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Modeling and Measurement of Thermally Induced Wavefront Distortion in High Power Optical Cavities.

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Aim of Research

To detect, analyse and reduce thermally induced wavefront distortion in high power optical cavities under operating conditions.

Contents

- Thermal effects in GWI.
- Experiments to measure thermally induced wavefront distortion.
- Modeling of expected temperature profiles and wavefront distortion.
- Hartmann sensors and their application here.

Thermal Effects

- GWI require very high intracavity powers to overcome shot noise.
- Significant power will be absorbed in the coatings and substrates of the optical components.
- E.g. Advanced LIGO - expect up to 1100mW absorbed in the ITM substrate and up to 500mW absorbed in the surface coatings.
- Absorbed power $\rightarrow$ temperature distribution $\rightarrow$ refractive index distribution $\rightarrow$ wavefront distortion.
- Wavefront distortion $\rightarrow$ mismatch between input mode and cavity eigenmode, reduced intracavity power build-up, non-zero power at the dark port.

Gingin Experiments to Measure Distortion.

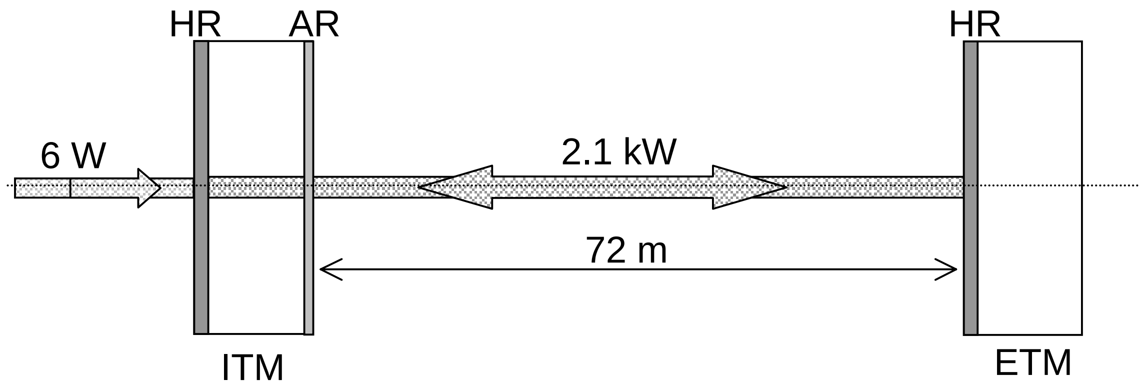
Aims:

- Measure wavefront distortion due to substrate and coating absorptions.
- Examine eigenmode shape.
- Validate Melody computer simulation.
- Test Hartmann sensor.
- Test compensation techniques.
- Test interferometer start-up techniques.

Three tests planned for Gingin:

1. Substrate absorption.
2. Coating absorption.
3. Combined effects in power recycled Fabry-Perot cavity.

Test #1 - Substrate Absorption Test



- Measure distortion and compare to Melody.

- Measure distortion when compensation applied.

- Power absorbed in substrate ≈1300mW (absorption 40ppm/cm, 8cm thick substrate and doubled due to reflection).

- Recall 1100mW absorbed in Advanced LIGO.

