CFM parameter optimization (cont.):

1. A correction factor of 2 to spherical power
2. Benchmark Alumnium and Copper as actuating ring and search for optimal geometry
3. Update of progress on making CFM 2” prototype

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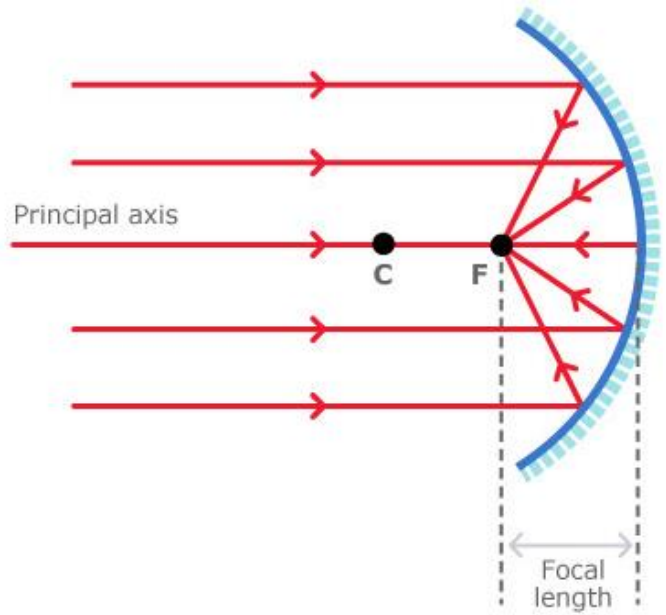
1. Correction factor of 2 to spherical power

- Simulation from COMSOL FEA → distortion of mirror surface, described by radius of curvature (ROC) R_{mirr}, then the spherical power S_{mirr} so far has been computed as $1/R_{mirr}$.
- Beam reflected off spherical mirror of ROC Rmirr has ROC changed by $R_{mirr}/2$, i.e $\Delta S = 2xS_{mirr}$.
- Assuming that 150 mD is change in beam ROC

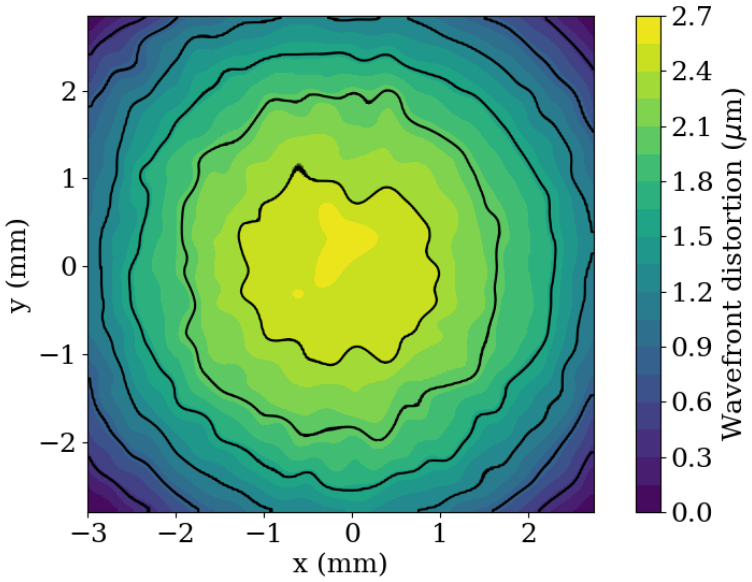
→ better results



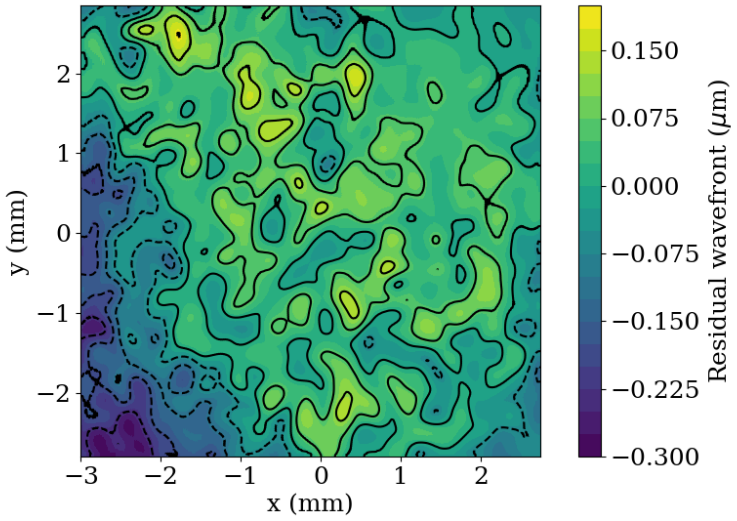
1. Correction factor of 2 to spherical power

