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Overview of optical characterisation capabilities for assessing suitability of optics for high-energy, high repetition rate lasers

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Abstract

- The DiPOLE concept is a world-leading, high average power laser technology based on diode-pumped, cryogenically cooled Yb:YAG amplifiers [1] combining multi-J pulses with multi-Hz repetition rates and high efficiency.
- High energy, high repetition rate lasers are required for applications in industry, science and medicine including laser shock peening [2], inertial confinement fusion [3] and high-resolution, time-resolved imaging [4].
- For successful operation of such lasers, high-quality components that fully comply with our specifications are required.
- To ensure optical components comply, we have devised a range of setups for optical characterisation which are detailed below.

1. Introduction to DiPOLE lasers

- Based on the DiPOLE concept [5]
  - **Di**ode **P**umped **O**ptical **L**aser for **E**xperiments
  - Multi-pass, multi-slab, cryogenically-cooled, Yb:YAG (1030 nm) laser amplifier architecture

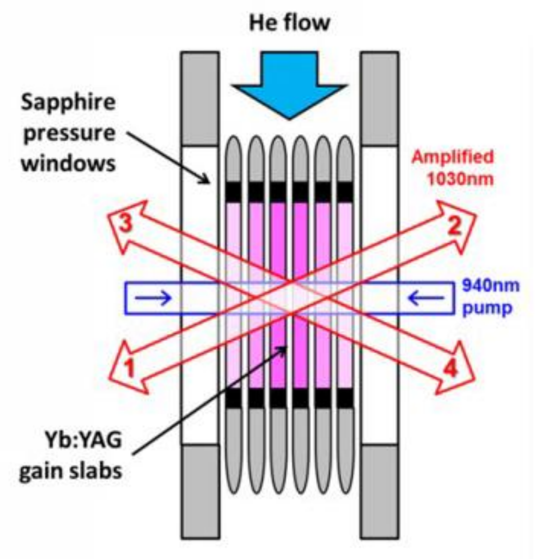

Fig 1: Schematic of DiPOLE 10 J amplifier head [6].

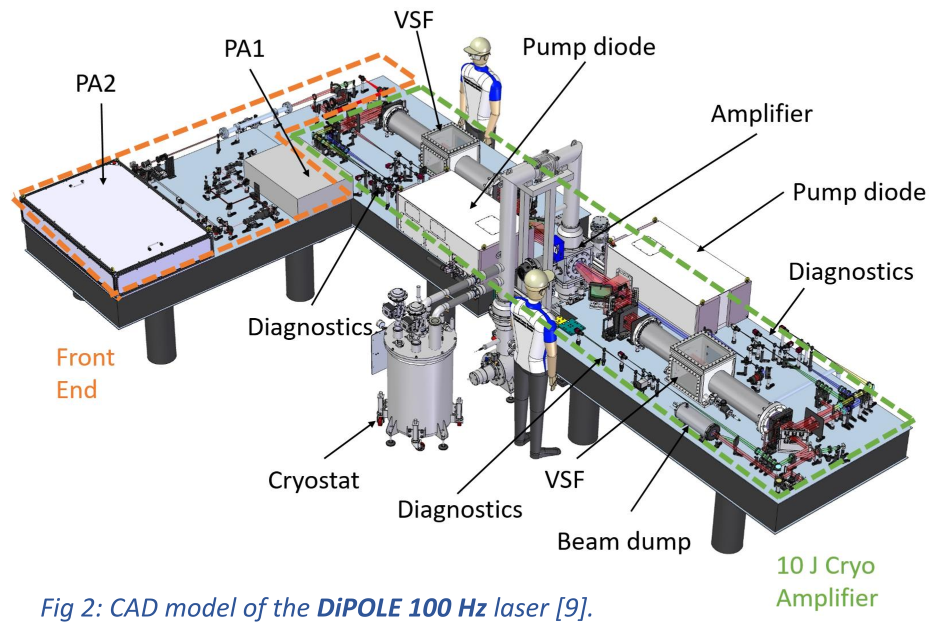

*Fig 2: CAD model of the **DiPOLE 100 Hz** laser [9].*

- DiPOLE technology is scalable in both energy and pulse repetition rate
- Evolution of DiPOLE lasers:
  - DiPOLE 10 J, 10 Hz (100 W) [6]
  - DiPOLE 100 J, 10 Hz (1 kW) [7,8]
  - **DiPOLE 10 J, 100 Hz (1 kW) [9]**