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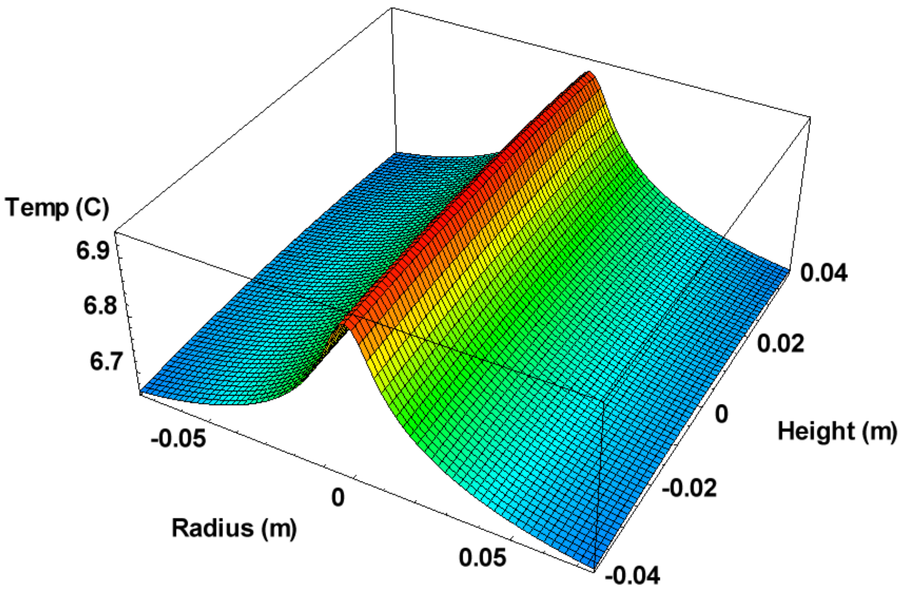
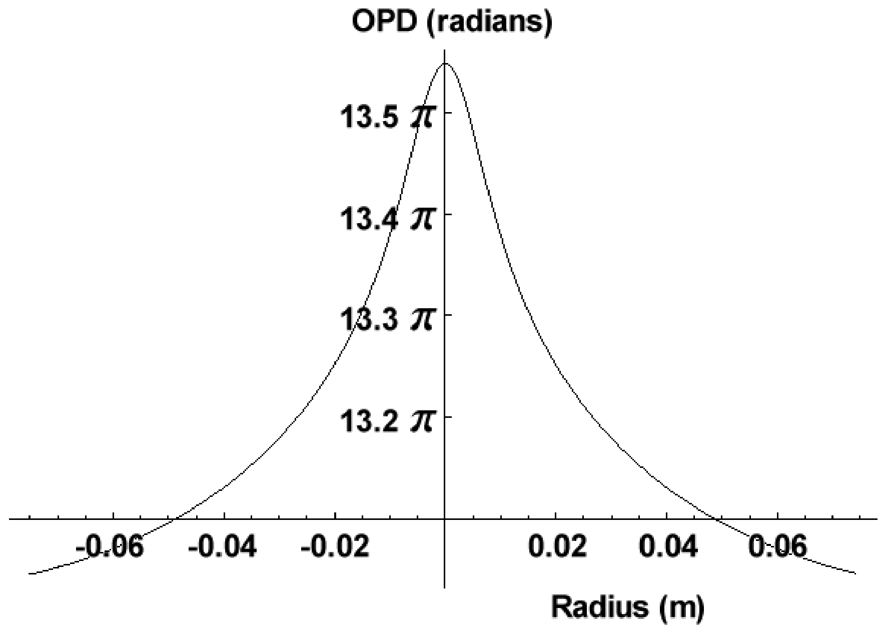
Substrate Absorption Prediction

An analytic solution for the temperature distribution produced by a Gaussian beam propagating through a cylindrical piece of glass allows us to determine the overall Optical Path Distortion (OPD).





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Magnitudes of distortion from different thermal effects expected for Test #1

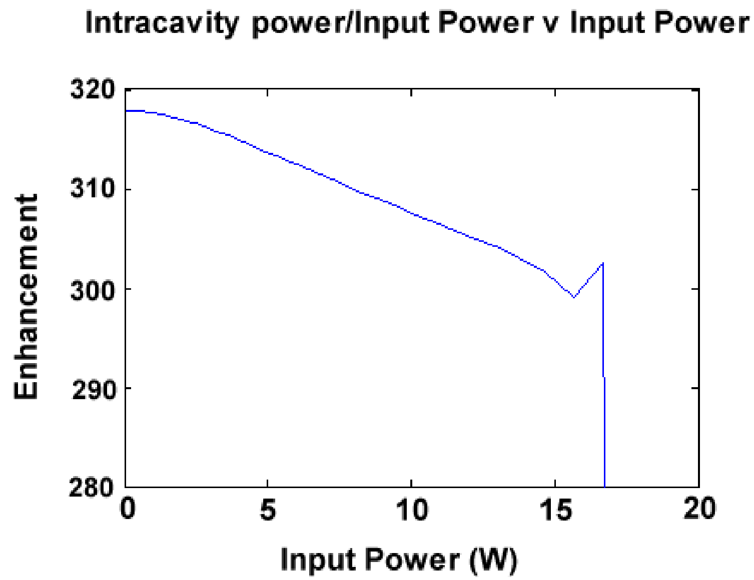
Thermally induced effects: thermoelastic, thermorefractive – coating and substrate.