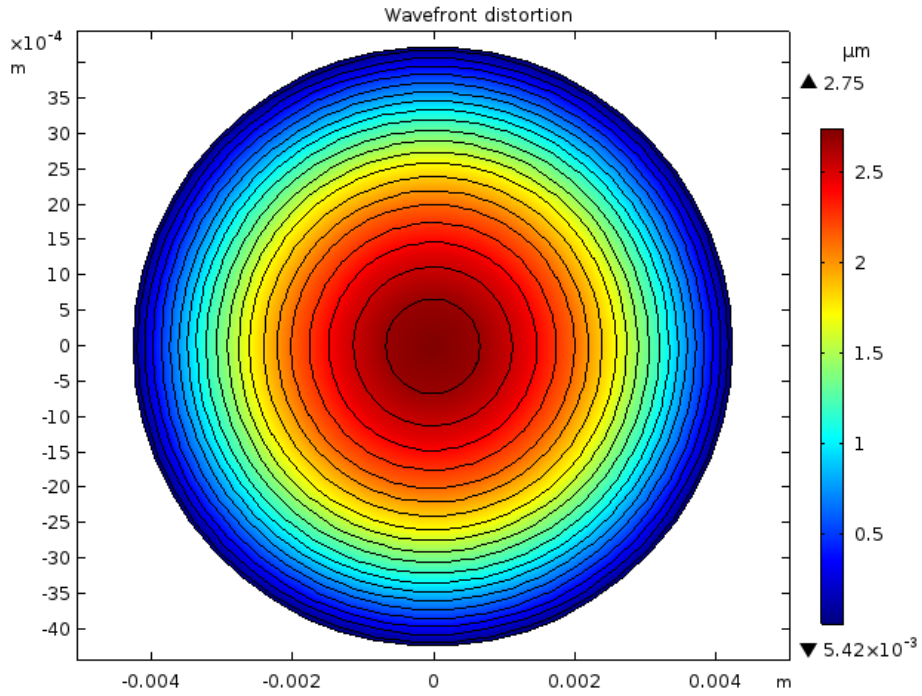
- Previous experimental result with 1 inch mirror