2. Transmittance/Reflectance

- **Anti-reflection coatings** ensure high transmittance through optics, e.g. lenses, windows
  - AR coated lenses should have reflectivity ≤ 0.15% at 1030 nm
- **High-reflectance coatings** ensure minimal leakage through optics upon reflection, e.g. mirrors
  - 45° HR coatings should have reflectivity (at 1030 nm):
    - ≥ 99.95% (p-pol)
    - ≥ 99.98% (s-pol)

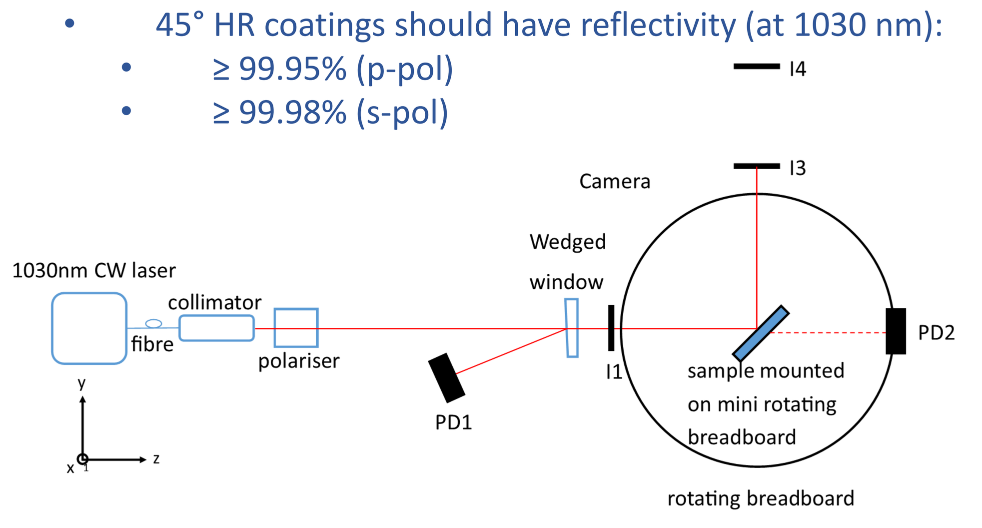

Fig 3: Layout of the setup used for measuring the transmittance and reflection of optical coatings over a range of angles.

