nm, under the assumption that transmission is the main source of loss. The polariser was used to define the polarisation.

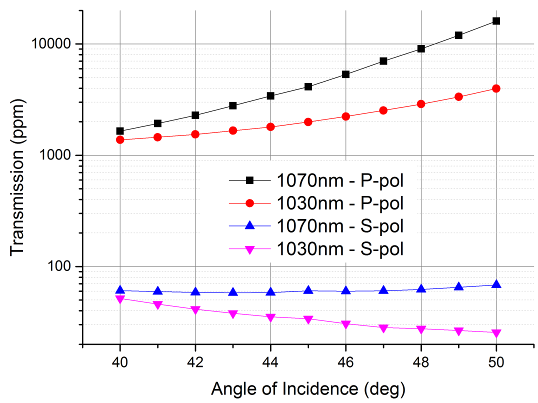

Figure 3: *Experimental results for a rectangular mirror, obtained using the room temperature CARAVAGGIO beamline. The scale is logarithmic in order to fit all results in a single graph.*

Once the desired wavelength and polarisation were selected, PD2 was placed immediately after the uncoated wedge to measure the total incoming power of the beam, in order to determine the calibration factor for PD1. The mirror was positioned on the rotating breadboard and aligned perpendicularly to the laser light by monitoring the direction of the reflected beam, before the breadboard was rotated to the 45° position. PD2 was positioned after the sample, and the transmittance was calculated as the ratio between the transmitted energy directly measured by PD2 and the calibrated PD1 measurement. This was repeated for both, s- and p- polarisations, at 1070 nm and 1030 nm.

The results for 1030 nm show that for s-polarised light, the reflectivity is well within its specified value. On the other hand, the transmission for p-polarised light is 0.2% at 45°, which lies on the higher limit and keeps rising for bigger angles, lying marginally outside of its specification. The transmission for 1070 nm light is higher for both polarisations, which means that more power might reach the mount. This could potentially cause more problems during the testing than would occur for the mirror's operational wavelength.

The cryostat beamline has only recently been commissioned, but so far has also been showing promising results. We will report on the operation of the cryogenic beamline in the near future.

4 Conclusion

The CARAVAGGIO experimental station is an invaluable accessory to the development of DiPOLE technology. It enables the testing of components, materials and ideas before using them in the DiPOLE system. CARAVAGGIO allows great flexibility of measurements. Offering a range of wavelengths and bandwidths, polarisation, angles of incidence and temperatures, it also allows different measurements to be taken, such as transmission and reflectivity. This provides an effective tool for optimising the system for minimum losses and maximum efficiency.

Further developments and additions to CARAVAGGIO will enable acquisition of even more detailed data. One of the upcoming upgrades is the addition of a scatter measurement to the room temperature beamline, which can help analyse and quantify another potential source of loss. Overall, CARAVAGGIO has been a successful tool and will continue to be so in the future.

References

[1] P. Mason et al. *Kilowatt average power 100 J-level diode pumped solid state laser.* Optica 4.4 (2017): 438-439