Full distortion



Higher order aberration



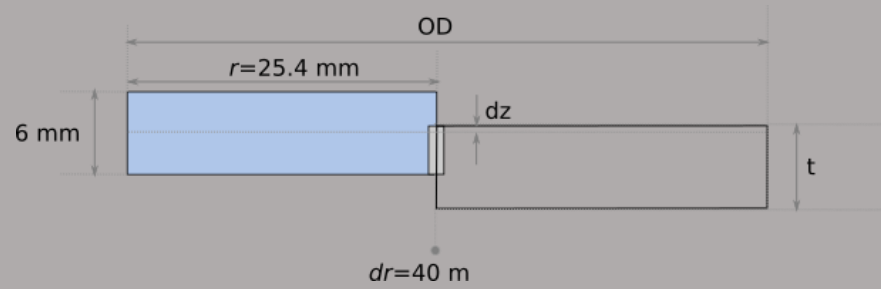


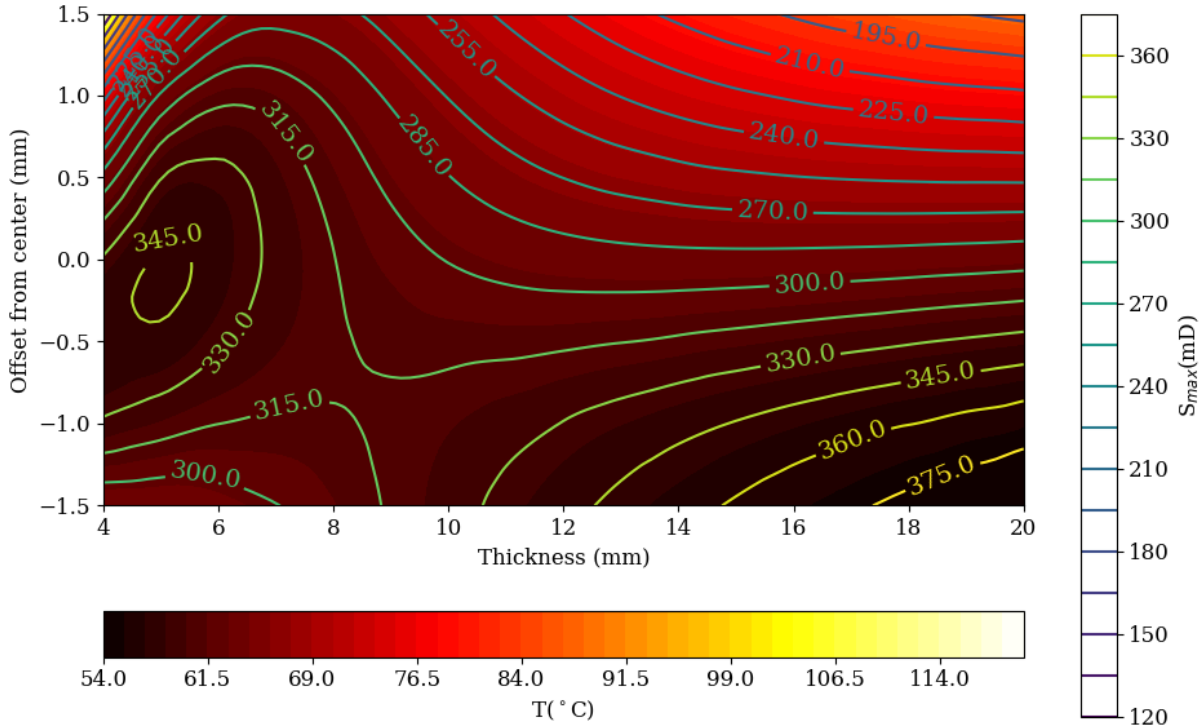
COMSOL simulation of wavefront distortion at cold state

Static deformation measurement of wavefront distortion by CFM

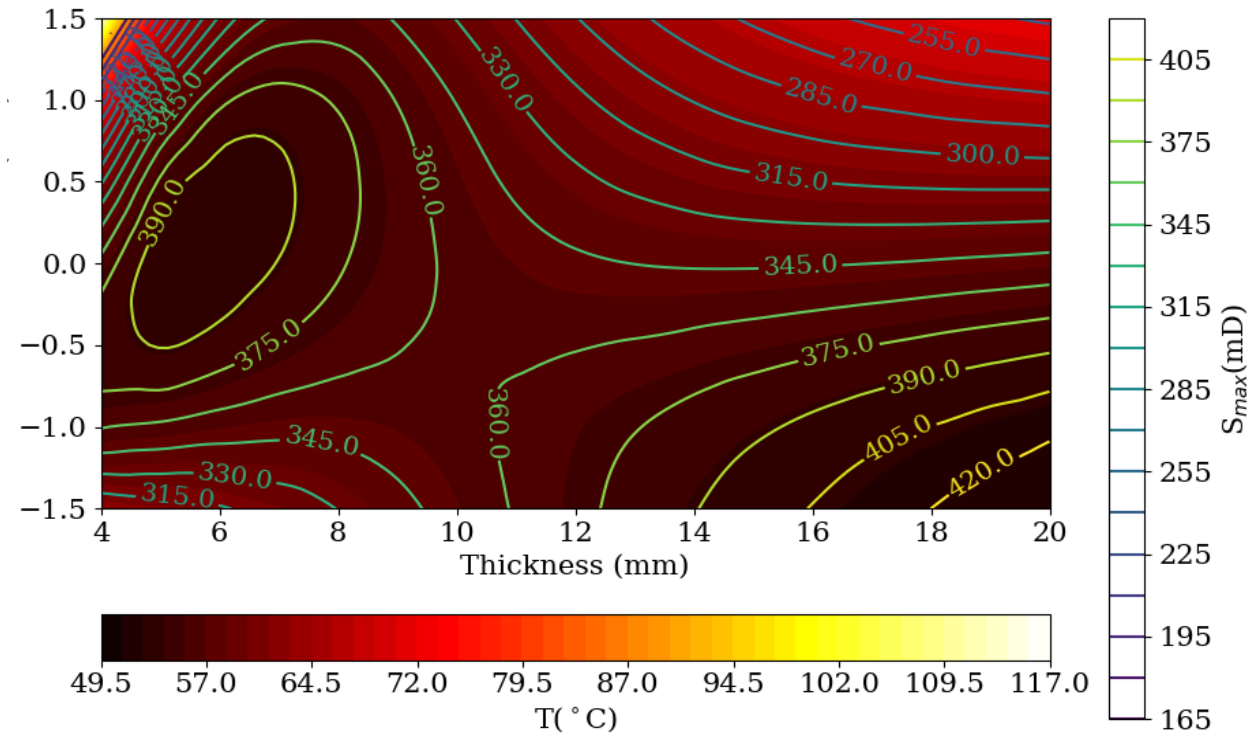
- 314 mD change in optical spherical power measured
- COMSOL simulation results in 320 mD for 18 µm radial interference and 302 mD for 17 µm radial interference → in good agreement with HWS static deformation measurement.