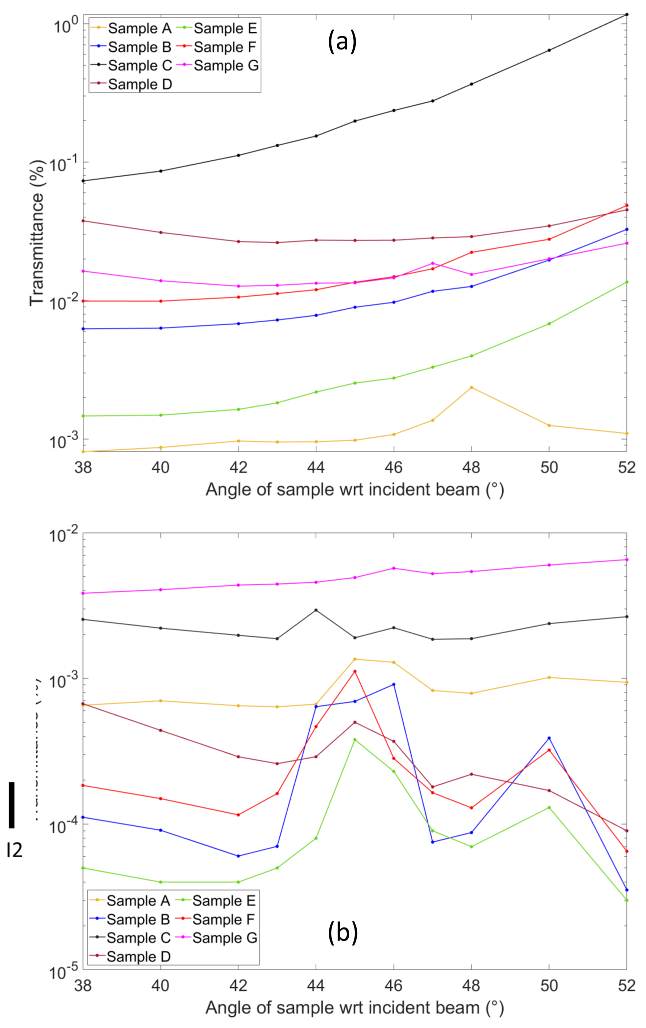

Fig 4: Experimental results for the transmittance of (a) p- and (b) s- polarised light through a number of samples from different suppliers with reflection optimised for 45°.

3. Angle-Resolved Scatter

- **Low scatter** from coatings prevents other components in the laser from overheating, e.g. optomechanics
  - Scatter from 45° HR coatings should be < 100 ppm/sr
- Low scatter also reduces losses and increases efficiency

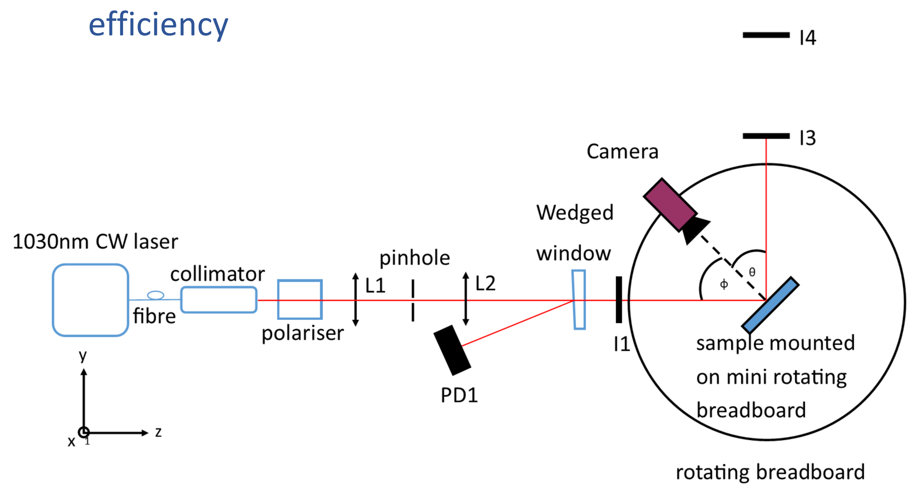

Fig 5: Layout of the setup used for measuring the angle-resolved scatter of optical coatings.

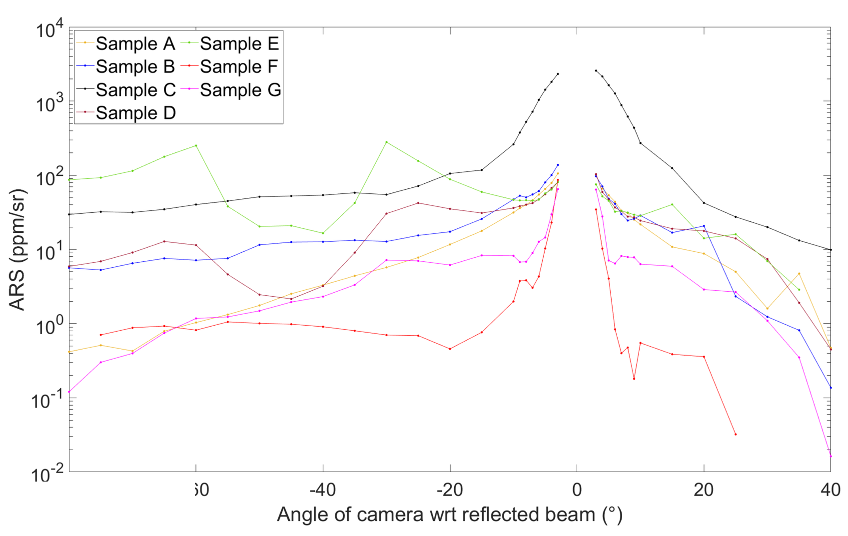

Fig 6: Experimental results of the angle-resolved scatter (ARS) from a number of HR mirror samples from different suppliers with reflection optimised for 45°.