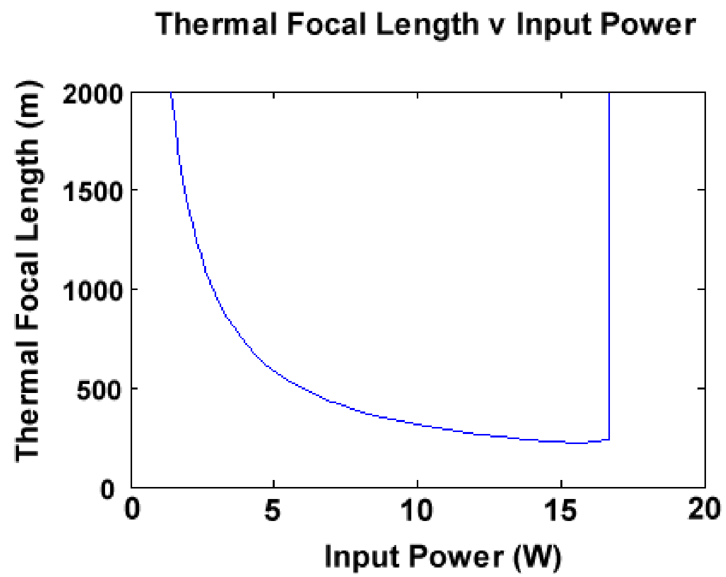
MELODY computer simulation, by Raymond Beausoleil, models optical cavities and different thermal effects.

Object	Relative Distortion
ITM Substrate – thermorefractive	1.0
ITM Coating – thermorefractive	0.003
ITM Substrate – thermoelastic	0.06
ITM Coating – thermoelastic	0.0002
ETM Coating – thermoelastic	0.0002

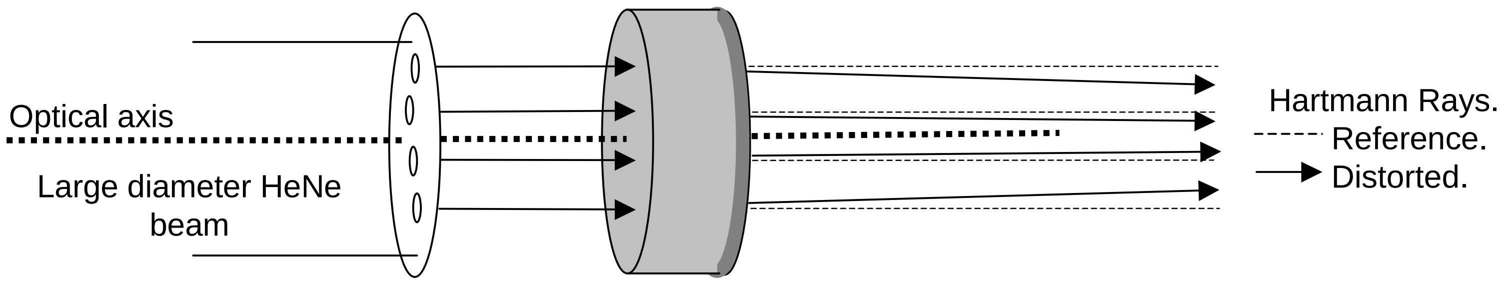
MELODY Results – Reduced Power Build-up and Increased Thermal Lensing

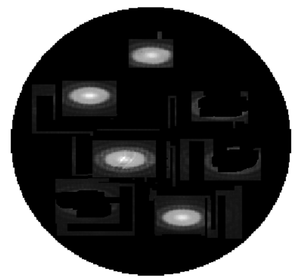
- Results from MELODY simulation of Test #1.
- Some power is reflected or mapped into higher order modes.
- Thermal focal length is calculated from the quadratic term.