2. Benchmarking Aluminium and Copper – Flat mirrors





Copper

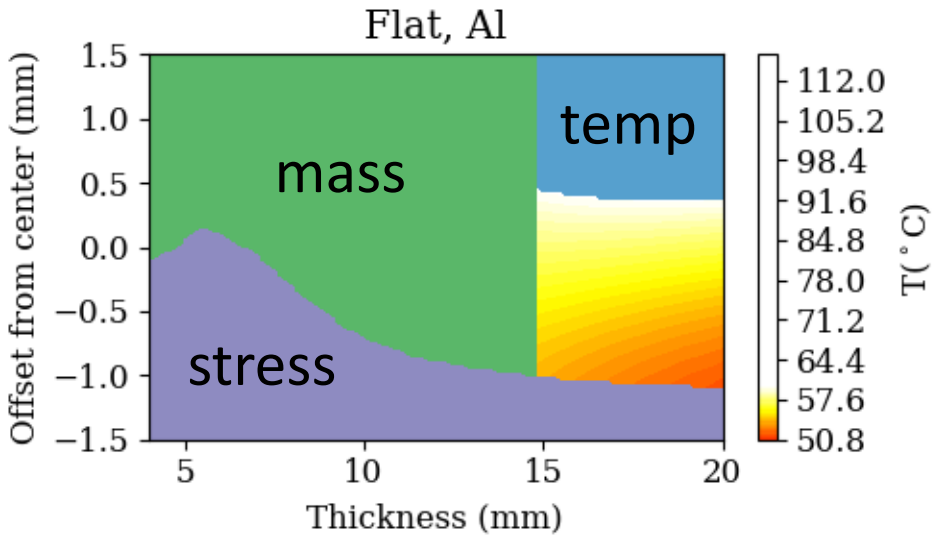


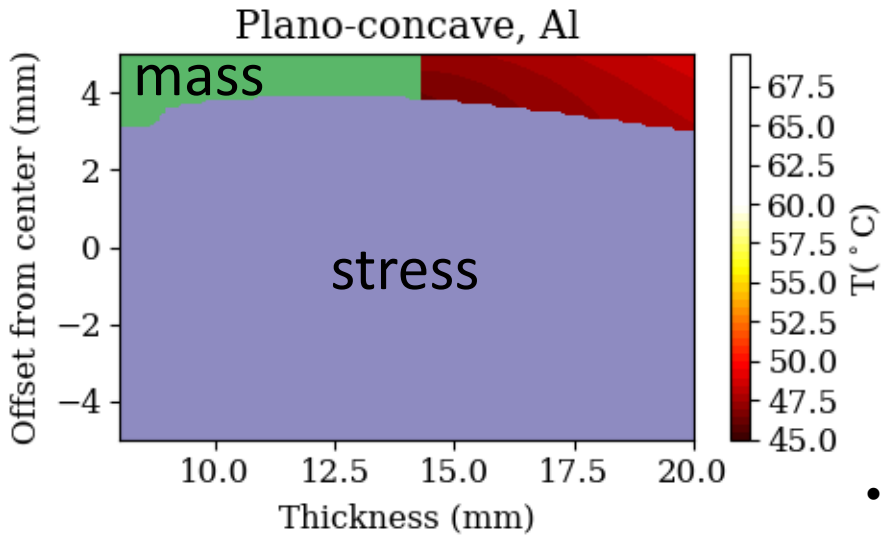
Aluminium

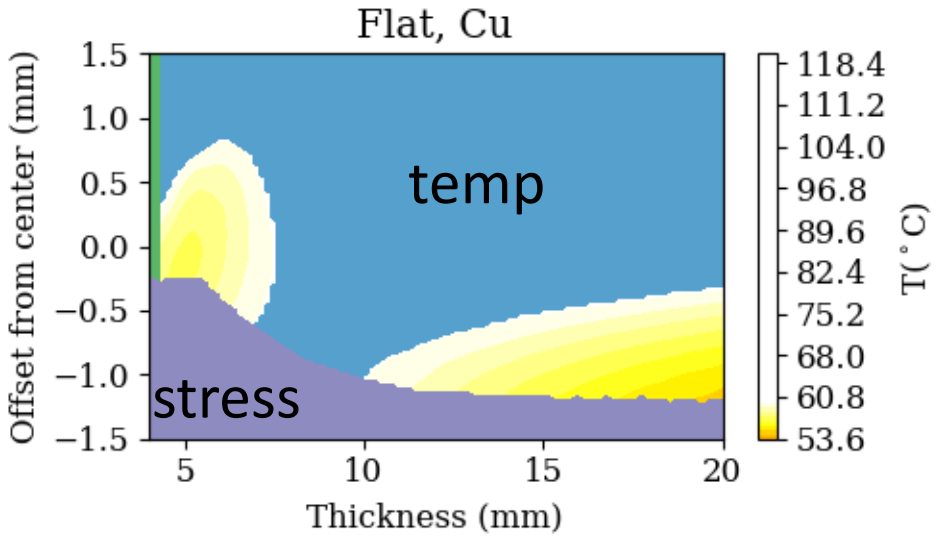
- From maximum ΔS achieved for ΔT=75K (contour line)→ Temperature required to achieve ΔS = 150 mD given assuming $T_{ambient}$ = 25°C (filled contour)
- Generally T required increases with more positive offset (mirror under pure compression, no bending)