- ARS of a 45° mirror is measured at a range of angles with respect to the specular reflection in the plane of incidence
- ARS cannot be isolated from specular reflection hence the gap around 0° in Figure 6

4. Damage Resilience

- **High damage resilience** is important for the optical components in DiPOLE lasers as the fluence reaches high values at high energies
- Intensity hotspots and fluctuations can also lead to areas of higher fluence which the optical components need to be resilient to
- Optics tested in DiPOLE 10 J, 10 Hz system up to 7 J/cm^2

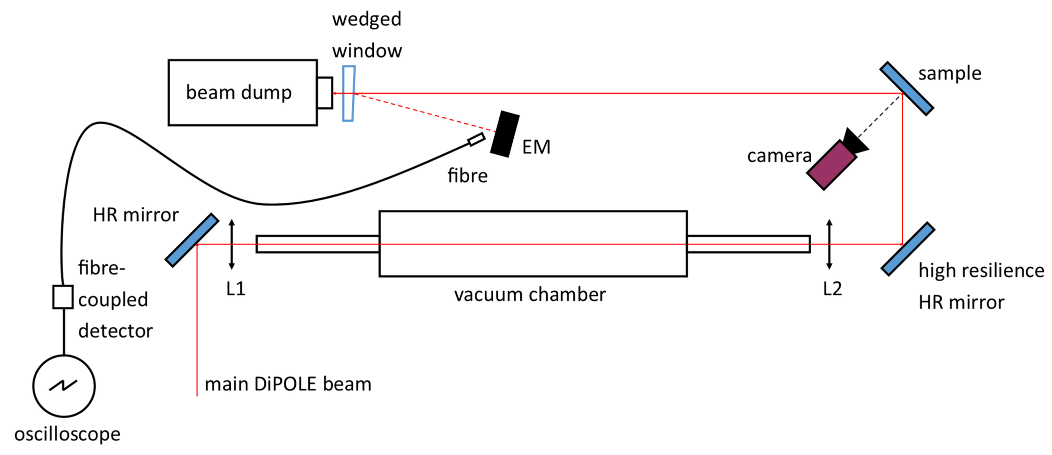

Fig 7: Layout of the setup using a DiPOLE 10 J, 10 Hz beam for measuring the laser induced damage threshold of optics using a 10 mm x 10 mm beam.

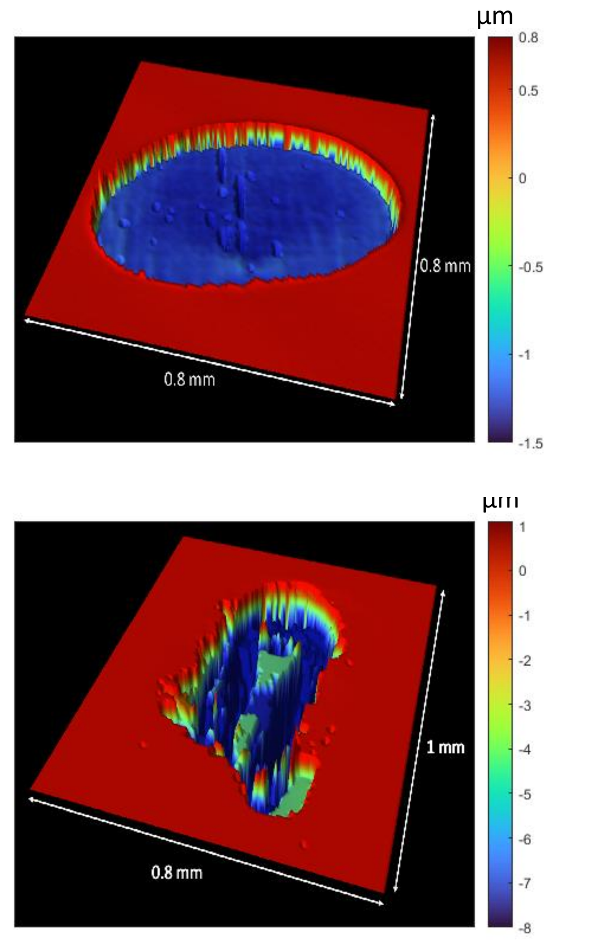

Fig 8: Images of the damage on two different optical coatings that was introduced when the fluence of the beam became too high as taken using a white light interferometer.