The Hartmann Sensor





- Rays are displaced from reference positions when a refractive index profile is present, ie when a pump beam is applied.
- Local slope of OPD can be evaluated from transverse aberration of rays.
- Less alignment issues than in interferometry.
- More sensitive than Shack-Hartmann.
- In a interferometer the sensor should be off-axis so that there are no additional optics in the high power beam.

Validate and Test Hartmann Sensor

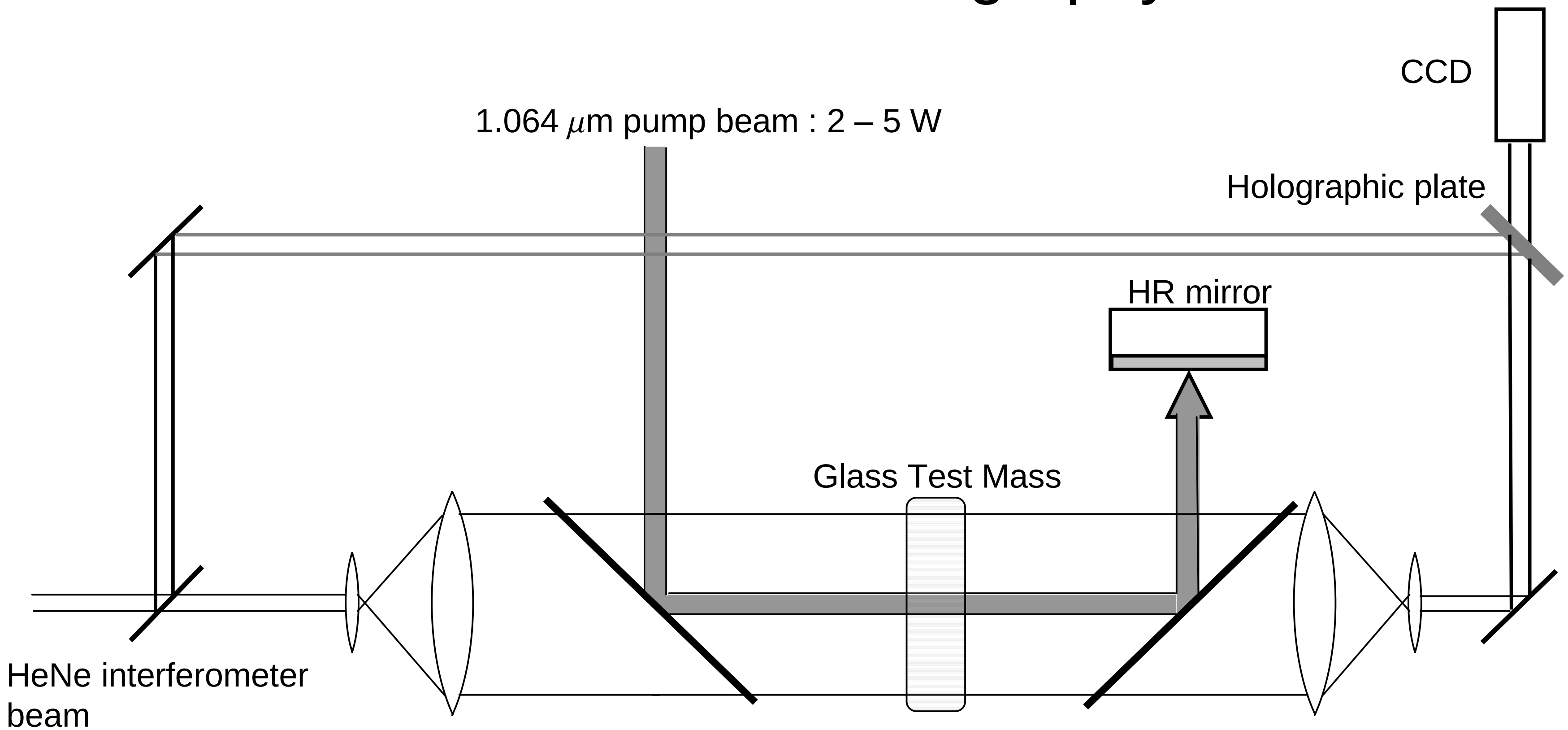
Validation

- Compare on-axis Hartmann sensor with interferogram.
- Compare off-axis Hartmann sensor with interferogram.
- Sensor results off-axis must undergo complicated transformation to determine the on-axis distortion $\rightarrow$ data analysis becomes more difficult.