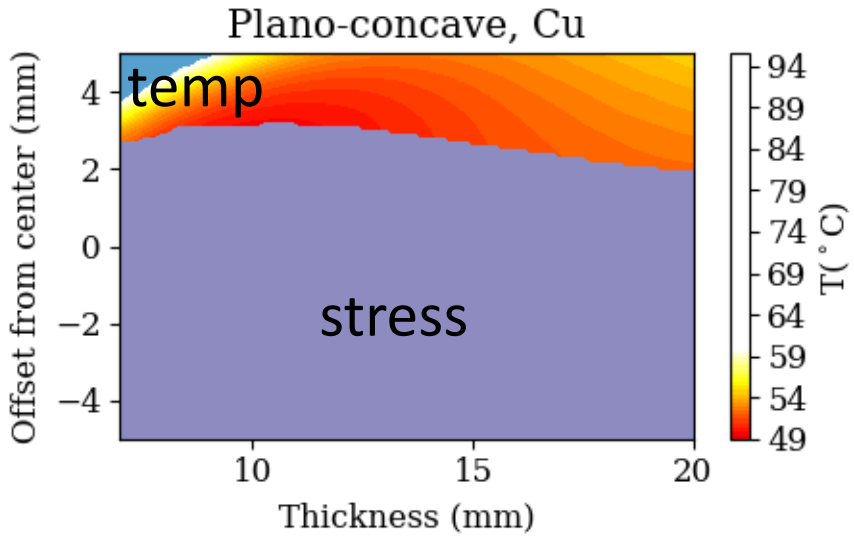
*All simulation assumed 120 mm OD, max ΔS reduced by approx. 8% if OD is reduced down to 100 mm

2. Benchmarking Aluminium and Copper – Applying constraints









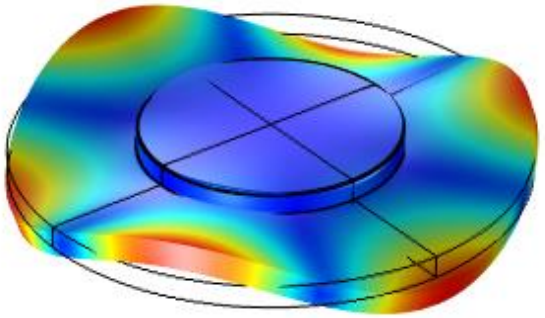
Constraint type	Requirement
Mass	>0.4 kg
Temperature	< 60°C
Max tensile stress	$S/P_{T,max}$ > 8.8 mD/MPa