5. Ellipsometry

- **Phase delay**: shift between s- and p- polarisation states of light upon reflection from a surface
- **Removal of phase delay** provides increased polarisation control

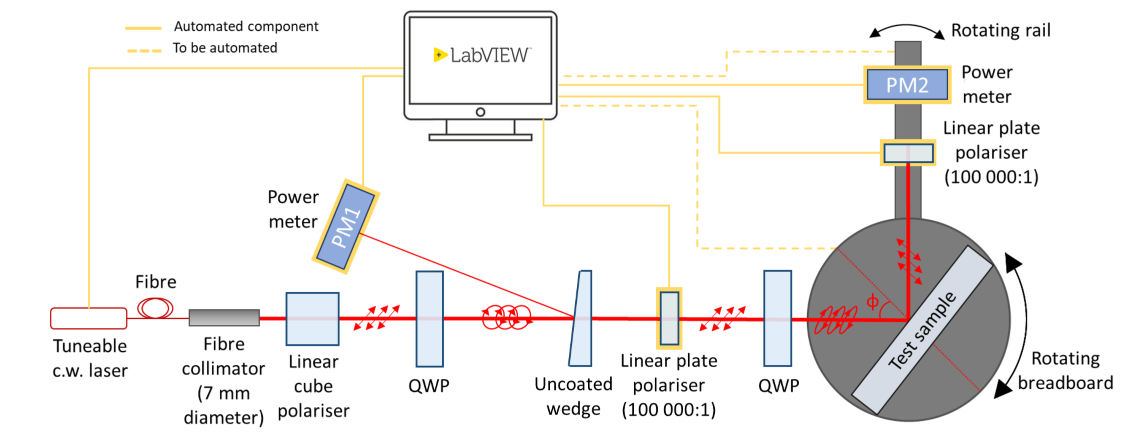

*Fig 9: Layout of the partially automated **null ellipsometer** used for characterising phase delay introduced by high-reflection coatings over a range of angles, ϕ, and wavelengths upon reflection.*

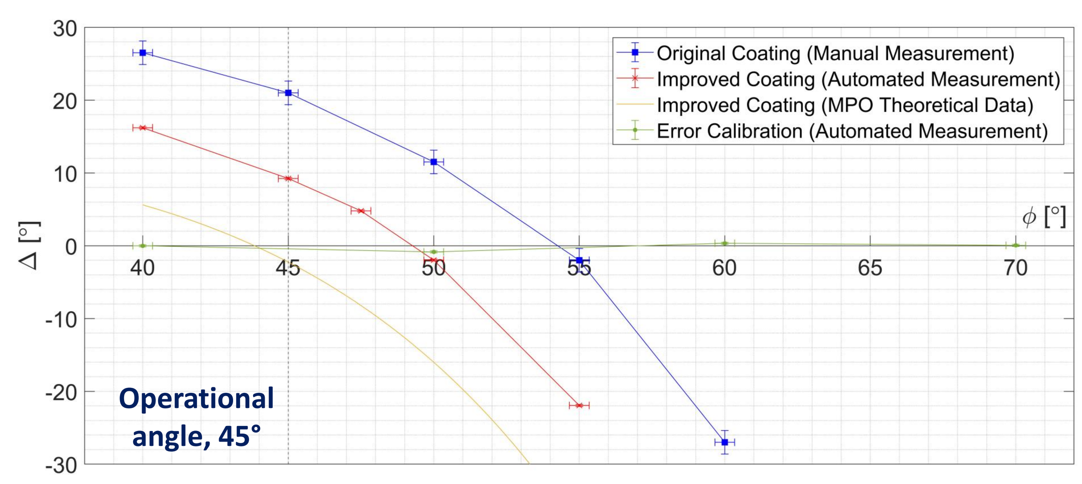

Fig 10: Experimental phase delay results for a 45° coating comparing a standard coating and an improved coating with theoretical values of the improved coating and error calibration measurements from Figure 9.