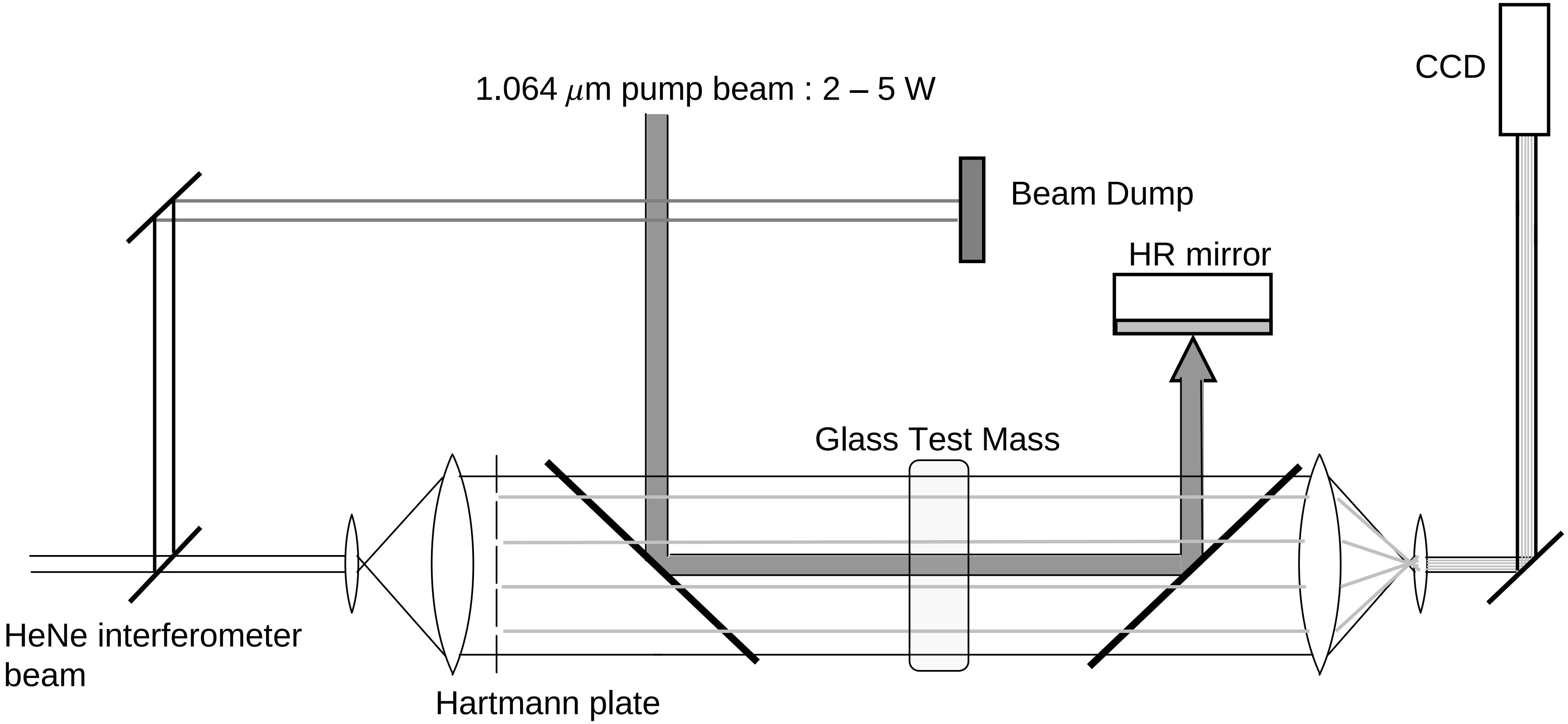
Testing

- Use OPD similar to that expected at Gingin.
- Estimate SNR.