- Copper alleviates mass issue
- Temperature limits operation at positive offset (low ΔS)
- Stress limits operation at more negative offset (more bending)
- Higher tensile stress with planoconcave
- Planoconcave, Al offers operation at lower temperature

2. Benchmarking Aluminium and Copper – Frequency constraint

- Eigenfrequency couples strongly to variation in thickness, not so much in offset
- Only considering feasible region:

Material	Mirror geometry	Lowest frequency of first eigenmode	Highest frequency of first eigenmode (kHz)
Aluminium	Flat	9.5 kHz @ t=14.5 mm	11.9 kHz @ t =20 mm
Aluminium	Planoconcave	7.1 kHz @ t= 14 mm	9.1 kHz @ t = 20 mm
Copper	Flat	3.8 kHz @ t = 4.5 mm	9.8 kHz @ t = 20mm
Copper	Planoconcave	4.0 kHz @ t = 7.0 mm	9.0 kHz @ t= 20 mm



First excitable mode

- From equation for frequency of fundamental mode of circular plate:
- $f \propto \frac{h\sqrt{E}}{\sqrt{\rho(1-\upsilon^2)}}$, i.e frequency increases proportionally with thickness (agrees well with Comsol result)
- $E_{Cu} = 1.6E_{Al}$, $\rho_{Cu} = 3.3\ \rho_{Al}$, $\upsilon_{Cu} \approx \upsilon_{Al} \rightarrow f_{Cu} = 0.7\ f_{Al}$ agrees well with FEA result for flat mirror

2. Benchmarking Aluminium and Copper

- Note: prioritise low temperature, then select minimum allowable mass to minimise thermal time constant

Material	Mirror geometry	Thickness (mm)	Offset (mm)	ΔS from 100°C (mD)	$T_{150\ mD}$ (°C)	Mass (kg)	$S/P_{T,max}$ (mD/Mpa)	1st eigenfrequency (kHz)
Aluminium	Flat	20	-1	405	53	0.53	8.9	11.9
Aluminium	Planoconcave	14	3.5	530	47	0.4	8.9	7.1
Copper	Flat	20	-1.2	375	56	1.69	8.9	9.8
Copper	Planoconcave	11.5	3	440	52	1.00	8.9	5.99