- Theoretical data from coating design software suggests the phase delay introduced by the coating at the operational angle is zero
- Experimental data indicates that this value is higher than theory suggests
- Errors between theoretical and experimental phase profiles arise from the manufacturing process

6. Polarimetry

- **Depolarisation**: where the polarisation state of the transmitted beam varies across the beam aperture due to stress-induced birefringence
- **Removal of depolarisation** allows for more output energy to be achieved as well as making polarisation sensitive processes, e.g. frequency conversion, more efficient

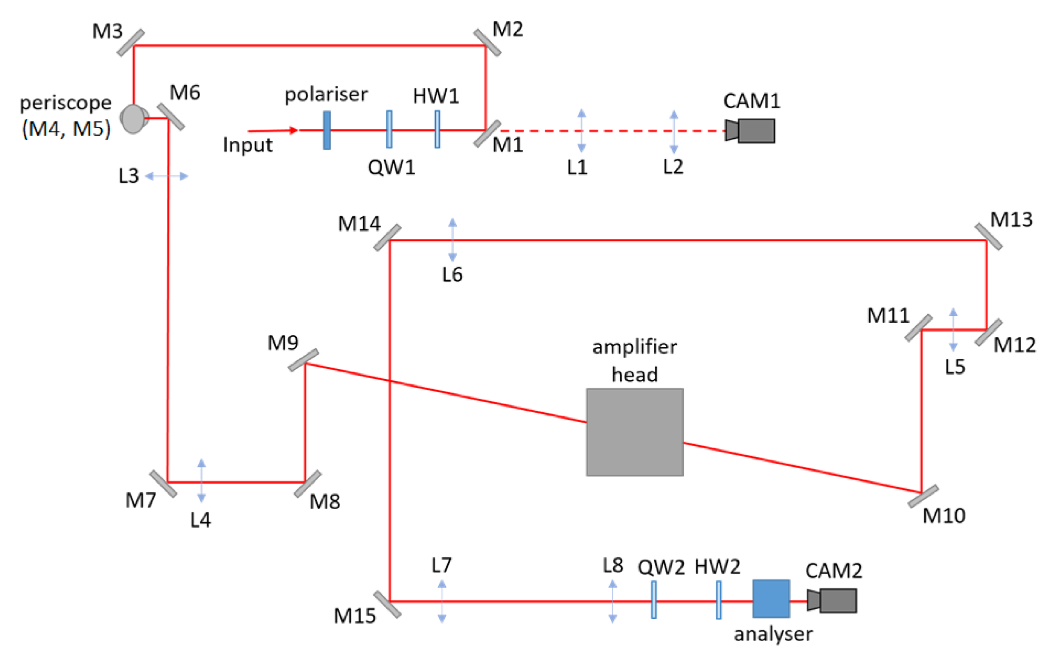

Fig 11: Experimental layout used to measure the depolarisation introduced by a single-pass through the 100 J amplifier head in a DiPOLE 100 J, 10 Hz laser.

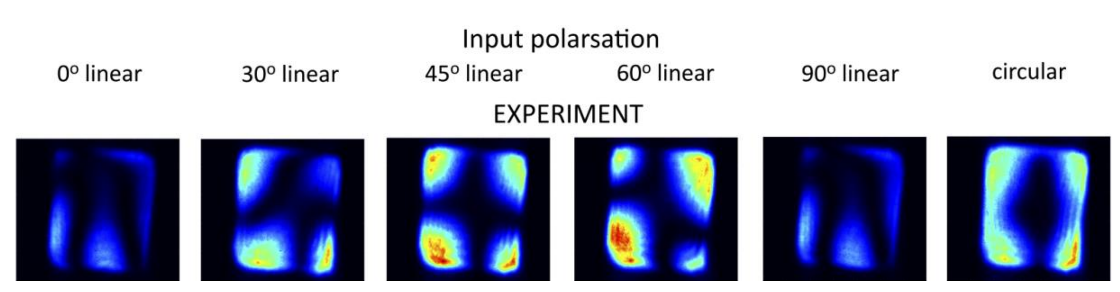

Fig 12: Experimental depolarisation patterns (with same scale).

- Experimental results show the input polarisation state has an impact on the degree of depolarisation

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