Measure the thermally-induced aberration using stored-beam holography



Measure the thermally-induced aberration using On-axis Hartmann Sensor



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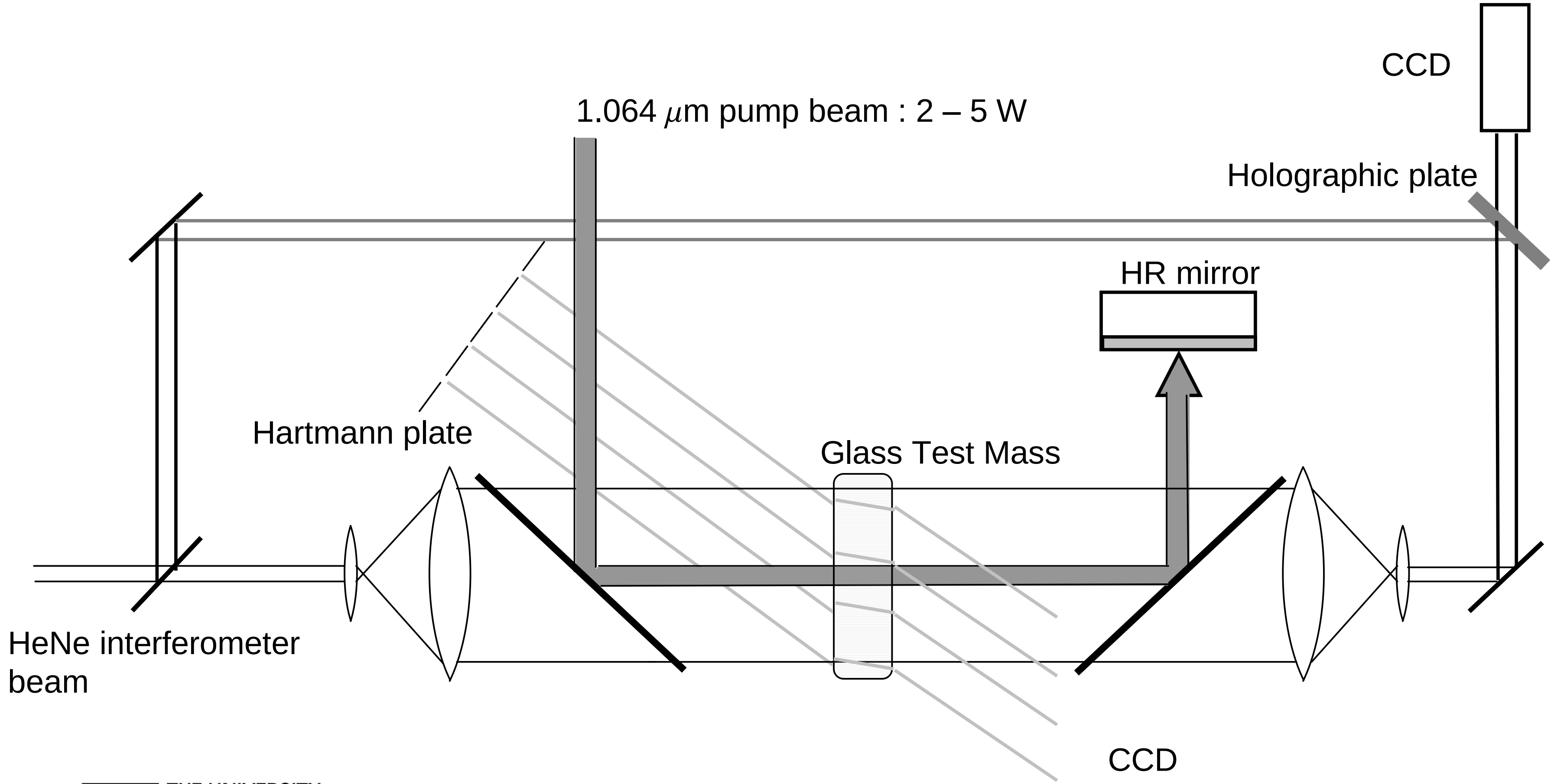
Measure the thermally-induced aberration using Off-axis Hartmann Sensor



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Conclusion

- Modelling mostly complete.
- Experiments have been planned utilizing facilities at Adelaide University and Gingin.
- Bench-top test being assembled.