Table of optimal geometry

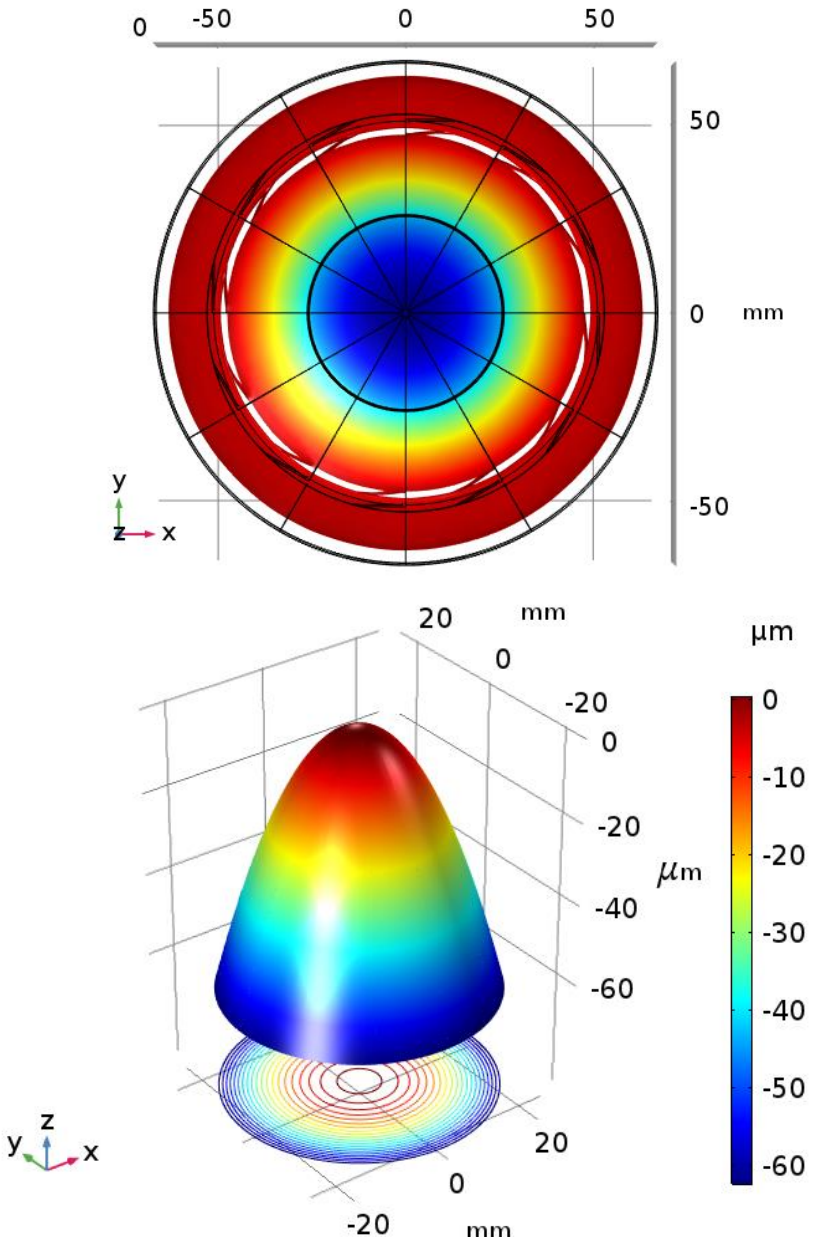
3. Update on testing 2” CFM prototype





- Thorlabs 2” fused silica with rear surface machined out using 5-axis ultrasonic mill
- Concave rear surface with ROC = 50mm, no polishing
- Aluminium actuating ring is currently machined for both flat and planoconcave mirrors
- Actuating ring is designed for maximum distortion
- Currently in contact with vendor for fabrication of plano-concave mirrors with high surface quality finish:
  - λ/20 over central 85% front surface
  - 10/5 surface roughness front surface
  - λ surface figure rear surface
  - 80/40 surface roughness rear surface

4. Deformation of mirror with flexure

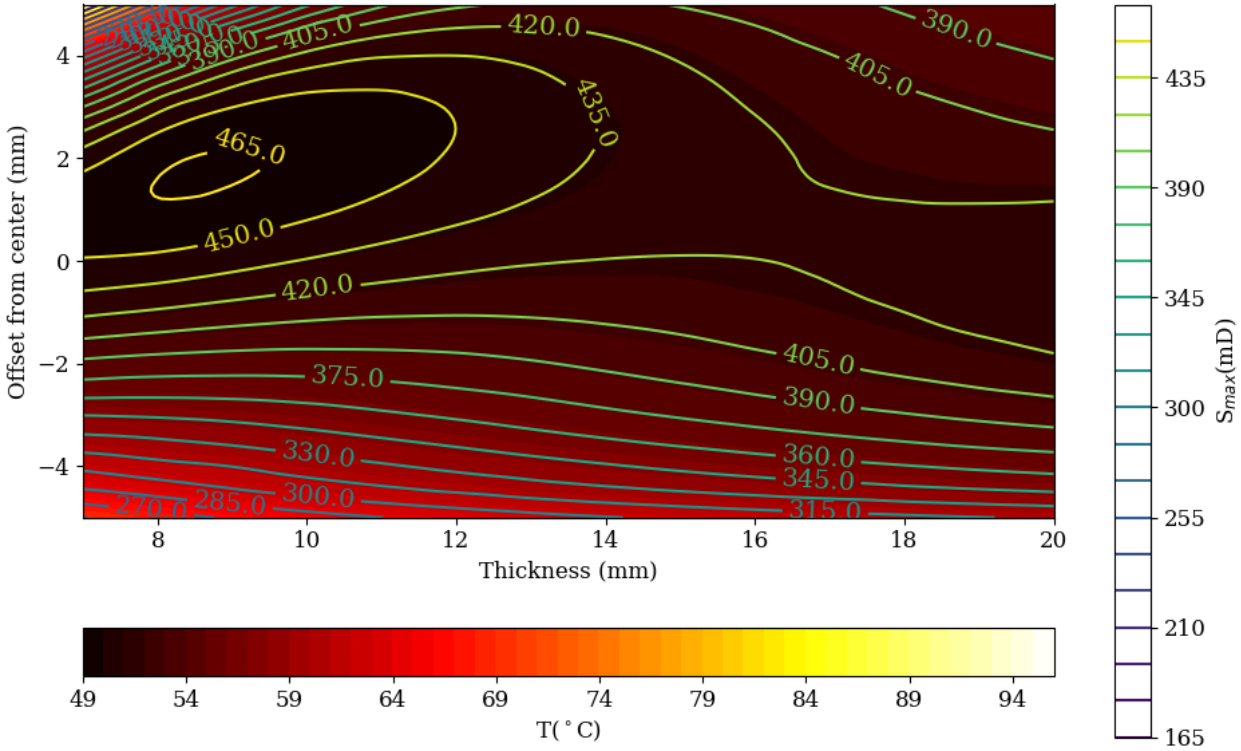


- Start investigating deformation of mirror held in flexures
- No apparent higher order aberration
- Similar amount of spherical power achieved compared to no flexures.

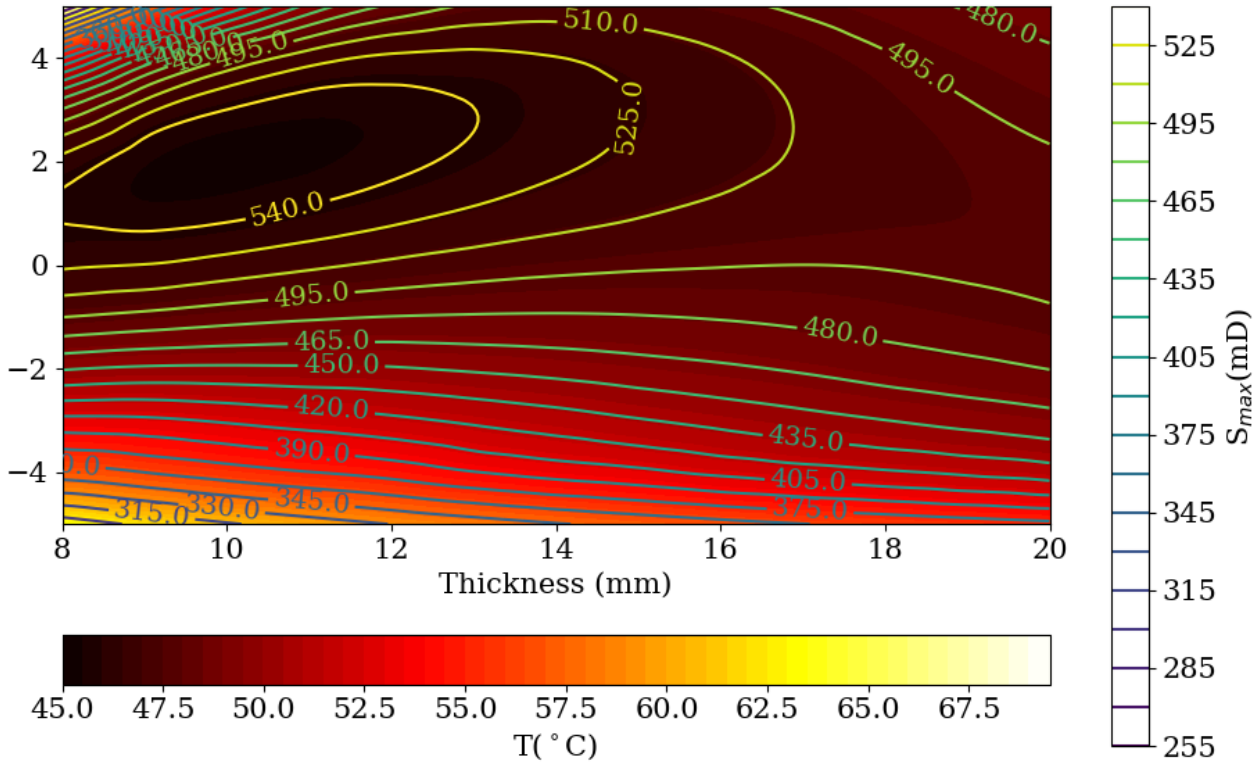
5. Summary

- Flat mirrors can meet requirement at higher thickness at the cost of longer thermal time constant
- Planoconcave mirror allows lower temperature operation. If the maximum operating temperature falls to 50 degree Celsius, planoconcave mirror with aluminum ring is the only option available
- Copper will decrease frequency of first excitable eigenmode of mirror, but generally mirror's geometry in the feasible window has eigenmode frequency outside dithering frequency range
- 2" prototype are currently fabricated for testing modelling
- Flexure should not affect higher order aberration of CFM

2. Benchmarking Aluminium and Copper – Planoconcave



Copper



Aluminium